# AURAVANA PROJECT

PROJECT FOR A COMMUNITY-TYPE SOCIETY

# The Habitat System

SSS-MS-HS-001 | July 2022

SOCIETAL SPECIFICATION STANDARD

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# THE AURAVANA PROJECT

## SOCIETAL SPECIFICATION STANDARD

# THE HABITAT SYSTEM

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# GREETINGS

**In an effort to provide the greatest possible clarity and value the Auravana Project has formatted the system for the proposed society** (of the type, 'community') **into a series of standard publications. Each standard is both a component of the total, unified system, as well as intended to be a basis for deep reflective consideration of one's own community, or lack thereof. These formal standards are "living" in that they are continually edited and updated as new information becomes available; the society is not ever established, its design and situational operation exists in an emergent state, for it evolves, as we evolve, necessarily for our survival and flourishing.**

Together, the standards represent a replicable, scalable, and comprehensively "useful" model for the design of a society where all individual human requirements are mutually and optimally fulfilled.

The information contained within these standards represent a potential solution to the issues universally plaguing humankind, and could possibly bring about one of the greatest revolutions in living and learning in our modern time. Change on the scale that is needed can only be realized when people see and experience a better way. The purpose of the Auravana Project is to design, to create, and to sustain a more fulfilling life experience for everyone, by facilitating the realization of a better way of living.

Cooperation and learning are an integral part of what it means to be a conscious individual human. A community-type societal environment has been designed to nurture and support the understanding and experience of this valuable orientation.

The design for a community-type society provides an entirely different way of looking at the nature of life, learning, work, and human interaction. These societal standards seek to maintain an essential alignment with humankind's evolving understandings of itself, combining the world of which humans are a regenerative part, with, the optimal that can be realized for all of humanity, given what is known.

The general vision for this form of society is an urgent one considering the myriad of perceptible global societal crises. Together, we can create the next generation of regenerative and fulfilling living environments. Together, we can create a global societal-level community.

# THE UNIFIED SOCIETAL SYSTEM: MATERIAL SPECIFICATION STANDARD

This publication is one of six representing the proposed standard operation of a type of society given the category name, 'community' (a community-type society). This document is a specification standard for a material system.

Every society is composed of a set of core systems. Different types of societies have different internal compositions of these systems. The composition of these systems determines the type of society. The type of society described by the Auravana Project societal standard is a, community-type society. The standard is a composition of sub-system standards. The Auravana societal standard may be used to construct and duplicate community at the global level.

For any given society, there are four primary societal sub-systems. Each of these sub-systems can be specified and standardized (described and explained); each sub-system is a standard within a whole societal specification standard. The first four primary standards of the six total standards are: a Social System; a Decision System; a Material System; and a Lifestyle System. Each standard is given the name of its information system. The fifth publication is a Project Plan, and the sixth is an Overview of the whole societal system. Together, these standards are used to classify information about society, identify current and potential configurations, and operate an actual configuration. Because of the size of some of these standards, they may be split into two or more publications.

- **This societal specification standard is the Habitat Sub-System of the Material System for a community-type societal system.**
- **There are more figures** (and tables) associated with this standard than are presented in this document; those figures that could not fit are freely available via the Auravana Project's website in full size, and if applicable, color [auravana.org/standards/models]. Tables that are too large to include in this document are referenced with each standard via the Project's list of standards webpage [auravana.org/standards].
    - *Figures and tables on the website are named according to their placement in the standard.*

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## List of figures

This is the list of figures within this document.
*There are more figures associated with this standard than are identified in this document; those figures that could not fit are freely available through auravana.org, in full size, and if applicable, color.*

## List of tables

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# Document revision history

*A.k.a., Version history, change log.*

This document is updated as new information becomes available.
The following information is used to control and track modifications (transformations, changes) to this document.

| VERSION | REVISION DATE | SECTIONS | SUMMARY (DESCRIPTION) |
|---|---|---|---|
| 001 | July 2022 | n/a | This is the first version of the Habitat System. The Material System grew so large it had to be split into two documents. There is now a master planning article. The architecture and cultivation sub-systems have been significantly filled in. There are various changes and additions throughout.<br><br>Note: The reader should understand that this document contains a high-level of conceptual linguistic detail, the reader should understand that this document is one of multiple documents that together provide a complete explanation of the proposed societal system. In order to visualize the whole societal system, its concepts and objects, and their interrelationships, must be modeled and reasoned.<br><br>Note: All figures associated with this standard, many of which are not published herein, are available via the Auravana Project's website. Oversized figures and tables are also published on the Project's website. It is not possible to publish via this page medium all figures and tables related to this standard. |

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# The Habitat Service System

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## Abstract

The term 'habitat service system' is the technical name of a 'city'. Cities are human habitats that localize services in a coordinated manner. A habitat can be designed, engineered, operated, evaluated, simulated, and recorded. For every current habitat state, there is a past state that may or may not have been recorded, and there is a future state depicted by the solution to some decision inquiry. Habitat services distribute informational and spatial services and objects to a population. In this sense, a city (localized habitat) is a service bus that connects all interacting functional services in a local environment to one another. A network of habitat service systems (network of cities) may share information and spatial resources in order to optimize service globally. The three core services a habitat service system can offer are life support, technological support, and exploratory support. These three service systems (as well as a biospheric) service form the foundational function of any habitat service system. Each individually localized habitat service system (city) has these three functional service systems, which are engineered into operation through an intersystem [habitat service] team. Contributing team members have intersystem access. The whole population has access via cities to these three core human life functions throughout the community network of cities. Each core functional service (life, technological, and exploratory) has a set of functional sub-service access systems from which users in the community access those services (and service-objects therein).

## Graphical Abstract

Figure 9 on page 3

# 1 Introduction

*A.k.a., The city system, the city operation architecture, the ecological city system.*

The material elements of a society exists within the material, physical environment. The location(s) where humans live and operate within this environment is referred to as a 'habitat'. A habitat (which is Latin for "it inhabits") is an ecological or environmental area that is inhabited by a particular species of animal, plant, or other type of organism. It is the natural environment in which an organism lives, or the physical environment that surrounds (influences and is utilized by) a species population 'habitat'. A habitat sustains a social population through the encoded recognition of a reciprocal interchange between that population and its material environmental reality. Fundamentally, a habitat service system coordinates the control and flow of material resources for human fulfillment.

A material environment can be restructured into "intentional" service environments. In other words, out of a common material environment, humans may cooperatively create an intentional habitat to service their common needs. The intentional output of these services systems is: freely and openly accessible services, goods and technical productions (i.e., "products").

Each specific habitat service system (or "service platform") acts as an organizational resource for the structured flow of energy and information (resources) into systems that by their very structure generate a higher potential state of existence within a commonly known environment. The habitat service systems structurally organize common resources toward the fulfillment of individual needs. It could be said that the habitat service system is a platform for the transforming of energy and information into a state that has a higher potential to "support a purpose" and "fulfill a need" [in response].

Herein, operational processes constitute the core functions of these systems and they represent the primary "value stream" (i.e., the end-to-end system process which delivers a service or "product" to an person, subject, or entity). A value stream is composed of a sequence of activities (and tasks) required to design, produce, distribute, and maintain a specific service, with all relevant accompanying information, materials, and knowingly desired conditions (i.e., values).

The habitat service system model represents the functional model of a city. Therein, functions can be defined as the abstracted behavior of a city. Functions are described in terms of the logical flow of information, energy, materials and signals. Functions and sub-functions can correspond to well-defined basic operations on well-defined flows leading to a taxonomy of functions (*as described below*). The functional structure (or, functional architecture) of a city is a form of a conceptual model of the functional domain. A conceptual model of the functional domain is a qualitative representation of the physical behavior of the informational and physical (spatial) structuring of a city as well as the [global] city network within which any city resides. Therein, the physical structure in interaction with a physical environment gives rise to a city's behavior. Behaviors are related to structural-physical descriptions of a city. Behaviors are derived from city functions and their interaction with a material environment. (Stepandic, 2019)

The habitat service system conceptualizes and models the city as a series of homogeneous (Read: alike) and sorted layers, structured around the set of domains representational of human life; that of life support, technology support, and exploratory support. Categorization and taxonomy are important here, as the resulting model seeks functional simplification. These layers are composed of relatively homogeneous, sorted and ordered components, the product of earlier phases of sorting and cataloguing of human life [without the market or State]. Each layer is configured and sorted according to a particular function, that of life, technology, and exploration. Each of its layers is an articulation of a specific logic.

Here, the habitat service system (Read: city) operates through connected classification and taxonomy, not only providing an order but, beyond that, establishing an ontology: categories, attributes and subcategories are created and, in doing so, they create their very object of intervention. Here, reality is thought of as an integrated organizational language and applied stack-a popular way of conceptualizing protocols, data formats and software amongst engineers-ensures that each layer [of the stack] handles the same base information simultaneously, but at different levels of abstraction. Extrapolating 'stack thinking' to the city means that, in a highly hierarchical fashion, different urban systems (such as health, transport, energy or waste) are modelled and understood in the same way (Read: are operationalized together). (Marvin, 2017: 95)

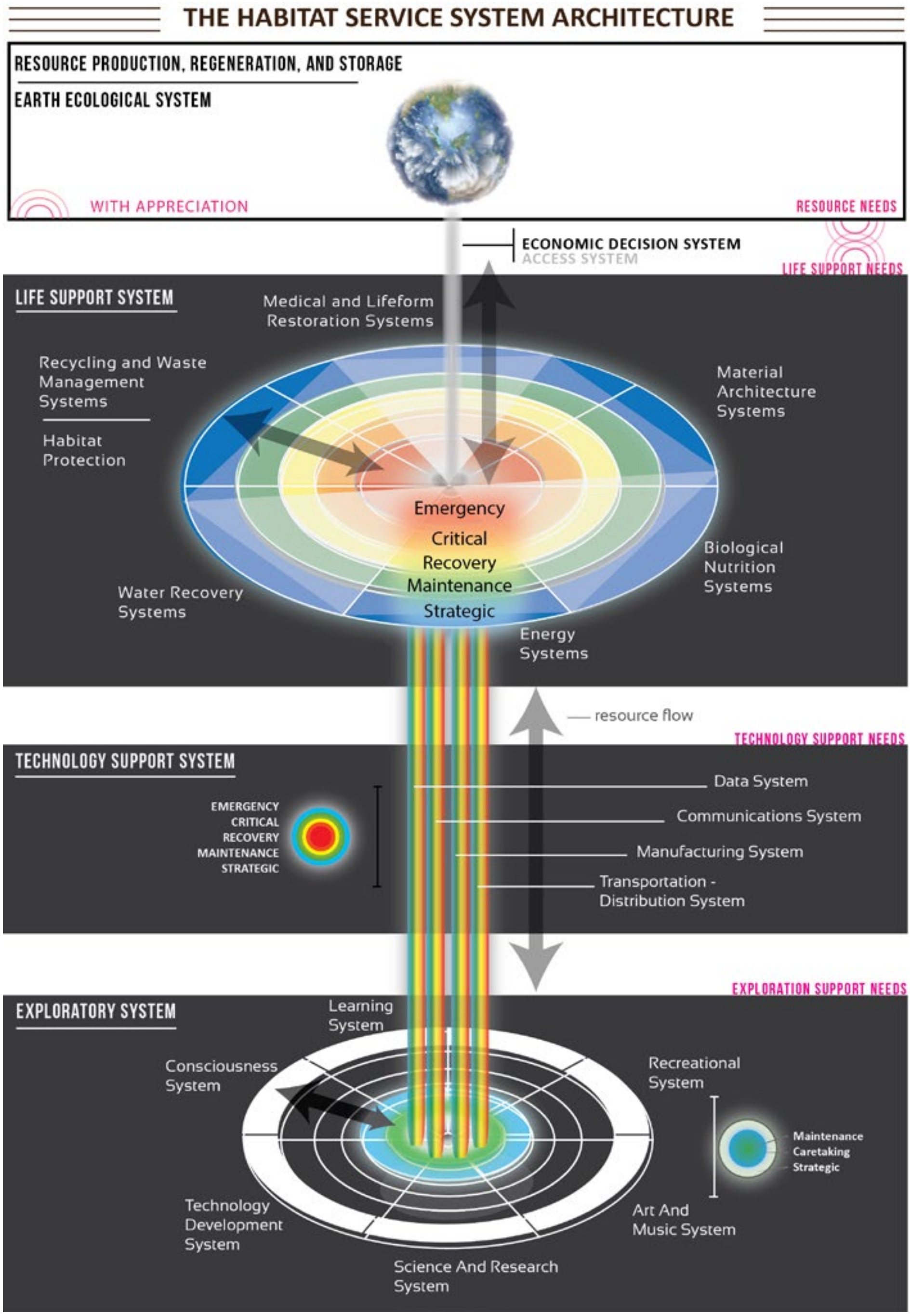
The city is, in essence, subject to a form of modularization and categorization according to a set of predefined [human and ecological] criteria that are then reflected in the realization of a global habitat software and hardware (hybrid) system. In order to integrate city organization, standardization, modularization and classification are fundamental processes. Therein, city planning analysis is the process of breaking down the city into a multiplicity of objects and components.

A service bus is a scheme used in computing, software, and spacecraft development to refer to a transferring interface between mutually interacting components. There are two core service buses to the city, one an information bus (with a particular focus on decisioning) and the other a material [service] bus. These buses represent the core, center or platform around which the wider ecosystem is organized. Within the total ecology of the city there is a form of interlayering of networks, interfaces and data integration that are assembled and operated together in a [decision] control system positioned within the layers of the city. Thus, the city may be viewed, decomposed, as a series of event rules, a set of semantic models, and a set of work-flows that are supported by indicators, directives, and alerts.

The information system of the city uses analytics (data analytics, predictive systems, modelling and simulation) that are based on a set of societal standards for habitat service systems. The analytics generated by habitat data are then related to a set of visualizations, such as dashboards for current operations and future possible operations (i.e., planning). Data integration and gateways for flow control occur along a information service bus and within the information system itself, which brings into existence a real-time, real-world visualization (Read: model) of the operation (or, potential operation) of the system. This visualization can be viewed from several core perspectives, including that of the support services themselves, the software therein, and the hardware therein. Such a holistic view of the habitat as an integrated information and spatial (Read: material) system, where everything is a data point, allows for flexibility, efficiency, and optimization of the planning and operation of the environment for all inhabitants.

Within the city (Read: habitat service system) network, there is the ability to access data globally, as well as the need for modularity, interoperability, and transferability across [service] systems and cities. An yet, each city within the network is also a customized package of sub-services (or, sub-customizations of service) depending upon the unique circumstances of individual cities. Local

**Figure 9.** *The Habitat Service System Decomposed Layered Reference Model.*



issues enter the global city information network in the form of data. Therein, by combining data sets, cities may be reconfigured in a multiplicity of ways. Therein, cities maintain a central processing system (or, central processing unit, CPU) as part of their information support service, which processes not only local city information, but distributed information pertaining to the global city network, which from an information viewpoint is known as, the societal information system. The societal information system works on comprehensive design solutions that may be applied to any city in the network. This process of disaggregation is made possible by reconfiguring the components of the city into data blocks that can later on be worked with, recombined or reprocessed. The city is viewed, like the society itself, as an information system (an assemblage of data), which may be disassembled into its constituent parts as defined by the categories of any human-based habitat service system, and then unproblematically re-assembled into new more desirable configurations and flows. Therein, [habitat service] operational processes can be analyzed as data packages and reconfigured in a variety of custom ways. (Marvin, 2017: 98-99) This technique is sometimes given the term ‘digitalization’; and, the logical computation of a digital (information) system for a city/habitat is often called, ‘habitat computational logic’ (a.k.a., city computational logic). Whereupon, the total logic of said environment for a operating system for the global habitat (a.k.a., habitat operating system or city operating system. In a global, technologically developed community-type society, computational logics have become ubiquitous, pervading every aspect of life.

> **INSIGHT:** *A comprehensive habitat systems approach recognizes that the fabric of the natural world, from human biology to the Earthly biosphere, to the electromagnetically gravitational arrangement of the universe itself, is one huge synergistically connected system, fully interlinked. Human cells connect to form organs, organs connect to form bodies, and since bodies cannot live without the Earthly resources of food, air, water and shelter, organisms are intrinsically connected to the Earth in each moment of breath.*

## 1.1 Societal access platforms

*A.k.a., Mapping habitat service systems.*

All societal-based platforms must account for a material system. When producing anything, access to objects must be accounted for. Access is necessary and two dimensional concept. Firstly, there is access to a team or working group through a contribution-based structure, and then, there is access to goods and service (without force of trade). Access can be accounted for many types of surveys including demand surveys, resource surveys, contribution surveys, etc. In the market, access is considered through the cost of a sale. In the State, access is acquired through authority. Humans require access to objects and information, which are composed into services. In a market, access is controlled by price, and the concept itself is mixed with "rights" (given by authority) and "property" (purchased in the market). In a community-type society, access refers to demands and other issues for service that are accessible to users. Ultimately, the goal is to have access to that which optimally meets user requirements (human needs) given that which is available at the time of access. In a community-type society, access centers and integrated transportation systems distribute products. Services are integrated, often modularly, into the infrastructure of the environment in order to optimize efficiency and produce a higher quality experience of access [to services] by a user. With sufficient technical knowledge and ability it is possible to apply automation technologies to increase the efficiency by which access occurs. Automation technologies can free individuals for access to opportunities they might otherwise not have had. Automation technologies can also make access to services, such as medical and informational more safe, reliable, and faster.

## 1.2 The habitat system states

> **NOTE:** *In nature, a ‘structure’ is a responding service. And herein also, the habitat service system is structurally designed as responding services (i.e., a service that responds appropriately to human need).*

In systems thinking the state of a system is a complete description of the system in terms of its condition, its parameters, its dynamics, values and variables, at a particular moment in time. This domain represents the formalized, existent structure of the community (the one actually operating or previously operating).

The Real World Community information system maintains a record of every known state of every system in the habitat. This includes both a model of the natural world, and a ‘state model’ of each service system.

There are three possible types of state for which the information system must account:

1. The **current state** of each habitat system (*quantitative* and *qualitative*).

2. The **past states** of each system of the habitat are identified as elements of the habitat's history (*quantitative* and *qualitative*).
3. The **future planned, predicted, and simulated states** that identify potential states as well as the next selected incremental state (*probabilistic*).

The 'past' represents a record of former re-structured iterations of the environmental habitat. A 'past state' represents a model of the prior state-dynamics of information, energy and services in our total environment.

The 'current state' space represents the current re-structured iteration of our environmental habitat -- the current state dynamic of information, energy and services (Read: the responding flow of resources) in the our total environment.

Individuals in community naturally seek the iterative improvement of their service system's trajectory toward greater states of human fulfillment. In other words, in community, our intention is to cooperatively create progressively more informed and fulfilling states of our habitat.

**NOTE:** *It is useful to know where we have been so that we can intelligently design where we are going. Further, it is useful to simulate where we are going so that our likelihood of a safe arrival is more certain.*

# 2 The service-oriented architecture of a global habitat service system

**INSIGHT:** *In any architecture, energy can be spatially and temporally positioned within that architecture in a variety of ways. For example, oil, coal, natural gas, and nuclear are highly centralized providers of energy [as electricity]. Solar, wind, and to a lesser extent hydro, geo-thermal, and biomass, can be localised and provide the energy requirements of a community that seeks electrical generation at a distributed level. In either case, the energy derived therefrom could be laterally decentralized [in time and space] into a series of backup batteries.*

The Habitat Service System is an integrated system for servicing the fulfillment of the material needs, wants, and preferences of individuals in the community. This type of an integrated service system is also sometimes known as an "functionally integrated city system"; yet, it might be otherwise referred to as an "functionally integrated habitat system". It is designed as a total "functional service platform" for the community in harmony with nature, existing within and through the habitat -- it is a part of the ecological habitat that we have formally and technologically redesigned to service our needs in a manner that is technically functional and commonly fulfilling.

When a group of people are living within the same community and sharing resources, the systems that support their lives together must be identified, operated, and optimized for the community's very survival.

A basic consideration in the design of habitat service systems is that of dividing work (as effort and services) into reasonable and prioritized tasks and activities (as time and spatial differentiation), while giving simultaneous attention to coordinating these activities and unifying their organization into a meaningful whole (as integration) so that the system can adapt and re-orient where said response is desired.

The Habitat Service System is principally divided into four service sub-systems. These systems are connected to one another within the larger and more encompassing Real World Community information model. In their layered portrayal, they are seen with the decision system running through each of their layers. Each service architecture functions to fulfill a particular category of need (in a temporal and spatial manner). Each system in the habitat involves the nesting of subsystems that must operate together for the overall system to work effectively.

The four global habitat service systems are (socio-technological productions):

1. **The Resource Production, Regeneration and Storage System (planetary biosphere)** - provides

for the community's resource needs - the natural phenomenological environment, the planetary lifeground. Strategic preservation of the lifeground is a requirement for the continuation of all other service support systems. This is the planetary system itself.

2. **The Life Support System (LSS)** - provides for the community's life support needs. This system might be equivocated with the idea of "needs". Provides for material life support functions; the life support platform. This is the life-sustaining platform, including necessary infrastructure, for a population. This could be considered a social infrastructural system with a dedicated life function.
3. **The Technology Support System (TSS)** - provides for the community's technology support needs. This system might be equivocated with the idea of "wants". Proves for technology support functions; the technology support platform. The is the technical infrastructural system for a population.
4. **The Exploratory Support System (ESS)** - provides for the community's exploration (and therein, discovery, self-/social-development, and recreational) needs. This system might be equivocated with the idea of "preferences". Provides for self and social exploration functions; the exploration support platform. This is the self- and social-development platform, including necessary infrastructure, for a population. This could be considered a social infrastructural system with a dedicated exploration function.

Each of these systems represents a functional service, a platform, that has been separated out to meet the [frequency] needs of humanity using resources from the common environment. Essentially, these service systems differentiate the different functions that control the 'phenotypic expression' (to use a term from genetics) of a community. Fundamentally, a functional approach allows for the identification of root concerns and the implementation of systemic solutions.

The primary four functional service systems are each sub-composed of a further set of functional subsystems. These subsystems exist to meet the ongoing and delineated functional requirements of each of the four primary categories of need. These sub-service systems fulfill needs by generating [responsive] access to technical production services. Wherein, for instance, the Life Support System is sub-composed of six systems, each of which transfers energy and resources into a particular category of good or service designed to meet the ongoing functional life support needs of individuals in the community. Essentially, these service sub-systems sustain the functioning of the community and are permanent structural elements of the Habitat system. They exist as long as our need for them exists.

The integrated habitat service sub-systems are:

1. The Life Support System is sub-composed of:
   A. *Architecture System*
   B. *Water System*
   C. *Power System*
   D. *Medical System*
   E. *Cultivation System*
   F. *Recycling And Waste Management System*
   G. *Defense System (non-primary)*
2. The Technology Support System is sub-composed of:
   A. *Information System*
   B. *Production and Recycling System*
   C. *Transportation and Distribution System*
   D. *Communication System*
3. The Exploratory Support System is sub-composed of:
   A. *Science and Research System*
   B. *Technology Development System*
   C. *Learning System*
   D. *Recreational System*
   E. *Consciousness System*
   F. *Art and Music System*

**NOTE:** *All habitat service systems provide the economic function of fulfilling human needs.*

All service systems act independently as well as interdependently - they follow dynamic, distributed systems principles - they are centralized and decentralized. It is inaccurate to label them as centralized *or* decentralized, as one or the other. Most issues involve a spectrum of subsystem requirements, and therefore, necessitate the involvement of distributed multi-system effort (i.e., multiple systems acting together to meet a need or accomplish a purpose).

Each sub-system may be seen not only as an area of service, but also an area of inquiry. As such, the word "science" is sometimes appended to the end of the name of each system. For example, "water recovery sciences" or "biological health sciences", and so forth.

In concern to measurement of the community system as a whole:

1. These functional processing systems are a measure of the technical efficiency of the community.
2. The alignment of these systems with the community's current understandings and technological development is a measurement (indirectly) of the technological age of the community
3. The functioning of these systems are [in part] a measure of the technical resiliency and health of the community.

Issues of greater urgency and those of a strategic nature are more likely to involve multiple system interdependencies, and are sought resolution through an interdisciplinary systems approach (i.e., a systematic solution orientation). In particular, "urgent" issues have the potential of impacting the stability of service systems, and therefore, they require rapid response and a high degree of systems-level coordination. Similarly, "strategic issues" involve the planning of future states of a the total habitat system, and therefore,

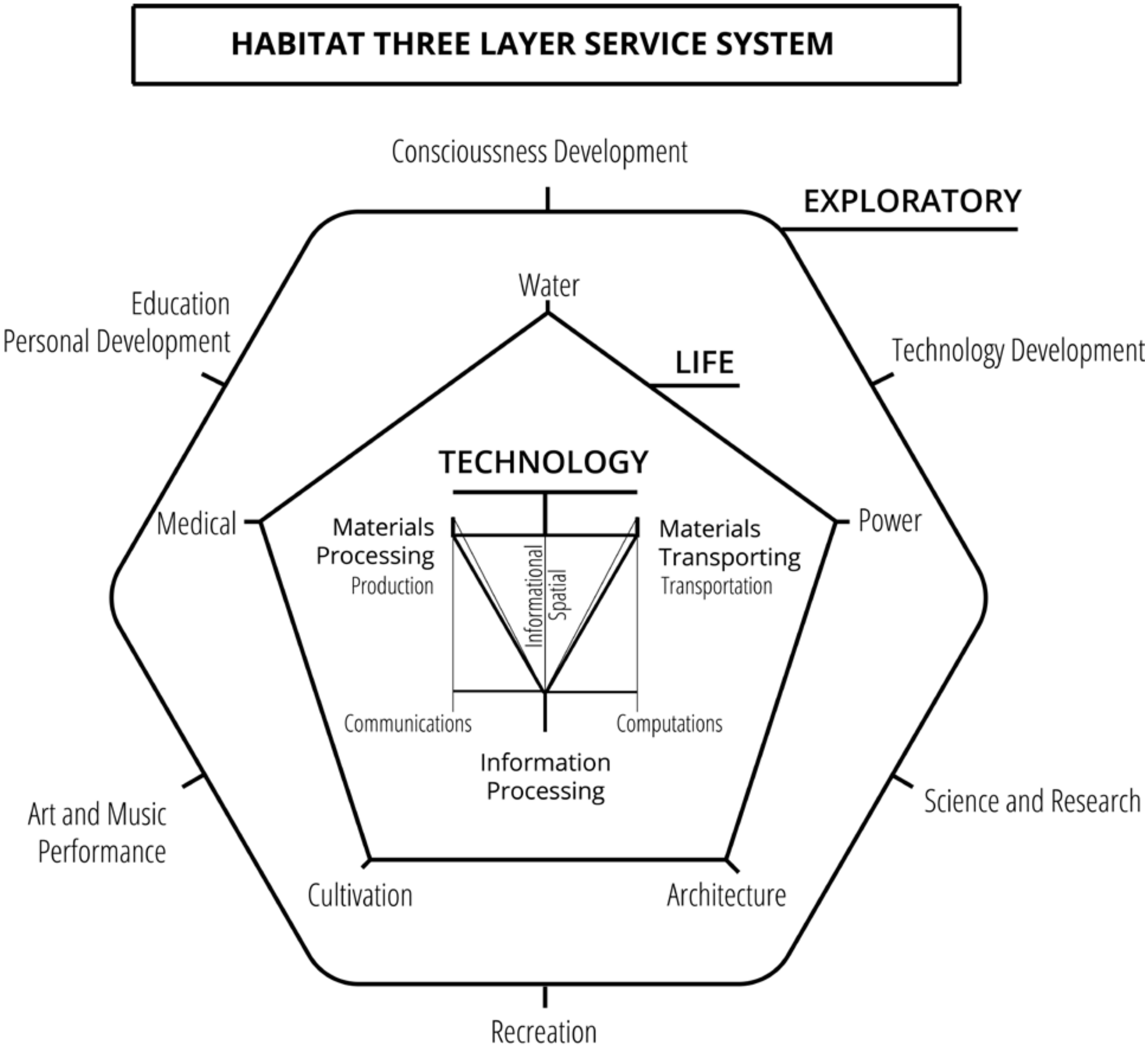



**Figure 10.** *This diagram shows a habitat service system's primary system classifications. Herein, the three axiomatic (fundamental) systems of a habitat service system (city) are: Life Support, Technology Support, and Exploratory Support. The sub-systems of each of these primary systems are identified: 5 Life sub-systems, 6 Exploratory sub-systems, and 4 Technology sub-system. These are the habitat service systems to which resources and effort can be allocated. It should be noted here that in its operation, by means of a contributing habitat service team, all habitat work is completed through InterSystem access coordination.*

coordination among systems is relevant. "Operations and maintenance" issues assume a more direct and targeted approach by individual sub-systems, and they have fewer interdependencies; although, it does occur that some maintenance issues involve multiple systems.

*The Life Support* and *Technology Support Systems* represent the Habitat's **core service systems**. The Exploratory Service System is one of the four primary Habitat systems, but it is not a "core system"; it is a secondary system because it relies on outputs of the two core systems to maintain its existence. The Exploratory system exists because:

1. The critical life support needs of individuals in the community are sufficiently fulfilled (i.e., the Life Support System is functionally operational), and
2. The Technology Support systems is functioning at a sufficient threshold to then begin meeting the needs of the Exploratory System (i.e., The Technology Support System is functionally operational).

Thus, exploratory system issues are prioritized after the critical requirements of the Life Support and Technology Support Systems, for if they fail then every system "downstream" will fail also.

Here, functional community design relates an individual organisms resilience to the resiliency of the community as the ability resist illness, the ability to resist injury, the ability repair, the ability to reproduce, to have movement, to generate energy, and to direct energy into a functional state rather than just lose energy to the universe.

The sub-systems of the primary four service systems maintain an operating structure that involves the operational processes of *integration and planning*, *operations* and *maintenance, and incident response*. 'Operational processes' define the primary tasks (or activities) that must be performed to ensure the stability and continuity of the whole Habitat Service System.

The three operational processes are:

1. **Strategic integration and strategic preservation planning** - The process of integrating goals, values and new understandings into the design of future services and technical productions. This operational process involves decision planning. A society with a purpose must have a set of blueprints, as well as a planned set of blueprints. This operational process is also sometimes known as "Strategic Planning and Preservation". The community uses the operational process of Strategic Preservation Planning to ensure that needed goods and services are continuously accessible.
2. **Operations and Maintenance** - The process of preserving and improving the ongoing functioning of the system so that it continues to provide goods and services as planned and as happens to occur. The Maintenance and Operations process ensures the continuation of systems which provide for individual access to products and services. This process approaches the concepts of integrity, availability, and transparency through increasingly efficient and automated action. As a structure, this operational process transforms resources in an effort to maintain, and improve the quality of access and use of resources, goods and services.
3. **Incident Response** - The process of responding to malfunctions and other [potentially harmful] incidents within the habitat system to maintain the urgent homoeostasis (i.e., critical self-regulation) of the system. Incident response is essentially the critical resolution of a point of identified failure in the system. Highly reactive issues are urgent and they have the potential to impact the integrity, availability and transparency of systems. This operational process includes processes involved in the recovery from malfunctions and other incidents.
   - **Fail-safe** and **fail-secure** (as a task for safe systems engineering and redundancy planning) - in the event of failure, the system responds in a way that will cause no harm, or at least a minimum of harm, to other systems or danger to individuals. Fail-safe means that a device will not endanger lives or other systems when it fails. A system's being "fail-safe" means not that failure is impossible/improbable, but rather that the system's design prevents or mitigates unsafe consequences of the system's failure.

**Table 1.** Habitat*: Protocols for habitat coordination and control operations.*

| Access Service Control Types | Control protocols |
|---|---|
| Resource service control | Resource Accounting |
| Production service control | Strategic preservation |
| | Strategic safety |
| | Strategic efficiency |
| Demand and Distribution service control | Strategic proximity |

Each habitat service support system is composed of the same three operational processes. The operational processes generate actions that provide for the community's purpose, orientation, requirements, and needs. A system process can be decomposed into several sub-processes, which have their own attributes, but also contribute to achieving the goal or purpose of the super-process. The analysis of system processes typically includes the mapping of processes and sub-processes down to an activity and task level, including a description of the "constructor entities" as well. Each operational process can be subdivided into its base activity and task level, which are interrelated within a comprehensive, real world information system.

The 3 material process phases of a habitat service system:

1. Using of materials: Life, technology, and exploratory service system processes - use it.
2. Moving of materials: Logistics service system processes - move it, distribute it, and return it.
3. Organization of materials: Materialization service system processes - create it, produce it, and recycle it.

All of the above systems-level tasks are planned for through a decision system, and carried out by [inter-] systems teams who have demonstrated experience, or are being mentored by those who have demonstrated experience.

> **NOTE:** *The operation of a service function necessarily takes up material space and time.*

## 2.1 The Resource Production, Regeneration And Storage System

> *A.k.a., The natural environmental domain, the world, the planet, the life-ground, the Earth's ecological system, the ecology, the biosphere.*

Necessarily, a society must construct in, and account for, its environment, continuously. The Resource Production, Regeneration, and Storage System is the natural [planetary and solar] environment; it is the world that creates (or "has created") all of the resources humanity has access to; it provides for humanity's resource needs, including the production, regeneration, recycling, and storage of resources. The natural environment is the material basis for human survival and socio-economic (socio-technical) development; it is the environment from which humanity acquires resources, discovers knowledge, and into which the material systems of a society (i.e., the habitat service systems) are produced and integrated. Fundamentally, the natural world provides for humanity's resource needs and life experience.

The planet is ultimately where all resources that humanity has temporarily accessed return to, after they are used, or when access is no longer required. The products that humanity produces from the planet's resources will eventually decay and be recycled. Physical life requires resources from the environment for its development and continuance. Therein, there is no life without death.

The Earth and the services that it provides represent a common [life]ground for all of humankind, and all present symbiotic life. Hence, to simply treat the natural environment as a physics lab is folly, potentially beyond repair, and is the ultimate form of irresponsibility. Planetary resources are finite, and it is important to be responsible (and efficient) in their use.

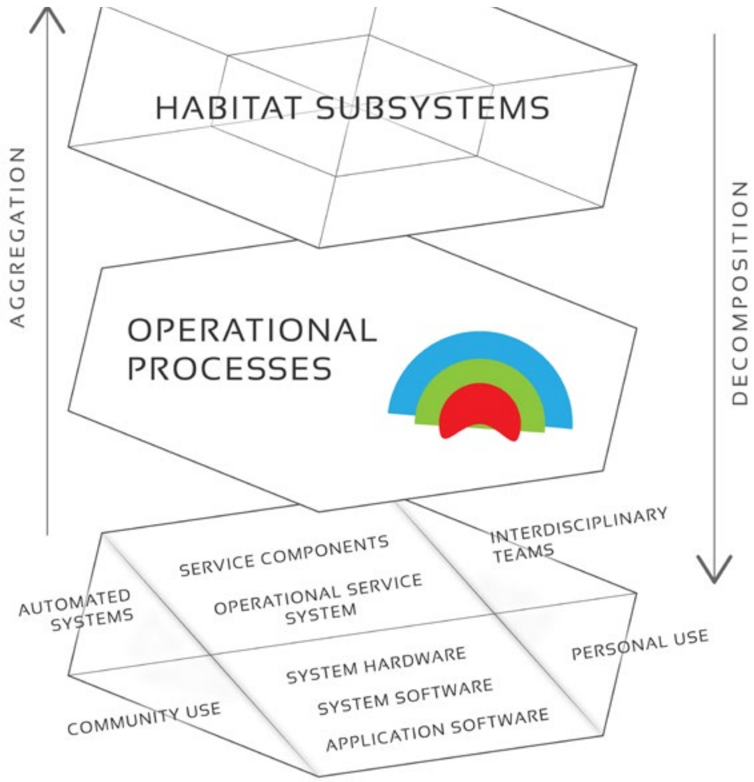
Technological systems can facilitate and optimize this system. For example, a building can store harvested resources, and production technologies can increase the nutrition content and yield of a harvest.

## 2.2 The Life Support System (LSS)

> *A.k.a., Life support service system, life sustaining system, life system, environmental control system and life support (ECLSS).*

This Life Support System exists to meet the functional *life support needs* of the community. The life support system is further divided into subsystems representing the essential service categories (or functional processing categories) for the direct support of human life within a habitat. Effectively, life support refers to the vital service functions (and their outputs) for sustaining human life.

**Figure 11.** *High-level aggregation/decomposition layering of the Habitat Service Support System.*



These systems provide services and products for which everyone in the community has a life-need. In other words, everyone in the community has a direct bio-psycho-social primal need for the outputs, and other technically service productions available *through* each of these subsystems. Each one of these core functional processes (or subsystems) is required for life stability and is a possible point of resiliency failure for a habitat (i.e., is somewhere that a community can fall out of the state of resiliency).

Individuals will always have a need for food, water and shelter. They will always have a need for the production of energy. They will always have a need for medical care and the recycling of waste in their ecology. These life support needs are critically common. Every habitat service system needs at least these systems on a continuous basis - these are components of a core habitat service system.

The Life Support System maintains the idea of 'social assurance' as the basis of community resiliency and true economic "security" -- that the systems that compose the habitat may be accessed in such a way that the lifeground is preserved and humanity's life needs are fulfilled.

The subsystems of the Life Support System are:

1. **Architectural service system** (a.k.a., building and clothing service)
   - All the activities and objects associated with architectural buildings and clothing, including but not limited to: design, storage, transportation, and usage.
2. **Water service system** (a.k.a., hydrology service, water cycling service)
   - All the activities and objects associated with water, including but not limited to: storage, transportation, recovery, processing, and usage. The water service system includes other liquids and atmospherics.
3. **Power service system** (a.k.a., energy service, energy-power system)
   - All the activities and objects associated with power, including but not limited to: production, transportation, energy storage, and usage.
4. **Cultivation service system** (a.k.a., nutrition and textile service)
   - All the activities and objects associated with cultivation of food and organic textiles, including but not limited to: cultivation, storage, transportation, and usage.
5. **Medical service system** (a.k.a., life-form restoration)
   - All the activities and objects associated with medical, including but not limited to production, storage, usage, and procedures.
6. **Defense service system**
   - All the activities and objects associated with defense of the habitat.

Note that because the whole habitat system is not yet complete, there are currently several different views on the specific sub-composition of the Life Support Service System. These differences are:

1. Defense as a core life support service, or defense not included at all.
2. Recycling and waste management as a core life support service, or the placement of this system with the Technology Support Service System as part of the Production System (a.k.a., Materialization System).

### 2.2.1 Survival

In the wild, in a true survival-based situation, there is an ordering to human efforts toward need fulfillment. The prioritization in a survival situation is:

1. Shelter
2. Water
3. Fire
4. Food

These are the original four survival needs for which humanity can produce technologies that function toward improving those conditions necessary for survival.

> **NOTE:** *Many in early 21st century society have become ignorant to what it takes to survive and thrive together on this planet. Our actions, at the incremental level, can generate a greater likelihood of suffering for all others. Today we are becoming far more aware and realize that we are all connected in our lifestyles and materializations on this planet. We are all connected; the boundaries that we may perceive do not exist. We need symbiotic relationships, particularly between our individual selves.*

Of note, the primary functions of shelter are:

1. One of the primary functions of a shelter is to enable you to maintain a homeodynamic body temperature.
2. The buildings we construct, which provide an environmentally controllable space
3. Clothing, including shoes and hats, is a form of sheltering.

### 2.2.2 Defense

Defense is the expression of force to counteract incoming force. As with any defensive system it can be your best friend or your worst enemy. Our biological immune system is a great example of this: if there is nothing to defend against and the defense system wants to be active, then it might start attacking things around it (e.g., the modern military-industrial-prison complex). In medicine, such behavior is casually called "innocent bystander activity" wherein the immune system begins creating inflammatory diseases like autoimmunity, allergies, and neuropathy -- it is trying to do battle against a feigned enemy that doesn't really exist. There are three interrelated ways to prevent the triggering of self-/social-harm:

1. By redesigning the structure of the system with an improved understanding of how to limit the regeneration of conflict between engineered structures and other structures in the ecological habitat [by learning from mistakes and correcting].
2. By redesigning the structure so the triggers of conflict are not present.
3. By removing the "offender".
4. By "cooling" the system (i.e., behaving in a way that avoids inflammation while stimulating healthy behaviors). In other words, the defense system of our habitat service architecture needs to be of a particular [emergent] structural design so that we aren't unwittingly harmed by it.
5. By facilitating the evolution of consciousness through the techniques of self-development.
6. By individually releasing trauma.

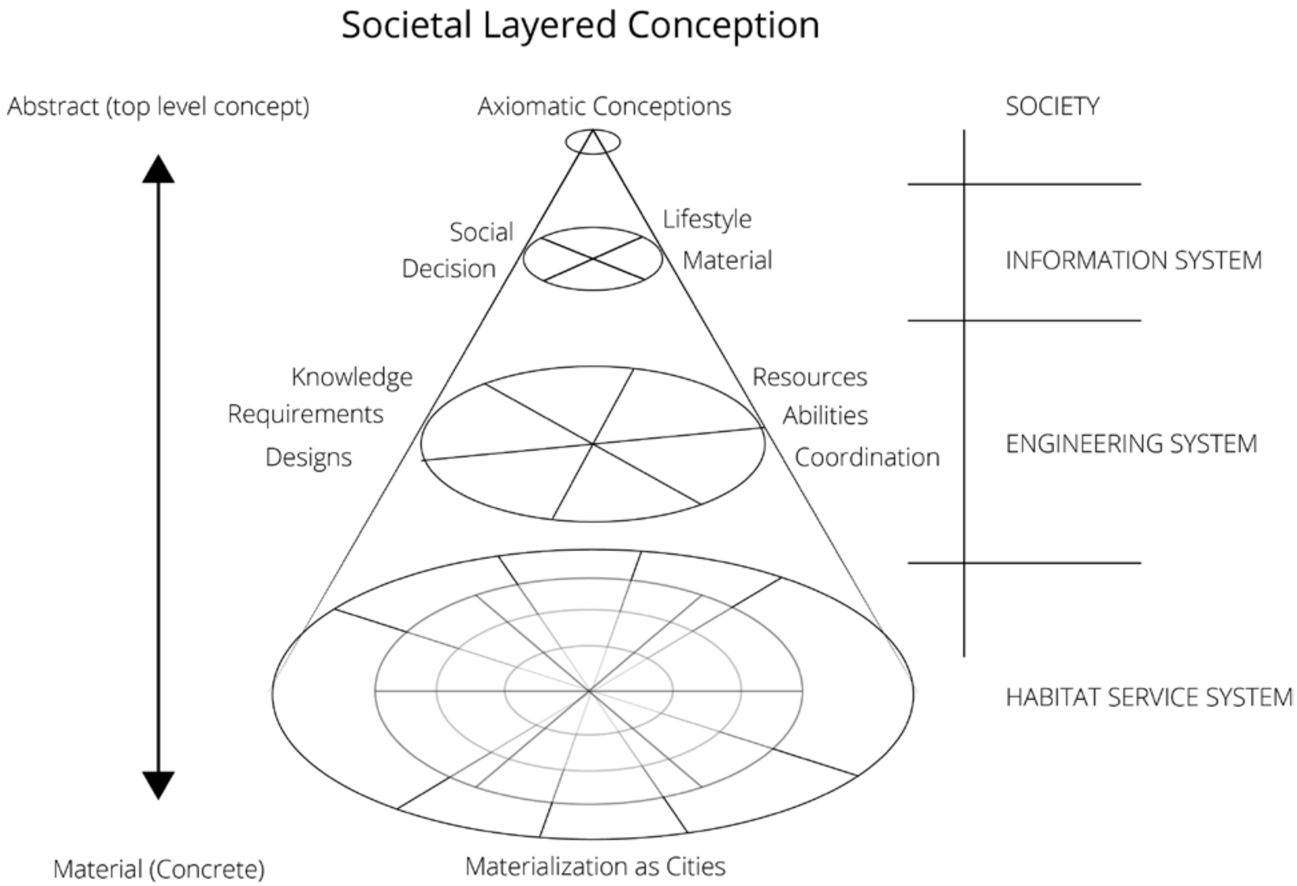
## *2.3 The Technology Support System (TSS)*

*A.k.a., Technology support service system.*

The Technology Support System functions to meet the *technology support needs* of the community. Technology is the application of scientific knowledge for practical, socially identifiable purposes. The Technology Service Support System acts as a conduit for information, energy and resources as they move through habitat. The technical optimization of their flow generates a greater potential for the extension of ourselves into our environment (i.e., they extend our functions). Both individuals as well as other systems in the Habitat System have a need for technological support services.

**INSIGHT:** *What good is technology if a society does not have the wisdom to use it to better itself and enhance the lives of everyone? Anything less than this will simply lead to a dysfunctional,*

**Figure 12.** *The materialization of a society as a unified whole composed of a set of systems/dimensions representative of data (information processing), teamwork (the human effort), and physicality (the habitat operating system).*



*technologically dangerous society.*

The subsystems of the Technology Support System are:

1. **The information system** (a.k.a., information storage and processing)
    - All the activities and technologies required to process information including computing technology and software systems. This system involves information processes.
2. **The communications system**
    - All the activities and technologies required to communicate including communications technology and software systems. This system involves communications processes.
3. **The transportation system** (a.k.a., transportation and distribution, transport and material distribution)
    - All the activities and technologies required to transport and distribute materials. This system involves logistical processes.
4. **The materialization/production system** (a.k.a., production and recycling service system, materialization service system, materials cycling, technical production and recycling, materials cycling and waste management)
    - All the activities required to acquire materials, produce technologies, and cycle materials, including. This system involves materialization processes.

Solid waste results from the following:

1. Metabolic output of humans and other organisms.
2. Food preparation
3. Material primary system operation (e.g., production, packaging, etc.)
4. Material subsystem operation (e.g., residual substances from water processing)

Firstly , the waste is collected and, if necessary, separated. According to its composition and the applied concepts for disposal, it is shredded, compressed, chemically and biologically stabilized, and then stored.

> **NOTE:** *A "facility" is designed to afford the function of a convenience or service. The term, 'facility', comes from the French language word "facile", which means easiness or with ease. This model defines 'facilities' as - those systems that make life easier, more liveable, and support the community's highest development by meeting the quality-of-life [social and recreational] needs of a community.*

## *2.4 The Exploratory Support System (ESS)*

*A.k.a., Exploratory support service system, exploration support system.*

The Exploratory Support System functions to meet the exploration requirements of the population. Herein, exploration includes, but is not limited to discovery, expression, and self-development activities. The Exploratory Support System is aimed at providing the services and products to facilitate exploration of the world and of one's own higher potentials.

> **CLARIFICATION:** *Exploration is the act (or actions) of searching, discovering, developing, and/or expressing.*

Humans have desires beyond basic needs. If this were not true then there would be no inventors, designers, no exploration and creativity. The Life Support and Technology Support Systems together allow for the stable existence of the Exploratory System. Although the Exploratory System is a separate system, it relies in great part on services from the Technology and Life Support Systems to operate.

The Exploratory Support System is composed at a high-level of the following sub-systems:

- **Science and Research System** (a.k.a., scientific research and engineering development)
- **Technology Development System**
- **Learning System**
- **Recreational System**
- **Art and Music System**
- **Consciousness System**

> **NOTE:** *The term "sciences" could be added to the names of these subsystems: the learning sciences system; the recreational sciences system; the art and music sciences system, the learning sciences system; the research sciences system, the technology development sciences system, and the consciousness sciences system.*

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# TABLES

**Table 2.** Habitat Service System > SubSystems: *Habitat service system tiers.*

| First Tier System | Second Tier Systems (Subsystems) | Third Tier Systems (Subsystems) | Fourth Tier Systems (Operational Processes) | Activities & Tasks |
|---|---|---|---|---|
| **The Habitat System** | **Resource Production, Regeneration And Resource Storage; Life Support System; Technology Support System; Facility/ Exploration System** | **Shelter/Architecture; Power/Energy; Nutrition; Water/Atmospherics; Medical; Recycling & Waste Management; Data Processing; Communications; Manufacturing; Transportation & Distribution; Recreational; Art & Music; Science And Research; Technology Development; Consciousness; Learning** | **Strategic Planning And Preservation; Operations & Maintenance; Incident Response** | **Not Identified In This Table** |

**Table 3.** Habitat Service System > Sectors: *The Habitat Service Systems and their secondary sub-systems. This table layout of the service systems (i.e., their aggregation) allows for, or otherwise facilitates, economic calculation. Life, technology, and exploratory services all have a final user demand. Life and Technology services have an intermediate demand, and two exploratory services of Scientific Discovery and Technology Development, also have an intermediate demand. To have an intermediate demand means to require something necessary for production of the final demand by the user.*

| Top-level Habitat Aggregated Service Systems | Secondary-Level Habitat Aggregated Service Systems | Service Platform Tasks | Service Platform Resource Compositions and Allocations |
|---|---|---|---|
| NEEDS | DEMANDS | OPERATIONS | RESOURCES |
| **Life Support Service** System | Architectural service | ... | ... |
| **Life Support Service** System | Water service | ... | ... |
| **Life Support Service** System | Cultivation Service | ... | ... |
| **Life Support Service** System | Power Service | ... | ... |
| **Life Support Service** System | Medical Service | ... | ... |
| **Technology Support Service** System | Information Service *(Storage and Processing)* | ... | ... |
| **Technology Support Service** System | Communications Service *(Devices and Protocols)* | ... | ... |
| **Technology Support Service** System | Transportation Service *(Machines and Protocols)* | ... | ... |
| **Technology Support Service** System | Materialization Service *(Machines and Protocols)* | ... | ... |
| **Exploratory Support Service** System | Scientific Discovery Service | ... | ... |
| **Exploratory Support Service** System | Technology Development Service | ... | ... |
| **Exploratory Support Service** System | Learning Service | ... | ... |
| **Exploratory Support Service** System | Recreation Service | ... | ... |
| **Exploratory Support Service** System | Art & Music Service | ... | ... |
| **Exploratory Support Service** System | Consciousness Service | ... | ... |

# Habitat System Master Planning

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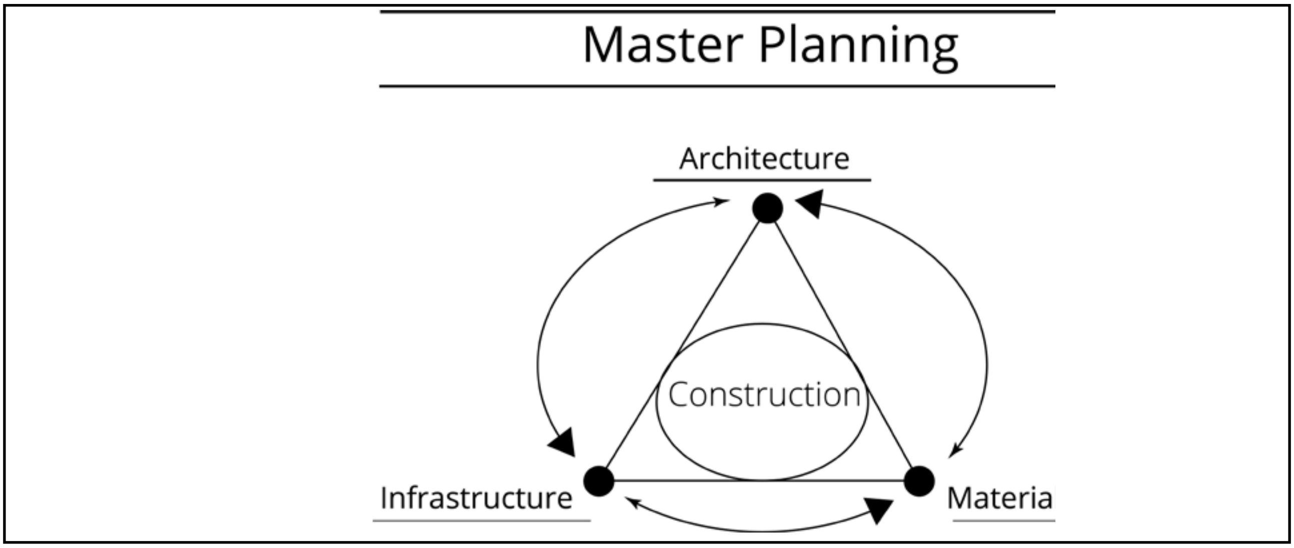
## Abstract

A planning approach is required in order to construct in alignment with the need fulfillment of all of humanity. Human fulfillment can be planned and optimized through master planning (i.e., planning the next iteration of the material environment in a unified and cooperative manner). It is possible to plan out a habitat service system network composed of many individual habitats where services are designed and operate to meet human need. Master planning is the method of developing, operating, and modifying a real-world environment. Master planning optimizes the flow of information and materials throughout the material environment. Master planning is essential for developing habitats/cities in community. A master plan is a dynamic, long-term planning documentation set. A masterplan (masterplan) is developed and operate for the whole network of habitats, with a masterplan existing for each individual habitat and the network as a whole. Everyone in the network can see the masterplan. In a way, the term masterplanning is simply another term for systems development, and in the material system, the system under development is a habitat service system network. Material master plans include necessary accountings for the material system (land, resources, etc.) as well as habitat service solutions (life, technology, and exploratory).

## Graphical Abstract



# 1 Master planning a habitat

*A.k.a., Habitat master planning, city master planning.*

The master planning of resources for a [state] of the habitat involves many sub-plans and solutions. For example, architectural life-support service plans ensure that architectural services are planned for within the decisioning for a material/habitat service system. The planning of the new state of the habitat service in general, and the architectural sub-system in particular requires an adequately informed and coordinated [master] plan. Master plans are material state change processes (i.e., plans that allow for changes to the state of the material, habitat service system. In other words, master planning is the process of creating a plan that will intentionally modify the material state of the material/ habitat service system. Master planning merges the human experience [of needs] and science [knowledge] to realize the visions of individuals among society. Simply put, master planning is a process (framework) for how a location can change [its state]. Optimally experienced habitat service systems (cities) are brought into, and sustained in, existence due to the decision to integrate master plans (i.e., the integration of master plans into societal decisioning).

Master plans define long-term development for specific built objects and sites. For architecture master plans include considerations related to current and future infrastructure, site development, site circulation, and spatial relationships. A master plan may establish the process for staged implementation over time.

The given or future state of the habitat service system includes:

1. Plans (master service and object plans)
2. Materiality (visible and invisible; resources)
3. People (teams)

Outputs of Decision System Inquiry Processes results in state changes to the habitat environment. The state of the habitat service system is changed based upon a unified and controlled master plan. Each service and object within the habitat service system needs to be planned. These service and object master plans are organized as projects, completed, and then added to Decision System processes:

1. Organize for pre-project planning
2. Select project alternatives
3. Develop a project definition package
4. Develop a master planning package
5. Decide whether to proceed with project
6. Integrate master planning package into the Decision System Solution Inquiry Process

There are two types of master plans decided upon within the societal information system:

1. **A unified master plan** for the habitat. This is a/the master specification plan for the habitat (global and local).
   A. Future master plan for the habitat (i.e., for the state of the habitat service system).
   B. Currently active master plan for the habitat (i.e., for the state of the habitat service system).
2. **Specification plans (block plans)** for habitat service sub-systems and associated objects. These are individual plan "packages" that represent possible changes to the habitat service system for which they represent. These plans are integrated into the decision system as possible solution plans (a.k.a., solution systems) for the habitat and its various services and objects. Each habitat system and object has its own [solution] specification plan (a.k.a., service block plan).

## 1.1 Master planning for projects

**NOTE:** *It is desirable to obtain total agreement from the entire project team regarding these objectives and priorities to ensure alignment.*

The project planning of a habitat involves a set of phases that continuously design, build, and close (or, operate) new states of a habitat [service system]:

1. **Phase 1: Building the project team**
   A. List stakeholders
   B. Identify working group (if applicable)
   C. Identify habitat InterSystem service team or InterSystem Habitat Team (if applicable)
   D. Identify resources and tools
2. **Phase 2: Project definition (establish the context)**
   A. Define project (goals, purpose, objectives)
   B. Establish current state
   C. Identify needs
   D. List priorities
   E. Define objectives
   F. List available data and gaps to be filled
3. **Phase 3: Solution definition**
   A. List requirements
   B. List outcomes of project
   C. List available solutions to project
4. **Phase 4: Plan definition**
   A. Approach identification
      1. Outline of phasing, tasking, and scheduling (project coordination)
      2. Local context
   B. Direction identification
      1. Purpose and goals (mission and needs)
   C. Execution identification

   1. Operational criteria
   2. Evaluational criteria
5. **Phase 5: Execution (implementation)**
   A. Execute the phases of the plan, either synchronously or asynchronous as appropriate.
   B. Control the implementation of the plan by means of monitoring, communication, deciding, and acting (working) for three types tasks:
      1. Coordination tasks
      2. Human action tasks
      3. Automatic action tasks
   C. Schedule plan by means of time line association between available locations, resources, and actors (e.g., personnel and/or systems).

Master planning for habitat projects is a socio-technical project that involves economic, technical, social, and environmental categories of data:

1. Economic resources - visualization of the flow of objects (resources).
2. Economic production - mechanism by which resources are transformed into good and services to meet needs.
3. Technical knowledge and tools - using knowledge and tools to change, advance, and modify the habitat.
4. Social fulfillment - accounting for the fulfilment of needs in habitat services.
5. Environmental regeneration - accounting for the carrying capacity of the environment, controlled [in part] by site modification.

## *1.2 Master planning openness objectives*

The construction of systems in the real world can be oriented toward specific value states and objectives. The resolution of decisions in a principled manner ensures social navigation is possible:

1. **Objective 1: Open by default**
   A. Use of freely accessible open data has significant social and economic value; therefore, data should be open by default unless there are safety concerns.
      1. Open data improves transparency of decisioning and the community's trust.
   B. Transparency has significant social and economic value; therefore, systems should be transparent by default unless there are safety concerns.
      1. Transparency ensures that true needs are being identified and addressed.
2. **Objective 2: Timely and comprehensive**
   A. Data is valuable only if relevant to its users.
   B. Data should be accessible to its users.
   C. Data should be provided as accurate, comprehensive, and high quality.
3. **Objective 3: Unified integration of system (comparable and interoperable)**
   A. The potential effectiveness and usefulness of datasets increases with improved quality and ease of comparison within and between sets over time, aided with compliance to common data standards.

## *1.3 Master planning of a system's performance, including evaluation and criteria*

A system design and building delivery process is goal oriented and can be represented by a basic system model with the goal of achieving universal design performance criteria for the built system:

1. **Goals (G)** - Herein, user goals are conceptually linked to the elements in the system that are described in the following items. Subgoals (Gs) for achieving system quality can be related to the basic system through modified evaluators (Es), outcomes (Os), and performance (Ps). Thereby, the outcomes becomes the subgoals (Gs) of the subsystem with respective criteria (Cs), evaluators (Es), and performance of the subsystem (Ps). The total outcome of the combined basic and subsystems is then perceived (P) and assessed (C) as in the basic system.
   A. **Performance evaluation criteria (C)** - derived from the user's goals, standards and criteria for the system type. Universal design performance is tested or evaluated against these criteria by comparing them with actual performance.
   B. **Evaluator (E)** - refers to such activities as planning, programming, designing, constructing, activating, occupying, and evaluating a system (e.g., environment, building, etc.).
   C. **Outcome system/object (O)** - represents the objective, physically measurable characteristics of the system (e.g., environment, building, etc.) under evaluation. This includes but is not limited to its physical dimensions, lighting levels, thermal performance, etc.
2. **Actual performance (P)** - refers to the performance as observed, measured, and perceived by those using, occupying or assessing the system (e.g., environment, building, etc.), including the subjective responses of users/ occupants and objective measures of the system.

A built system can be designed and developed by a process that includes a set of development phases, and therein, analytical feedback loops that present a set of evaluation criteria for each phase:

1. **Continuous feedback** into the next design and building cycle
2. **Continuous system performance evaluation** (e.g., building performance) - a qualitative and quantitative measurement that represents the outcome of the system delivery cycle, as well as system performance during its life cycle.
3. **Development cycle (development phases)**
   - Note: Each of the following phases has internal reviews and feedback loops. Each phase is connected with its respective knowledge. This knowledge is contained in system (e.g., building) type-specific data--bases, as well as global knowledge and the literature in general.

   A. **Planning (phase 1)** - A strategic plan that establishes medium- and long-term needs of an organization through needs analysis (and market analysis), which in turn is based on the purpose (mission), goals, and possibly, objectives.

   B. **Programming (phase 2)** - A process leading to the statement of an architectural problem and the requirements to be met in offering a solution. Programming is the search for sufficient information to clarify, to understand, and to state the architectural problem. Note that programming is problem seeking and design is problem solving.

   C. **Design (phase 3)** - The steps of schematic design, design development, working drawings, simulations, and construction documents.

   D. **Construction/fabrication (phase 4)** - The steps of construction and quality control to ensure design and contractual compliance.

   E. **Occupation/usage (phase 5)** - The steps of moving in and starting up the system (e.g., facility/building). The steps of turning on and utilizing the system (equipment/technology). This includes, but is not limited to fine-tuning of the system (e.g., facility, technology) and its occupants/usage to achieve optimal functioning.

   F. **Recycling (phase 6)** - The building or technology may be remodeled for a different function, or this phase may constitute the end of the useful life of a system (e.g., building), where the building is decommissioned and removed from the site. In cases where construction and demolition waste reduction practices are in place, building materials with the potential for re-use will be sorted and recycled into new products. At this point, hazardous materials, such as chemicals are removed in order to reconstitute the site for new purposes.
4. **Analytical feedback loops (for each phase)**
   - Note: Human needs analysis - identification and analysis of all human needs for service.

   A. **Effectiveness review (Loop 1)** - Outcomes of strategic planning are reviewed in relation to issue categories, including but not limited to: site, technology, efficiency, effectiveness, flexibility (modularity), adaptive re-use, initial capital cost, operating and maintenance cost, costs of replacement and recycling at end of the useful life. For the market, this includes: cost estimates and budgeting.

   B. **Program review (Loop 2)** - Outcomes include a comprehensive documentation of the program review involving the user (client), the programmer (InterSystem Team), and representatives of the actual occupant groups (user/client).

   C. **Design review (Loop 3)** - Evaluative loops in the form of design review or troubleshooting. The development of knowledge-based and computer-aided design (CAD) techniques that make it possible to apply evaluations during the design phase. This allows designers to consider the effects of design decisions from various perspectives, while it is not too late to make modifications to the design.

   D. **Post-construction evaluation (Loop 4)** - An evaluation of the construction/fabrication, including an inspection that results in a checklist ("punch list"). A "punch list" lists items that need to be completed prior to acceptance and occupation of the system (e.g., building or technology).

   E. **Post-occupation evaluation, POE / post-startup evaluation (Loop 5)** - An evaluation of the system's (e.g., building or technology) performance. Feedback over time is provided on what works in the system (e.g., facility) and what does not. This evaluation can be used to identify issues and problems in the performance of occupied buildings and further suggest ways to solve these problems. This evaluation is ideally carried out in regular intervals, that is, in two- to five-year cycles, especially in organizations with reoccurring system/building programs.

## *1.4 Habitat customization*

Local habitat service systems are to some extent customized by their inhabitants and what is possible. The buildings, landscapes, and other services are, in a way, like reflections of the people who manifest them.

Their design and appearance give an indication of the occupiers' personality and characteristics. They are a reflection of their integration and realisation, as well as their individuality and sociality.

### 1.5 Habitat dwelling carrying capacity

It is possible to designed with a buffer capacity for housing. Therein, something akin to 5-15% of the dwelling could remain unoccupied. This allows for:

1. Temporary expansion of the population (as in the case of visitation).
2. Always available housing alternatives.
3. Possible emergency housing in case of a disaster.

### 1.6 Master planning construction

The master planning of construction involves the following data sets:

1. **Surveying to produce surveys:** All land surveys and assessments must be present.
    - Surveys are databases and drawings that show what sub-systems are to be located where.
2. **Architectural-engineering to produce a full system plan:** Design and select component systems (fixtures, fittings, and appliances).
    - Fixtures, fittings, and appliances are levels of immobilization of functional systems/ technologies in the architecture. In a sense, these are technologies (equipment or accessories) that are fixed in some way to the architectural environment. They are the components that makeup the technological infrastructure of an architectural unit.
3. **Constructing to produce a fully realized system:** herein, the components (fixtures, fittings, appliances)have tools applied to them to form the completed operational-habitat system [as planned in the architectural-engineering plan].
    A. The plan, including tools, to fully construct the system in the real world.

## 2 Master planning: Market interface

Market master planning includes three primary financial categories and an fourth contracts (conditions and restrictions list):

1. **Total currency available now** *(capacity for action in the market-State; budget)*
2. **Total inflow of currency** *(contribution of currency; contributions)*
    A. Funding (including: business funding plan)
    B. Selling (including: business sales plan)
3. **Total outflow of currency** *(purchasing of services; expenses)*
    A. Costs (including: fees, taxes)
4. **Contracts** *(identification of accountability; legality)*
    A. Agreements (associated with: all relationship accountabilities and financial costs)

The procurement of services and systems from the market necessitates financial documentation:

1. Bid tabulations
2. Purchase orders
3. Vendor information
4. Receipt *for procured system*
5. Inspection *of procured system*
6. Dispute mediation (contracts and law)

1. Accounting reports - a financial statement consists of:
    A. Balance sheet - tells the user the financial status of assets and liabilities by a given date.
    B. Earnings statement (profit and loss): tells the user the financial status by Income Less Direct (job) costs, and Indirect (overhead) costs = profit, or loss.
2. Contract negotiations
    A. Estimate scope of services.
    B. Estimate time, costs, and profit.
    C. Determine method of compensation:
        1. Percent of construction cost.
        2. Lump sum.
        3. Hourly rates.
        4. Hourly rates with maximum "upset" ("not to exceed")
3. Contract checklist (checklist; everything must be put in writing)
    A. Detail scope of work, no interpretation necessary.
    B. Responsibilities of both parties.
    C. Monthly/weekly/daily progress payments.
    D. Interest penalty on overdue payments.
    E. Limit length of construction administration

phase.

F. Construction cost estimating responsibilities.
G. For cost-reimbursable contracts, specify provisional overhead rate (changes year to year).
H. Retainer, applied to fee but not to costs.
I. Date of agreement, and time limit on contract.
J. Approval of work:
    1. Who
    2. When
    3. Where
K. Ways to terminate contract, both parties.
L. For changes in scope, bilateral agreement and an equitable adjustment in fee.
M. Court arbitration remedies and who pays legal fees.
N. Signature and date by both parties
O. Limits on liability.
P. Time limit on offer.

# 3 Master planning: Local population relationships

Relationship master planning involves engagement with the local population. Positive working relationships must be developed with the local and surrounding populations.

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# **Life Support:** Architecture Service System

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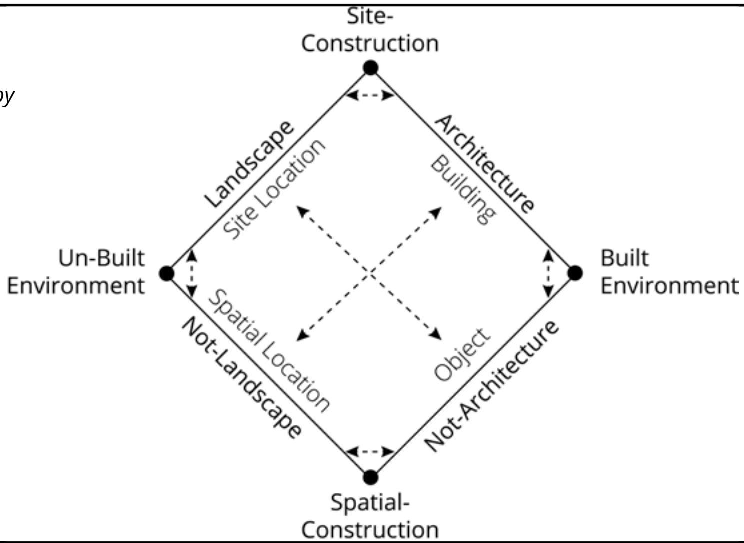
## Abstract

There are several different common names for that which has been engineered to separate humans and their objects from external environmental influences. The name given to the results of this process is varied, and often, discipline dependent. Most simply, the name given to any such deliverable could be "structure" - something created on land or some other platform used to contain ("house") humans and selected objects. The fundamental purpose of any structure is to control the separation of two objects or two concepts. In the process of separation, a pre-existing flow of information and/or matter may be changed. Hence, structural change often conveys functional change, because there is always motion. Other names for a structure include, infrastructure, architecture, buildings, and clothing *(these are all structures)*. Structures can be on a physical individuals person, such as clothing. Structures can be positioned on land and on other surface platforms. Most structures are buildings. Inside building structures are a sub-structure called a room. Buildings (structures) can consist of one or more rooms. Some structures are not buildings. Some structures are not buildings per say, but are containers of objects with useful function (for example, a light post or radar array). Technically these structures are still buildings; they are just buildings designed to "house" technology and not humans. Similarly, there are structures used (interacted with) directly by humans, such as merry-go-rounds and boats. There is also the possibility of structures with purely aesthetic (Read: look and/or feel) function and no ability to contain other objects.

## Graphical Abstract

**Figure 13.** *The architectural representation of a structure on a landscape or other platform for use by humans or having some other function.*



# 1 Architecture

*A.k.a., Architectural engineering, architectural-engineering.*

**NOTE:** *Architecture is the most interconnected habitat service system because architectural constructions includes and contain many, if not all, of the other habitat service systems.*

Architecture is the designing, building, and operating of human and/or machine utilized, generally static, structures on land; however, there are related architectural constructions that are not land based. Architecture is any built structure that occupies space on land, water, or in space. More simplistically, architecture is both the process and the product of planning, designing, and constructing buildings and other physical structures into the physical environment. It refers to the materially built environment and necessarily involves mathematics and engineering. Another possible definition is based on enclosure -- architecture is a sturdy enclosure. If a person or object can go inside of a structure, then it is considered architecture. In this sense, architecture is the reordering (reorganization) of the material environment to produce and operate enclosures for biological life and machines. When expressed materially, architecture becomes the spatial structures we use to contain objects and pass time within. Architecture is the physical structures, both permanent and impermanent, which are created into the habitat's landscape (or oceanscape/spacescape) for any period of time. Therein, an architectural space is the void between physical boundaries of the enclosures where its existence is independent of the user's presence. In a design sense, architecture is a communicable representation of that which has been constructed or could be constructed into the "built" environment, and is not, a device. In its physical application, architecture becomes the integration of structures, materials, and construction technology. Architecture (or, architectural structures) are human-made constructions simultaneously driven by functional, engineering, and often, aesthetic considerations (Read: feeling and beauty). Most architecture is expression of function and aesthetics -- an architectural space exists is to meet both (often) physical and psychological needs. The design of structures (i.e., when doing "architecture") involves working with elements that are put together to accomplish a life-orienting function - the use of structure to control for environmental variables in a given space. Architectural structures must satisfy the needs and aesthetics of their users. They must also be safe, since they will ultimately be used by people and/or machines.

Architecture has to do with planning, designing and constructing form, space and ambience to reflect functional, technical, social, environmental and aesthetic considerations. Its realization involves the reconfiguration and coordination of materials and technology. Just like social organization can produce a social "navigational" model, decision organization can produce a decision resolution space, the product of architectural work is typically drawings, plans and technical specifications, defining the structure and/or behavior of an architectural system that is to be, or has been, constructed. Architecture concerns the behavior of humans in how they use an environmental space, as well as how the structure of the space relates to its own surrounding.

**NOTE:** *The definition of architecture as a permanent structure, or even, a land-based structure, is imprecise. In concern to permanence, what is temporary? One hour, one day, one year?*

Some architecture is spatially mapped to a specific geographic coordinate (e.g., buildings). Other types of architecture move position regularly (e.g., boats, vehicles, and clothing) move, and so their geographic coordinates change, sometimes rapidly, with time. From a high-level view, architecture may be depicted as objects on a geo-spatial map that represent relationship boundary elements and circulation spaces.

**NOTE:** *In the habitat service system standard, architecture that relates to neither the building nor non-building architectural categories is generally detailed in its own section of the standard. Note that most Life Support and Technical Support service systems in the habitat are interrelated and interconnected.*

1. Building architecture (a.k.a., building structures, buildings) - a building or shelter.
2. Non-building architecture (a.k.a., non-building structures) - something other than a shelter.
   A. Bridges.
   B. Tunnels.
   C. Pools.
   D. Canals.
   E. Furniture.
   F. Coastal defenses.
   G. Etc.
3. Landscape architecture (a.k.a., cultivation architecture).
   A. Planters.
   B. Ponds.
   C. Etc.
4. Transportation architecture.
   A. Road (including specialized roads like runways).
   B. Railways.
   C. Paths.
   D. Pipelines (pipeline architecture, pipeline engineering).
   E. Vehicles (vehicular architecture, vehicular engineering).
   F. Boats (naval architecture, maritime engineering).

   G. Spacecraft (space architecture, spacecraft engineering).
   H. Etc.
5. Power architecture.
   A. Dams.
6. Clothing architecture.
7. Monuments (a.k.a., monumental architecture; generally classified as a form of art and not traditional architecture).
8. Hardware architecture (a.k.a., devices, tools, and equipment; note this type of architecture is classified separately from traditional; software architecture is similarly classified separately).

It is relevant to note here that the most generalized use of the term 'architecture' is used to refer to the design of a structure. A 'design' is a set of relationships that form a constructable and functional object or service, which necessarily has a structure. In other words, a 'design' is a description of a construction, which may or may not have been constructed.

> **NOTE:** *In the broadest sense, every material construction is the result of 'architecture'. Physical architecture is not limited to buildings. If something involves a relationship with material form, then it involves the generalized concept of architecture. However, not all processes are architectural processes.*

Architecture is a life-support functional service, which has historically been given the survival-oriented term "shelter". A shelter is designed to protect its occupants from weather fluctuations and functions to cancel out a large portion of the 'variety' of the surrounding environmental climate. Clothes, shoes, and buildings are all part of this "primitive skills" category known as "shelter". In community, that which has historically been known as "shelter" is now called "architecture" (which, is inclusive of platforms, technologies, and decor).

> **CLARIFICATION:** *There is a significant requirement here to clarify some common architectural terminology. The term, 'structure', has many contextual applications. In general, a structure is an arrangement and organization of interrelated elements in a material object or system. Material structures include man-made objects such as buildings and machines, as well as natural objects such as biological organisms, minerals and chemicals. Abstract structures include data structures in computer science and musical form. Conceptual structures include information structures in the form of information models.*

An architectural space is not an independent entity from its environment; separations and integrations between the space and its environment shape experiences. An architectural space is defined by its geometry and materiality. Geometrical characteristics define its form, proportions and dimensions, while materials express its appearance. Generally speaking, there are several high-level categories of architecture: A complete architectural design ought to include all aspects of perception, including human and machine (where applicable) perception. Space perception is a concept that includes the use of all human senses, and also machine sensors. Sight and hearing are the two most important ones. The other minor senses of smell, touch and taste are involved in a secondary way when experiencing a space. (Rodríguez-Manzo, p.1, 2010)

Note that many types of society are capable of being identified by their architectural constructions. However, such a label would be an imprecise representation of the totality of a given society because it doesn't account for the societal living system as a whole, which necessarily includes a social organization, a decisioning organization, and an expressed lifestyle.

> **NOTE:** *Among community there is always a purpose to [architectural] presence, where architecture becomes an emergent completion of nature for climactic survival and flourishing.*

## *1.1 Architecture as a service*

Within a habitat service system, architecture is the service that develops, constructs, disassembles, and sometimes, operates, architectural systems. Architecture is a life support service function within the habitat service system. Some architectural systems are used and operated by the architecture service system, whereas other are used and operated by other service systems, although they still include architectural service InterSystem team functions.

As a life support service, architecture provides:

1. Buildings.
2. Non-building structural architecture, such as:
   A. Bridges.
   B. Tunnels.
   C. Pools.
   D. Furniture.
   E. Etc.
3. Clothing.
4. Architectural objects and systems for other habitat service systems, including but not necessarily limited to:
   A. The cultivation service system, such as: planters, ponds, etc.
   B. The transportation service system, such as: roads (including, bridges and tunnels), paths, vehicles, boats, spacecraft, etc.
   C. The art and music service system, such as monuments.

**TERMINOLOGICAL CLARIFICATION:**
*Throughout this article, the word 'building' may sometimes, depending on context, be used to mean any architectural system, such as a tunnel, pool, or even clothing.*

### 1.1.1 Architectural design

*A.k.a., Building design.*

In the market-State, building design (though more generally, architectural design) is separated at a high-level into the following categories (or disciplines):

1. Architecture.
2. Structural engineering.
3. Civil engineering.
4. Construction engineering.
5. MEP engineering (mechanical, electrical, and plumbing).
6. Other engineering (e.g., fire suppression, rainwater flow, etc.).

These disciplines all involve:

1. Connecting design to function[al] operation.
2. Connecting design to fabrication/construction and eventual disassembly/destruction.
3. Connecting design to site.
4. Incorporating architectural system data or building data (i.e., data about the current and/or future operation of the architecture and the architectural-engineering services within it; for example, about a building and the services within it).

### 1.1.2 Architectural design considerations

Different architectural types have different goals for the type of space and usage they want to create. The design of any given architectural construction confers the following four characterizations (i.e., the design of an architectural system can be categorized by the following high-level design elements):

1. **Architecture type:**
   A. What is the primary function(s) of the architecture?
   B. If a building, what is the occupancy size of the building (for persons and/or equipment)?
   C. If a non-building system, what is the size requirement?
   D. What materials compose the construction of the system?
2. **Activity type** *(function transfers from architecture type)***:**
   A. What activities will occur within and around the architecture?
   B. What equipment do those activities require?
3. **Space type** *(equipment transfers from activity type)***:**
   A. What are the interior dimensions of areas in the architecture?
   B. What are the surfaces of the spaces composed of?
   C. What objects will be used in those space?
4. **Affect type** *(felt sensation transfers from space type)***:**
   A. How will the user/occupant be affected by the building, what will the user(s) sense (as being present) in and around the system?
   B. What feelings will the system drive/promote in users?

## *1.2 Building architecture*

In the context of a building, architecture is the conceptual design and fundamental operation of a building-type structure. Building architecture is the sculpting (i.e., re-configuration) of the physical environment to meet a set of user requirements/demands for shelter. Historically, it was the craft of building a shelter. Architecture is the design and process of constructing (and operating) buildings. A building may be regarded as simply an envelope which encloses and subdivides space in order to create a protected environment, one that may serve additional functions. Here, architecture is the designing and building and operating of human and/or machine occupied, generally static, structures positioned on, in, and/or above Earth's surfaces. Herein, an architectural structure is a human-made, free-standing, relatively immobile outdoor (or, underground) construction. Note here that architectural forms are always functional and aesthetic, always three-dimensional, and always user driven. Similarly, architecture is the science and practice of designing and organizing buildings for human and machine occupation.

**CLARIFICATION:** *The language here can sometimes be confusing, for example, it is often said that, "building architecture is the design and construction of a building, while structure is a building or other object built." Of course, architecture includes more than just buildings, and all of materiality has structure. Additionally, building architecture, which generally refers to the overall process of designing, engineering, and constructing a building, also may describe the design/style of a building. Finally, note that the terms building, architecture, and construction can all be used as an object or verb. Structure can only refer an object, whereas structuring can refer to the process of designing, developing, and creating a structure.*

### 1.2.1 Buildings

**INSIGHT:** *The function of architecture is to design spaces that generate wellbeing.*

Human physiology and machines are capable of tolerating only a narrow range of environmental conditions. Beyond this range, health and wellbeing are compromised, and machines fail. Buildings protect their occupants from climactic environmental elements (Read: provide shelter) and protect other habitat system services (Read: provide a built structure within which other services are provided). Through the materialisation of specific types of masses (volumes), architecture is able to create enclosed spaces in the form of structures. A building is a systems; it is an integrated assembly of interacting architecturally related elements, designed to carry out cooperatively predetermined shelter-type functions. A building consists of a collection of spaces bounded by separators of the interior environment, and separators of the exterior environment (the enclosure). The word 'building' is commonly considered to refer to an enclosed structure within which people and/or machines can perform activities (Designing Buildings, 2021). Buildings offer unique possibilities for human flourishing. In general, the term, building, refers any permanent or temporary building but not any other kind of structure or erection, and a reference to a building includes a reference to part of a building.

There are many ways of classifying types of building, including but not limited to:

1. Construction type.
2. Use class (i.e., function or activity type, nature of occupancy).
3. Size.
4. Style.
5. Historic period.
6. Design (for example, form, structure, etc).
7. Performance (for example, energy consumption, accessibility, etc).
8. Jurisdictional-legal definition.

A building is a complex assemblage of physical elements, components, and systems, wherein:

1. **Building assembly (building complex)** - a combination of components.
2. **Building enclosure (building envelope)** - the name given to any part of a building that physically separates the external from the interior environment. Sometimes 'enclosure' is defined as a mass/volume that creates a feeling of contained space.
3. **Building component** - a constituent part of a building (or other built asset) that is manufactured as an independent unit, subsystem or sub-assembly, that can be joined or blended with other elements to form a more complex item. Generally, components are 'self-contained' and sourced from a single supplier, typically the complete unit provided by that supplier rather than its constituent parts.
4. **Building elements** - the main components of a structure like a bridge (foundations, piers, deck) or a building (floors, walls and roofs).

Enclosures are either monolithic or composite assemblies. Monolithic enclosures involve a single material acting as the structure, the cladding, and the interior finish. In composite assemblies, separate materials or combinations are assigned critical control functions, such as control of heat transfer or air leakage.

The physical components of a building enclosure include:

1. The roof system.
2. The above-grade (above ground) wall system (including windows and doors).
3. The below-grade (below ground) wall system.
4. The base floor system.

The principles of a building enclosure include:

1. Strength and rigidity.
2. Control of heat flow.
3. Control of air flow.
4. Control of water vapour flow.
5. Control of liquid water movement.
6. Stability and durability of materials.
7. Control of fire.
8. Control of climactic elements.
9. Aesthetic considerations.
10. Cost (market only).

In general terms, enclosure types include can be categorised as the following:

1. Compact or distributed.
2. High rise or low rise (relative).
3. Massive or lightweight.
4. Passive or active.
5. Permeable or impermeable.
6. Single or multiple units.
7. Temporary or permanent.
8. Transparent or opaque.
9. Hybrids: Combinations of the above.

In the design of buildings, there are also considerations relating to the natural phenomena occurring in the external world, and the functions required to sustain structures within that environment. Some of the environmental phenomena, or 'loadings', that can impact on enclosure include:

1. Gravity (i.e. structural loads).
2. Climate and weather.

3. Seismic forces.
4. Noise and vibration.
5. Soil type.
6. Topography.
7. Organic agents (i.e. aerobic life forms such as insects and mould).
8. Inorganic agents (i.e. natural and artificial substances such as radon and methane).

The general functions of the building enclosure may be divided into four areas:

1. **Support** - to resist and transfer all structural forms of loading imposed by the interior and exterior environments.
2. **Control** - of air transfer, heat, sound, access and security, privacy, the provision of views and daylight, and so on.
3. **Finish** - the enclosure surfaces in terms of visual, aesthetic, durability, and so on.
4. **Distribute** - services or utilities such as electricity, communications, water, and so on.

### 1.2.2 Building systems

**NOTE:** *The term building herein refers to the built structure, not the process of constructing the built structure.*

Building systems refers to all of the sub-systems within a building, including coordination and control systems. These systems include, but not limited to:

1. Atmospheric systems
2. Building automation and control systems
3. Curtain systems.
4. Building energy management systems
5. Building heating systems
6. Building management systems
7. Electrical control systems
8. Fire detection and alarm systems
9. Floor systems
10. Heating and cooling systems
11. Intelligent building management systems.
12. Infrastructural systems
13. Lighting systems (light control systems, illumination control systems)
14. Networking systems
15. Roof systems
16. Sanitary and septic systems
17. Security systems
18. Shading systems
19. Solar thermal systems
20. Structural systems
21. Thermal systems
22. Walling systems
23. Water systems (plumbing systems)

### 1.2.3 Building spaces

In buildings, spaces are provided for various activities to take place. In some cases a space is only suitable for one activity, for example a kitchen, but an "activity hall/room" may, for example, be used for assemblies, sports, concerts and dramas. Also classed as spaces are transport corridors that run between two locations. There are hundreds of different types of spaces, each related to the category of activity or general types of activities that can take place in those space. There are also open spaces. Note here that large areas upon a landscape, which may or may not have buildings placed on them, are also called 'spaces', but more commonly known as 'zones'.

Note here that building complexes (buildings with many spaces) can also be broken down into individual activities, such as exercise space, sleeping space, eating space, working, etc.

#### *1.2.3.1 Interior design*

Interior design is the science of understanding behaviors and preferences to design functional and aesthetic rooms within a building. Interior design includes both technical and aesthetic solutions.

## *1.3 Architectural processes: architecture, engineering, construction, and demolition*

There are several processes and accompanying roles (a.k.a., architectural disciplines) involved in bringing an architectural structure (object, building, etc.) into existence, and possibly, removing it from existence:

1. **Architecting (role: architect) is:**
   A. The process of coming up with some kind of solution for some kind of architectural problem with an associated set of architectural requirements.
   B. The process of creating and building an architectural object/structure.
   C. The process of conceiving, defining, expressing, documenting, communicating, certifying proper implementation of, maintaining, and improving architecture throughout an architectural system’s life cycle.
2. **Engineering (role: engineer) is:**
   A. The process of calculating the structure (notably, load bearing structural elements) of an architectural system.
   B. The process of designing and calculating the utility infrastructure for an environment.
3. **Architectural-engineering (role: building engineer) is:**
   A. Understand and design the architecture.

   B. Understand and design the engineered sub-systems of the architecture (e.g., structural, electrical, HVAC, etc.)
   C. Integrate engineeried systems in the building envelop.
4. **Constructing or fabrication (role: construction manager, fabrication coordinator, constructor, builder, contractor) is:**
   A. The process of constructing (fabricating and assembling) an architectural system.
5. **Demolition or recycling (role: demolisher, and also, constructor, builder, contractor) is:**
   A. The process of disassembling and possibly recycling an architectural system.

The **role of the architect** (or, architectural processes) generally involves:

1. **Concept design** - produces concept design documents.
2. **Total object development planning and monitoring** - produces object development documents.
3. **Construction planning and monitoring** - produces construction documents.

The **role of the architectural-engineer** (or, architectural engineering processes or building engineering processes) generally involves:

1. **Calculating what is physically possible and optimal for architectural related subsystems** - produces engineering documents with complete descriptions, formula, calculations, results, and alternatives for both the structure and utilities infrastructure.
2. **Architectural-engineers design, assess, and inspect** - infrastructural systems to ensure that they are efficient and stable.

The **role of the structural engineer** (or, engineering processes) generally involves:

1. **Calculating what is physically possible and optimal for structural related subsystems** - produces engineering documents with complete descriptions, formula, calculations, results, and alternatives for both the structure and related elements of the infrastructure.
2. **Structural engineers design, assess, and inspect** - structures to ensure that they are efficient and stable.

The **role of the civil engineer** (or, engineering processes) generally involves:

1. **Calculating what is physically possible and optimal for civil related subsystems** - produces engineering documents with complete descriptions, formula, calculations, results, and alternatives for both the structure and utilities infrastructure.
2. **Oversee** - a variety of workers, including construction managers, architects, and mechanical engineers.
3. **Civil engineers design, construct, maintain and improve** - the non-building systems (e.g., bridges, tunnels, roads, etc.).

The **role of the constructor** (or, constructing process) generally involves:

1. **On-site construction coordination** - uses construction documents. This phase produces the final object(s).

The **role of the demolisher** (or, demolition process) generally involves:

1. **Pre-demolition design** - to ensure the building can be demolished safely by means of a analysis and plan.
2. **On-site disassembly and demolition coordination** - uses construction and demolition documents. This phase removes the final object(s) from existence.

## *1.4 Architectural-engineering*

> *A.k.a., Architectural engineering, building engineering, structural engineering, infrastructural engineering.*

All architecture is [also] engineered; it is often more correct to use the term architectural-engineering as opposed to the term architecture alone. Architectural-engineering is always dependent on the allocation of resources, physics, and human effort. Architectural-engineering combines all aspects of building design and construction, including mechanical, electrical, structural, infrastructural, calculations, and other mathematical precision notions.

> **CLARIFICATION:** *In academia and the building industry, architects are guided more by aesthetic, functional, and spatial design [of buildings], whereas architectural-engineers are guided more by an integration of functional design, aesthetic design, and engineering principles [in the construction, planning,*

*and design of buildings]. It is often observed in the early 21st century that architectural-engineers use more technology and integrated design methods than architects whose creations are deeply rooted in subjective artistic expression. In this sense, it is possible to think of architectural-engineering as an extension of architecture. The architecture uses spatial planning to produce drawings (floor plans, sections, and elevations) evaluated by engineers for physical constructability. Note that in the architectural industry in the 21st century, some architecture firms are also architectural engineering firms, which means that they don't have to outsource their projects and can maintain full control of a project from start to finish.*

### 1.4.1 Engineering

**CLARIFICATION:** *In general, engineering is the process of designing, inventing, building and maintaining machines, structures, tools and other things that are a part of daily technical life fulfillment.*

Architecture is an operational service process accounted for by habitat design and development. Engineering is a knowledge application process for designing and developing systems and services, including architectural services. Engineering is the application of mathematics, empirical evidence, as well as scientific and practical knowledge in order to invent, design, build, maintain, research, and improve structures, machines, tools, systems, components, materials, and processes. All architecture is engineered. Engineering involves the application of scientific principles to a design to ensure it functions as intended. Engineering necessarily involves mathematical calculations.

When it comes to architecture there are rules. There are rules because you don't want a roof caving in on you or your clothing failing when you are at risk to exposure.

In the context of the socio-technical decisioning of a community-type society, architectural-engineering is part of the solution inquiry process of the Community's common decision space. One could state that "architectural engineering" is the application of engineering principles and technology to architectural design and construction.

To understand the interrelationship between architecture and engineering in community design it is important not to have your thinking limited by the language of a paradigm where all economic work is segregated into labor disciplines like "mechanical engineering", "architecture", and "industrial engineering". Instead, it is important to think in terms of systems and the ecologies of systems. All architectural design requires engineering, and we engineer everything that comes into material service as part of the habitat service system, which exists in an ecological dynamic with a larger environment.

**NOTE:** *In engineering, adventurousness is akin to incompetence.*

#### *1.4.1.1 Architects and civil engineers*

In the market-State there are differences between the architectural and civil engineering professions (note, however, that these differences are not universal and may not always carry over to a community-type society):

1. Civil engineers manage a broader range of projects encompassing transportation infrastructure and water systems, while architects focus on buildings.
2. Architects are more deeply involved in the pre-construction phases, while civil engineers directly oversee all phases of construction work. However, in the case of residential project, it is often the construction manager, or sometimes the architect, that oversees all phases of construction.
3. Civil engineers oversee a variety of workers, including construction managers, architects, and mechanical engineers.
4. Architects spend a majority of their time in offices, while civil engineers divide their time between desk work and direct site supervision.
5. Both roles require a bachelor's degree and state licensure, but civil engineers often earn advanced degrees to secure a senior position.

#### *1.4.1.2 Architects and structural engineers*

In the market-State there are differences between the architectural and structural engineering professions (note, however, that these differences are not universal and may not always carry over to a community-type society):

1. Architects manage the whole architectural project.
2. Structural engineers run do analysis and run calculations on the structural efficacy and viability of the architectural structure.

### 1.4.2 Building science

*A.k.a., Building physics, building engineering physics, architectural science, etc.*

In general, building science (a.k.a., building physics) refer to the knowledge of the physical behaviour of buildings and other built systems (a.k.a., architectural system) and their impact on energy efficiency, comfort, health, safety, durability, etc. This is the application of the principles of physics to the built environment. An understanding of building science is vital if the design of buildings is to be optimised and the performance of buildings maximised. The term, 'building engineering physics', usually relates more specifically to the energy performance of buildings and the impact of a building on the indoor and outdoor environments. By properly understanding the physics of the built environment it is possible to develop high performance buildings that are comfortable and functional, and to minimise the negative environmental impacts of their construction and operation. Building science applies empirical techniques to architectural design problems, and explains why buildings work and why they fail.

Aspects of building design that might be considered 'building science' could include, but are not limited to:

1. Acoustics.
2. Air movement.
3. Building construction.
4. Building demolition.
5. Building life cycle assessment.
6. Building materials.
7. Building structures.
8. Building services and operations.
9. Building systems integration.
10. Climate and weather.
11. Energy modelling.
12. Façade engineering.
13. Fire and hazardous materials analyses and control.
14. Heating, ventilation and air conditioning.
15. Natural and artificial lighting.
16. Moisture and condensation analyses and control.
17. Passive building design.
18. Physiology and thermal comfort.
19. Smart/intelligent building technology (automation technology).
20. Sustainability.
21. Thermal performance.

> **QUESTIONS:** *How do we scientifically respond to architectural needs, and how we might best design our architectural environments to fulfill our requirements?0.*

## *1.5 Architecture and consciousness*

> **APHORISM:** *We shape our buildings and later our buildings shape us. We build the roads, and then, the roads build us. We make the house, and then, the house makes us. We build architecture, and then, the architecture builds our lifestyles and shapes our lives.*

Architecture reflects consciousness and directs its experience. Architecture can facilitate or get in the way, of us experiencing the fullest from our environment. We don't want to put up façades that block our direct experience. Our creations can just as easily trap things in, as keep things out.

> **NOTE:** *Space has socio-technical power relative to its configuration. Architecture can reconfigure "power" relationships in society. Who is excluded and included from the space is essentially the difference between utopia and dystopia. Architecture that uplifts everyone.*

Architecture is, in a way, a reflection of those people who have manifested it and maintain its construction. Materializations (e.g., buildings, landscapes, and technologies) are, in a way, like reflections of the people who manifest them. Their design and appearance give an indication of the occupiers' characteristics and understandings. They are a reflection of their integration and realisation as well as their individuality. The materializations of a population are a chosen representation of its character.

> **INSIGHT:** *Momentum represents forward movement. Monuments represent movement in the past. A current theory is like a monument made to an old fact. Most of early 21st century society has lost all momentum and has become a monument to old thoughts.*

Architecture can shape us (our thinking and behaviors) in ways that we don't realize, and yet, are highly predictable.

> **INSIGHT:** *All architecture with a habitat service system exists within a social context.*

## *1.6 Atmospheric sightlines*

> *A.k.a., Sight line, visual axis.*

Ground foundationed (a.k.a., above ground) buildings take up space on the land. A sightline is an unobstructed line of sight through the atmosphere between an intended observer (spectator) and a subject of interest, such as a building, area, etc.

> **INSIGH***t: In community, buildings turn into "sculptures" when seen from a distance.*

### 1.6.1 Architectural aesthetic pollution

Early 21st century sightlines are highly polluted with human [mental and commercial] "defecant". The question must be asked, Why are people "defecating" in their visual environment? For their very well-being, people do not defecate in the same water they drink from. Why then are they expelling into their visual environment, whatever is in their mind, without consideration given to the larger environment and its many users?

## *1.7 Starchitects*

Modern cities are monuments to "great names" and amusing attractions, most of which are not representative of humankind's true potential for fulfillment. Many architects in the architectural industry, and even among the resource-based economy (RBE) movement, are more akin to "starchitects". The prefix "star-" is intended to mean that an architect has become a celebrity, a "star". Starchitects often copy protect their works. Most starchitects designs buildings as sculptures distinctive to their own subjective whims or the whims of a collective. Here, the term 'starchitect' is a pejorative. Besides copy protecting their work, starchitects create environments where people have to live in and among their artistic and subjective mental creations.

In modern commercialized society the architect designs the look, and the engineer determines how (if the design is novel) to make the look feasible. In community, the results of architecture are a whole integration into a materialized service system, wherein everything encoded into the system has been systematically engineered to do so. The distinction here is between starchitects in the market-State who (1) protect their efforts (thus, limiting cooperation and unification) and (2) do not account for others fulfillment in their work, and material design in a community-type society, where there is (1) no copy protection and (2) recognition of a social population with the potential for greater and lesser states of fulfillment, (and this, the effort to produce integrated and functional systems for that fulfillment).

> **INSIGHT:** *In early 21st century society, architecture works on the principle of money: no money, no building; no money, no access to the architectural drawings.*

Here are some characteristics of the labor-market appearance of a starchitect:

1. Refusal to share their designs openly.
2. Disregard the effort and energy required to construct, maintain, disassemble, and clean the structure.
3. Disregard integration with the surrounding environment.
4. Disregard the integration of service functions, both within the structure itself and with concern to infrastructure.
5. Disregard nature-patterned aesthetics.
6. Disregard the nightmare/headache that an abstract piece of architecture will give to a structural engineer who has to design around the modernist structure.

The labor role of an architect involves the building of structures for others. In community, we build structures for ourselves. Instead of a contextual world of harmonious geometric relationships and connectedness, architects tend to see a world of objects set apart from their contexts, with distinctive, attention-getting qualities. There are many such confirming studies. For example, Gifford et al. (2002) surveyed other research and noted that "architects did not merely disagree with laypersons about the aesthetic qualities of buildings, they were unable to predict how laypersons would assess buildings, even when they were explicitly asked to do so." The researchers traced this disagreement to well-known cognitive differences in the two populations: "Evidence that certain cognitive properties are related to building preference [was] found."

The division of construction by labor role has important consequences for the kinds of constructions that are produced into an environment. The same could be said for the field of engineering. Consider the engineering of living environments around the form of transportation we know as a "car", and the consequences that has had on our movement throughout life space engineered around vehicles. The architectural label, the architectural labor role, and socio-economic compartmentalization can prevent someone from seeing how certain designs disconnect and isolate people, and create hostile environments that cannot be shared well by people physically. Reward in service of effort is unhelpful; it decouples the designer from the context of human fulfillment.

An article by Mehaffy and Salingaros (2011) describes why, in the last half-century, the clear result of architectural construction is buildings whose makers have been so concerned with the drama of their appearance that they fail on the most fundamental human criteria. The following are some adapted quotes from the article.

> *Instead of a contextual world of harmonious geometric relationships and connectedness, architects (people providing the profession of architecture) tend to see a world of objects set apart from their contexts, with distinctive, attention-getting qualities. Their buildings celebrate the individuated form, as objects standing dramatically apart from context. Why do architects see the world in this unique way? Historically, and in part, this behavior is due to the conditioning present in architectural schooling (Gifford et al., 2002). Architectural students are typically asked to produce drawings that are pinned up next to one another, and then evaluated in a "crit" (or critique). In such an abstract setting, it is difficult for anyone to evaluate how well a project integrates with its context, if at all. Moreover, projects that are especially distinctive — object designs that stand out visually in an imaginative way by presenting an unusual structure — tend to get more attention from the faculty, and often, better grades. Those architects get rewarded, and selected out to be the later stars of the profession. Hence, architecture in the market-State has turned into something of a "novelty spectacle". However surprising and novel the forms of today's new architecture might appear, they remain tightly bound within this almost century-old model. The novelty spectacle approach has become the model not just for buildings, but also for whole cities.*
>
> *This focus on object-design has a deeper history in architecture. Up to about 1900, architects were understood to be practicing an*

*adaptive craft, in which a building was an inseparable part of a dynamic living environment. "Blending in" respects the extant complex connective geometry, where components contribute to overall coherence. A building was assumed to meet the physiological and social needs of the people of that neighborhood first and foremost, and only then it would express its aesthetic qualities.*

*Yes, our architect friends share much of the blame for the state of architecture, but let us remember that city officials, corporate executives, urban developers, mortgage bankers, and many others were part of this process of "architectural commodification", creating attention-getting product design rather than good sustainable environmental design. Clients, following what they took to be general consensus on what is great architecture, commissioned architects to build inhuman structures.*

*All of these things are not, of course, trivial. They are the essence of a functional whole community, in which people are able to walk, navigate, feel well, and even feel any desire to live there in the first place. In short, the desires and gut reactions of the individual are the very essence of a great, living city, as opposed to a banal and dysfunctional one. The dysfunction of such image-based urban places — sadly all too common in the post-war era — is what has sent many people fleeing for the suburbs, with their simplistic ideas of retreat into a private garden. This too has turned into a dysfunctional failure of traffic congestion, blighted strip development, and isolated, car-dependent homes.*

*In the early 21st century, many leading architects feel compelled to change the world drastically to make it conform to their preferred industrial paradigm. Unless non-architects (i.e., the rest of the population) stand up to this pressure, we risk the slow loss from attrition of all of humankind's most emotionally-nourishing creations. For example, architects see a well-functioning and beloved urban space but perceive it as ugly and offensive, desperately in need of immediate "re-qualification" to turn it into a contemporary hard industrial object. Politicians are happy to go along so as to please construction companies who profit from the unnecessary tearing down and rebuilding. The result is a sterile open space, unused, dysfunctional, and dead — but in the eyes of the architects, the operation has been a success!*

*Architects spend more time talking to their users, sharing their perception and understanding their needs: not just the architect's selfish need for artistic self-expression, or worse, his/her need to impress other architects and elite connoisseur-critics.*

*We are now dealing with an environment in which such image-based sculptural buildings are imposed upon people, whether they choose them or not. If such buildings "fall down on the job" of meeting human needs — if they are unduly stressful, or damaging to the quality of life — then that is a kind of architectural malpractice, and nothing less.*

*And thus we conclude that "architectural myopia" is a symptom of adopting a contradictory and opposite way of viewing the world. It also explains architects' insistence — continuous, strident, and bordering on the obsessive — of the need to "educate" the public. For every time public debate focuses upon the basic dichotomy in perceiving architectural form between architects and non-architects, the standard response by the former is to beg for more "education" of ordinary citizens, and to dismiss natural human responses to their work as being "unsophisticated" and "philistine". Architects really wish that normal people would undergo the same reversal, and then everyone might agree on the same non-contextual, non-adaptive building aesthetics.*

*Since the non-indoctrinated continue to see complexity and coherence in the living environment and refuse to accept "architectural myopia", the architect's strategy is simply to replace the built environment so that it no longer contains those essential elements of living structure.*

*For example, architects see a well-functioning and beloved urban space but perceive it as ugly and offensive, desperately in need of immediate "re-qualification" to turn it into a contemporary hard industrial object. Politicians are happy to go along so as to please construction companies who profit from the unnecessary tearing down and rebuilding. The result is a sterile open space, unused, dysfunctional, and dead — but in the eyes of the architects, the operation has been a success!*

*A culture based upon an abstract, disconnected conception of space is re-shaping our world right now for the worse. The parallel reality is replacing the living* *one. Enthusiastically supported by politicians and the building industry, architects have been commissioned to destroy historic buildings and urban spaces worldwide. Because "architectural myopia" is justified as perfectly normal in the press, such interventions are praised by their promoters but turn out disastrous for the urban fabric, and are hated by potential users. Those projects all tend to look and feel the same. This is not surprising, since the designs are generated by the same abstract modernist images in the minds of architects oblivious of the connective geometry that would catalyze the eventual life in such a space.*

*We desperately need a new kind of architect: one more focused on process than on systems and context, rather than just objects. We need an architecture that actually optimizes the user (human) experience of the built environment.*

*Firstly, it is important to re-integrate the needs of human beings, including their sensory experience of the world, and their participation into the process of designing buildings and cities. Preparing our new type of architect for practice, we should re-examine the ways that architects are rewarded today: the corrupt and incestuous system of financial incentives, corporate branding, and image-making that rewards the extravagant "starchitect" over the contextual practitioner. Once we have created a consensus for radical change, it will be straightforward to find new ways of compensating good work, through more incentives such as awards, commissions, scientific research that identifies both successes and failures, and other, stronger feedback.*

# 2 Architectural planning

*A.k.a., Building planning, built environmental planning.*

The Life-Support Service Sub-System of Architectural (-Engineering) can be planned, and its plan can be integrated into a unified plan for the Life-Support Service System, and therein, the Habitat Service System as a whole.

## *2.1 Architectural-engineering design timeline*

Architectural-engineering design involves at least the following deliverables:

1. **Services (utility services, architectural services) deliverables**
   A. **Analysis** of identifiable need(s) and selection of specific [architectural] service functions. [Documentation of decision analysis]
   B. **List** of specific architectural service functions. [Documentation of list]
2. **Architectural engineering design deliverables**
   A. **Design development documentation** (A.k.a. design associated development documentation; project planning the architectural sub-systems; including, planning and documentation)
      1. Architectural design plan
      2. Structural design plan
      3. Mechanical design plan
      4. Electrical design plan
      5. Civil design (Municipal hookup design) plan
      6. Landscape design plan
      7. Interior design plan
         i. Fittings, fixtures, and equipment design plan
         ii. Illumination design plan
         iii. Acoustic design plan
      8. Materials plan
      9. Construction (fabrication) plan
      10. Software plan
   B. **Schematic designs** (A.k.a., producing specification designs; including, visualization and text)
      1. Architectural design drawings
      2. Structural design drawings
      3. Mechanical design drawings
      4. Electrical design drawings
      5. Civil design (Municipal hookup design) drawings
      6. Landscape design drawings
      7. Interior design drawings
         i. Fittings, fixtures, and equipment design

drawings
    ii. Illumination design drawings
    iii. Acoustic design drawings
8. Materials specifications
9. Construction (fabrication) drawings
10. Software specifications

## *2.2 Architectural-engineering development*

Architectural-engineering development involves a timeline of tasks, deliverables, and events that include:

1. **Pre-design (Phase 1)**
    A. Project coordination (project administration; project management)
        1. Coordination with team (internal coordination)
        2. Coordination with market
        3. Coordination with State (government)
            i. Who are the authorities that have jurisdictional requirements?
                1. What are the taxation requirements?
                2. What are the duty and customs (etc.) requirements?
            ii. What are the regulatory issues:
                1. Zoning requirements?
                2. Building code requirements?
    B. Programming (a.k.a., functional program, design brief, facilities program, architectural program, user's/owner's statement of requirements, space needs analysis, program) - refers to adding function to form. A functional program describes the requirements which a building must satisfy in order to support and enhance human activities. Generally, functional programs are prepared as part of a design report. The programming process seeks to answer [at least] the following questions:
        1. What is the nature and scope of the problem?
        2. What information is required to develop a proper architectural solution to the problem? What are the site requirements (e.g., parking, circulation, orientation, vegetation, soil type, etc.)?
        3. How much and what type of space is required? What activities will take place in each space or sub-space? What is the functional relationship of the spaces? Visualize spatial relationships in a spatial relationship diagram and/or flow diagrams.
        4. What space will be needed in the next five to ten years to continue to operate efficiently? What is the size of each space? Are there special technical requirements of each of the spaces and systems?
    C. Space diagrams
    D. Survey of existing facilities
    E. Studies
        1. Market studies
        2. Economic studies
        3. Location/situational studies
            i. What are the community goals and concerns?
            ii. What are environmental and ecological concerns?
        4. Jurisdictional studies
        5. Geopolitical studies
        6. Site studies
    F. Project financing - What are the financial requirements for the project?
        1. Permanent financing
        2. Interim financing
    G. Project budgeting - What is the preliminary and post-preliminary budget for the project?
        1. At the predesign phase or beginning of a project, determine the likely budget and what it includes. Verify that this project is financially viable to the greatest extent possible.
            i. Object design cost (OD)
            ii. Object construction cost (OC)
            iii. Fixed equipment cost (FC)
            iv. Site development cost (SC)
            v. Total construction (demolition) cost (TCC) = OD + OC + FC + SC
            vi. Site acquisition cost (AC)
            vii. Transporation cost (TC; movable equipment cost)
            viii. Risk cost (RC)
            ix. Project coordination cost (administration cost) (PC)
            x. Total budget required = TCC + AC + TC + RC + PC
2. **Site Analysis (Phase 2)**
    1. Project coordination (project administration; project management)
        i. Coordination with team (internal coordination)
        ii. Coordination with market
        iii. Coordination with State (government)
    2. Surveys
        i. Needs analysis (program of needs)
            1. Questionnaire / survey
            2. Identification of needs
            3. Identification of functions and services to meet needs.
            4. Analysis of needs; assess capabilities.
                a. Identification of space needed to support functions.

ii. Identify stakeholders
1. List stakeholders - stakeholders which affect and are affected by.
2. Mapping stakeholders - viewpoints and positions (relationships) to each other.
3. Ranking stakeholders - influence and power within the stakeholders.
4. Categorizing stakeholders - set up of groups with identification of their influence to the process.
a. Collaborators
b. Affected by
c. Could affect
3. Site analysis and site selection
4. Site development planning
5. Site utilization studies
6. Utility studies
7. Environmental studies
8. Zoning
9. Project scheduling - What is the time frame for the project?
10. Project budgeting

3. **Design Development (Phase 3)** and **Schematic Design (Phase 4)**
A. Project coordination
1. Coordination with team (internal coordination)
2. Coordination with market
3. Coordination with State (government)
B. Architectural-engineering design deliverable
1. Architectural line and cut measurement and whole 3D object/environment visualization in line layout of whole space with all appropriate cuts, wholes, and all associated data:
i. Space identifiers; boundary identifiers; floor plans; terrain plans; shows locations, positions, and relevant data in a whole space.
ii. Sub-architectural engineering design plans (as sub-deliverables)
1. Structural design
2. Mechanical design
3. Electrical design
4. Civil design
5. Landscape design
6. Interior design
7. Software design
2. Materials research and specifications
i. Materials analysis
ii. Materials specifications
3. Fabrication design and specifications
i. Constructability analysis
ii. Construction specification
C. Project scheduling
D. Cost controlling and cost estimating
1. Cost of land
2. Cost of financing
3. Cost of architectural/engineering (A/E)
4. Cost of terrain modification
5. Cost of construction/fabrication
6. Cost of Furniture, Fixture, and Equipment (FF&E)
7. City or government fees
8. Account for lifecycle costs
i. Initiating costs
ii. Development costs
iii. Operations costs
1. Market costs (obsolescence/replacement costs)
2. Updating, adapting, or module modifying costs
3. State costs (tax, fees)
iv. Maintenance costs (rental costs)

4. **Construction Documents (Phase 5)**
A. Project coordination
1. Coordination with team (internal coordination)
2. Coordination with market
3. Coordination with State (government)
B. Architectural documents
C. Structural documents
D. Mechanical documents
E. Electrical documents
F. Civil documents
G. Landscape documents
H. Interior documents
I. Materials specifications documents (material engineering documents)
J. Fabrication specifications documents (construction documents)
K. Software specifications documents
L. Project scheduling
M. Cost controlling and estimating
1. Cost of land
2. Cost of financing
3. Cost of architectural/engineering (A/E)
4. Cost of terrain modification (sitework)
5. Cost of construction/fabrication (sitework)
6. Cost of Furniture, Fixture, and Equipment (FF&E)
7. City or government fees

5. **Bidding and Negotiating (Phase 6)**
A. Project coordination
1. Internal team coordination check
2. Market plan check
3. Government plan check
B. Pre-qualification of bidders
C. Bidding materials
D. Bidding / negotiations
E. Alternatives / substitutions

  F. Special bidding services
  G. Bid evaluation
  H. Construction contract agreements
6. **Construction and contract coordination (Phase 7)**
  A. Project coordination
    1. Internal team coordination check
    2. Coordination with market
    3. Coordination with government
  B. Field observation
  C. Inspection coordination
  D. Supplemental documents
  E. Change orders
  F. Schedule monitoring
  G. Construction cost accounting
  H. Project closeout
7. **Post construction services (Phase 8)**
  A. Project coordination
    1. Internal team coordination check
    2. Coordination with market
    3. Coordination with government
  B. Maintenance and operational programming
  C. Startup assistance
  D. Warranty review
  E. Post construction evaluation
8. **Supplemental services (Phase 9)**
    1. Special studies
    2. Renderings
    3. Model construction
    4. Life cycle cost analysis
    5. Valve engineering
    6. Quantity surveys
    7. Detailed cost estimates
    8. Energy studies
    9. Environmental monitoring
    10. Client related services
    11. Furnishings design
    12. Equipment
    13. Project public relations
    14. Materials and systems testing
    15. Disassembly services
    16. Relocation/transportation services
    17. Demolition services
    18. Special disciplines consultants
    19. Special building type consultants

**Clarifications:**

1. Costs (including, resources, financial, and labor) can be affected by weather, season, materials shortages, work practices (labor practices).
2. Construction scheduling (timing) can be affected by weather, season, materials shortages, person shortages, work practices (labor practices).

### 2.2.1 Simplification of an architectural project

The following is a simplified procedure with different phases that include tasks that must be completed to complete the whole architectural/building project (note: the project plan for an architectural project consists of multiple simultaneous and following phases):

1. Pre-designed, conceptual design, and research
  A. Building type selection
  B. Building function(s) selection
  C. Building aesthetics selection
  D. Site assessment
  E. Budget analysis
2. Schematic design (preliminary site plan)
  A. Architectural concept design (floor plans, architecture and interiors, preliminary ste plan)
  B. Architectural materials selection (structure, envelope)
  C. 3D massing
  D. Preliminary cost estimate
3. Detailed design (design development, technical drawings and specifications)
  A. Architectural detailed modeling, detailed drawings
  B. 3D model of exterior and interior
  C. BIM model
  D. Architectural materials selection (structure, envelope)
  E. Energy modeling.
  F. Structural engineering
4. Finish, fixture, and appliance selection and integration
  A. Detailed cost estimate.
  B. Construction documents
  C. Architectural documentation.
  D. Structural documentation.
  E. Construction plan
  F. Assemblage (fittings, fixtures, appliances) plan.
  G. Building permit documentation
5. Materials, technologies, and permission procurement
  A. Manufacture and supplier documentation
    1. Manufacturer (made by; works with supplier)
      i. Cost of system
      ii. Availability of system
      iii. Name
      iv. Location
      v. Website
    2. Supplier (distributed by; works with manufacturer)
      i. Cost of system
      ii. Availability of system
      iii. Name
      iv. Location

- v. Website
- B. QTQ and cost estimating
- C. Project scheduling
- D. Building permissioning

6. Project execution
   - A. Site development.
   - B. Work with manufacturers, suppliers, fabricators, transporters, and builders/constructors.
   - C. Unit development
     1. Geometry
     2. Physical properties
     3. Color
     4. Material
     5. Texture
   - D. Punch list
7. Utilization
   - E. Site operation.

The following is a simplified view of the above project phases (architectural-engineering project timeline):

1. Pre-design.
   - A. Needs analysis.
   - B. Initial concept vision.
2. Schematic design.
   - A. Architectural concept design.
   - B. Architectural material selection (structure, envelope).
   - C. Preliminary cost estimating.
3. Detailed design.
   - A. Architecture material selection (structure, envelope).
   - B. Architectural detailed model.
   - C. Energy and other sub-system modeling (e.g., acoustic, etc.).
   - D. Structural engineering.
   - E. Interior design.
4. Construction documents.
   - A. Architectural documentation.
   - B. Structural documentation.
5. Procurement.
   - A. QTQ and cost estimating/budgeting.
   - B. Project scheduling.
   - C. Material procurement.
6. Project execution.
7. Utilization.

The following is an even more simplified view of the above project phases using more general project language (architectural-engineering project timeline):

1. Architecture needs program - what is needed?
2. Feasibility study - what is feasible?
3. Preliminary study - does the concept feasibly meet the need?
4. Preliminary design - the schematic design.
5. Pre-executive project - the detailed design.
6. Executive project - all the architectural, engineering, and construction documentation.
7. Legal architecture project - all legal documentation.
8. Construction project - construct the architecture.
9. Post work project - review the construction.

### 2.2.2 Other views of the architectural planning process

Simplistically, a typical architectural-engineering-construction project might follow stages such as:

1. Stage 1: Societal decisioning (a.k.a., societal justification, or business justification in the market).
2. Stage 2: Feasibility studies.
3. Stage 3: Project brief.
4. Stage 4: Concept design.
5. Stage 5: Detailed design.
6. Stage 6: Production information.
7. Stage 7: Tender (market only).
8. Stage 8: Preparation (mobilisation).
9. Stage 9: Construction.
10. Stage 10: Occupation and defects evaluation period.
11. Stage 11: Post occupancy/usage evaluation.

In 2020, The Royal Institute of British Architects (RIBA ) 'plan of work' stages are [architecture.com]:

1. 0 - Strategic definition.
2. 1 - Preparation and briefing.
3. 2 - Concept design.
4. 3 - Spatial coordination.
5. 4 - Technical design.
6. 5 - Manufacturing and construction.
7. 6 - Handover.
8. 7 - Use.

The BIM Task Group Digital Plan of Work and the Government Soft Landings process map is based on an alternate set of stages:

1. 0 - Strategy.
2. 1 - Brief.
3. 2 - Concept.
4. 3 - Definition.
5. 4 - Design.
6. 5 - Build and commission.
7. 6 - Handover and close-out.
8. 7 - Operation and end-of-life.

The Construction Industry Council (CIC) scope of services adopts [cicbca.org]:

1. Stage 1 - Preparation.

2. Stage 2 - Concept.
3. Stage 3 - Design Development.
4. Stage 4 - Production Information.
5. Stage 5 - Manufacture, Installation & Construction Information.
6. Stage 6 - (Post Practical Completion)

## *2.3 The architectural development process*

*A..k.a., The architectural construction process.*

The standard building and construction process is:

1. Engage stakeholders to determine requirements.
2. Pre-design (which includes programming.
3. Site analysis.
4. Schematic design.
5. Design development.
6. Construction documents.
7. Contract administration during actual construction following documentation and procedures set by a larger authority (or, standards setting organization).

The abbreviations for these phases are generally:

1. Schematic design (SD).
2. Development design (DD).
3. Construction documents (CD).
4. Contract administration (CA; contract documents).

The design through to construction of an architectural structure in the market generally involves the following phases. From start to completion, the industrial-State construction process usually maintains the following phases:

> **NOTE:** *these phases may be repeated, skipped, or modified as necessary for each uniquely purchased construction project.*

1. **Pre-design** - the project is defined by the customer in terms of its function, purpose, scope, size, and economics.
2. **Schematic design (SD)** services develop study drawings, documents, or other media that illustrate the concepts of the design and include spatial relationships, scale, and form for the owner to review. Schematic design also is the research phase of the project, when zoning requirements or jurisdictional restrictions are discovered and addressed. This phase produces a final schematic design, to which the owner agrees. The architect provides a preliminary evaluation of the program, schedule and construction budget developed in the pre-design phase and prepares a number of Schematic Design drawings illustrating the project to review with the owner. The designs lay out the program on the site and address schedule and construction budget requirements. The architect submits a preliminary estimate of construction cost to the owner.
   - Meet with client to determine design objectives, site conditions
   - Form design concepts and compare pros/cons of each
   - Designs incorporate preliminary code and materials research
   - Internal review
   - While client is reviewing design options, consultants such as interior designer, landscape architect, builder, manufacturers, engineers also review for added insight
3. **Design development (DD)** services use the initial design documents from the schematic phase and take them one step further. This phase lays out mechanical, electrical, plumbing, structural, and architectural details. Typically referred to as DD, this phase results in drawings that often specify design elements such as material types and location of windows and doors. The level of detail provided in the DD phase is determined by the owner's request and the project requirements. The DD phase often ends with a formal presentation to, and approval by, the owner. Based upon the approved Schematic Design plans and required adjustments to program, budget and schedule, the architect prepares more detailed Design Development drawings describing the architectural, structural, mechanical and electrical systems, and makes adjustments to the preliminary estimate of construction cost.
   - Refine client-selected schematic design
   - Materials selection
   - Determine alternates for design influenced by phasing or budget
   - In-depth code research
   - Incorporate consultant comments
   - Develop construction details
   - Internal review
   - While client is reviewing final design, consultants review again
   - Drawing may be sent for preliminary review by municipality or other appropriate authorities
4. **Construction documents (CDs; contractors documents)** - Once the owner and architect are satisfied with the documents produced during DD, the architect moves forward and produces drawings with greater detail. A set of construction documents is a set of drawings and specifications that an architect (or, architectural processes) produce during the design/development phase

of a construction project. These documents serve as a project [construction] manual during the construction phase, and they assist the public, private, and governmental organizations in having an open source and clear view of the project. These drawings typically include specifications for construction details and materials. Once CDs are satisfactorily produced, the architect sends them to contractors for pricing or bidding, if part of the contract. The level of detail in CDs may vary depending on the owner's preference. If the CD set is not 100% complete, this is noted on the CD set when it is sent out for bid. This phase results in the contractors' final estimate of project costs. The construction document phase produces a set of drawings that include all pertinent information required for the contractor to price and build the project. Based upon the Design Development documents, the architect prepares bidding information, conditions of the contract, and an Architecture Institute of America (AIA) agreement between owner and contractor. The architect advises the owner of adjustments to preliminary construction cost estimates and assists in filing documents for approval of governmental authorities.

- Construction details are refined and specifications are finalized
- Alternates are explicitly defined
- Code analysis is generated, if applicable
- Consultant drawings and documents are incorporated as appropriate
- Internal review
- While client is reviewing, consultants prepare final drawing tweaks for inclusion in construction set
- Incorporate final client and consultant comments.
- Final internal review

5. **Contract administration (CA)** services are rendered at the owner's discretion and are outlined in the owner-architect construction agreement. Different owner-architect contractor agreements require different levels of services on the architect's part. CA services begin with the initial contract for construction and terminate when the final certificate of payment is issued. The architect's core responsibility during this phase is to help the contractor to build the project as specified in the CDs as approved by the owner. Representing the owner, the architect observes the construction and administers the agreement between the owner and the contractor, determines that work is done in accordance with the contract documents, and certifies the contractor's pay applications. The architect reviews shop drawings, prepares change order documents, determines a date of substantial completion, and issues a final certificate for payment.
6. **Bidding & negotiation** *(market only)* - The owner approves the Construction. Documents and the estimate of construction cost. The architect assists the owner in obtaining bids from General Contractors, negotiating proposals, and preparing and awarding contracts for construction.
7. **Construction phase** - Construction of the system.
8. **Post-construction phase** - Occupation and evaluation of the system.

> **Note:** *Architectural industry institutes notably state that pre-design and CA are not "basic services", but should be considered additional services.*

In the construction industry there are a whole host of labor positions including architects, engineers, consultants, contractors, sub-contractors, and government agencies. The relationships therein can make a construction process a very tedious and challenging task to coordinate.

## 2.4 The architectural plan

An architectural plan is a design and planning framework for a building, and can contain:

1. Architectural drawings.
2. Specifications of the design.
3. Calculations.
4. Materials (including, interior fixed and fitting equipment).
5. Quantities.
6. Time planning of the building process..
7. Tools, techniques and building technologies & equipment.
8. Other documentation.

## 2.5 Architectural material controls

Architectural master planning includes the requirement for material controls, of which the axiomatic controls are:

1. Terrain (platform) - platform control.
    A. Ground.
    B. Water.
    C. Structural platform (building platform).
2. Structure (surface) - structural control.
    A. Architecture.
    B. Structure.
    C. Interior composition.
    D. Surface.

3. Atmospheric gases - atmosphere control.
   A. Air.
   B. Other gases.
4. Liquid (water) - liquid control.
   A. Water.
   B. Other liquids.
5. Power (electromagnetics) - energy/power and signals control.
   A. Power.
   B. Data.
   C. Illumination.

Secondary material controls include:

1. Structural control (shape control).
2. Integrity control (weight control).
3. Thermal control (temperature control).
4. Acoustic control (sound and seismic control).
5. Atmospheric (air control).
6. Production control (construction, FAIT, and transport control).

# 3 Architectural documentation and coding

*A.k.a., Construction documentation and coding, fabrication documentation and coding.*

There are two document types included in construction documentation:

1. **Drawings** - visualizations. Note that written information about materials and workmanship should not appear on drawings or in bills of quantities as this can result in contradictory specifications and can cause considerable confusion, instead they should refer to the appropriate clauses in the specification. Drawings include:
   A. Legends.
   B. Areas lists (a.k.a., area table, table of areas, general frame table).
   C. Architectural/construction schedule (a.k.a., materials list and quantities)
2. **Specifications** - all other information about the architecture and construction, including:
   A. Written descriptions.
   B. Architectural/construction schedule (a.k.a., materials list and quantities)
   C. Costs list (sometimes included; market only)

All construction documents follow this standard, which helps the reader/user to know where to look among the hundreds of pages of architectural drawings and technical/written/list specifications. Each affiliated building practice (discipline) provides both types of construction documents:

1. Architecture
2. Structural
3. Mechanical
4. Electrical
5. Illumination
6. Plumbing
7. Landscape
8. Civil

Both the drawings and specifications follow standards, respectively. There are different standards present on the planet. The MasterFormat, for example, is a specification standard from the Construction Specifications Institute. The MasterFormat is a common method of specification in construction documents. Similarly, construction drawings follow a standard coding in order to organize the documentation. Different standards use different coding for the identification of construction drawings.

## *3.1 Drawings*

The following types of drawings are generally included in a complete architectural drawing set/plan:

1. **Architectural drawing board** - includes all drawing related information on one paper (e.g., drawings, legends, area lists, etc.).
2. **General drawings** - plans (views from above) and elevations (side or front views) drawn on a relatively small scale. Both types of drawings use a standard set of architectural symbols. The most common construction plans are site plans, plot plans, foundation plans, floor plans, and framing plans:
    - A. **Site plan** - A site plan is a large scale drawing that shows the full extent of the site for an existing or proposed development. Site plans, along with location plans, may be necessary for planning applications. It shows the contours, boundaries, roads, utilities, trees, structures, and any other significant physical features on or near the construction site. It shows the locations of proposed structures in outline. This plan also shows corner locations relative to reference lines, shown on the plot, which can be located at the site. By showing both existing and finished contours, the site plan furnishes essential data for the graders and excavators.
    - B. **Plot plan** - shows the survey marks, including the bench mark (BM), with the elevations and the grading requirements. Surveyors use the plot plan to set up the corners and perimeter of the building using batter boards and line stakes. The plot plan furnishes the essential data for laying out the building.
    - C. **Structural plans** - shows the structural characteristics of the building at the level of the plane of projection. Includes plans (views from above) and elevations (side or front views).
        1. **Foundation plan** - is a plane view of a structure. That is, it looks as if it were projected onto a horizontal plane and passed through the structure.
        2. **Framing plan** - a plan view of the layout of girders, beams, and joists. Types of framing plans include, but are not limited to: floor framing plans and roof framing plans.
    - D. **Floor plans (and ceiling plans)** - views of a building as though cutting planes were made through the building horizontally. The cutting plane is generally taken 5 feet 0 inches above the floor being shown.
    - E. **Infrastructural (utility) plans** - shows the utilities in the building.
        1. **Plumbing plans** - shows the plumbing system. Includes plans (views from above) and elevations (side or front views).
        2. **HVAC plans** - shows the HVAC system. Includes plans (views from above) and elevations (side or front views).
        3. **Electrical plans** - shows the electrical system. Includes plans (views from above) and elevations (side or front views).
        4. **Illumination plans** - shows the illumination system. Note that the electrical and illumination plans are linked. Includes plans (views from above) and elevations (side or front views).
        5. **Gas plans** - shows the gas system. Includes plans (views from above) and elevations (side or front views).
        6. Etc.
3. **Elevation views (elevations)** - shows different side views of the building (e.g., north, east, west, south). Elevations show the front, rear, and sides of a structure, as they would appear projected on vertical planes. Studying the elevation drawing gives a working idea of the appearance and layout of the structure. Elevation views are vertical projections.
4. **Section views (sections; a type of detail drawing)** - a vertical cut view of the building selected by the designer. Includes plans (views from above) and elevations (side or front views). Section views provide important information about the height, materials, fastening and support systems, and concealed features of a structure. The cutting plane is not necessarily continuous, but, as with the horizontal cutting plane in building plans, may be staggered to include as much construction information as possible. Like elevations, sectional views are vertical projections. They are also detail drawings drawn to large scale. This aids in reading, and provides information that cannot be given on elevation or plan views. Sections are classified as typical and specific. Selected sections should represent the average condition throughout a structure and are used when construction features are repeated many times. They give a great deal of information necessary for those constructing the building.
5. **Detail views** - large-scale drawings of construction assemblies and installations that cannot be clearly shown in the sections. These enlarged drawings show the various parts in more detail and how they will be connected and placed. The scale depends on how large the drawing needs to be magnified to explain the required information clearly. Details are usually drawn at a larger scale than the sections.

6. **3D whole view** - a three-dimensional perspective view of the whole building.
7. **3D cut view** - a three-dimensional cut-view from a certain perspective.

**NOTE:** *Architectural symbols provide reference locations for all architectural sub-elements, including fixtures and fittings.*

### 3.1.1 Construction plan documents

*A.k.a., Construction plans.*

The process of building something is called construction. In order to construct something effectively, efficiently, and safely, the constructor requires access to all possible visual documents and relevant lists. The construction documents (construction plans) below are standard documents:

1. **A0 sheets:** These project information documents serve as cover sheets for a permit set or construction set. They lay out the general scope of work, including a site plan with the general condition of the work site, and plans that show fire protection and accessibility.
2. **A1 sheets (demolition):** Demolition plans show the current state of the structure and indicate what must be demolished as part of the construction project.
3. **A2 sheets (floor plans, blueprints):** Working drawings that show an aerial view of each level of the building. They include building dimensions, interior walls, exterior walls, and relevant fixtures.
4. **A3 sheets (elevations):** Elevation drawings are architectural drawings that show cross-sections of a building. Also called section drawings, they show ceiling heights, wall construction, foundation plans, and framing plans.
5. **A4 sheets (finish plans):** An architect or design team provides these plans to show what materials will be laid atop the core structure. A4 sheets include a reflected ceiling plan, which shows the ceiling as viewed from the floor, including any lighting fixtures. These sheets also show the location of power outlets, and they make reference to what's known as a finish schedule (found later in the plans).
6. **A5 sheets (interior elevations):** A more detailed variation on the A3 sheets, these elevations might show furniture, light switches, and wall finish types.
7. **A6 sheets (schedules):** In the construction industry, the word "schedule" refers to lists or spreadsheets of certain materials. Construction sets and permit sets feature door schedules (showing all the doors that appear on other sheets) and window schedules (showing all the windows that appear on other sheets).
8. **S sheets (structural drawings):** These building design drawings are the work of a structural engineer, who has a different role than an architect. The structural engineer's S sheets show the structural schematics of a building, including concrete footings, wall-to-roof connections, joist layout, and any specially engineered pieces in the building's framing. Complex projects may require greater levels of detail in these engineering drawings.
9. **M sheets (mechanical drawings):** These types of drawings show mechanical systems in a building, most notably an HVAC system (which controls heating and air conditioning and is required in most new homes and office buildings).
10. **P Sheets (plumbing drawings):** These show the location of pipes, water tanks, and plumbing fixtures. These drawings show deailed information about a buildings plumbing plan.
11. **E Sheets (electrical drawings):** These drawings show detailed information about a building's electrical plan.

*Note that the following are not necessary for construction directly, and are generally not included in a building permit set or construction set [of documents]: bidding documents, contract documents, project management agreements, legal conditions of the contract, cost estimates, interior design proposals, informal shop drawings, contract modifications, supplementary conditions, and other contract addenda.*

### 3.1.2 Materials list and quantities

In order to complete the construction a materials list and associated quantities are required. This information is often included within the drawings, but may be separately associated with (i.e., included within) the specifications.

1. **Architectural schedule (a.k.a., construction schedule)** - a schedule as applied to architectural construction drawings is an organized method of presenting lists of materials, building components (doors, windows, etc.), equipment, and so forth in a drawing in tabulated form.
2. **Architectural bill of quantities (a.k.a., construction bill of quantities; BOQs, BoQ or BQ)** - a document prepared by a quantity survey (or, the cost consultant) that provides project specific measured quantities of the items of work identified by the drawings and specifications.

### 3.1.3 Construction drawings standards

There are a variety of construction drawing standards, and usage depends of region/jurisdiction.

#### 3.1.3.1 *United States National CAD Standard*

The United States National CAD Standard [nationalcadstandard.org] places a code in the lower right hand corner of each drawing sheet contains a series of letters and numbers (the sheet number). The sheet number lets the reader know where they are in the drawing set, and allows the reader to know where to look in the drawing set for specific information.

1. Discipline [L] //letter, one letter
2. Drawing type [#] //number, one number
3. Sequence [##] //numbers, two or more numbers
4. For example, F-6-49

The first part of the construction drawing sheet number is a letter which lets us know the discipline for the drawing. These disciplines are arranged in the same order (United States National CAD Standard), for consistency in construction documents.

The common disciplines (Read: specialized construction plan sheet names) are:

- G - General: Sheet list, symbols, summary, life safety and code analysis.
- C - Civil
- L - Landscape
- S - Structural
- A - Architectural
- F - Fire Protection
- P - Plumbing
- M - Mechanical
- E - Electrical
- T - Telecommunications

There are other disciplines which can be included, such as

- H - Hazardous materials
- B - Geotechnical
- I - Interiors
- W - Distributed energy
- O - Operations
- Z - Contractor/shop drawings

The second component of the sheet number is a number referencing a type of drawing. This organizes the discipline's drawings into a consistent, standard sequence of drawing types:

- 0 - General (legends, symbols, general notes)
- 1 - Plans
- 2 - Elevations
- 3 - Sections
- 4 - Large Scale Drawings: plans, elevations, sections
- 5 - Details
- 6 - Schedules and Diagrams
- 9 - 3D Drawings (isometric, perspective, renderings)

*Note: 7 and 8 are reserved for user defined drawing types.*

## *3.2 Specifications*

*A.k.a., Architectural specification, construction specification.*

**ASSOCIATION:** *This section is linked to a related section of The Material System: Habitat System > Technology Support: Materialization Service System > Materialization Specification standards.*

Specifications are precisely written documents that go with the construction documents and describe intent, decisioning, materials as well as installation methods. Specifications describe the all, or some combination of, the following (Construction Specification, 2021):

1. Reasoning (decisioning).
2. Description of the final result (description of design).
3. Quality standards and indicators.
4. Procedures for determining final quality.
5. Products.
6. Materials.
7. Quantities.
8. Costs.
9. Work and/or installation.

They detail the project to be constructed, supplementing drawings, and describe qualities of materials, their methods of manufacture and their installation, and workmanship and mode of construction. Specifications may, or may not, include: materials, quantities, costs, or drawn information. Specifications are written, whereas drawings (and plans) are visualizations (and lists/tables). Specifications may also include supplemental drawings as well as lists/tables. Specifications should complement principal drawings, not overlap or duplicate them. All aspects of the works are generally specified with different sub-specifications.

Specification writing has two principal objectives: to define the scope of work and to act as a set of instructions.

### 3.2.1 Construction specification standards

Efficient information retrieval is only possible when a standard filing system is used by everyone. There are a variety of standards that provide such a standard filing and retrieval scheme. The Construction Specifications Institute (CSI) MasterFormat is the most widely used standard for organizing specifications for building projects in the United States and Canada.

Architectural construction specifications standards are generally divided into "divisions" with [at least] the following elements:

1. Entire Project Team:
   A. Division 00 - Procurement and Contracting Requirements
   B. Division 01 - General Requirements
2. Structural (and Architectural):
   A. Division 02 - Existing Conditions
   B. Division 03 - Concrete
   C. Division 04 - Masonry
   D. Division 05 - Metals
   E. Division 06 - Wood, Plastics, Composites
3. Architectural (and Interiors):
   A. Division 07 - Thermal and Moisture Protection
   B. Division 08 - Openings
   C. Division 09 - Finishes
   D. Division 10 - Specialties
   E. Division 11 - Equipment
   F. Division 12 - Furnishings
   G. Division 13 - Special Construction
   H. Division 14 - Conveying Equipment
4. MEP (Mechanical, Electrical, Plumbing):
   A. Division 21 - Fire Suppression
   B. Division 22 - Plumbing
   C. Division 23 - Heating, Ventilating, and Air Conditioning (HVAC)
   D. Division 25 - Integrated Automation
   E. Division 26 - Electrical
   F. Division 27 - Communications
   G. Division 28 - Electronic Safety and Security
5. Landscape and civil:
   A. Division 31 - Earthwork
   B. Division 32 - Exterior Improvements
   C. Division 33 - Utilities

Note that green building specifications can be easily incorporated into construction specification standards in three general ways:

1. Environmental protection procedures.
2. Green building materials.
3. Practical application of environmental specifications.

# 4 Architectural standards

*A.k.a., Architectural specification standards, architectural regulations, building standards, building regulations, construction standards, construction regulations, building standards, building engineering standards.*

A technical standard is a datum document established through a systems science process that provides for common and repeated need of technology for, use, protocols, guidelines, or characteristics of activities or their results. A standard in this technical form is usually a formal document that establishes uniform engineering or technical criteria, methods, processes and practices.
Clarification: The term standards can also refer to the interoperability of connecting objects/systems. In this case, higher standardization (as a technical objective) will allow for interchangeability of parts, system interoperability, and possibly ensure higher quality, reliability and safety.

A code is the market-State term for a set of [legal, State enforced] rules and specifications for the correct methods and materials used in a certain product, building or process, which exists because of State legislation. Codes can be approved by local, state or federal governments and can carry the force of law. In the market-State, the main purpose of codes is to protect the public by setting up to some minimum acceptable level of safety for buildings, products and processes. In community, the term code is replaced by protocol. This protocol has been decided in the decision system by contributors to the InterSystem team who form the protocol(s) from systems science into safe and appropriate engineering rules.

**NOTE:** *It is possible for code to limit progress toward community due to restrictions on building locations and techniques in a specific jurisdiction.*

Every architectural service in an building, from its structure to the installation of plumbing and electricity has an associated standard, somewhere in the world. Building standards are often just called building codes, building regulations, etc. Different criteria may be selected for optimization in different jurisdictions using different standards (codes, laws, etc.). Standards explain how do to something, they may also explain why, and provide for community requirements. In the market-State, because optimality is often not possible, there is "cost cutting", which must be handled by the State using building regulations and building codes. Different jurisdictions have different rule making processes as well as different objectives. Different codes, for example, what criteria this proposal meets. You may select more than one.

It the market-State it is understandable why some standards intentionally introduce lower quality designs and materials, because they are cheaper. Designs and materials can be allowed for economic reasons and not for health or optimization reasons. In the market-State, businesses use the regulatory power of the government to enhance and/or improve the sale of their products by having the government create standards that unnecessarily mandate their usage (e.g., using flame retardant chemicals in mattresses was lobbied by the chemical industry and incorporated into legislation in some jurisdictions). Fundamentally, in the market-State, some standards are composed of stupid rules, and some are composed of sensible rules. In political contexts, standards can serve as a vehicle by which some corporate and/or State members use leadership positions within the standards setting organization to promote their own interests and harm competitors.

Changes to a building code occur to:

1. Corrects errors and omissions.
2. Integrate new understandings and knowledge.
3. Address a critical life/safety need.
4. Clarify the intent or application of the code.
5. Address a specific state policy or statute (market-State only).
6. Address consistency with state or federal regulations (market-State only).

The following are the most common building-related standards (note: some are more related to categorization and others to safety and optimization engineering):

1. Master specifications (Masterspec®, SPECSystem™, MasterFormat™, SpecText®, BSD Speclink®, ezSPECS On-Line™, 20-20 CAP Studio, and many others).
2. Local and national codes and ordinances.
3. Federal specifications (Specs-In-Tact, G.S.A., N.A.F.V.A.C., N.A.S.A.).
4. National standards organizations, such as:
   A. U.S. American National Standards Institute.
   B. U.S. National Institute of Building Sciences.
   C. U.S. National Fire Protection Association [nfpa.org]
   D. U.S. National Institute of Standards and Technology.
   E. U.S. Association for Contract Textiles
5. Manufacturers' industry associations (Fire Equipment Manufacturers' Association, American Plywood Association, The Brick Industry Association, etc.).
6. Testing societies (American Society for Testing and Materials, American Society for Nondestructive Testing, Underwriters Laboratories).
7. Manufacturers' catalogs (Sweet's Catalog File, Man-U-Spec, Spec-data).
8. Industry-related magazines and publications (Construction Specifier, Architecture, Green Magazine On-line, Interior Design, Architectural Lighting, Architectural Record).

## *4.1 Architectural categorization by means of titling and numbering*

*A.k.a., Construction titling and numbering, material specification titling and numbering, architectural categorization.*

All the architectural elements of a building of a building (including, fixtures, fittings, and utilities) fit in a set of titling and numbering categories for organizational and integration purposes. In the market-State, different organizations (e.g., international organizations, national organizations, and businesses) often follow different titling and numbering standards. All architectural elements are associated with construction classifying titles and numbers.

In the market-State, there exist a variety of materialization and other construction specification standards, including but not limited to:

- **American Institute of Architects (AIA)**, [aia.org] - publishes the AIA MasterSpec, which is produced for AIA by Deltek [deltek.com]. MasterSpec is a library of master specifications. MasterSpec is organized by MasterFormat number, but it fills in the actual specification content that MasterFormat isn't intended to provide.
  - *Student Access to MasterSpec*. (2018). Deltek. [avitru.com]
- **ASTM**, [astm.org] - ASTM International, formerly known as American Society for Testing and Materials, is an international standards organization that develops and publishes voluntary consensus technical standards for a wide range of materials, products, systems, and services. ASTM specifications and codes address material and testing procedures. The specifications issued by ASTM are organized on the basis of the type of material, and the letters prefixed to the specification number are indicative of the material type. For example, letter A is for all ferrous materials; B is for all nonferrous materials, etc.
  - *Construction standards*. ASTM. Accessed: January 7, 2020. [astm.org]
  - *Additive Manufacturing Standards Activities*. ASTM. Accessed: January 7, 2020. [amcoe.org]
- **British Standards Institution (BSI)**, [bsigroup.com]
  - *Standards and schemes for certification*. BSI. Accessed: January 7, 2020. [bsigroup.com]
- **Building and Construction Authority of**

**Singapore**, [bca.gov.sg]
- *Publications*. Building and Construction Authority. Accessed: January 7, 2020. [bca.gov.sg]
- *Guide on Construction of Industrial Developments in Singapore*. (2010). Building and Construction Authority. [bca.gov.sg]

- **Building Information Standards**
- **Construction Specification Institute (CSI)**, [csiresources.org] - publishes the CSI MasterFormat. MasterFormat is the intellectual property of the Construction Specifications Institute. MasterFormat is a numbering system for specifications. Construction specifications used in the United States typically conform to the guidelines of the Construction Specifications Institute's "MasterFormat". The MasterFormat index groups specification sections into identifiable disciplines using a six-digit system with digits in groups of two, such as: 01 24 30. Construction Specifications Institute (CSI) and Construction Specifications Canada (CSC). MasterFormat is the protected intellectual property of the Construction Specifications Institute (CSI) so there is no publicly provided full list of numbers and titles. Unfortunately, CSI no longer makes the list available for free. MasterFormat is used throughout the construction industry to format specifications for construction contract documents. MasterFormat is a coding system for organizing construction documents, contracts, design specifications, and operational manuals. MasterFormat is also a publication created and maintained by the Construction Specification Institute (CSI) and Construction Specifications Canada (CSC). CSI MasterFormat is the standard used to provide synchronicity between manufacturers and builders. The MasterFormat is used by manufacturers to ensure that their products meet requirements such as size, weight, or material types.
  - *MasterFormat: Numbers and Titles*. (2016). Edmonton Construction Association. [edmca.com]
  - *MasterFormat Specification Divisions (CURRENT). (2018).* ArchiMat. [archtoolbox.com]
  - *CSI 3-Part Formatted Specifications*. ARCAT. Accessed: January 7, 2020. [arcat.com]
  - *CSI MasterFormat™ Division List.* Builders Exchange of St. Paul. Accessed: Januayr 7, 2020. [plainsbuilders.com]
  - *Master Construction Specifications (PG-18-1).* (2019). US Department of Vetrans Affair, Office of construction and facilities management. [cfm.va.gov]
- **European Committee for Standardization (CEN)**, [cen.eu]
  - Search Standards. CEN. Accessed: January 7, 2020. [standards.cen.eu]
- **International Code Council (ICC)**, [iccsafe.org]
  - *Standard Development & Consensus Committees*. International Code Council. Accessed: January 7, 2020. [iccsafe.org]
- **International Construction Information Society (ICIS)**, [icis.org]
  - *ArchiveSpecifications*. ICIS. Accessed: January 7, 2020. [icis.org]
- **International Standards organization (ISO)**, [iso.org]
  - *ISO and Construction*. (2017). ISO. [iso.org]
- **U.S. Occupational Safety and Health Administration (OSHA)**, [osha.gov]
  - *Law and Regulations*. OSHA. Accessed: January 7, 2020. [osha.gov]
- **The Associação Brasileira de Normas Técnicas** (ABNT), Brazilian Technical Norm (Norma Tecnica Brasieira, NBR) [abnt.org.br; braziliannr.com]
  - ABNT NBR ISO 9001:2015
- **Panamerican Standards Commission; Comisión Panamericana de Normas Técnicas (COPANT)** [copant.org]
- **Asociación Mercosur de Normalización (AMN)** [amn.org.br] - Asociación Mercosur de Normalización is a civil, non-profit, non-governmental association, recognized by the Common Market Group (GMC). It is the only body responsible for the management of voluntary standardization within the scope of Mercosur.

**NOTE:** *There are a variety of terms that relate to construction costing standards. For example, construction measurement standards refer to the way construction costs are calculated, classified, analysed and presented.*

## *4.2 State building codes*

*A.k.a., Building regulations, building law, construction code, construction law, building legislation, construction legislation.*

Building codes (regulations, laws restricting building) state building requirements, given by a jurisdiction, for any number of purposes. Ideally, a building code, or building control standard, is a set of rules that specify the minimum standards for constructed objects such as buildings and non-building structures. The main purpose of building codes are to protect human health and safety while supporting human fulfillment and ecological restoration. A building code becomes law of a particular jurisdiction when formally enacted by the appropriate governmental or private authority. Enacted building legislation exists to regulate individuals and business.

What makes a good shelter? For thousands of years we've been attempting to regulate the idea. Even the bible had building codes. The book of Deuteronomy mandates railings on roofs to prevent falls. After the great London fire of 1666, cities began creating stricter regulations for how we build. Over the centuries the codebooks have only grown thicker. It's undeniable that building codes have saved lives, but something has changed over the past couple decades. Now thanks to the Internet the average homeowner has unlimited access to building techniques (both traditional and experimental) so we're experimenting more than ever, often without regard for the rulebooks.

Like most things in early 21st century society, codes have turned into big business. They are a key source of revenue for governments. They're also leveraged by many industries and organizations to push their political and economic agendas. These groups all benefit from code complexity.

These codes/standards become the backbone of justification for the very existence of hundreds of government [building] departments. With these departments come [building] codes, plan reviews (for permission), zoning, permits (plan and operating permission), and inspection (and safety review), and [code/law] enforcement. This hierarchy, along with associated fees and expenses is, by design, supposed to protect human beings from serious harm under market conditions, and to keep them safe from scientifically unproven, dangerous building/materialization practices and or materials. Rules, regulations, certifications, licensing requirements, bonding, and insurance requirements are all claimed to work toward the common goal of "protecting and keeping safe under market conditions".

In general, the [building/materialization] codes are based on the minimum requirement at every level. Additionally, many States/governments use different standards. In practice, from zoning to permissioning, to code requirements, most States in the 21st century follow a market-type form of oversight, planning and inspecting. Habitat (city/rural) zones are split into: residential, commercial, industrial, etc. Planning creation (and permissioning) is not at the habitat level. Codes are often written to a standards minimum requirements.

In the market, without control, building can become a "free for all" where those who assume the labor role of "constructor" frequently display behavior indicating a lack of consideration for anyone but themselves and construct constructions that are dangerous or damage other constructions when doing their own. Or, create an unaesthetic environment brought forth from their own ego. Others who have assumed the labor role of "constructor" may have the best intentions, but either forget something, or just don't know how to build something safely, and their construction fails and hurts something or someone.

State building codes reduce problems [in the market] through coercion and force. In community, we design and test so that our active designs don't hurt us. Community is a place where everyone desires and decides to build safely. In community, we masterplan for our global fulfillment. In community, we integrate our builds into a habitat service system designed to regeneratively fulfill our lives. In the market, buildings are integrated into the market; and, they are be bought, sold and taxed (by the State to provide some semblance of safety under market conditions).

Coding [law] refers to the code requirements of a jurisdiction in order to construct something, including identifying and conforming to them (in community, coding is part of the decision system). Different jurisdictions may have different codes, but a safely designed building should meet and often exceed building code, unless the code is purposefully restrictive due to cultural norms.

The International Building Code (IBC) is often used to architect buildings that meet safety code requirements. Some common steps in the IBC include:

1. Establish occupant load.
2. Determine occupancy classification.
3. Determine allowable area.
4. Determine allowable height.
5. Determine construction type.
6. Determine hourly ratings of construction components for construction type.
7. Determine required occupancy separations.
8. Determine sprinkler requirements.
9. Determine if area separation walls are needed.
10. Determine if exterior walls and windows have adequate fire protection.
11. Check exiting and entering.

Building regulations generally include, but may not be limited to, the following categories:

1. Structure.
2. Fire safety.
3. Site preparation and resistance to contaminants and moisture.
4. Toxic substances.
5. Resistance to the passage of sound.
6. Ventilation.
7. Sanitation, hot water safety and water efficiency.
8. Drainage and waste disposal.
9. Heat producing appliances.
10. Fuel storage systems.
11. Protection from falling, collision and impact.
12. Conservation of fuel and power.
13. Access to and use of buildings.
14. Glazing - Safety in relation to impact, opening and cleaning.
15. Electrical safety.

16. Security - Dwellings.
17. Physical infrastructure for high-speed electronic communication networks.
18. Materials and workmanship.
19. Illumination.
20. Data and communications.

### 4.3 State construction permits

*A.k.a., Construction permits, building permits, zoning permits, construction waiver, etc.*

A "construction permit" (a.k.a., "building permit") is a permit/license required [as permission] in most jurisdictions for new construction. Building permits are to a large degree considered the profit end of building code, for they come with fees and taxes. The question is, Who can *issue (sell)* permits and who can *obtain (purchase)* permits? Note here that the word "obtain" is the word which jurisdictions often use when speaking of acquiring a permit. However, "obtain" is deceptive language -- what is really occurring is that the authority is forcing the purchase. Codes are enforced by the authority, and there is socio-economic punishment if they are not followed. The jurisdiction sells the permits, which have a financial cost associated with them. In most jurisdictions, the only person who can obtain a permit is a State licensed contractor, who pays the State for a license to do contract work in accordance with the standards (i.e., "building codes") of the State.

## 5 Architectural decisioning

Any architectural process will include most of the following data-oriented decisioning elements:

1. **Decision of function:**
   A. Purpose of architecture.
      1. Functional usage mapping of architecture to users.
      2. Psychological (aesthetic) mapping of architecture to users.
   B. Space requirements.
   C. Intended length of existence.
2. **Decision of materials** (note: materials may be individual isolated, such as pain, or formed into mechanisms and appliances, such as motors and faucets):
   A. Material flow mapping of material decision data:
      1. Material composition.
      2. Material amount.
         i. Amount of decided material(s). Quantities of materials.
      3. Cost of material (market-only)
      4. Material origin.
      5. Material transportation
         i. Amount of energy needed for transportation of materials.
      6. Material processing.
         i. Material [pre-]processing requirements. Material processing requirements prior to allocation in construction.
         ii. Amount of energy needed for processing materials into constructions.
      7. Material positional allocation in HSS.
         i. Amount of technology and energy needed for positioning materials, as constructions, into the environment.
      8. Material post-allocation, including usage, disposal, and recycling.
         i. Amount of technology and energy needed for re-purposing or recycling materials.
3. **Decision of construction and assembly (technology):**
   A. Technology flow mapping of construction and assembly decision data:
      1. Type of technology.
      2. Technology materialization requirements.
      3. Amount of effort per technology.
      4. Amount of energy required per

technology.
5. Cost of technology (market-only).
6. Operation and maintenance requirements (and associated market costs).
7. Time to realization (construction time duration).

4. **Decision of structure** (integration of structure and infrastructure:
   A. Structural engineering the optimal structure given architectural building shape and functional requirements. This includes all performance assessments on the structure (e.g., acoustic, thermal, etc.).
   B. Viable construction processes (on site), including assembly process.
   C. Amount of human effort for construction of structure.
   D. Amount of human effort for maintenance of construction.
   E. Amount of energy for maintenance of construction.
   F. Durability of systems and materials deployed.
5. **Decision of modularity**:
   A. Viable future dismount and disassembly, or deconstruction.
   B. Modularity of the indoor use of the construction. Indoor use flexibility (internal modularity).
   C. Modularity of the structure of the construction. Structural re-use of the system (con-structural modularity).

## *5.1 Architectural decisioning requirements for optimality*

*A.k.a., Architectural performance, architectural optimization requirements.*

The optimization of an architectural construction for society can be achieved by accounting for each of the following factors:

1. Local production or prefabrication cost and energy requirements (i.e., footprint).
2. Relatively fast, simple and automatable construction method.
   A. Low/reduced labor requirements for construction.
3. Water-proof (including, moisture-proof).
4. Termite-proof (Read: insect-proof).
5. Rodent-proof (Read: pest-proof).
6. Mold-proof.
7. Fireproof.
8. Earthquake resistant.
9. Sufficiently thermally (climactically) insulated.
10. Possibly applicable to all climatic conditions.
11. Highly sound insulation and appropriate acoustics.
12. Highly durable, and repairable if damaged (relatively).
13. Interior adaptations and modularity.

Simplistically speaking, selection is based on:

1. Reproducability (i.e., continued producability), regenerability, and/or sustainability.
2. Costability - Spend sufficiently and don't spend more than you have to spend.
3. Duplicability - how long into the future can the system be duplicated using available resources and finances.
4. Material resource availability.
5. Labor resource availability.
6. Beneficial health impact (physical, emotional, psychological, communal, and environmental).

### 5.1.1 Structural decision requirements

The structure must be sufficiently impermeable to:

1. **Impermeable to water (a.k.a., water resistant, water tightness, moisture resistant)** - under normal conditions, the building should be impermeable to water.
   A. Water should not be able penetrate the exterior surface of the building.
   B. Water within the building should be appropriately conduited and drainable (if a water-related incident occurs).
2. **Impermeable to adverse weather (a.k.a., weather tightness, weather resistant)** - under regular adverse weather conditions, the building should be impermeable to snow, hail, wind, and water (including, wind-driven spray of water).
3. **Impermeable to mold (a.k.a., mold resistant)** - under normal conditions the structure of the building should be impermeable to mold and molding.
4. **Impermeable to fire (a.k.a., fire resistant)** - the building should be less likely catch and sustain a fire.
5. **Impermeable to pests (a.k.a., pest resistant)** - the building should be impermeable to pests.

#### *5.1.1.1 Moisture resistant*

In terms of resistance to moisture, the regulations state that the building should be protected from harmful effects caused by:

1. Ground moisture.
2. Precipitation including wind-driven spray.

3. Interstitial and surface condensation.
4. Spillage of water from, or associated with, sanitary fittings or fixed appliances.

#### *5.1.1.1 Environmental relative mold index (ERMI) test*

The 'environmental relative mold index' (ERMI) is an algorithm used to calculate a ratio of water damage-related species (that are likely to harm human health) to common indoor molds and the resulting score is called the. The ERMI test is based on an instrument that uses quantitative polymerase chain reaction (MSQPCR) testing.

## *5.2 Building lifecycle performance*

There are a variety of standards and indices for building appropriate resource lifecycle coordination into buildings and other structures. Some of these standards are optional, and others are legal (market-State only) and/or community-protocol, decided. While these minimums and/or optimums may vary from jurisdiction to jurisdiction. Some of these standards and indices have been turned into certifications businesses; wherein, businesses sell the certification of a piece of architecture as representing the alignment with their criteria. There are no businesses in community, and so community uses community goals and objectives in conjunction with physics-engineering performance of systems to meet user requirements. In community, an algorithmic decision protocol is used by InterSystem teams to fulfill requirements. In the market, there are many competing businesses, which leads to secrecy, uncooperative, and cost-cutting behavior. Thus, the certification business exists to inform consumers (and States) as to what criteria are appropriate for what objectives.

For example, the LEED ("leadership in energy and environmental design") Green Building Rating Systems (Read: index) are voluntary systems that assess the environmental performance of built projects across a spectrum of key energy and environmental criteria. From water and energy use efficiency to location, the impact of materials used, etc. In 2013, members of the US Green Building Council (USGBC) voted (85 percent) to include cradle-to-cradle certification in LEED V4, which will even more stringently enforce the environmental qualities of materials used in green buildings, the opposite of what industry interests want. Now, those seeking LEED certification will get credits for Materials & Resources for disclosing and optimizing where building materials are sourced and purchased.

The following organizations and standards provide information the design and development of high-performance buildings:

- **The International Green Construction Code (IgCC)**, [iccsafe.org] - The IgCC is a model code that provides minimum requirements to safeguard the environment, public health, safety and general welfare through the establishment of requirements that are intended to reduce the negative impacts and increase the positive impacts of the built environment.
  - IgCC: A member of the International Code Family. (2018). ASHRAE. [ashrae.org]
- **US Green Building Council (USGBC)**, [usgbc.org]
  - USGBC Publications. USGBC. Accessed: January 7, 2020. [usgbc.org]
- **World Green Building Council,** [worldgbc.org]
  - Green building rating tools. World Green Building Council. Accessed January 7, 2020. [worldgbc.org]
- **Cradle-to-Cradle (C2C),** [c2ccertified.org]
  - Cradle to Cradle Certified Version 4. (2019). Cradle-to-Cradle. [c2ccertified.org]

### 5.2.1 Building performance requirements

Performance requirements typically comprise a set of criteria which stipulate how things should perform or the standards that they must achieve in a specific set of circumstances.

The design of a building can be divided into precise performance requirements which might include:

1. Capacity.
2. Appearance (aesthetics).
3. Durability (reliability).
4. Strength (and rigidity).
5. Stability.
6. Acoustic performance.
7. Thermal performance.
8. Comfort.
9. Weather tightness.
10. Fire protection.
11. Pest protection.
12. Accessibility of design.
13. Automation (or manualness) of design.
14. Lighting.
15. Ventilation.
16. Security (market-State only).
17. Safety.
18. Privacy.

19. Energy efficiency.
20. Cost (market only).

### 5.2.1 Common building performance issues

Some examples of building performance issues include, but are not limited to:

1. **Structural stability** - The architecture should not have any progressive structural movement that could cause any part of the building to fail or collapse.
   A. Concerns include, but are not limited to:
      1. Leaning chimney stacks and pots.
      2. Sagging roofs.
      3. Bulging brickwork to the main external walls.
      4. Settlement cracks above windows and doorways.
      5. Distorted window and door openings.
      6. Sloping floors.
2. **Damp (structural integrity to water)** - The architecture should be free from rising and penetrative dampness (which could damage health).
   A. Concerns include, but are not limited to:
      1. Rising dampness to ground floor walls - this is normally indicated by a damp tide mark.
      2. Rising dampness to ground floors - old quarry tile floors and poorly constructed solid concrete floors with no damp-proof membrane are particularly susceptible.
      3. Penetrating dampness to walls and ceilings due to leaking roofs and gutters, perished external brickwork and mortar joints, leaking hot or cold water pipes.
3. **Condensation (structural integrity to water)** - The architecture should be free from condensation.
   A. Concerns include, but are not limited to:
      1. Condensation can lead to mould growth on walls and ceilings in kitchens and bathrooms.
      2. Condensation gathers on bedroom walls behind cupboards and wardrobes and beneath windows.
4. **Heating and cooling (structural integrity to thermal energy)** - The architecture should heat and cool efficiently, safely, and be energy/cost efficient to operate.
   A. Concerns:
      1. Cracking due to heating and cooling.
      2. Architecture heats and cools at different rates.
      3. Architecture heats to dangerous levels.
      4. Architecture does not, where appropriate, hold heat or cold.
5. **Insulation (structural integrity to thermal energy transfer)** - The architecture should have good/appropriate thermal insulation.
   A. Concerns:
      1. Insulate all structural surfaces, including: roofs, floors, walls.
      2. Insutate windows.
      3. Replace draughty, ill fitting windows and doors; louvre blade windows are particularly wasteful in terms of heat loss as well as being an added security risk.
      4. Draught proof external doors and windows, (but not rooms containing an open-flue gas appliance).
      5. Make sure that all water pipes likely to be exposed to frost, such as those in the roof space are properly insulated or take other suitable steps to prevent burst pipes during the winter.
      6. Make sure that the hot water tank is fitted with a good quality insulation jacket and/or insulated storage location.
6. **Lighting (structural illumination)** - The architecture must have adequate lighitng for human health and functioning.
   A. Concerns:
      1. All appropriate rooms need adequate natural lighting to allow people to: 1) do functional activities; and 2) maintain naturally lighted circadian rhythms.
      2. All staircases, landings, kitchens, bathrooms and toilets should have a window wherever practical.
      3. There should be adequate, electric lighting to all accessible parts of the architecture including: light switches suitably positioned so that you can switch on quickly when entering any room, hallway or landing two way switches that switch on and off at the top and bottom of stairs.
7. **Ventilation** - The interior of the architecture should have adequate ventilation.
   A. Concerns:
      1. Lack of fresh air and fresh air exchange.
      2. All habitable rooms should be ventilated directly to the open air by opening a window. Kitchens, bathrooms and toilets should have a window which opens wherever possible. Where this is not possible, there should be adequate mechanical ventilation. In kitchens and bathrooms with windows, it is good to install an automatic humidistat extractor fan to remove moist air before it condenses on walls and ceilings.
      3. All rooms containing an open flue gas heating appliance and all kitchens, bathrooms and

toilets should be provided with enough suitable permanent ventilation by air brick or similar.

## 5.3 Maintenance and cleaning performance

The optimization of the maintenance and cleaning of architecture involves the following factors.

1. Services:
   A. Hygienic floor drains that are resistant to corrosion from blood and chlorine should be provided in all “wet areas” of the mortuary and should be directly connected to the sewer system. These areas include body preparation, autopsy space, etc. These areas require thorough cleaning after every procedure, using large quantities of water and decontaminating and disinfecting chemicals and soaps.
   B. Open floor channels should be avoided. Where this is not possible, these should be covered by durable, flush-fitted stainless steel grids.
2. Structural cleaning:
   A. Cleaning of the outside surface of the building requires pressure washing, which needs to be integrated. The exterior of the building, including the veranda area needs conduits and outlets for a pressurized washing system for the surface of the structure. The utility for this pressurized washing system is located in the utilities room.
3. Finishes:
   A. Wall and floor finishes should be impervious to liquids and easily cleanable; by what measure of resistance?
   B. Structure should be weather proof; by what measure of resistance?
   C. Surface of structure must be cleaned periodically; by what optimal method of timing, method, and material?
   D. Surface of structure must be re-applied periodically; by what optimal method of timing, method, and material?
4. Common cleaning and replacement issues:
   A. Water heater [flushing] - Flushing the water heater. It can extend the life of your water heater, and it needs to be done once a year. If it’s not done often enough, mineral sediment can build up inside the tank, causing banging, popping or rumbling noises as water bubbles up through it. That layer of sediment will make it harder to flush your water heater. Eventually, the sediment layer will cause the bottom of the tank to rust out, and you’ll need a new water heater much sooner than you otherwise might have.
   B. Dryer vent [cleaning] - Lint build-up in dryer vent ductwork is a leading cause of house fires, and that’s why cleaning your dryer vent ductwork every six months. A blocked duct can extend drying times or make the house smell strange.
   C. Window cleaning [cleaning]
   D. Refrigerator [cleaning] - dust off refrigerator coils every three months.
   E. Illumination - replacement of ceiling bulbs.
5. Assembly, positioning, disassembly, and removal:
   A. Assembling and positioning the subsystem should not damage the surrounding area.
   B. Removing and disassembling a subsystem should not damage the area surrounding it.

# 6 Planning architectural functions

Functional material planning refers to the design, development, and construction of 3D objects and systems, particularly material architecture at the level of human and other organismal habitation size spaces. Material-space (material-object) systems and flows may be fully visualized, understood, and constructed to be correct functional operations in the real world where precision, efficiency, and safety are [decision system inquiry] values. A complete architectural systems engineering deliverable includes all possible known functions for a space/environment/system. This model allows for efficient and effective integration in production (and society as a whole) to economically calculate social object/environment constructions optimally and in a coordinated matter [toward the optimal fulfillment of each and every human individual being].

## *6.1 Basic architectural functions*

Architecture has a set of basic functions (i.e., a building has functional demands place upon it):

1. Providing shelter from the elements (user demand for shelter service).
2. Provide structural control within the environment (e.g., bridge or tunnel), possibly of some element (e.g., pond or pool).
3. Providing a workable sub-functional environment (user demand for other services).
4. Emotional stimulation (user demand for aesthetics).

Material interfaces requirements between architectural systems include:

1. Physical interfaces (e.g., pipes/conduits and wires).
2. Electrical interfaces (e.g., voltage).
3. Pressure interfaces (e.g., water pressure, gas and atmospheric pressure).
4. Signals interfaces (e.g., communications signaling).

More completely, architectural functions include (all functions may not be included in a specific, unique architectural object):

1. **People functions (people requirements)**
   A. Follow flow of occupants from one space to another. This includes sources of vertical transportation (stairs, elevators, etc.) including pathways to service equipment.
   B. Follow flow of occupants to enter building from off site.
   C. Follow flow of occupants to exit building as required by code, and in case of an emergency code.
   D. Follow flow of accessible route as required by law (jurisdiction).
   E. Follow flow of materials to supply an architecture construction.
   F. Follow the timing of the materials in the supply to the architectural construction.
   G. Follow flow of input and output (e.g., ) to leave building (including to Off-site).
2. **Structural functions (structural requirements)**
   A. Follow flow of gravity loads from roof down columns, through floors, to foundations and soils/terrain/water.
   B. Follow flow of lateral loads:
      1. Earthquake from ground up through foundations, columns, walls, floors, and roof.
      2. Wind from side walls to roof and floors, through columns, to foundations and the earth.
      3. Follow flow of uplift loads from wind and earthquake by imagining the roof being pulled up and that there are positive connections from roof to columns and walls (through floors) down to foundations and the earth.
3. **Acoustic and seismic functions (structural mechanical waves, structural vibration; seismic; seismic requirements)**
   A. Identify potential mechanical wave sources, potential receiver locations, and the potential vibration paths between the two.
   B. Follow sound through structure from source to receiver. Mitigate by isolation of source or receiver, and/or dampen.
   C. Identify potential dampening materials and locations for positioning in the environment.
   D. Identify potential sound sources, potential receiver locations, and the potential sound paths between the two.
   E. Follow sound through air from source to receiver. Mitigate with distance or barrier or absorber.
4. **Hyrdological functions (water, moisture, and drainage requirements)**
   A. A building's floors, walls and roof should adequately protect the building and its users from harmful effects that may arise from:
      1. Ground moisture.
      2. Precipitation, including wind-driven spray.
      3. Interstitial and surface condensation.
      4. Water spillage from sanitary fittings, fixed appliances and associated fittings.
   B. Follow rainwater from highest point on roof to drain ("drain the rain"), through the piping system to outfall, including direction and conduits thereafter to where data is accessible.
   C. Follow rainwater from highest points of site,

around building, to outfall off site.
   - D. Follow rain or moisture at exterior walls and windows down building sides or “weeped” through assemblies to outfall. Remember: Moisture moves from more to less. Moisture moves from warm to cold.
   - E. Follow vapor from either inside or outside the building, through the “skin” (roof and walls) to outfall. Things get wet. Let them dry out.
   - F. Follow water supply from source to farthest point of use.
   - G. Follow contaminated water from farthest point of use to outfall (fathers point where data is available).
   - H. Follow atmospheric and water flow into materials, including conduits over years and allow for blockage, swelling, or shrinkage.
5. **Thermal functions (thermal requirements)**
   - A. Follow sun paths to and into building to plan for access or blocking. Use position and orientation on some surface (compass directions and geo-positional data with associated object orientation.)
   - B. Follow excessive external (or internal) heat through building skin and block, or if necessary, allow.
   - C. Follow source of internal heat loads (lights, people, equipment, etc.) to their “outfall” (natural ventilation or AC, etc.).
   - D. Follow heat flow into materials over a year, a day, etc. and allow for expansion and contraction.
6. **Atmospheric functions (atmospheric requirements)**
   - A. Follow wind patterns through site to encourage or block natural ventilation through building, as required.
   - B. Follow air patterns through building. When natural ventilation is used, follow flow from inlets to outlets. When air is still, hot air rises and cold air descends.
   - C. Follow forced air ventilation patterns through building to address heat (add or dissipate) and odors. CFM out equals CFM in.
7. **Illumination functions (light requirements)**
   - A. Follow paths of natural light (direct or indirect sun) to and into building. Encourage or block as needed.
   - B. Follow paths of circulation and at spaces to provide artificial illumination where necessary. This includes both site and building.
8. **Power functions (power requirements)**
   - A. Follow electric or gas supply from off site to transformer, to breakers or panels to each outlet or point of connection.
9. **Communications functions (communications requirements)**
   - A. Follow data source/supply from off site to switches, routers, etc. to each port or point of connection.

## *6.2 Baseline functional standards for architecture*

There is a minimum baseline "fitness" standard for all architecture. To meet the "fitness" standard, the architecture must:

1. Be structurally stable.
2. Be free from serious disrepair.
3. Be free from dampness and dangerous/toxic materials that could damage the occupant's health or performance.
4. Have adequate provision for lighting, heating and ventilation and piped water.

To meet the "fitness" standard for dwellings, architecture must also have:

1. Have satisfactory facilities in the house for the preparation and cooking of food, including a sink with hot and cold water.
2. Have a suitably located water-closet for the occupant's exclusive use.
3. Have, for the occupant's exclusive use, a suitably located fixed bath or shower and wash-hand basin each with hot and cold water.
4. Have an effective system for the draining of foul, waste and surface water.

# 7 Planning architectural materials

Materials include manufactured products such as components, fittings, items of equipment and systems; naturally occurring materials such as stone, timber and thatch; and backfilling for excavations in connection with building work.

There are two categories of application concerning materials generally used within the bounds of a building-type structural object:

1. **Structural materials** - materials used because of its compressive (or other force characteristic) strength.
   - **Primary materials -** the materials that make up the majority of the structural components, foundation and envelope of construction projects.
2. **Non-structural materials**: materials used that have little to no significant compressive strength.
   A. Non-structural architectural elements (internal).
   B. Non-structural architectural elements (surface).

## *7.1 Materials analysis*

*A.k.a., Materiality analysis.*

A complete materials analysis for a building includes:

1. Analysis of materials for structural elements.
2. Analysis of materials for non-structural elements.

### 7.1.1 Structural materials

The shapes which are adopted for structural elements are affected, to a large extent, by the nature of the materials from which they are made. The physical properties of materials determine the types of internal force which they can carry and, therefore, the types of element for which they are suitable.
(Macdonald, 2001)

Types of structural (and infrastructural) materials include, but may not be limited to, the following types of (note: some of these categories overlap):

1. **Masonry** - a composite material in which individual stones, bricks or blocks are bedded in mortar to form columns, walls, arches or vaults. Note that the range of different types of masonry is large due to the variety of types of constituent. Bricks may be include, but are not limited to, the following materials:
   A. Fired clay
   B. Baked earth
   C. Concrete
2. **Earth** - inclusive of dirt, soil, and clays.
   A. This can be achieved through the use of labor-efficient techniques like reusable molds and lego-type bricks.
   B. Earth-type material choices could be based on local availability like the earth itself for walls, lime for plastering, and wood/bamboo/hemp for other rigid structures.
3. **Timber (wood)** - composed of long fibrous cells aligned parallel to the original tree trunk and therefore to the grain which results from the annual rings. The material of the cell walls gives timber its strength and the fact that its constituent elements are of low atomic weight is responsible for its low density. The lightness in weight of timber is also due to its cellular internal structure. Timber is a regenerative material because it comes from living organisms. The use of wood carries risks:
   A. Wood construction can be costly in resources and labor.
   B. Wood is not significantly fire-proof. Timber can be safety hazard in an uncertain social environment, and could facilitate sabotaging (a possibility that should not to be discarded).
   C. Wood molds easily.
   D. Wood is a source of food for some insects.
   E. Timber suffers from a phenomenon known as 'moisture movement'. The precise dimensions of any piece of timber are dependent on its moisture content. The moisture content of timer is affected by the relative humidity of the environment and as the latter is subject to continuous change, the moisture content and therefore the dimensions of timber also fluctuate continuously. Timber shrinks following a reduction in moisture content due to decreasing relative humidity and swells if the moisture content increases.
      1. One of the most serious consequences of this is that joints made with mechanical fasteners tend to work loose
4. **Non-timber plants**.
   A. Hempcrete - made by mixing the pulpy core of the plant with a lime binder to create a light concrete (bio-composit) material that can be used as infrastructural filling for insulation and support. Hempcrete retains thermal mass well and is highly insulative. Hempcrete is a type of non-structural material. Hempcrete has to be case around a timber, steal, or concrete frame. Highly resistant to mold and pests due to alkalinity of limestone. Low density material resistant to cracking under movement. Can be applied through a spray apply technique. Pre-

cured hempcrete blocks can also be created.

B. Bamboo (note: untreated bamboo will get eaten to dust by insects):
   1. It is possible to improve the pest resistant characteristics of bamboo with additives:
      i. Silica soak.
      ii. Boric acid soak (borax soak).
      iii. Metal soak (e.g., copper soak).
   2. Strengthener material.
   3. Strengthener bamboo oragami.
   4. Surface coating.

5. **Steel (and other metals)** - a material that has good structural properties. It has high strength and equal strength in tension and compression and is therefore suitable for the full range of structural elements and will resist axial tension, axial compression and bending type load with almost equal facility. Its density is high, but the ratio of strength to weight is also high so that steel components are not excessively heavy in relation to their load carrying capacity, so long as structural forms are used which ensure that the material is used efficiently.
6. **Concrete and cement** - is a composite of stone fragments (aggregate) and cement binder, may be regarded as a kind of artificial masonry because it has similar properties to stone and brick (high density, moderate compressive strength, minimal tensile strength). It is made by mixing together dry cement and aggregate in suitable proportions and then adding water, which causes the cement to hydrolyse and subsequently the whole mixture to set and harden to form a substance with stone-like qualities. Concrete has one considerable advantage over stone, which is that it is available in semi-liquid form during the building process and this has three important consequences. Firstly, it means that other materials can be incorporated into it easily to augment its properties. Secondly, the availability of concrete in liquid form allows it to be cast (and pre-cast) into a wide variety of shapes. Thirdly, the casting process allows very effective connections to be provided between elements and the resulting structural continuity greatly enhances the efficiency of the structure.
   A. Concrete - Aggregates make up some 60 -80% of most concrete mixes. They provide compressive strength and bulk to concrete. Recycled concrete can be used as aggregate in new concrete, particularly the coarse portion.
   B. Cement - Chemically, cement is a mixture of calcium silicates and small amounts of calcium aluminates that react with water and cause the cement to set. Calcium derives from limestone and clay, mudstone or shale as the source of the silica and alumina. The mix is completed with the addition of 5% gypsum to help retard the setting time of the cement.
   C. Non-reinforced concrete - has similar properties to masonry and so the constraints on its use are the same as those which apply to masonry.
   D. Reinforced concrete - semi-liquid concrete is mixed with steel in the form of thin reinforcing bars which give the resulting composite material (reinforced concrete) tensile and therefore bending strength as well as compressive strength. Reinforced concrete possesses tensile as well as compressive strength and is therefore suitable for all types of structural element including those which carry bending-type loads.
   E. Foamed concrete (lightweight concrete, aircrete) - made from (ingredients): Portland cement, shampoo to create a foam, and some glass fiber for extra strength. Made by mixing ingredients.
      1. Aircrete blocks often have at least one metal frame within them.
   F. Shotcrete - a sprayable mix of concrete.
      1. Uses an interior foam surface, that has a metal frame placed on its surface. The shotcrete is then sprayed on top of the foam, and ends up covering the metal frame.

## *7.2 Material stresses*

Types of stresses on materials:

1. Mechanical stresses.
   A. From equipment.
   B. From the earth.
2. Chemical stresses (chemicals and biologicals consuming or decomposing "eating away" material and making it weak, brittle, etc).
3. Animal stress.
   A. Insects.
   B. Mammals.
4. Electromagnetic stresses.
   A. Sunlight.
5. Thermal stresses.
   A. Sunlight.
   B. Equipment producing heat.
   C. Temperature changes from climate and equipment.

## *7.3 Surface system specification*

Surfacing (e.g., Weather proofing) specification involves:

1. Surface additions diagram.
2. Surface modification diagram.

3. Surface functional diagram.

## *7.4 Materials sourcing and transportation*

Market related materials application elements include:

1. All materials are sourced.
   A. Local wild ecological environment.
   B. Habitat Service System Materialization Sub-System.
   C. Material supply businesses.
2. All materials are transported.
   A. From local wild ecological environment.
   B. From local habitat service system.
   C. From habitat service system network.
   D. From local market-State region.
   E. From non-local market-State locales.

## *7.5 Material selection consideration*

Materials are considered in relation to their:

1. Life-cycle analysis on material.
2. Material characteristics.
3. Material handling requirements.
4. Reliability analysis.
5. Maintenance.
6. Weather proofing (finish type).
7. Fire proofing.
8. Durability.
9. Regenerability/sustainability.
10. Ease of upgrade.
11. Financial cost.

# 8 Planning architectural services

*A.k.a., Building services, architecturally connected sub-systems, utilities and fixtures and fittings mapping, fixtures and fittings and equipment (FF & E), infrastructural connections, infrastructural services, public/utility services.*

Most building and non-building architecture houses utilities, fixtures, and fittings. Fittings, fittings, and utilities represented an association of hierarchies of material connections to the architecture. Utilities are integrated into the architecture in some manner, either through conduits or into the architecture itself. Utilities allow for user usage of the architecture. Utilities (Read: services) are generally considered to include: electricity, gas, water and sewage, and communications/networking services. Fixtures are physically and permanently (within reason) attached to the architecture. Fittings are not permanently or physically attached to the architecture. Effective service systems need planning and demand surveying/forecasting to ensure that supply meets demand. In general, architectural service systems are also known as infrastructural systems. These systems interconnect the within and between architectural objects in the habitat. These service systems include but are not limited to: transport, power, water, atmosphere, etc.

## *8.1 Architectural service sub-system classification*

The following hierarchy of categories will define an architectural service sub-system:

1. Standards.
   A. Documentation.
   B. Requirements.
   C. Hazards.
2. Sub-systems definition.
3. Sub-system objects (a.k.a., fittings, fittings, and appliances).
4. Sub-system installation of objects (construction and maintenance).
5. Sub-system operation of objects (production and usage; supply and demand).
6. Sub-system load identification (identify all loads).
7. Sub-system engineering calculations.

In order to sustain full understanding, the definition of the system and the definition of object must be given. The system must be conceived (planned) and the objects positioned. Herein, fixtures and fittings are the fundamental objects and technologies that are part of the operation of a specific sub-system.

### 8.1.1 Building services

*A.k.a., Architectural services.*

Building services are the systems installed in buildings to make them comfortable, functional, efficient and safe. Building services design must be integrated into the overall building design from a very early stage. The detection of clashes between building services and other building components is a significant cause of delays and variations on site, not just in terms of the physical services themselves, but also access to allow the builders work in connection with those services. The final result of building services arrangement can simplify building maintenance and operations or complexify it beyond reproach. Note here that the use of 3D computer aided design (CAD) systems and building information modelling (BIM) reduces the occurrence of such problems.

Primary building services include, but are not limited to:

1. Structural
2. Electricity.
3. Water
4. Gas and fuel.
5. Atmospheric (HVAC).
6. Electrical.
7. Illumination.
8. Surfaces.

Secondary building services include, but are not limited to primary optimization functions:

1. Thermal.
2. Insulation.
3. Accessway.
4. Automation.
5. Accessibility.
6. Safe access.
7. Acoustics.
8. Fire and contaminant protection.
9. Pest control.
10. Modularity.

Secondary building services include, but are not limited to secondary optimization functions:

1. Building control systems.
2. Thermal energy transfer systems.
3. Transportation systems.
   A. Escalators.
   B. Moving walkways.
   C. Elevators.
4. Fire safety, detection and protection systems.
5. Security and alarm systems.

Note that specialist building services might also include, but are not limited to:

1. Pathogen and bacteria control.
2. Humidity control.
3. Specialist lighting.
4. Specialist security.
5. Emergency power.
6. Specialist gas distribution.
7. Fume cupboards.
8. Operating theatres.
9. Etc.

## *8.2 Architectural service connection system*

*A.k.a., Engineering utilities.*

The primary architectural sub-elements of material-architecture include:

1. **Utilities** - primary functional services.
2. **Fixtures** - fixed equipment (i.e., equipment fixed to the architecture).
3. **Fittings** - appliances, movable equipment, easily unfixed equipment, etc.

### 8.2.1 Architectural connection network

Architectural utilities, fixtures and fittings are connected throughout an architectural structure by means of conduits that run through conduits from a source point to an outlet (endpoint).

#### *8.2.1.1 Architectural conduits*

An architectural conduit specification includes:

1. Conduit analysis
   A. Atmospheric (ducting).
   B. Gas (piping).
   C. Water (piping).
   D. Electrical power (wiring).
   E. Data and network communications (wiring).

#### *8.2.1.2 Architectural service outlets*

*A.k.a., Endpoints.*

Outlets (a.k.a., endpoints) are the end distribution points (a.k.a., outlets) of utilities and other flows within architecture. An endpoint analysis includes, but may not be limited to:

1. Utility analysis - what utilities are present.
2. Technology analysis - what technologies provide the utility services.
3. Atmospheric outlets (vents).

4. Gas outlets.
5. Water outlets.
6. Electrical outlets:
   A. Power outlets.
   B. Illumination outlets.
7. Data outlets.

#### *8.2.1.3 Architectural service controls*

There are both spatial mechanisms and modes for control of service systems.

Spatial service mechanisms of control include, but may not be limited to:

1. Physical controls:
   A. Barrier lock control.
   B. Open/close control.
   C. Liquid and atmosphere control.
2. Electromagnetic controls:
   A. Light control.
   B. Climate control.
   C. Electrical power control.
3. Mechanism control:
   A. Pump control.
   B. Fan control.
   C. Electrical pump control.
4. Programmatic control:
   A. Alarm control.
   B. Motion and/or [spectral] color change control.
   C. Schedule control.
5. User control:
   A. Identity control.

Modes of controlling [environmental] variables in a service space include, but may not be limited to:

1. **Manual** control (switch).
2. **Sensor** control:
   A. Motion/presence sensor
   B. Electromagnetic sensor (light and/or climate).
   C. Thermal sensor (climate and/or temperature).
3. **Schedule** control (pre-defined timing).
4. **Analytical** control (pre-defined decisioning - quantitative output of an information process passes a threshold).

### 8.2.2 Utilities

*A.k.a., Utility service, service utility, architectural service, etc.*

The characteristics of a utility include:

1. Service: Is this a service that is provided by an external source, or by a point source within the building?
2. Connection: Does the service use conduits (or other transportation mediums such as raceways and open web floor trusses) that are within the wall, ceiling, or flooring (or atmosphere in the case of wireless communications)?
3. Adaptability (modification): Is the service difficult to modify?
   A. Providing designated, decoupled, and accessible space for utilities can reduce cost and time during construction. It can also allow utility systems to be modified or repaired over time without performing major demolition and reconstruction. Some products exist today that can help alleviate entanglement (disentanglement; for example, raceways and open web floor trusses). Decoupling utilities from the structure can occur with appropriate technologies.

Utilities common to most architecture include, but are not limited to:

1. Electricity
2. Gas
3. Water
4. Sewage
5. Communications services

### 8.2.3 Fixtures

The characteristics of a fixture include:

1. Method of attachment: Is the item permanently affixed to the wall, ceiling, or flooring by the use of a connecting component (e.g., nails, glue, cement, pipes, or screws)? The method used to attach it might make it a fixture, even if it can be removed it relatively easily. Ceiling lights (i.e., light fixtures) can be removed although they're attached by wires, and they're a house fixture.
2. Adaptability: The item becomes an integral part of the architecture when it can't be removed. A floating laminate floor is a fixture, even though it's snapped together. A built-in sub-zero refrigerator is considered a fixture because it fits inside a specified space even though it can be unplugged.
3. Intention: The item is a fixture if the intent was to make the item a permanent attachment when the installation took place.
4. Removal: Not usually removed when the architecture is re-occupied for a similar purpose (i.e., a home is occupied by another family).

Fixtures common to most architecture include, but are not limited to:

1. Air conditioners

2. Bathtubs
3. Built-in mirror
4. Built-in shelving
5. Built-in furniture
6. Built-in electronics
7. Cabinets
8. Carpeting
9. Ceiling fans
10. Chandeliers
11. Conduits.
12. Doors
13. Door bells
14. Drapery rods
15. Fences
16. Fireplaces
17. Garage door opener
18. Handrails
19. Heating systems
20. Home automation system
21. Hot water heater
22. Light fixtures
23. Security systems
24. Shutters
25. Sinks
26. Smoke detectors (and other detectors)
27. Wall sconces
28. Windows
29. Window shades
30. Etc.

### 8.2.4 Fittings

The characteristics of a fitting include:

1. Method of attachment: Is the item free standing and not permanently attached to the architecture?
   A. Adaptability: The item does not become an integral part of the architecture.
   B. Removal: May be changed or removed when the architecture is re-occupied for a similar purpose (i.e., a home is occupied by another family).

Fittings common to most architecture include, but are not limited to:

1. Cabinet/cupboard fittings
2. Door handles
3. Door knockers
4. Hangers and hooks
5. Locks
6. Window fittings
7. Signs
8. Switches and sockets.
9. Faucets
10. Appliances (e.g., kettle, coffee maker, washing and drying machine, etc.)
11. Etc.

## 8.3 *Utility localization and transportation*

*A.k.a., Utility sources and utility resource flows.*

All architecture, given utility requirements and distribution requirements can compute the optimal design for utility localization and utility transportation within the architecture. The localization and transportation of utility services requires architectural space. That space can be pre-defined with conduits, or not:

1. Entangled utilities (no conduit) - utilities without predefined accessible pathways, without conduits. Embedding pipes, ducts, and wires in walls, floors, and ceilings haphazardly without planning or dedicated spaces can lower efficiency and increase negative variables, including cost and team time. is built, entangled utilities are difficult to modify, Because utilities are embedded in the structure and hidden behind surfaces. Unfortunately, access to utilities almost always becomes necessary at some point due to adaptation or other changes. For example, replacing wiring or repairing household plumbing. Entangled utilities can:
   A. Lead to inefficiency in initial construction.
   B. Compromise structural integrity.
   C. Negatively affect utility function.
   D. Negatively impact sound, electromagnetic, and heat insulation function.
   E. Obstruct rework, renovation, and repair.
2. Disentangled utilities (conduit) - utilities with predefined accessible pathways, with conduits. designated, decoupled, and accessible space for utilities can reduce cost and time during initial construction. It can also allow utility systems to be modified or repaired over time without performing major demolition and reconstruction. While not technically disentangling, flexible utilities with faster connections can ease installation and subsequent alteration and are included as related topics. Disentangled utilities are essential for modular floor plans.

Utility localization and transportation planning includes:

1. **Using software and digital libraries** of building components to allow efficient and accurate planning to predefine utility pathways before construction begins.
2. **Separating building layers** by lifespan, decoupling utilities from structure with open web floor trusses and raceways, and providing for access. The most important system in the home, and the most critical

one in examining entanglement, is the structure itself.

3. **Creating an integrated utility gateway** that brings all of the services into the home in a single location.
4. **Creating integrated utility modules**, for example a fully plumbed bathroom wall, which can be manufactured as one piece in a factory in a disentangled manner.
5. **Increasing the use of quick connect** electrical and plumbing components to allow even greater gains in efficiency and ease of renovation from disentangling.
6. **Anticipating potential future utility systems** before they are widely implemented and making allowances for their eventual installation.
7. Working with the technical utility sub-systems to create a distributed modular system that limits distribution requirements and reduces entanglement.
8. Creating a single shared low-bandwidth data network to replace proprietary lighting control, HVAC control, security, and sensor networks.

Common types of conduits in architecture that are useful for disentangling utilities include, one or more of the following:

1. Structural precast conduits
   A. Pre-case structural materials, such as conduit paths pre-case with concrete or bioceramic.
2. Architectural conduits
   A. Architectural raceways (raceway conduits)
   B. Architectural floor trusses (trussed conduits)
   C. Architectural panels and panelling (e.g., false ceilings, drop ceilings, false/drop floors, removable ceiling and floor)
3. Interior conduits (e.g., piping, enclosures, etc.)
   A. Conduit types (names) include:
      1. Pipes
      2. Tubing
      3. Ductwork
   B. Conduit materials include, but may not be limited to:
      1. Rigid metal conduit (RMC)
      2. Electrical metallic tubing (EMT)
      3. Intermediate metal conduit (IMC)
      4. Flexible metal conduit (FMC)
      5. Concrete or bioceramic
      6. Bamboo
      7. Plastic piping
         i. PVC
         ii. Cross-linked polyethylene (PEX) tubing (a plastic material used for water supply piping systems)

The positioning of conduits within other conduits often involves:

1. Stands
2. Hangers
3. Spacers

Some utilities may have their own architecturally separate conduits, or they mare share conduits. Often conduits that could cause serious injury are separated in some manner so that mixing is unlikely, if not impossible (e.g., gas and electrical, or gas and atmosphere).

### 8.3.1 Structural utility distribution

*A.k.a., Structural utility transportation.*

The structure is used for containing function (the utility source point localizations) and for transport-distribution of those utilities throughout the architecture for end-point distribution. The common utility distribution systems in architecture include:

1. Electricity distribution
   A. Electrical power cabling is run from a central breaker box to separate circuits to provide power to distribution endpoints
   B. Hard-wired switches that physically break the circuit to prevent power from continuing to a particular endpoint (or set of endpoints).
   C. Requirement: The wiring should be easy to disconnect and remove, and connect and replace.
2. Data distribution
   A. Data cabling is installed in a similar (or, the same) manner to electrical cabling. Data is usually run to fewer endpoints than power.
   B. Wireless data spreads through atmosphere and structure to space/area endpoints.
3. Atmospheric distribution
4. Gas distribution
5. Water distribution

### 8.3.2 Localization of internal utility sources (and distribution nodes)

Utility source points can be stored in [appropriately] enclosed spaces with accessible and non-interferable panels. Utilities may be centrally distributed from an exterior source, such as for electricity or clean water, or package transportation between buildings and habitats. A building could filter its own water for drinking, as well as its own air, or a centralized space external to any particular building, but feeding multiple buildings could exist. Package utility transportation refers to the transportation of packages (anything, food, tools, prints, etc.) around the habitat and necessarily involves a networked transportation system external to any given building.

## 8.4 *Structural integration design of utilities (architectural functions)*

*A.k.a., Planned utility mapping.*

Designing the structural mapping of [functional] utilities involves:

1. **Delivery method** - how utilities are brought to the user.
2. **Construction method** – how the architectural object is built and how utilities are installed.
3. **User interaction** – how people interface with utility systems.

Herein, the functional mapping of utilities involves the following data elements:

1. In the market-State, all utilities are metered for a fee.
2. Some utilities may come from the market-State.
3. All utilities have centralized unit operations.
4. All utilities have distribution endpoints.
5. Some utilities have returns and/or exits.

## 8.5 *Visualization of utility-service flow*

The complete flow of utility-services can be visually mapped as a flow diagram of the utility service system within an architectural system. This flow diagram (flow visualization) shows how these utilities are converted, transformed, or redistributed into services, and finally, endpoint usages.

## 8.6 *Architectural equipment*

Architectural equipment related factors include:

1. All equipment is sourced.
   A. Tools (movable equipment).
   B. Fixtures and fittings (fixed equipment).
   C. Appliances and other equipment (flexible equipment).
2. All equipment is transported.
3. Equipment may require servicing and repair.

Sources and characteristics of equipment include:

1. Source.
2. Relative sizes.
3. Weights.
4. Location.
5. Capacities.
6. Materials and tools of construction.
7. Resources, tools, and personnel of operation.
8. Insulation and painting (aesthetic) requirements.
9. Equipment related access.
10. Vendor, model, and serial number.
11. Equipment delivery time.
12. Equipment financial costs.

# 9 Planning architectural construction

*A.k.a., Architectural fabrication, construction work, construction engineering.*

Construction is the process of moving and assembling materials and equipment into completed forms for use. Construction is the process of building something. Architectural construction is the process through which architecture is sufficiently defined to be materialized, and then, materialized. In other words, architectural construction is the process by which material and non-material elements and overall spatial setting are made fixed in the form of a building or non-building structure. Herein, building construction is the process of preparing for and forming buildings and building systems; it is the process of adding structures to land-, sea-, and space-scapes. Different types of architecture may be constructed in different ways. This section primarily relates to the construction of building and non-building architecture, and not necessarily cultivation, transportation, or clothing architecture (although, there may be similarities to the methods by which such type of objects are created).

Note that construction may also be considered to include:

1. Fabrication and assembly.
2. Demolition and disassembly.
3. Rebuilding.
4. Alterations of or additions to architecture (remodeling).
5. Etc.

Construction work refers to the carrying out of any work related the actual construction (materialization or re-materialization) of an architectural structure.

More completely, construction work may be characterized by (Construction Design and Management, 2015):

1. The construction, alteration, conversion, fitting out, commissioning, renovation, repair, upkeep, redecoration or other maintenance (including cleaning which involves the use of water or an abrasive at high pressure, or the use of corrosive or toxic substances), de-commissioning, demolition or dismantling of a structure.
2. The preparation for an intended structure, including site clearance, exploration, investigation (but not site survey) and excavation (but not pre-construction archaeological investigations), and the clearance or preparation of the site or structure for use or occupation at its conclusion.
3. The assembly on site of prefabricated elements to form a structure or the disassembly on site of the prefabricated elements which, immediately before such disassembly, formed a structure.
4. The removal of a structure, or of any product or waste resulting from demolition or dismantling of a structure, or from disassembly of prefabricated elements which immediately before such disassembly formed such a structure.
5. The installation, commissioning, maintenance, repair or removal of mechanical, electrical, gas, compressed air, hydraulic, telecommunications, computer or similar services which are normally fixed within or to a structure.
6. But, does not include: the exploration for, or extraction of, mineral resources, or preparatory activities carried out at a place where such exploration or extraction is carried out.

Similarly, it could be said that construction work includes all activities associated with a construction:

1. Construction (fabrication).
2. Reconstruction.
3. Demolition.
4. Repair or renovation.
5. Associated activities such as:
   A. Site preparation.
   B. Excavation.
   C. Erection.
   D. Building.
   E. Assembly and disassembly.
   F. Installation of equipment or materials (site installation).
   G. Decoration and finishing.
6. As well as services incidental to construction such as:
   A. Drilling.
   B. Mapping.
   C. Satellite photography.
   D. Seismic investigations.
   E. Similar services.

Because there are several types (categories) or architecture, there are simultaneously several types of construction and construction work.

For example, building work means:

1. The erection or extension of a building.
2. The provision or extension of a controlled service or fitting in or in connection with a building.
3. The material alteration of a building, or a controlled service or fitting.
4. Work required by regulation 6 (requirements relating to material change of use).
5. The insertion of insulating material into the cavity

wall of a building.
6. Work involving the underpinning of a building.
7. Work required by regulation 22 (requirements relating to a change of energy status).
8. Work required by regulation 23 (requirements relating to thermal elements).
9. Work required by regulation 28 (consequential improvements to energy performance).

For clarification, sometimes the term, 'building operations', is applied to building work, in the case of:

1. Demolition of buildings.
2. Rebuilding.
3. Structural alterations of or additions to buildings.
4. Other operations normally undertaken by a builder.

**CLARIFICATION:** *The operations and maintenance (O&M) of architectural structures is no considered construction.*

## *9.1 Fabrication location*

Fabrication of architectural elements used in construction can either be on-site or prefabricated off-site (as in, the degree of pre-fabrication, modularity and flexibility of fabrication):

1. **Pre-fabricated (factory built)** - The architecture is constructed in a factory; it is pre-fabricated in a factory.
    A. Prefabrication works most efficiently where there is repetition. In the market-State, there is little repetition (because of businesses and their "intellectual" properties).
    B. Prefabricated modules, limited by the size constraints of highway transportation, are shipped to the final site on truck beds and then joined in the field.
2. **Site fabricated (site built, site construction)** - The architecture is constructed on-site, which allows for larger constructions and possible usage of local materials.

In concern to the transportation of fabricated elements:

1. All fabrication efforts are sourced.
2. Some fabrication elements may require transport.
3. Some fabricated elements may require servicing and repair during construction

## *9.2 The construction process*

*A.k.a., Construction phases.*

Construction work involves at least the following phases:

1. **Site access** - access to the site.
2. **Site evaluation (a.k.a., site investigation, site assessment, site survey)** - evaluation of the site for construction purposes.
3. **Construction documents (including, a site plan)** - produced by architectural-engineering processes.
4. **Site layout plan and site safety plan** - a plan for the phased layout of the site prior to work commencement, including a plan for the safety of work. As sites will change in nature during the course of the works, there may be a number of different site layout plans for different phases, and there may be more detailed plans showing particularly complex areas or sequences or describing specific functions.
5. **Site preparation** - preparation of the site for construction.
6. **Site construction** - the actual construction process.
7. **Architectural evaluation** - the evaluation of the construction.

### 9.2.1 Site investigation

*A.k.a., Site evaluation.*

Sites must be thoroughly investigated prior and during construction. Site investigations should consist of four well-defined stages:

1. **Planning stage:** Setting clear objectives for the site investigation, including scope and requirements, which enable it to be planned and carried out efficiently and provide the required information.
2. **Desk study (remote study):** Reviewing historical, geological and environmental information about the site.
3. **Site reconnaissance (a walkover survey):** Identifying actual and potential hazards and the design of the main investigation.
4. **Main investigation and reporting:** Including intrusive and non-intrusive sampling and testing to provide soil parameters for design and construction.

Site investigations should include:

1. Susceptibility to groundwater levels and flow.
2. Underlying geology, and ground and hydro-geological properties.
3. Identification of physical hazards.
4. Identification of methane and other gases.
5. Determining an appropriate architectural and structural design.
6. Determining an appropriate location and orientation of buildings and other systems.
7. Providing soil parameters for design and construction.

## 9.2.2 Site layout plan

Site layout planning involves four basic processes:

1. Identifying the site facilities that will be required.
2. Determining the sizes, and other constraints of those facilities.
3. Establishing the inter-relationships between the facilities.
4. Optimising the layout of the facilities on the site.

Site layout plans might include locations for and sizes of:

1. Zones for particular activities.
2. Cranes (including radii and capacities).
3. Site offices.
4. Welfare facilities.
5. Off-loading, temporary storage and storage areas (laydown area)
6. Sub-contractor facilities.
7. Car parking.
8. Emergency routes and muster points.
9. Access, entrances, security and access controls, temporary roads and separate pedestrian routes.
10. Vehicle wheel washing facilities.
11. Waste management and recycling areas.
12. Site hoardings and existing boundaries.
13. Protection for trees, existing buildings, neighbouring buildings, and so on.
14. Signage.
15. Temporary services (including electrical power, lighting, water distribution, drainage, information and communications technology, site security systems, and so on)
16. Temporary works (such as propping solutions to retained structures, sheet piling details, and so on).
17. Areas for the construction of mock-ups for testing.
18. Fabrication facilities.

Problems caused by poor site layout planning can include:

1. Inappropriate storage which can result in damage to products and materials.
2. Poor siting of plant.
3. Poor siting of welfare facilities.
4. Inadequate space provision.
5. Unsatisfactory access.
6. Security and safety issues.
7. Poor wayfinding (due to complex layouts or inadequate signage).
8. Demoralised workers, delays and increased costs.

#### *9.2.2.1 Construction safety*

*A.k.a., Site safety, safety management.*

Safety practices and a safe culture are part of every construction operation. Some of the practices that can be employed on projects to facilitate safety include:

1. Involving workers in the safety process, through toolbox talks, safety briefings, site inductions, etc.
2. Analysis of potential site safety hazards during the pre-construction phase.
3. Adopting the principles of prevention:
   A. Avoid risks where possible
   B. Evaluate those risks that cannot be avoided
   C. Put in place measures that control them at source.
4. Encouraging an "open-door" policy (protocol) for workers to report accidents, injuries, hazards and near misses.
5. Conducting thorough near miss and incident investigations to ensure effective action is taken.
6. Utilize specific personnel assigned to coordinate safety.
7. Designating health and safety duties to on-site staff, such as a first aider.
8. Conducting regular project safety audits.
9. Developing a site-specific health and safety plan.
10. Site specific training programmes for workers and subcontractors.
11. Proper use of personal protective equipment (PPE).

#### *9.2.2.2 Construction risks*

The physical process of constructing something always entails some form of potential risk, because of the operation of equipment and usage of potentially hazardous materials.

Key health risks (a.k.a., occupational risks) in construction include:

1. Exposure:
   A. To climactic elements (e.g., sunlight, cold, etc.)
   B. To chemicals (e.g., asbestos, dusts including silica, concrete, lead, and exhaust emissions).
2. Frequent loud noise.
3. Frequent or excessive use of vibrating tools.
4. Frequent or excessive manual handling of loads.
5. Stress and fatigue.

A risk coordination/management cycle to identify and prevent risk includes:

1. Identification of hazards.
2. Assessment of risks.
3. Selection of controls.
4. Implementation and recording of findings.
5. Monitoring and review.

Construction sites can be dangerous places, and only authorised personnel should be allowed access. Dangers to non-authorised personnel include:

1. Falling materials or tools.
2. Falling into trenches.
3. Falling from height.
4. Being struck by moving plant and vehicles.
5. Standing on sharp objects.
6. Coming into contact with electricity or hazardous materials.
7. Dust, noise and vibration.

In addition, construction sites can be vulnerable to vandalism, theft, arson, protests, suicides and so on. Construction sites will generally adopt perimeter security measures to control access, both for safety purposes, and to prevent damage, theft or vandalism. Hence, construction sites present a challenge in terms of securing access as:

1. Their nature and layout is subject to frequent change.
2. Access is required by a large number of contractors, suppliers, consultants and so on.
3. They are often in highly-populated areas.
4. It may be necessary to maintain user access to neighbouring sites, or parts of the site itself.
5. There can be time pressures to complete the works quickly.

Methods of controlling access to construction sites include, but may not be limited to:

1. Security fencing (a.k.a., perimeter hoarding) creates a primary boundary for controlling access. Hoarding is a temporary construction, of at least 2.4m that is more difficult to climb than fencing and prevents viewing of the site interior. However, can also prevent people from seeing unauthorised personnel if they manage to gain access to the site.
2. Turnstiles, security gates and guards can then be used to ensure that only authorised personnel can enter. Other types of barriers and bollards may be used.
3. Electronic access control systems (ACS) and locks.
4. Signage.
5. sign-in and reception areas.
6. Storing materials and machines away from the perimeter.
7. Lighting.
8. CCTV.
9. Motion detectors.
10. Removal of ladders.
11. Protection of scaffolding, public address systems.
12. Keeping the site clean and tidy.
13. Secure storage.

Special measures may be necessary for works in the vicinity of vulnerable groups such as the elderly, children and people with disabilities. Children in particular may be drawn to construction sites, seeing them as places to play.

### 9.2.3 Site preparation

Before construction (building) work can start on a site, certain activities must be taken to ensure that construction is feasible, that maximum health and safety is achieved, and that construction operations will not be hindered; these include, but are not limited to:

1. The ground to be covered by the building shall be reasonably free form any material that could damage the construction process or affect the final construction's stability. This requires the clearing of vegetation, topsoil and any pre-existing foundations. This can include turf and roots, especially if they are close to the proposed construction.
2. Precautions should be taken to avoid danger to health and safety from contaminants in the ground and any other land associated with the building.
3. Installation of adequate sub-soil drainage, if required.

#### *9.2.3.1 Site contaminants*

> **NOTE:** *Where a site may be affected by contaminants, a combined geotechnical and geo-environmental investigation should be considered and remediation maybe necessary.*

Sites must either safely account for or be free from contaminants. A 'contaminant' as any substance that is or may become harmful to persons or buildings, including substances which are corrosive, explosive, flammable, radioactive or toxic.

Site contaminants include, but are not limited to:

1. Animal and animal products of processing works.
2. Asbestos works.
3. Ceramics and asphalt manufacturing works.
4. Chemical works.
5. Dockyards and dockland.
6. Gas works.
7. Landfill and other waste disposal sites.
8. Oil storage and distribution sites.
9. Power stations.
10. Scrap yards.
11. Sewage works.
12. Texile and dye works.
13. Molds.

Site contaminants are handled in [at least] the following ways:

1. Clearance or treatment of unsuitable material – includes guidance on various site investigation measures and types of unsuitable material.
2. Resistance to contaminants – includes risk assessment and remedial guidance on solid and liquid contaminants, methane and other gases from the ground, and radon.
3. Subsoil drainage.
4. Floors – includes guidance and technical solutions for ground supported floors, suspended timber ground floors, suspended concrete ground floors, floors exposed from below, and resistance to surface condensation and mould growth.
5. Walls – includes guidance and technical solutions for internal and external walls (moisture from the ground), external walls (moisture from outside), solid external walls, cavity external walls, cavity insulation, framed external walls, cracking of external walls, impervious cladding systems, joints between doors and windows, door thresholds, and resistance of external walls to damage from interstitial condensation, surface condensation and mould growth.
6. Roofs – includes guidance and technical solutions for roof resistance to damage from moisture from outside, interstitial condensation, surface condensation and mould growth.

Note, when contaminants are found on a site, it may be necessary to notify findings to regulatory authorities, for example:

1. Where contaminants are found that had not been previously known about.
2. In planning applications.
3. In relation to waste management and the protection of water quality and resources.

Some contaminants such as radon, landfill gases and those from organic solvents and fuel can penetrate the building by a variety of means. In most cases the rate of penetration can be reduced by sumps and sub-floor ventilation, as well as other ventilation strategies.

## *9.3 Construction technologies*

*A.k.a., Building technologies.*

The term 'building technology' and 'construction technology' refers to the technical processes and methods used in the constructing of architecture, particularly, buildings.

Construction technology factors includes, but are not limited to the following factors:

1. Materials and their applications.
2. Physical properties.
3. Capacities and vulnerabilities.
4. The functioning of components and systems.
5. The engineering principles.
6. Procedures and details of building assembly.
7. Procedures and details of building startup and operation.

Construction information factors include, but may not be limited to:

1. Technical drawings for the building and its construction.
2. Technical specifications for the building and its construction.
3. Site investigations and surveying.
4. Construction materials, components, systems and techniques.
5. Building services.
6. Operation and maintenance.
7. Energy supply and efficiency.
8. Structural systems.
9. Communications.
10. Smart technology.
11. Sustainability.
12. Waste water and water management.
13. Building engineering physics.
14. Building science.
15. Prefabrication and offsite manufacturing.
16. Modelling and assessment.
17. Collaborative practices.
18. Research, development and innovation.
19. Construction plant.

Construction technologies include, but are not limited to:

1. Bio-construction manual technologies.
2. Conventional manufacturing and construction technologies.
3. Pre-fabrication manufacturing technologies.
4. 3D automated and semi-automated technologies.

Note that crane technologies are most commonly used to position large architectural objects on-site.

## *9.4 Construction methods*

The basic methods of construction are:

1. **Cutting and joining** - includes the cutting of materials (on- or off-site) and then assembling them (on- or off-site), and then moving them into their final position on-site.

2. **3D printing** - involves the layering of a material and then the incorporation of other services, such as utilities, fixtures and fittings.
3. **Extrusion** - involves the extrusion of a solid element, usually in a factory, which is then transported to the construction site. The utilities, fixtures and fittings may be incorporated in the factory, or on-site.

### 9.4.1 3D printing systems

To print a 3D architectural structure requires:

1. The digital object (a basic template or CAD drawings).
2. A printer.
3. Materials.
4. Time, skills, and power.

The 3D-printed walls won't cracks, and are strong water proofing, better air permeability, better heat preservation and low carbon pollution.

Problems with 3D printing include, but are not limited to:

1. 3D printing takes time
2. Printed parts are mechanically weak
3. Material choices are limited

There are two main types of structure for 3D printers for the construction of buildings:

1. Gantry-based systems.
2. Robotic arm-based system.
3. Comparison [cobod.com]
   A. It is possible to mix robotic and gantry technologies using cooperative robotics. This allows for 3d print around other objects, such as around steel reinforcement with concrete objects.

The following are the possible material types for the 3D printing of architectural objects (Read: buildings):

1. **Concrete mixtures** - mixtures of concrete.
   A. Characteristics of concrete mixtures:
      1. Can be printed on-site, or printed in a factory, transported to the site, and assembled on-site.
      2. Does not cure instantly. Curing time can be lowered by replacing water with alcohol in the mixture (because alcohol evaporates more rapidly).
      3. Can be mixed with ethanol, which evaporates more rapidly than water and will harden and complete faster.
   B. Technology / development companies:
      1. **Winsun 3D Builders**, China [winsun3dbuilders.com]
      2. **COBOD**, Denmark [cobod.com]
         i. Purchasable gantry system consisting of
         ii. Advantages include:
            1. The materials are open source and the company advise customers to source materials locally.
            2. Inclined or overhangs (non vertical walls) can be accomplished with the BOD2. The degree that is possible to print is depending on material properties and geometry.
      3. **Constructions-3D**, France [en.constructions-3d.com]
         i. Purchasable robotic-arm system consists of: a mixing and pumping station, control system, and robotic 3D printer (comes in standard 20 foot container).
      4. **Lightweight concrete**, United States [website]
         i. https://www.bradenton.com/news/business/article247233154.html
      5. **Icon**, United States [icon.com]
         i. Purchasable gantry system consisting of: a robotic system, a software system, and materials. A fully automated system, including the mixing and pumping.
         ii. Disadvantages include:
            1. Uses a proprietary formula.
2. **Synthetic stone (a.k.a., light stone material, LSM)** - UV curable material combined with mineral filler (a.k.a., synthetic stone).
   A. Technology / development companies:
      1. **Mighty Buildings**, United States [mightybuildings.com] [youtube.com, *LIVE Factory Walkthrough: Webinar + Q&A*]
         i. Built in a factory and shipped to final destination (pre-fabricated).
         ii. Machine produces panels and building components, or an entire building.
         iii. Disadvantages include:
            1. In a promotional video an employee said the printer could not be purchased.
            2. Patents on materials.
         iv. Advantages include:
            1. Factory building means less setup and tear-down time to build multiple buildings.
            2. Cures almost instantly.
            3. Large gantry system.
            4. Zero-waste production process (eliminates 3-5kgs that normally go to

landfill).

5. Fiber reinforcement possible with strength similar to steal.
6. Reduced time duration of project.

3. **Clay mixtures** - mixtures of clays and/or ceramics.
   A. Objects can be printed by extruding layers of a ceramic / clay paste from a nozzle or by glue-bonding powder particles layer-by-layer.

**NOTE:** *These are additive processes (as opposed to subtractive where material is cut away from a block).*

# 10 Architectural modeling

Architectural modeling is the process of creating a model of a building, or other architectural structure. In this way, architectural modeling is the design of real (not virtual) 3D representations of architectural systems. An architectural model is an information model (artifact) that comprises all the possibilities in terms of construction. Architectural model capture all (or, some) of the design decisions that comprises a system's architecture. Architectural modeling is the reification and documentation of architectural design decisions.

All architectural models are made on a scale; for example, 1: 100, which means they are 100 times smaller than the original, although they could be 1: 1, which is normal or even larger, or for example 8: 1, where the model would be eight times the size of the original. In the early 21st century, architectural modeling is a computer-aided process of creating 2D and 3D representations of architectural designs. However, 3D models create a more complete picture of the project than 2D models, and should be used over 2D models wherever possible. There are many different benefits of using a 3D building model. Not only does it help visualize the completed project, but it also reduces conflicts in design of architectural sub-systems.

## *10.1 Modeling accuracy*

Models shall be checked for:

1. Scale.
2. Geometric accuracy of modeled components.
3. Locational accuracy in the horizontal and vertical dimensions.
4. Conformance with the BIM Standards identified in these standards.

## *10.2 Level of development and level of detail (BIM LOD)*

Level of development (LOD) is a set of specifications that gives developers the ability (through categorization) to document, articulate and specify the content of BIM effectively and clearly. LOD is an "industry" standard that defines the development stages of different systems in BIM. LOD is a measure of the information represented by a BIM element, developed by a standard that refers to the level of certainty about an object. By using LOD categorization, developers can clearly communicate with each other without confusion for faster execution. The specification defines six (previously five) different levels of development to define the detailing levels in a BIM model.

Level of development (LOD) is the degree to which the components' specification, geometry, and attached information have been thought through – the degree to which project team members may depend on the information when using the model. The LOD specification allows developers to state how an element's geometry and associated information has evolved throughout the entire process. It signifies the degree to which different members of the team can rely on information associated with an element. It also allows for developers to define the inherent characteristics of the elements in a model at different stages of development.

The LOD levels are:

1. **100 (Conceptual)** - The Model Element may be graphically represented in the Model with a symbol or other generic representation. Information related to the Model Element can be derived from other Model Elements. Any information derived from LOD 100 elements must be considered approximate.
2. **200 (Approximate geometry)** - The Model Element is graphically represented within the Model as a generic system, object, or assembly with approximate quantities, size, shape, location, and orientation. Any information derived from LOD 200 elements must be considered approximate.
3. **300 (Precise geometry)** - The Model Element is graphically represented within the Model as a specific system, object or assembly in terms of quantity, size, shape, location, and orientation. Non-graphic information may also be attached to the Model Element. The project origin is defined and the element is located accurately with respect to the project origin.
4. **350 (Precise geometry with connections)** - The Model Element is graphically represented within the Model as a specific system, object, or assembly in terms of quantity, size, shape, location, orientation, and interfaces with other building systems. Non-graphic information may also be attached to the Model Element.
5. **400 (Fabrication-ready geometry)** - The Model Element is graphically represented within the Model as a specific system, object or assembly in terms of size, shape, location, quantity, and orientation with detailing, fabrication, assembly, and installation information. Non-graphic information may also be attached to the Model Element.
6. **500 (Operations/As-built models)** - The Model Element is a field verified representation in terms of size, shape, location, quantity, and orientation. Non-graphic information may also be attached to the Model Elements.

For example, the following are three labels of precision and accuracy:

1. LOD 300 Generic BIM model.
2. LOD 350 custom model.
3. Manufactures 2D model.

Level of detail (LOD) refers to the proportion of detail enclosed within the model element. The Level of Detail can be thought of as input to the element, while the Level of Development is a reliable output.

## *10.3 Building information modeling (BIM)*

> *A.k.a., Engineering model, object materialization model and data, BIM data, BIM metadata.*

Building information modeling (BIM) is a rules-based design process that allows for configurable architectural products. Rules-based design enables the viewing of 3D product models that users or habitat teams can configure as needed, on demand, that account for allowable specifications and fabrication constraints. A decisioning system (i.e., decision engine) can be added to the collaborative engineering-production system to control for decision objectives, constraints, and requirements. Here, a database and configurator allows for the selection of custom products using rules-based design to control the allowable customization options without complex programming.

The application of BIM allows for:

1. Metadata integration (i.e., allows for association of parameters, values, with model elements).
    - BIM is a process where all data about an object is grouped into one [interoperable] system.
2. Model simplification and comprehensive calculation.
    - When all data about a model is available, calculations can be performed to optimize the model.

The workflow for a BIM configurator usually runs as follows:

1. Start with the fully detailed, configurable engineering model (engineering rule-base).
2. Create the architectural master model.
3. Create the MEP connections model.
4. Complete all object (e.g., BIM) metadata.
5. Upload for access to population user base.
6. Users chooses options, and see dynamic, high-detail 3D rendering/simulation.
7. The materialization system builds the product.

### 10.3.1 BIM model types

An engineered architectural system shall be created [in a software project] as either:

1. **Complete building** - A[n aggregated] building object.
   A. A combination of other architectural objects that form a complete building.
2. **Architectural-engineering elements** - The first aggregate of elements that form a building. These elements generally include walls, floors (slabs), and support structures. A generic or manufactured architectural-engineering element/object.
   A. A generic architectural-engineering object - intended for use in the initial stages of design, until a specific manufacturer's object is select (see B, directly below).
   B. A manufacturers architectural object - intended to represent an obtainable product provided by a manufacturer or supplier. The term 'manufacturer object' is also synonymous with proprietary object or product object.
3. **Fixtures and assemblage objects** - A component or layered object. Component objects include structurally assemblage objects such as doors, windows, sanitary ware, furniture, etc. These objects can be held outside the model and be imported into it. Component and layered objects can be aggregated together to form an assembly (e.g. a room).
   A. Component objects can be further defined as:
      1. Static objects - available in one size.
      2. Parametric object - available in a range of predetermined sizes (or else the size can be determined by the designer).
   B. Layered objects: Comprise walls, floors, ceilings, roofs, etc. These objects are typically constructed from a number of layers and do not have a fixed geometry; this is defined by the designer (e.g. a concrete floor layer thickness may be determined by the designer's structural calculations). The thickness of the object layers may also be determined by manufacturers (e.g. an insulation board may be available in a set number of thickness). Layered objects may comprise single or multiple products, for example: A single product layered object could be a composite insulation board with facings and core or a concrete slab. Alternatively, a multiple product layered object could be a warm roof, consisting of waterproof covering, underlay, insulation, vapour control layer and concrete slab.

Assembly objects refer to separate objects which have been combined and managed as a group in the model or object library. The assembled group of objects may contain metadata solely for the group; may have additional metadata relating to the group; or just contain the metadata of the constituent objects. As an example, an accessible toilet is an assembled group containing a toilet, handrails, cubical walls, and a door. Each of these objects will have their own metadata, but the assembly itself could also have metadata giving the overall size or the standard it complies with. In some instances, when aggregated together to form an assembly, some component information may become irrelevant. For example, a door handle that comes as part of an overall door assembly. Care must be taken when an assembly is made up of multiple objects where each material has performance criteria that may be unrelated to the assembly as a whole.

An object may be gathered into an assembly to aid understanding of the context in which a product can be used. For example, a manufacturer's wall insulation BIM object may be shown within a generic wall build-up, even if the insulation manufacturer does not supply any other objects within the wall. The accompanying objects forming the wall assembly should have a minimum graphical detail equivalent to a generic object.

Note that BIM objects are provided as either layered objects or component objects; both types can be found in generic, manufacturer and project object form. Additionally, the BIM object may, where relevant, be part of a larger collection of objects that forms an assembly, including an assembly that represents the context in which an object is used.

## *10.4 BIM object development*

In a general sense, every BIM object includes all of the following data categories:

1. **Naming** convention for files
2. **Objects** (architectural systems)
3. **Locations** (localization)
4. **Views** (visual representations)
5. **Materials** (surface / internal composition)
6. **Parameters** (properties)
   A. Software-related parameters
   B. Object-related parameters
7. **Values** (descriptions)

In other words, the organizational structure for architectural-engineering [software] includes the following top-level categories (Yori, 2020):

1. Locations (coordinates and extents)
2. Objects
   A. BIM systems (architectural components)
   B. BIM components (infrastructural components)
3. Properties (BIM parameters and classes)
4. Representations (views)
5. Coordination (BIM project phasing)
6. Modeling (creating masses/objects)

The four elements of a model in an architectural-engineering program are:

1. **Model parameters**
   A. Design-time parameters for the all data related to the model
      1. There are multiple parameter types, including but not limited to: dimension, visibility, materials, assembly, etc.
2. **Model geometry**
   A. Masses
      1. Voids
3. **Model data (model data views)**
   A. Orthographic views
   B. 3D views
   C. Sheet views (i.e., geometric views, orthographic views)
4. **Model materials lists and quantities**
   A. Material sheets (a.k.a., schedules, quantities)

**NOTE:** *A mass (a.k.a., model, object) is simply a form with geometric substance (solids and voids) that is not related to any specific building element category. It is intended to allow designers to create a lightweight component that can represent either an entire architectural system/building or a architectural/building system. Alternatively, it can serve as a guide for a single component, such as a complex wall or roof form. When a mass is created in the context of a whole building, it is possible to quantify the surface area, assign functional elements (e.g., floors) to the mass, and perform energy analysis—all without creating a single wall, floor, window, or roof. Massing is a term in architecture which refers to the perception of the general shape and form as well as size of a building.*

### 10.4.1 BIM file naming convention

**NOTE:** *The "BIM" object file name shall also include the default file extension for its respective "BIM" object creation and visualization platform or file format.*

The "BIM" object shall use naming by means of the approach taken by the parent resource. Naming conventions should be intuitive to aid information retrieval. They shall be composed of alphanumeric characters without text formatting (e.g. a - z, A - Z, 0 - 9 ) and single spaces. Names shall be limited to a maximum of 50 characters. Fields shall be separated by the underscore character ( _ ) or a hyphen ( - ). Note that the European BIP 2207 Guide to BS 1192 states that the use of hyphen (-) delimiters between the fields in a file identifier enable the use of varying length codes.

BIM software allows naming to be visible within both the object and the project model, offering the ability to provide search functionality and interactions with other databases.

The BIM object shall include properties and values that are consistently named. The BIM object and file name should be unique to avoid duplication of information and to aid export of information and interpretation.

The file and BIM object name shall be composed of:

1. <Role>_<Source>_<Type>_<Subtype/ product code>_<Differentiator>
   - **Role** - Used to convey the library object author by a 3 – 6 digit code.
   - **Source** - Used to identify the object manufacturer. The manufacturer name shall not be abbreviated. For a generic object this field may be omitted.
   - **Type** - Used to identify the object type.
   - Subtype - Used to convey additional information to further define the construction product such as the product range. The manufacturer product range shall not be abbreviated. This field can also be used to identify the predefined (Sub)type.
   - **Differentiator** - Used to convey additional specialist information not captured in property data.
2. <HSS>_<Type>-<Subtype/product code>-<Differentiator>
   - **HSS** - Used to identify the functional application of the object into the operation of the habitat service system.
   - **Type** - Used to identify the object type.
   - **Subtype** - Used to convey additional information to further define the construction product such as the product range. The manufacturer product range shall not be abbreviated. This field can also be used to identify the predefined (Sub)type.
   - **Differentiator** - Used to convey additional specialist information not captured in property data.

### 10.4.2 BIM object categorization (architectural systems)

Types of systems within an architectural object include, but are not limited to:

1. Architecture: common (non-structural architecture)
2. Architecture: structural
3. Infrastructure: Mechanical, electrical, plumbing (MEP)
   A. Heating, ventilation, and air conditioning (HVAC; mechanical, M)
   B. Electrical (E)
   C. Plumbing (piping; P)
4. Infrastructure: other
   A. Fire protection
   B. Telecommunications

C. Etc.
5. Landscape
6. Energy [assessment]
7. Acoustics [assessment]

The totality of architectural object classifications include:

1. Complexes (Co)
2. Entities (En)
3. Activities (Ac)
4. Spaces / locations / areas (SL)
5. Elements / functions (EF)
6. Systems (Ss)
7. Products (Pr)
8. Tools and equipment (TE)
9. Project management (PM)
10. Form of information (Fi)
11. Roles (Ro)
12. CAD (Zz)

#### *10.4.2.1 BIM infrastructural components*

Architectural-engineering software uses families [of CAD/BIM blocks] to represent infrastructural components:

1. **BIM families (e.g., Revit families)** - fully parametric models or drawings that can be used in a greater variety of ways. It is possible to embed families within families, allowing you to create a hierarchy of parametrically controlled models.
   A. **System families** - (also called host families) are content that is part of the project environment and are more akin to rule sets rather than physically constructed components. These elements are not created and stored in external files; instead, they are found only in the project file. If another type of a system family is required, then it will be duplicated from an existing type from within the project. System families can be 3D elements such as walls, curtains, floors, roofs, ceilings, stairs, and railings, or 2D elements such as text, dimensions, and revision clouds.
      1. 2D examples:
         i. Text
         ii. Dimensions
         iii. Details
         iv. Lines (drafting)
         v. Filled regions
         vi. Revision bubble
         vii. Match line
      2. 3D examples:
         i. Wall
         ii. Curtains
         iii. Floor
         iv. Roof
         v. Ceiling
         vi. Stair
         vii. Railing
         viii. Ramp
         ix. Model lines
   B. **Component families** - are created in the a family editor and are either 2D or 3D content. This means someone (or some algorithm) will have to create and load these kinds of families outside the project environment. When a component family is initially created the designer (or algorithm) will need to select an appropriate family template. By selecting the correct family template, the designer (or algorithm) will be certain that the component being created is going to behave, view, schedule, and (if necessary) export properly.
      1. 2D examples
         i. Annotations
         ii. Detail components
         iii. Profiles
         iv. Sheets
      2. 3D examples
         i. Doors
         ii. Windows
         iii. Furniture
         iv. Equipment
      3. Spaces
         i. Rooms
         ii. Areas
         iii. Volumes
2. **Blocks (e.g., AutoCAD Blocks)** - blocks are the collection of geometries that act as a single object and they can be used in a drawing repetitively.
   A. Static blocks (static geometry)
   B. Dynamic blocks (dynamic geometry)

One of the primary reasons for using a block is its ability to modify all its references by modifying a single block. For example, if creating a block for windows in a floor plan, and then after adding the windows, it is decide to modify the type of window. In this case, the designer can simply modify the window block and all its references used in the drawing will change automatically.

> **NOTE:** *Blocks also help you in keeping the file size under control. A drawing made with blocks for repetitive objects will be far smaller than the drawing which uses copied instances of repetitive objects.*

### 10.4.3 BIM coordinates and extents (locations and positions)

Location data consist of references, grids, and levels. Location datum objects establish geometric behaviors by controlling the location and extents of objects (i.e., model content).

The four types of software specific location data are:

1. **References** - datum objects that are allow a user to work with any working point, line, or plane.
   A. Points
   B. Lines
   C. Planes
2. **Levels** - datum objects that are parallel to the ground plane.
   A. View
   B. Reference
3. **Grids** - datum objects used to locate structural elements in a project.
4. **Coordinates** - data about object position in the world space.
   A. **Project base point** - This point is used almost exclusively for internal purpose. It is used to place dimensions relatively to the building. It can also be used to set the angle difference between the True North and the Project North.
   B. **Survey point** - This is used to create a "shared coordinates" system among multiple linked files. That means it's location is most useful when exporting and importing files. It is usually placed relatively to the Site.
   C. **Internal origin** - This point is invisible and cannot be moved (but, it can be made visible). In most software, by default, importing or exporting a file will be made relatively to this point (and when invisible, it confuses people).

**NOTE:** *References, levels, and grids can be used as extents in some architectural software.*

### 10.4.4 BIM representations (views)

Object engineering software uses views to display infrastructural components. Views are the visualizations a user interacts with.

1. 2D examples:
   A. Planes
   B. Sections
   C. Elevations
   D. Callouts
   E. Drafting
   F. Legends
2. 3D examples:
   A. Orthographic
   B. Perspective
3. Tabular examples:
   A. Schedule
   B. Material takeoffs
4. Simulation (animation) examples (motion of objects with magnitude; in time):
   A. Animation (films)
   B. Virtual environments (virtual reality simulations)

### 10.4.5 BIM parameters (properties)

*A.k.a., Model parameters, object parameters.*

Parameters store and communicate information about all elements in a model. Parameters create a rule or relationship that has user-editable properties. All content (i.e., objects) in an architectural-engineering project have associated parameters, which are simply the information or data about some thing. Here, parameters can affect many different aspects of an object, such as visibility, behavior, size, shape, materiality, assembly code standard, etc. Parameters are used to show and control an element's information and properties. Parameters are used to define and modify elements, as well as to communicate model information in tags and schedules.

Essentially, parameters are placeholders for data and should have descriptive names, for example:

- Asset tag
- Building code
- Serial number
- Length
- Material surface
- Etc.

In BIM software, there are two top-level categories for parameters:

1. **Software-related parameter categories** - relate to how the parameters are stored, accessed, and usable by the software.
   A. System
   B. Shared
   C. Project
   D. Global
   E. Family
2. **Object-related parameter categories** - relate specific objects (object properties).
   A. Assembly
   B. Non-assembly
   C. Habitat service

#### *10.4.5.1 BIM software-related parameter categories*

Software-related parameter types and their usages include:

**NOTE:** *Different software products will have different categories of parameters. The following parameter categories are specific to REVIT.*

1. **System parameters** - are built-in (default) to the

software and cannot be changed or deleted, and they are always available.

   A. In REVIT software:
      1. Value available for schedule/sheet: Yes
      2. Value available for tag: Yes
2. **Shared parameters** MOST COMMONLY USED)
   - Shared parameters are parameter definitions that can be used in multiple families or projects. In REVIT, the definition of a shared parameter is stored in a separate file (not in the project or family), it is protected from change. For this reason, shared parameters can be tagged and scheduled. In REVIT, if a parameter in a family or project needs to be scheduled or tagged, that parameter must be shared and loaded in both the project (or element family) and the tag family.
   A. In REVIT software:
      1. Value available for schedule/sheet: Yes
      2. Value available for tag: Yes
3. **Project parameters** - specific to a single project file. A project parameter can be used to categorize views within a project. Note that in REVIT, information stored in project parameters cannot be shared with other projects. Project parameters are used for scheduling, sorting, and filtering in a project.
   A. In REVIT software:
      1. Value available for schedule/sheet: Yes
      2. Value available for tag: No
4. **Global parameters** - Global parameters are specific to a single project file, but are not assigned to categories. In REVIT, a global parameter can assign the same value to multiple dimensions.
   A. In REVIT software:
      1. Value available for schedule/sheet: No
      2. Value available for tag: No
5. **Family parameters** - Family parameters control variable values of the family, such as dimensions or materials. They are specific to the family. In REVIT, a family parameter can also be used to control a parameter in a nested family by associating the parameter in the host family to the parameter in the nested family.
   A. In REVIT software:
      1. Value available for schedule/sheet: No
      2. Value available for tag: No

There are two general kinds of project parameters:

1. **Type parameters** - control information about every element of the same type. For example, if the material of a piece of furniture is designated as a type parameter and it can be changed, the material for all the furniture of that type will change.
2. **Instance parameters** - control only the instances that a user have selected. So if the material of the piece of furniture that has been selected is an instance parameter, the user will be editing only the selected elements. Instance parameters should be constantly exposed in a properties panel. In REVIT, selecting something initially displays the instance parameters.

#### *10.4.5.2 BIM object-related parameter categories*

*A.k.a., BIM parameter organization.*

At the highest level, all parameters are sub-divided into groups, which are then sub-divided into parameter types, which are then sub-divided into parameter classes:

1. Architectural parameter group (property group)
   A. Architectural parameter type (parameters)
      1. Architectural parameter classes (classes)

In general, there are three types of groups for a BIM model:

1. The assembly code group.
2. The non-assembly code group.
3. The habitat service group.

An example of the **assembly code group** is as follows:

1. Parameter group: Assembly code standard
   A. Parameter type: OmniClass Code
      1. OmniClass code class: 23-31 25 25 11
   B. Parameter type: OmniClass Title
      1. OmniClass code class: Electric Heated Towel Bars

An example of a **non-assembly code group** is as follows:

1. Parameter group: Material
   A. Parameter type: Material
      1. Material class: Metal

An example of the **Habitat Service group** is as follows:

1. Parameter group: Habitat service
   A. Parameter type: Habitat Service Sub-System
      1. HSS class: Life Support
   B. Parameter type: Habitat Service Sub-System
      1. HSS-S class: Water
   C. Parameter type: Object Function
      1. HSS-S class: Bathroom sink

#### *10.4.5.3 Assembly classification data (assembly code group)*

*A.k.a., Assembly classifications, construction classifications, building classifications, building and construction codes, BIM data exchange classification, etc.*

All assembled objects have codes associated with them within a branching (tree-like classification) structure. Every BIM asset (entity, element, etc.) is classifiable within a standardized (and codified) classification tree. Most assets are physical, but some standards also allow for conceptual entities (e.g., tasks). Some coding standards are more detailed and others are less detailed. These codes represent identity data about the object(s), and allow for the comprehensive classification of BIM assets. Functional elements, also referred to as systems or assemblies, are common major components in buildings that perform a known function regardless of the design specification, construction method, or materials used.

Herein, building life cycle refers to the observation and examination of a building over the course of its entire life. The life cycle of a building considers everything about the building from design, commissioning, operation, and decommissioning.

> **NOTE:** *The classification of products/system is essential for economic calculation and planning within the habitat.*

A classification system for an assemblies includes:

1. **Codes** - coded identifier of [functionally unique] assembly.
2. **Titles** - label of [functionally unique] assembly.
3. **Descriptions** - description of [functionally unique] assembly.
4. **Tree levels** - location of [functionally unique] assembly within a classification tree.

> **NOTE:** *Assembly code files are tab delimited (to create a tree-like structure).*

#### *10.4.5.1 Assembly classification standards (assembly code group)*

*A.k.a., BIM assembly code classification group types, assembly code format standards, assembly code parameter types, BIM assembly code formats, BIM data exchange standards.*

These standardized parameters (i.e., parameter types) may be associated with any physical object, and some may be associated with concepts.

> **NOTE:** *Some BIM standards are more focused on construction and not so much focused on operation and coordination (lifecycle management).*

The following are the master list of producers of standards that include titles and numbers (codes) used to organize specifications and other project information for most building design and construction (BIM) projects:

1. International standards include, but may not be limited to:

A. **Industry foundation classes (IFC)** [buildingsmart.org] - developed by buildingSMART International. Open standard for BIM data exchange. Semantic schema which defines the way the building related data is described and inherited. The classes can described anything, from a physical object (e.g., wall) to an concept (e.g., task).

B. **United Nations Standard Products and Services Code (UNSPSC)** [unspsc.org] - an open, global, multi-sector standard taxonomy for accurately classifying goods and services.

C. **NBS** [thenbs.com] - the National Building Specification (NBS) is a UK-based system of construction specifications used by architects, engineers and other building professionals to describe the materials, standards and workmanship of a construction project.

D. **Uniclass 2015 (2020 update)** [thenbs.com/our-tools/uniclass-2015] - non-proprietary classification system. For all aspects of the design and construction process. In particular, for organizing library materials and structuring product literature and project information. Uniclass originated in the United Kingdom and is produced by the Construction Industry Project Information Committee (CPIC) and the National Building Specification (NBS).

E. **MasterFormat (CSI)** [csiresources.org] - proprietary classification system. A master list for organizing construction work results, requirements, products, and activities. Mostly used in bidding and specifications, MasterFormat originated in North America and is produced by the Construction Specifications Institute (CSI) and Construction Specifications Canada (CSC).

F. **UniFormat (CSI)** [csiresources.org] - classifying building specifications, cost estimating, and cost analysis in the U.S. and Canada (primarily). | For arranging construction information, organized around the physical parts of a facility known as functional elements, and mainly used for cost estimates. UniFormat originated in North America and is produced by the Construction Specifications Institute (CSI) and Construction Specifications Canada (CSC).

G. **OmniClass** [higherlogicdownload.s3.amazonaws.com] - OmniClass Construction Classification System, also known as OmniClass (OCCS) is a proprietary classification system. For organization, sorting, and retrieval of product information for all objects in the built environment in the project lifecycle. OmniClass originated in North America and is produced by the Construction Specifications Institute (CSI) and Construction Specifications Canada (CSC).

H. **Construction Operation Building information exchange (COBie)** [nbis.org] - a non-proprietary data format for the publication of a subset of building information that primarily includes equipment and spaces.

2. National standards include, but are not limited to:
   A. **BRAZIL** - **Associação Brasileira de Normas Técnicas (ABNT)** [abnt.org.br]

**NOTE:** *Because different industrial organizations have created different assembly codes for the same item, a mapping table may be required to map codes from one industrial standard to another (generally, a competitor). A mapping table for multiple classification systems may be necessary in BIM. Governments may force the use of a specific assembly format.*

**Table 4.** *Table shows BIM classification standard and associated example values.*

| BIM Category | Example Value/Identification |
|---|---|
| BIMobject Category | HVAC - Heaters |
| IFC Classification | Furnishing Element |
| UNSPSC Name | Heating equipment and parts and accessories |
| UNSPSC Code | 401018 |
| Uniclass 1.4 Code | L75626 |
| Uniclass 1.4 Description | Heated towel rails |
| Uniclass 2.0 Code | PR-47-36 |
| Uniclass 2.0 Description | Heat Emitters |
| Uniclass 2015 Code | Ac_60 |
| Uniclass 2015 Description | Heating, cooling and refrigeration activities |
| NBS Reference Code | 47-36 |
| NBS Reference Description | Heat Emitters |
| CSI MasterFormat 2014 Code | 23 82 29 |
| CSI MasterFormat 2014 Title | Radiators |
| CSI MasterFormat 2016 Code | |
| CSI MasterFormat 2016 Title | |
| CSI MasterFormat 2020 Code | |
| CSI MasterFormat 2020 Title | |
| OmniClass Number | 23-31 25 25 11 |
| OmniClass Title | Electric Heated Towel Bars |
| CSI UniFormat II Code | D3020 |
| CSI UniFormat II Title | Heat Generating Systems |
| ABNT NBR Code | |
| ABNT NBR Title | |

#### *10.4.5.2 Assembly classification categories (assembly code group)*

*A.k.a., BIM object categories.*

Architectural classes for architectural objects include, but may not be limited to:

1. Annotation symbols
2. Cable trays
3. Ceilings
4. Columns
5. Constructions
6. Curtain panels
7. Curtain wall mullions
8. Detail items
9. Division profiles
10. Doors
11. Electrical equipment
12. Electrical fixtures
13. Floors
14. Furniture
15. Furniture systems
16. Generic models
17. Mechanical equipment
18. Parking
19. Planting
20. Plumbing fixtures
21. Profiles
22. Railings
23. Roofs
24. Site
25. Speciality equipment (appliances)
26. Stairs
27. Structural columns
28. Structural foundations
29. Structural framing
30. Walls
31. Windows

#### *10.4.5.3 Non-assembly parameter group types (non-assembly code group)*

Non-assembly code parameters types include, but may not be limited to:

1. Length
2. Text
3. Integer
4. Number
5. Area
6. Volume
7. Angle
8. Slope
9. Currency
10. Mass density
11. URL
12. Material
13. Image
14. Yes/No (boolean)
15. Multiline text

16. Family type

The most common non-assembly code parameter types are:

1. Length - width, depth, height.
2. Material - surface/finishes.
3. Text - coding.
4. Yes/no - movement (e.g., table folding ability).

#### *10.4.5.4 Habitat service type parameter group*

These Habitat Service System parameters (i.e., parameter types) associate physical objects with the [service system] functioning of the habitat in three ways:

1. Habitat service system
2. Habitat service sub-system
3. Object function

**Table 5.** *Table shows classification for the Habitat Service Type parameter group.*

| Parameter Group Name | Example Value/Identification |
|---|---|
| Habitat Service System | Life Support |
| Habitat Service Sub-System | Water |
| Object Function | Bathroom sink |

### 10.4.6 BIM Material classes (non-assembly code parameters group)

*A.k.a., Object surface composition parameter classes.*

Material classes for architectural objects include, but may not be limited to:

1. Ceramic
2. Concrete
3. Earth
4. Enamelled, cast iron
5. Gas
6. Generic
7. Glass
8. Glassy
9. Liquid
10. Masonry
11. Metal
12. Miscellaneous
13. Non-assigned
14. Paint, coating
15. Plastic
16. System
17. Stone
18. System
19. Textile
20. Unassigned
21. Wood

## 11 Architectural software

*A.k.a., Architectural-engineering software, architectural-engineering-construction-operation software, building software, building construction and operations software, building information software, architectural-engineering collaborative design and visualization software.*

Architectural-engineering uses databases that store architectural-engineering related data (possibly including construction and operations data also), and software to compute and visualize data. Data (plural) are sometimes referred to in object/building engineering software as datum objects. A community-based architectural-engineering software system facilitates a common data environment where all the stakeholders can work from the design phase all the way through to operations.

The purpose of the software can be summarized in the following elements:

1. **Collaborate** – Multiple project contributors can access centrally shared models. This results in better coordination, which helps reduce clashes and rework. The software must enable coordination of projects.
2. **Design** – Model building and environmental components, analyze and simulate systems and structures, and iterate designs. Generate documentation from object models. The software must enable the development and calculable design of systems.
3. **Visualize** – Communicate design more effectively to project stakeholders and team members by using models and model animation (simulation) to create high-impact 3D visuals and visual timelines. The software must enable visualization of systems.
4. **Document** - The software must enable documentation (and recording) during the entire life cycle of the project (plan, design, build, operation, maintenance).
5. **Operate** - The software must enable coordinated operation of the building.

In general, architectural-engineering software uses the following design restrictions (i.e., categories of restriction) to develop architectural elements:

1. Locations (position, orientation, coordinates).
2. Phasing (i.e., phase of execution).
3. Design options.
4. Design templates.
5. Worksets:
   A. System managed.
   B. User managed.
6. Line styles.

7. Object styles.

The six universal tasks of 3D software for architectural development are:

1. Creation (object creation).
2. Navigation (scene navigation).
3. Manipulation (object manipulation).
4. Selection (object selection).
5. System control (object and scene parameters).
6. Text input.

The following types of software (collaborative software design and decisioning) are required:

1. **Architectural-engineering software (collaborative architectural-engineering design software) -** Uses building information modelling software for architects, landscape architects, structural engineers, mechanical, electrical, and plumbing (MEP) engineers, designers and constructors. BIM (Building Information Modeling) is the process of creating a model of a building (or environment) and embedding into it all of the data regarding that building (or environment). A building is an object, and in a unified information system, this category of software is more optimally known as OIM (Object Information Modeling; or, Physical Information Modeling, PIM). This software provides an intelligent model-based process to plan, design, visualize, construct and manage buildings and infrastructure (and all objects in general). Software for the BIM/OIM process must facilitate the representation of the physical and informational properties of a building/object as an object-oriented model tied to a database. This software enables the users to create a dynamic database model which is tied to geometry, with constraints on connected features that adjust parametrically. As the model is developed and edited, all other linked drawings within the project are updated. Summarily, this software encompasses the design, infrastructure, and construction of all objects in an integrated manner.
    A. **Coordinated building software** - There are three categories of software required for the coordinated development and construction of a building project:
        1. **Project coordination software (building information modeling, BIM software)** - the project coordination software for a building project. The whole software package connects design and construction processes, and project teams, in one service system (to inform decisioning, as well as provide effective and efficient project execution). This is sometimes known as project coordination and integration software, project management software, and workflow management/coordination software.
        2. **Design building software (design software)** - The creation of an intelligent 3d model. Intelligent in that the software understands surface differences. The BIM process starts with the creation of an intelligent 3D model. AuraCurve uses building design and building information modeling (BIM) software by means of computer-aided design (CAD) services to architect buildings.
        3. **Engineering calculation software** - AuraCurve uses structural analysis software to design and operate a BIM environment. There are several sub-categories of systems herein:
            i. Structural
            ii. Electrical
            iii. Hydrologic and hydrologic
            iv. Atmospheric
            v. Construction
2. **Visual rendering software -** Uses a a rendering engine to enable visualization of model components. The user can view and interact with the model in three-dimensional (3D) views as well as orthographic two-dimensional plans, sections and elevation views of the model, and in time (i.e., simulation, animation). The user can also view the 3D environment in virtual reality.
3. **Construction operations software (a.k.a., construction management)** - facilitates oversight of all construction operations.
4. **Building operations software (a.k.a., facilities management software)** - enables the coordinated operation of the constructed building. This is facilities management software for building operations.

Specific software products for these services currently include, but are not limited to:

1. **Building modeling software:**
    A. Autodesk REVIT (3D architectural design and development) [autodesk.com]
    B. Autodesk AutoCAD [autodesk.com]
    C. Autodesk Navisworks (3D model review software for architecture, engineering, and construction) [autodesk.com]
    D. Archicad [graphisoft.com]
2. **Infrstructure modeling software:**
    A. Autodesk REVIT [autodesk.com]
    B. Autodesk Civil 3D (civil infrastructure design and development) [autodesk.com]

3. **Building information modeling coordination software** (with issue tracker):
   A. AutoDesk BIM 360 [autodesk.com]
   B. SmartSheet [smartsheet.com]
   C. Projet Manager [projectmanager.com]
   D. GitHub [github.com]
   E. Etc.
4. **Engineering calculation software:**
   A. Autodesk Architecture, Engineering & Construction (AEC) Collection [autodesk.com]
      - Autodesk Robot Structural Analysis Professional - structural load analysis software that verifies code compliance and uses BIM-integrated workflows to exchange data with Revit. Available only as part of the Architecture, Engineering & Construction Collection.
   B. SAAP 2000 [csiamerica.com]
   C. Bently STAAD Pro [bently.com]
   D. RISA [risa.com]
   E. Clearcalcs [clearcalcs.com]
   F. **Concrete specific software:**
      1. Multiplus Cypercad [multiplus.com]
   G. **Metallic specific software:**
      1. Multiplus Metalicas 3D [multiplus.com]
5. **Landscape modeling software:**
   A. Autodesk REVIT [autodesk.com]
   B. Viz Terra (3D landscape design) [structurestudios.com]
6. **Visual rendering software:**
   A. AutoDesk REVIT
   B. Epic Unreal engine
   C. Epic Twinmotion
   D. Lumion
   E. Cryengine
   F. Unity engine
   G. Etc.
7. **Construction operations software (a.k.a., construction management software)**:
   A. AutoDesk Construction Cloud [construction.autodesk.com]
   B. BuilderTREND [buildertrend.com]
8. **Building operations software (a.k.a., facilities management software)**:
   A. AutoDesk BIM 360 Ops [autodesk.com]

# 12 Architectural sub-systems organization

Each architectural sub-system performs a [possibly] necessary role in the actualization/materialization of a designed architectural unit (or, architectural object in the habitat service system).

The architecture-based subsystem categories are as follows:

1. **Structural** sub-system *(see title 13, next page)*.
2. **Water** sub-system *(see architecture water sub-system)*.
3. **Atmospheric** sub-system. *(see atmospheric water sub-system)*.
4. **Gas** and **oil** sub-system.
5. **Electrical** sub-system.
6. **Illumination** sub-system.
7. **Surface** sub-system.
8. **Furniture** sub-system.

The hierarchical sub-layout of these systems is as follows:

1. **Standards:**
   A. Documentation.
   B. Requirements.
   C. Hazards.
2. **Conception of System:**
   A. System's primary sub-types.
3. **Conception of Sub-System(s):**
   A. Sub-system's primary sub-types.
4. **Objects in System.**
   A. Fixture objects.
   B. Fitting objects.
   C. Appliance objects.
5. **Engineering calculations for system.**
   A. Mathematical mechanics.
6. **Installation of System**
   A. Installation mechanics.
7. **Operation of System:**
   A. Load demands on system.

In order to install a system, that system must have had (in the past), all engineering calculations certifiably (traceably) performed on it. These calculations ensure that in the operational phase of the system, that it is capable of safely and optimally meeting [user] load demands.

All architectural sub-systems are all organized categorically in the same way:

1. **The standards:** There are standards that define how the system is to be understood and integrated

into the whole architectural system.
   A. Standards are documented somewhere.
   B. Standards are designed to meet requirements.
   C. There are hazards in the design of systems.
2. **The definition and conceptualization [of the function] of the system's sub-systems:** Each system is composed of sub-systems with specific functions relative to the whole system.
3. **The objects in the system**: Because each system is composed of physical matter in the form of objects. The components of each sub-system are:
   A. Fixtures (fixtures list).
   B. Fittings (fittings list).
   C. Appliances (appliances list).
   D. Map of components (positioned in architectural views). These components are visualized in a map.
4. **The routing rules (if applicable):** The sub-systems can be interconnected [optimally] given a set of protocols governing implementation.
   A. Drawings (positioned in architectural views).
   B. Reasoning (written explanation of decision).
5. **The mathematical calculation of the system:** The systems can be assured to operate as expected given engineering calculations.
   A. Load demands.
   B. Structural engineering calculations on load demands.

Architectural systems can be optimized, given physical understandings related to:

1. **Thermal energy** design optimization.
2. **Insulation** design optimization (including, thermal, acoustic, etc.).
3. **Accessway and security** design optimization.
4. **Automation** design optimization.
5. **Safe access** design optimization.
6. **Fire and contaminant protection** design and optimization.
7. **Pest control** design optimization.
8. **Modularity** design optimization.

# 13 Architecture structure sub-system

*A.k.a., Structural engineering.*

Structural systems are those elements of construction that are designed to form part of an architectural structure, either to support the entire architectural system (e.g., building or bridge), or just a part of it. Fundamentally, a structure is responsible for maintaining the shape and form under the influence of subjected forces. A structure is a system to channel loads from one place to another, and to equalize forces (either locally, i.e., load bearing, or over a distance, i.e., non-load bearing). Effectively, an architectural structure is the part of an architectural system that resists the loads that are imposed on it. In concern to most buildings, an architectural structure is anything that is constructed or built from interrelated parts with a fixed (relatively) location on the ground. Note that the common definition of structure within the built environment is, anything that is constructed or built from interrelated parts with a fixed location on the ground. This includes buildings, but can refer to any body that is designed to bear loads (internal and/or external), even if it is not intended to be occupied by people or fixed to the ground:

1. Building structures (i.e., buildings are generally fixed, or rest on, the ground).
2. Non-building structures (e.g., bridges, tunnels, etc.).
3. Other architectural structures (e.g., vehicles, cultivation architecture, doors, windows, etc.; note that although clothing is architecture, it is not considered load bearing).

Structural form is mathematically based, it seeks the greatest efficiency, economy of resources, and simplicity that the engineer can create [given a set of architectural requirements, which may or may not be flexible].

Most built structures are assemblies of large numbers of elements and the performance of the complete structure depends principally on the types of element which it contains and on the ways in which these are connected together. Every structure is a designed and engineered system. To achieve an ideal structural system, architectural design must factor between all of the following:

1. Function.
2. Form (look, aesthetics).
3. Availability of materials.
4. Availability of construction technologies.
5. Physical principals.

Physical principals and laws must be evaluated critically so that structural designs are stable and the elements that make them up are in equilibrium. Each element that makes up an architectural structure must be in balance or equilibrium with every other structural element in the structure so that it stays together and remains stable. The elements and the structures that make them up must be resistant to the forces that act on them.

The function of a structure is to supply the strength and rigidity which are required to prevent a system from collapsing. More precisely, it is the part of an architectural system that conducts the loads that are imposed on it from the points where they connect to the ground underneath the system, where they can ultimately be resisted.

In an architectural structural system there are two categories of structure depending on load transfer type:

1. **Load bearing (a.k.a., the structural framework)** - structural components that are capable of transferring loads.
    A. A **structural support** is a part of a building or structure that provides the necessary stiffness and strength in order to resist various forces.
2. **Non-load bearing** - structural components that are not capable or intended to transfer loads, and may need to hold themselves us against gravity and vibration. These are often called "space dividing" structures. Non-load bearing elements often fill-in the gaps between the structural frame. The components that fill in such gaps have many names, including but not limited to: facade, infill, non-load bearing walls ("curtain walls"), sheeting, etc.

**IMPORTANT:** *Unlike the other architectural sub-systems, there are no fixtures and fittings for the structural system. Instead, the structural system is divided by load and non-load bearing elements*

It is important to note here that not all structure is considered load bearing structure. Non-load-bearing architectural [surface] elements are not part of the structural support framework for a building system, but they are part of the total structure. Non-load bearing walls, however, do hold themselves up, and hence, are part of the structure. Structural frameworks can contain non-load bearing elements, such as non load bearing partitions in a building, or redundant members in a framework. So by that logic, a non load bearing wall in a building would only support its own weight and play no part in the distribution of loads imposed by other building elements such as the roof or intermediate floors. Conversely, a load-bearing wall is part of the structure of the building, used to support floors, ceiling, roof, and other walls.

All building and non-building architecture contains a structure, because there is always the necessity to resist force. Note, however, that there is a continuum here. Some buildings are almost entirely structure, whereas others have very little structure. It is possible to produce a building which consists of little other than structure. And, it is possible to produce a building with minimal structure.

Load-bearing structure (ak.a., structural supports) can be applied in two ways:

1. Enclosed inside the architecture.
    - The location of the structure within a building is not always obvious because the structure can be integrated with the non-structural parts in various ways.
2. Visible (exposed) and contribute to the aesthetics of the building.

The most common types of structural support systems include, but are not limited to:

1. Continuous structures.
2. Framed structures.
3. Shell structures.
4. Tensile structures.
5. Arches.
6. Barrel vaults.
7. Cantilevers.
8. Domes.
9. Shell and core.
10. Space frame.
11. Trussed rafters.
12. Portal frame.

The most common elements of a structural support are:

1. Frame: A member that forms part of the structural frame of a building (Read: architectural system), or any other beam or column.
2. Load bearing wall: A load bearing wall or load bearing part of a wall.
3. Floor: A floor.
4. Gallery: A gallery (but not a loading gallery, fly gallery, stage grid, lighting bridge, or any gallery provided for similar purposes or for maintenance and repair).
5. External wall: An external wall.
6. Compartment wall: A compartment wall (including a wall that is common to two or more buildings).

## 13.1 Structural standards

*A.k.a., Structural engineering standards.*

In structural engineering, standards (and codes) are the factors needed to make the design structurally safe and effective ("sound"). Different jurisdictional regions have different structural engineering design standards and codes (for various reasons, sometimes political).

Structural design criteria categories for safety, include, but are not limited to:

1. Seismic analysis reference standards/code.
2. Concrete design standards/codes.
3. Minimum load design requirements (standards/ code).
4. Material type standards codes (and, material reinforcement)

## 13.1.1 Standard structural documentation

*A.k.a., Structural system specification and drawings.*

Structures are documented via specifications and drawings.

1. Structural drawings illustrate the system that will support loads and other forces, transfer loads, and support other services.
2. Structural specifications include all written content, reasoning for decisions, and calculations.

#### *13.1.1.1 Structural system plan*

The structural plan is a plan view that shows the complete structural system. The structural plan shows the following parameters for all units of structure:

1. Material composition of structure.
2. Amount of material.
3. Method of construction (and destruction) of structure.
4. Positional mapping of structure and all structural elements.
5. Calculation of all structure.
6. Type of equipment for de-/construction.
7. Calculation to determine optimal equipment type.

The structural plan includes standards for safety and structural engineering quality for all buildings. It also covers requirements for the prevention of collapse and other hazards.

## 13.1.2 Standard structural requirements

What is required for a viable structural production-distribution system is:

1. **For architecture** - structure production proportionate to environmental disturbances (e.g., gravity and other environmental forces) as well as human and machine demand [via a load].
    - Herein, a load means the amount of motion produced at a specific temperature required by a building to support without breaking.
2. **For economic calculation** - Data sheet about structural configuration and loads (weights and moving weights) to produce optimization calculation.
3. **For life support demand** - structure proportionate to human demand.
4. **For technology and exploratory demand** - structure proportionate to human demand.

## 13.1.3 Standard structural hazards

*A.k.a., Structural risks.*

The primary structural risks include, but may not be limited to:

1. **Collapse** - improperly engineered structures that fail existing conditions.
2. **Water and humidity/moisture control** - moisture from the ground can degrade structural materials rapidly. This is particularly the case with foundations -- foundations must be protected from water and moisture ("damp"). Moisture control in walls, floors, and roofs may also be significantly important.
    A. Waterproof impermeable membrane.
    B. Permeable membrane (a.k.a., vapor or humidity membrane, vapor barrier).
3. **Rain** - that is water from clouds in the higher atmosphere, especially when wind-driven, can cause moisture problems in walls (and as well as roofs, etc.). Rain leaks through exterior walls are usually a result of improper installation of:
    A. Siding materials.
    B. Poor quality flashing.
    C. Impermeabilization layers.
    D. Weatherstripping or caulking around joints in the building exterior (such as windows, doors, and bottom plates).
4. **Flooding** - liquids pooling in areas where they are not intended to pool.
5. **Earth movement** - including earth movements including earth slides (erosion) and earth quakes.
6. **Thermal expansion and contraction** - as structures expand and contract due to changes in temperature they can weaken and/or become loose.
7. **Thermal bridging** - are sinks of thermal (heat) energy that transfer it to undesirable and/or unintended locations. These unintended thermal connections will heat or cool additional surfaces that are not intended to be heated or cooled. The thermal energy generally comes from the outside environment, such as the sun when heating and snow (or cold wind) when cooling.

8. **Vibration (uncontrolled oscillations)** - usage occupancy leads to uncontrolled oscillations that damage the structure.
9. **Construction risks** - These are risks associated with the construction of he structure. Structures necessarily involve material objects of sufficient weight to seriously harm humans.

## 13.2 Conception of the structural service system

A structural system specification will include all the different types of structures used in the system.

#### 13.2.3.1 Types of structure

Structures can be classified in a number of ways:

1. **By type:**
   A. Composite.
   B. Frame.
   C. Liquid.
   D. Membrane.
   E. Shell.
   F. Solid.
2. **By structural system:**
   A. Bending.
   B. Composite.
   C. Compressive.
   D. Shear.
   E. Tensile.
3. **By application:**
   A. Aqueducts and viaducts.
   B. Building.
   C. Bridges.
   D. Canals.
   E. Cooling towers and chimneys.
   F. Dams.
   G. Railways.
   H. Roads.
   I. Retaining walls.
   J. Tunnels.
   K. Coastal defences.
4. **By form:**
   A. One-dimensional (e.g., ropes, cables, struts, columns, beams, arches).
   B. Two-dimensional (e.g., membranes, plates, slabs, shells, vaults, domes, synclastic, anticlastic).
   C. Three-dimensional (e.g., solid masses).
   D. Composite. A combination of the above.

   **NOTE:** *A three-dimensional structure can be expressed in terms of geometric principles such as spatial limits and shapes.*
5. **By material:**
   A. Adobe.
   B. Composite
   C. Concrete.
   D. Glass.
   E. Masonry (e.g., brick, block, stone, etc.).
   F. Metal (e.g., steel, aluminium, etc.).
   G. Timber.
   H. Etc.
6. **By element:**
   A. Substructure.
   B. Superstructure.
   C. Foundation.
   D. Roof.
   E. Shell and core.
   F. Structural frame.
   G. Floor.
   H. Wall: load-bearing walls, compartment walls, external walls, retaining walls, as well as non-load bearing walls.
7. **By overall building form:**
   A. Low-rise.
   B. Multi-storey.
   C. Mid-rise.
   D. High rise.
   E. Groundscraper.
   F. Skyscraper.
   G. Supertall.
   H. Megatall.
   I. Super-slender
   J. Megastructure.
   K. Anticlastic.
   L. Synclastic.
   M. Hyperbolic paraboloid.
   N. Conoid.
   O. Tower.
   P. Dome.

#### 13.2.3.2 Superstructure and substructure

The most broad definition of superstructure includes all works above ground level; however, this is an ambiguous definition. A more complete definition of superstructures includes, but may not be limited to the following elements:

1. Frame: The load-bearing framework, including main floor and roof beams, ties and roof trusses of framed buildings; casing to stanchions and beams for structural or protective purposes.
2. Upper floors: Floors suspended over, or in basements, service floors, balconies, sloping floors, walkways and top landings, where part of the floor rather than part of the staircase.
3. Roof: the roof structure, roof coverings, roof drainage, roof lights and roof features.

4. Stairs and ramps: Construction of ramps, stairs, ladders, etc. connecting floors at different levels.
5. External walls: External enclosing walls including walls to basements but excluding walls to basements designed as retaining walls.
6. Windows, doors and openings in external walls (e.k.a., fenestration). Internal walls, partitions, balustrades, moveable room dividers, cubicles and the like.
7. Doors, hatches and other openings in internal walls and partitions.

> **NOTE:** *This definition excludes; the substructure, finishes, fittings, furnishings, equipment and services.*

The most broad definition of substructure includes all works below ground level; however, this is an ambiguous definition. A more complete definition of substructures is, all work below the underside of a screed (Read: first leveled layer of material) or, where no screed exists, the underside of lowest floor finishes including damp-proof membrane, together with relevant excavations and foundations (includes walls to basements designed as retaining walls). In this sense, the function of the substructure is to,transfer the load of the building (or non-building structure) to the ground and to isolate it horizontally from the ground.

A narrow definition of substructure includes (while excluding finishes, basement walls not in contact with earthwork, retaining walls not providing external walls, etc.):

1. Foundations up to and including the damp proof course.
2. Lowest floor assembly below the underside of the screed or the lowest floor finish.
3. Basement excavation.
4. Basement retaining walls up to and including the damp proof course.

## *13.3 Conception of the structural support system*

*A.k.a., , Structural lading system, structural members, structural loading members.*

A structural support system is generally classified in two ways:

1. **By material composition** - types of structural supports by material.
2. **By component position** - types of structural supports by component position.

### 13.3.1 Types of structural supports by material

There are many different types of support structures, including but not limited to:

1. Metal based structures.
2. Metal and concrete based structures.
3. 3D printed concrete (or similar material) structures.
4. Etc.

#### *13.3.1.1 Metal-based structuring (metallic structure)*

Metal frame that some other material (e.g., blocks of concrete) are fitted into. The metal frame can be prefabricated with approximate location conduits and connectors connected together.

#### *13.3.1.2 Metal- and concrete-based structuring*

One of the ways found to improve the concrete's strength and durability is to incorporate tensioned steel tendons before casting (e.g., reinforced steal, rebar, or wire framing).

### 13.3.2 Types of structural supports by position

There are two primary positions for structural supports:

1. **Horizontal** (a.k.a., horizontal inter-connectors, horizontal supports).
2. **Vertical** (a.k.a., vertical inter-connectors, vertical supports).
3. **Combination** (e.g., archway).

It is relevant to note here that in the case of 3D printing, the interconnections (3D printed structure) may also act as a vertical and horizontal support structure, whereupon additional horizontal and vertical supports are not necessary.

#### *13.3.2.3 Horizontal supports as beams*

*A.k.a., Beaming.*

A beam is a horizontal structural element that withstand vertical loads, shear forces and bending moments. The loads applied to the beam result in reaction forces at the support points of the beam. The total effect of all the forces acting on the beam is to produce shear forces and bending moment within the beam, that in turn induce internal stresses, strains and deflections of the beam. They transfer loads imposed along their length to their end points where the loads are transferred to columns or any other supporting structural elements.

Types of loads on beams are (includes a requirement for calculation of each):

1. Self-weight of the beam.
2. Dead load includes point load for instance column constructed on beam, distributed load for example setting slabs on a beam.

3. Live load.
4. Torsional load.

#### 13.3.2.4 Horizontal support inter-connectors as floors

The floors are both structural and space-dividing elements. Some floors (Read: those not on the ground) have ceilings suspended underneath them.

#### 13.3.2.5 Horizontal support inter-connectors as slabs

*A.k.a., Slabbing.*

A slab is an important structural element which is constructed to create flat and useful surfaces such as floors, roofs, and ceilings. It is a horizontal structural component, with top and bottom surfaces parallel or near so. Commonly, slabs are supported by beams, columns (concrete or steel), walls, or the ground. The depth of a concrete slab floor is very small compared to its span. The primary function of slabs is to safely control loads. Slabs can have additional functions, and are sub-classified thereby.

Types of loads acting on a slab are (includes a requirement for calculation of each):

1. Dead load of the slab.
2. Live load.
3. Floor finish load.
4. Snow load in the case of roof slab.
5. Earthquake loads.

Slabs can be sub-classified by:

1. Composition.
2. Size and dimensions.
3. Secondary functions (primary function is always loading):
   A. Has installation inside?
   B. Has open spaces inside?
      1. Has conduits space(s)?

#### 13.3.2.6 Vertical supports as columns

*A.k.a., Columning.*

Column is a vertical structural member that carry loads mainly in compression. It is assumed to be the most crucial structural member of a building because the safety of a building rest on the column strength.
Columns transfer vertical loads from a ceiling, floor or roof slab or from a beam, to a floor or foundation. They also carry bending moments about one or both of the cross-section axes.

Types of loads on columns are (includes a requirement for calculation of each):

1. Self-weight of the column multiplies by number of floors.
2. Self-weight of beams per running meter.
3. Load of walls per running meter.
4. Total Load of slab (Dead load + Live load + Self weight).

Columns are purely structural, although they do punctuate the interior spaces and are space-dividing elements, to some extent.

#### 13.3.2.7 Horizontal support inter-connectors as walls

Load-bearing (bearing) walls support the weight of a floor or roof structure above and are so named because they can support a significant amount of load. Load bearing walls are both active structural elements and space-dividing elements. Load bearing walls are designed differently (in concern to their non-surface elements) than non-load-bearing walls.

#### 13.3.2.8 Foundational supports

*A.k.a., Footing, platforming, etc.*

Footings are structural elements that transmit load of entire superstructure to the underlying soil below the structure. Footings are designed to transmit these loads to the soil without exceeding its safe bearing capacity. Thus, prevent excessive settlement of the structure to a tolerable limit, to minimize differential settlement, and to prevent sliding and overturning. All building structures are built on a foundational support. A foundation is generally concrete in or on dirt, or packed dirt itself.

Types of loads on footings are (includes a requirement for calculation of each):

1. Dead load.
   A. Self-Weight of the elements.
   B. Superimposed loads such as finishes, partitions, block work, services.
2. Live load.
3. Impact load.
4. Snow load.
5. Wind load.
6. Earthquake force.
7. Soil pressure.
8. Rain loads.
9. Fluid loads.

Soil is the root support of the footing. All the forces that come in contact with the footings will be transferred to the soil. The soil shall bear these loads by the aspect known as bearing capacity. The bearing capacity changes from one type of soil to another and it is the key factor in estimating the size of footings.
The calculations for the foundation depend on soil conditions. These calculations are completed after

calculating for the structure of the building itself.

## 13.4 Conception of the in-fill sub-system

Whereas the structural support system transfers loads, the structural in-fill system is non-load bearing. The most common element in a structural in-fill system is the non-load bearing wall.

Types of non-load bearing walls include, but are not limited to (based on the wall unit specifics):

1. Hollow concrete block wall - are semi-hollow blocks of concrete formed into an immovable block or wall.
2. Facade bricks wall - are bricks positioned to create a facade on a pre-existing wall.
3. Hollow bricks wall - are semi-hollow bricks formed into an immovable block or wall made of bricks.
4. Brick walls - are made of an immovable block or wall made of brick.

5. Sub-system objects (a.k.a., fittings, fittings, and appliances).
6. Sub-system installation of objects (construction and maintenance).
7. Sub-system operation of objects (production and usage; supply and demand).
8. Sub-system engineering calculations.

## 13.5 Objects in the structural system: fixtures, fittings, and appliances

*A.k.a., Structure-based technologies.*

Structural fixtures and fittings are equipment that interface with the water in a building:

1. **Structural load bearing fixtures** - are structural elements designed to bear structural supporting loads. The most common fixtures include, but may not be limited to:
   A. Columns.
   B. Beams.
   C. Foundations.
   D. Floors (and sometimes roofs)
   E. Load bearing walls.
2. **Structural non-load bearing solid fixtures** - are structural elements not designed to bear structural supporting loads. The most common fixtures include, but may not be limited to:
   A. Non-load bearing walls.
   B. Roofs (if not load bearing).
   C. Infill (whatever material goes in between structural supports; e.g., bricks).
   D. Bollards and similar barriers.
   E. Railings and similar barriers.
   F. Doors (accessway and insulation).
   G. Windows (illumination and insulation).
   H. Staircase (accessway).
   I. Ramps (accessway).
   J. Escalators, moving walkways, and elevators (transportation).
3. **Structural non-load bearing void fixtures** - are gaps in the whole structure designed to contain doors and windows.
   A. Door void.
   B. Window void.
   C. Space void (is a void not filled with any solid object).
4. **Structural fitting** - a device designed to control or connect non-load bearing structures. The most common fittings include, but may not be limited to:
   A. Mechanisms (e.g., locks).
   B. Levers (e.g., handles).
5. **Structural appliances** - appliance devices that change structural elements, the most common of which include:
   A. Garage door machine (for opening and closing garage door).
   B. Automated door opener.
   C. Automated window opener.

### 13.5.1 Doors and windows

*A.k.a., Frames, fenestrations, openings in the building envelope, etc.*

Doors and windows are structural non-load bearing solid fixtures:

1. A door is a moving structure used to block off, and allow access to a separated area, such as a building. Doors normally consist of a panel that swings on hinges on the edge or a motor that retracts and extends. Typically, doors have an interior side that faces the inside of a space and an exterior side that faces the outside of that space.
   A. A lintel (lintol) is a type of beam (a horizontal structural element) that spans openings, such as doors, windows, and fireplaces.
2. A window is an opening in the structural enclosure (e.g., wall, door or roof) that allows the passage of light and/or air. Modern windows are usually glazed or covered in some transparent or translucent material. Generally, windows are held in place by frames.

**NOTE:** *In phases of construction, frames (doors and windows are a separate construction phase from the infrastructure as well as superstructure construction.*

## 13.6 Construction of a structural system

*A.k.a., Structural construction.*

**ASSOCIATED:** *Also see the section entitled, "Planning architectural construction" (earlier in this section).*

There are many ways to construct structures.

## 13.7 Operation of a structural system

In general, there are no significant operational characteristics to structures. In some cases, non-load bearing walls can be made to be movable (e.g., rotated). The movement of such walls would be considered part of the operation of a structure.

### 13.7.1 Structural load demands

*A.ka., Structural loading.*

Structure loads are measured in several ways, most notably:

1. Mass,
2. Gravity,
3. Vibration, and
4. Surface temperature.

In order to resist, structural systems are split into load transfer bearing and non-load transfer bearing:

1. Load transferring system:
   A. Energy absorbed by structure.
      1. Permanent load (a.k.a., static load, dead load) - are essentially constant during the life of the structure and normally consist of the weight of the structural elements. The structure first of all carries the dead load, which includes its own weight, the weight of any permanent non-structural partitions, built-in cupboards, floor surfacing materials and other finishes. It can be worked out precisely from the known weights of the materials and the dimensions on the working drawings. Although the dead load can be accurately determined, it is wise to make a conservative estimate to allow for changes in occupancy; for example, the next owner might wish to demolish some of the fixed partitions and erect others elsewhere.
      2. Dynamic load (a.k.a., live load) - All the movable objects in a building, and usually vary greatly. The weight of occupants, snow and vehicles, and the forces induced by wind or earthquakes are examples of live loads.
         i. Wind loads
         ii. Snow loads
         iii. Earthquake loads
         iv. Thermal loads
         v. Settlement loads
         vi. Dynamic loads
      3. Most structural loads are measured in weights of mass. Often, the weight expressed as [amount of possible motion in]:
         i. Newtons per meter squared ($N/m^2$)
2. A structural service system:
   A. Structural volume - is volume of area consumed by a structure:
      1. Meters cubed per liter ($m^3/L$)
   B. Structural materials - the material resources that are occupied by the structure.
      1. Quantities of material units.
   C. Temperature transfer is measured in kelvins or Celsius (or Fahrenheit in imperial).
3. Non-usage, but presence, will still equate to system service usage.
   - If a usage has no demand in the form of a structure factor of zero the user would consume NO usage per minute (i.e., no usage), but the land would still occupy, and the supplier would still have to maintain the structure. Structural factor is the relationship (phase) of volume and material in a structural support system.

## 13.8 Structural engineering calculations

*A.k.a., Structural analysis, structural engineering.*

Structural analysis is concerned with mechanical science, which is concerned with statics, equilibrium and the properties of materials; it includes all structural principles (i.e., force, load, materials, and components). Structural analysis is primarily concerned with finding the structural response to given [set of] forces and loads (internal and/or external) composed of a set of materials and fabricated into a component(s). Structural analysis is used to analyze and calculate the effects of the forces and loads acting on any component of the structure, and on the structure overall. A structural model is what is analyzed, and only after analysis is the model accepted for construction.

Structural analysis calculations for a building include:

1. Structural analysis (with specific materials)
   A. Engineering calculations for building alone.
   B. Engineering calculations for foundation, including building and soil/terrain.

Engineering in architecture involves (at least) the following components and their inclusion in calculations for the building:

1. Weight (gravity) distribution calculation.

   A. Material specifics (or, combined material specifics).
   B. Volume relative.
2. Vertical structural support(s).
3. Horizontal structural support(s).
4. Walls.
5. Windows.
6. Doors (if heavy).
7. Floors.
8. Ceilings.
9. Conduits.

#### *13.8.1.1 Entry-level formulae for structural analysis*

Use the following formulas for entry type calculations on ideally simple structures:

1. Shape Formulae
   - Circle A = π r2
   - Triangle A = ½ bh
   - Rectangle A = bh
2. Formula for pressure on a column
   - Pressure (P) = Force (F) / Area (A)
   - P = F / A

#### *13.8.1.2 Bearing capacity calculation*

Bearing capacity refers to the capacity of soil to support applied loads that are acting on it. This typically relates to the capacity of soil to support architectural foundations, in which case, the bearing capacity can be calculated from the maximum average contact pressure between the foundation and the soil that would not produce shear failure.

Three modes of failure limit bearing capacity:

1. General shear failure.
2. Local shear failure.
3. Punching shear failure.

The ultimate bearing capacity of soil (qu) is the maximum pressure which can be supported without failure occurring.

The net ultimate bearing capacity (qnu) does not take into consideration the over-burden pressure and can be calculated as:

- qnu = qu - Ydf
- Where,
  - Y = unit weight of soil
  - Df = foundation depth

The net safe bearing capacity (qns) considers only shear failure, and can be calculated as:

- qns = qnu / F
- Where
  - F = factor of safety.

The allowable bearing capacity (qs) is the ultimate bearing capacity divided by a factor of safety, and can be written as:

- qs = qu / F

Note that on particularly soft soil, significant settlement can occur without shear failure. In such instances, the maximum allowable settlement is used as the allowable capacity.

### 13.8.2 Engineering calculations for structure

Structural design and calculation is based on structural engineering principles.

The four categories of structural principles are:

1. **Forces** - interactions that changes the motion of an object when it is unopposed.
2. **Loads** - a type of force.
3. **Materials** - physical composition.
4. **Structural elements (structural members)** - constructed system.

#### *13.8.2.1 Forces (impact on structure)*

Forces are interactions that changes the motion of an object when it is unopposed.

The two broad categories of forces between objects are:

1. **Contact forces** - occur when the two interacting objects physically connect with one another.
   A. **Friction** - the force that resists the relative motion of solid objects, surfaces, fluid layers and material elements sliding against one another.
   B. **Tension** - the force transmitted through a string, rope, cable or wire when pulled tight by oppositional forces.
   C. **Normal force** - the support force exerted upon an object that is in contact with another stable object. For example, an object on the surface of a table is supported by an upward force being exerted by the table surface.
   D. **Air resistance** - the frictional force air exerts against a moving object. This is also known as 'drag'.
   E. **Applied force** - a force applied to an object by a person or another object.
   F. **Spring force** - a restoring force exerted by a spring, which acts to restore a spring towards equilibrium.
2. **Forces that result from action-at-a-distance** - occur when two interacting objects are not in

physical contact with one another but still exert a push or pull.

A. **Gravitational force** - the phenomenon by which all things with mass are brought toward one another.
B. **Electrical force** - the attractive or repulsive interaction between any two charged objects.
C. **Magnetic force** - the attraction or repulsion that arises between electrically charged particles due to their motion.

The three properties of forces are:

1. **Magnitude:** The size of the force.
2. **Direction:** The direction in which the force is acting.
3. **Position:** The position on which the force acts.

The three laws of motion that act on a structure are:

1. **Inertia (first law):** An object will remain at rest or in uniform motion unless compelled to do otherwise by some external force acting on it.
2. **Force = mass * acceleration ( F = ma; Second law):** A force is caused by an acceleration acting on an object.
3. **Action and reaction (Third law):** Action and reaction are equal and opposite.

In concern to a building, one of the main structural principles is that elements such as the roof, floor and walls must remain stationary. For this to happen, there needs to be an equilibrium of forces – when the forces acting on them are equal and opposite. Under loading, some deflection and deformation – in the form of bending and buckling – may occur, and if this movement is not allowed for then structural failure may be the result. Therefore, a principle of structures is that they be designed to maintain a state of equilibrium; resisting external loads without moving.

The study of the causes and effects of stationary forces acting on rigid objects is 'statics'. When a structure is stationary or in equilibrium, it is a ‘static body’. For a structure to remain static, three basic equations must hold true:

1. Sum of all vertical forces must be zero.
2. Sum of all horizontal forces must be zero.
3. Sum of all bending forces, or moments, must be zero.

Elements in architectural structures are subjected, principally, to one of the following:

1. Axial internal force .
2. Bending-type internal force.
3. A combination.

Axial internal force can be resisted more efficiently than bending-type internal force. The type of internal force which occurs in an element depends on the relationship between the direction of its principal axis (its longitudinal axis) and the direction of the load which is applied to it (Macdonald, p37, 2001)

#### *13.8.2.2 Force factors*

The two force factors created by a given application of a load are:

1. The type of internal force.
2. The magnitude of the internal force.

The shapes of structural elements determine the types of internal force which occur within them and influence the magnitudes of these forces.

#### *13.8.2.3 Loads (impact on structure)*

In structural design, a load is a weight or mass (force) applied to a component of a structure or to the structure as a unit. A structural load or structural action is a force, deformation, or acceleration applied to structural elements. A 'load' is a force that a building (structure) needs to be able to resist. Loads cause stresses and deformations. The effects of loads on physical structures are determined through structural analysis, which is one of the tasks of structural engineering. The surfaces that form the architecture (or, architectural envelope; e.g., walls, floors, roof, etc.) are subjected to various types of loads. For example, external surfaces are exposed to the climatic loads of snow, wind and rain; floors are subjected to the gravitational loads of the occupants and equipment and their combined effects; and most of the surfaces also have to carry their own weight. A load causes stress, deformation, and displacement in a structure. Structural analysis, a discipline in engineering, analyzes the effects loads on structures and structural elements. Examples of load-bearing structures include, but are not limited to:

1. Buildings
2. Aircrafts
3. Dams
4. Bridges

> **NOTE:** *A load-bearing wall is part of the structure of the building, used to support floors, ceiling, roof, and other walls. A non load-bearing wall, also called a partition is used to divide rooms but does not hold anything up apart from its own weight.*

To perform its function of supporting an architectural system in response to loads applied to it, a structure must possess three required properties (Macdonald, 2001):

1. **It must be capable of achieving a state of equilibrium** - Structures must be capable of

achieving a state of equilibrium under the action of applied load. This requires that the internal configuration of the structure together with the means by which it is connected to its foundations must be such that all applied loads are balanced exactly by reactions generated at its foundations. Architectural structures must be capable of achieving equilibrium under all directions of load.

2. **It must be stable** - Geometric stability is the property which preserves the geometry of a structure and allows its elements to act together to resist load. The fundamental issue of stability is that stable systems revert to their original state following a slight disturbance, whereas unstable systems progress to an entirely new state. The fundamental requirements for the geometric stability of any arrangement of elements is that it must be capable of resisting loads from orthogonal directions (two orthogonal directions for plane arrangements and three for three-dimensional arrangements). In other words, an arrangement must be capable of achieving a state of equilibrium in response to forces from three orthogonal directions (x, y, and z). If an arrangement is not capable of resisting load from three orthogonal directions then it will be unstable in service even though the load which it is designed to resist will be applied from only one direction. Note that It frequently occurs in architectural design that a structural geometry that is potentially unstable must be adopted in order that other architectural design requirements can be satisfied. In such cases, additional components are added to the structural geometry. These additional components (Read: bracing elements) are often problematic in that they use additional materials, complicate space planning, and change the buildings appearance. Optimized architectural-engineering arrangements do not generally require bracing elements, either because they are fundamentally stable or because stability is provided by rigid joints, are said to be self-bracing. Note that when bracing elements are included it is common practice to include more bracing elements than the minimum number required so as to improve the resistance of three-dimensional frameworks to horizontal load.
3. **It must have adequate strength and rigidity** - The application of load to a structure generates internal forces in the elements as well as external reacting forces at the foundations, and the elements and foundations must have sufficient strength and rigidity to resist these. The structure must not rupture when the peak load is applied; neither must the deflection resulting from the peak load be excessive. The requirement for adequate strength is satisfied by ensuring that the levels of stress which occur in the various elements of a structure, when the peak loads are applied, are within acceptable limits. Structural calculations allow the strength and rigidity of structures to be controlled precisely. The calculations can be considered to be divisible into two parts, but carried out together:
   A. **The structural analysis (a.k.a., load assessment)** - the evaluation of the internal forces which occur in the elements of the structure. The assessment of the loads which will act on a structure involves the prediction of all the different circumstances which will cause load to be applied to a building in its lifetime and the estimation of the greatest magnitudes of these loads. The purpose of structural analysis is to determine the magnitudes of all of the forces, internal and external, which occur on and in a structure when the most unfavourable load conditions occur. The engineer must anticipate all of these possibilities and also investigate all likely combinations of them. The maximum load could occur when:
      1. The building is full of people.
      2. Particularly heavy items of equipment are installed.
      3. It is exposed to the force of exceptionally high winds.
      4. It is exposed to moving earth.
      5. Or, as a result of many other eventualities.

   B. **The element-sizing calculations** - carried out to ensure that they will have sufficient strength and rigidity to resist the internal forces which the loads will cause. The size of a cross-section for a structural element must provide adequate strength and adequate rigidity. In other words, the size of a cross-section must allow the internal forces (determined in the load analysis) to be carried without overloading the structural material and without the occurrence of excessive deflection. These calculations involve the use of the concepts of stress and strain.

Most buildings (structures) are polyhedrons. A polyhedron is a three-dimensional form whose surfaces are polygons. A polygon is a closed plane figure with at least three sides. The sides intersect only at their endpoints and no adjacent sides lie on the same plane (colinear). The polygons are faces of the polyhedron.

**Table 6.** *Types of polygons with their associated number of sizes.*

| Polygon | Number of sides |
|---|---|
| Triangle | 3 |

| | |
|---|---|
| Quadrilateral | 4 |
| Pentagon | 5 |
| Hexagon | 6 |
| Heptagon | 7 |
| Octagon | 8 |

The main types of load which a structure must be able to resist are:

1. **Dead loads** (e.g., fixtures and structural elements).
2. **Live loads** (e.g., occupants, furniture, traffic).
3. **Environmental loads** (e.g., wind, snow, earthquake, settlement).

Factors that need to be considered when considering loads on structures include:

1. Magnitude.
2. Frequency of occurrence.
3. Distribution.
4. Nature/type (static/dynamic).

Based on the way in which deformation occurs to an element, five different modes of load transfer can be identified:

1. Load transfer by compression--when the resistance of a body to a load tends to decrease one of its dimensions.
2. Load transfer by tension--when the resistance of a body to a load tends to increase one of its dimensions.
3. Load transfer by bending--when the resistance of a body to a load tends to curve it.
4. Load transfer by shear--when the resistance of a body to a load tend to change the angle.
5. Load transfer by torsion--when the resistance of a body to a load tends to twist it.

It is important to note that a one-dimensional linear element may transfer loads only by compression or tension. Only two-dimensional surfaces are able to transfer loads by bending or by shear. Load bearing elements can be classified according to how they respond to stress and forces because of a particular geometric form:

1. **Surface forms** - one whose two dimensions are clearly larger than the third. Curved surface forms include shells, folded plates, and membranes. Flat surface forms include slabs, walls, and disk-like shapes.
2. **Linear forms** - are defined as forms that have a minimal cross-section. Load transfer takes place linearly, along the axis of the element. For this reason, only tensile and compression stresses can develop within this type of bearing element.
3. **Beam** - a linear surface element that acts on bending and shear; crucially important in determining the way in which the form operates as a bearing element. Beams in buildings are subject to forces of compression and tension because they have to support weight across a span.
4. **Column/pillar** - a linear element that transfers loads to the base of a structure.
5. Composite forms - these forms incorporate straight, polygonal, or curved bearing elements with a statical function. They include nets, trusses, space frames, and various kinds of geodesic domes.
6. Forms with a mass statical function - are those forms with a three-dimensional load bearing function in which all three dimensions are involved in the load transfer.

#### *13.8.2.4 Materials (impact on structure)*

The effectiveness of a structure depends on the mechanical properties of the materials from which it is constructed. These properties include:
Strength.

1. **Strength** - the stress that something can endure before failing.
2. **Toughness** - a measure of the energy required to break a material. Toughness measures the ability of a material to resist crack propagation.
3. **Elasticity (elastic limit)** - a measure of the maximum stress per unit area it can withstand before there is permanent deformation.
4. **Plasticity (plastic deformation)** - a measure of the capacity to resist plastic deformation (dislocation movement).
5. **Ductility** - the amount of tensile stress a material can take before enduring deformation.
6. **Malleability** - measure of a material's ability to be rolled or hammered into some form (e.g., thin sheets).
7. **Brittleness** - a measure of how easily broken, damaged, disrupted, cracked, and/or snapped.
8. **Hardness** - a measurement of the strength of a material (its ability to resist plastic deformation).
9. **Stiffness** - the extent to which an element is able to resist deformation or deflection under the action of an applied force.
10. **Flexibility (pliability)** - a measure of how flexible a component is (i.e. the less stiff it is, the more flexible it is).
11. **Durability** - a measure of how long a material will last under usage and environmental conditions.

#### *13.8.2.5 Structural members (impact on structure)*

Structural members are the primary load bearing components of a building, and each have their own structural properties which need to be considered. Structural members include, but are not limited to:

1. Beams - horizontal members which transfer loads to supports.
2. Columns - vertical members which transfer compressive loads to the ground.
3. Bracing - members that interconnect and stiffen columns and beams.
4. Roof trusses - load-bearing frames constructed of connected triangular shapes.
5. Retaining walls - support soil where a sloping site requires excavation.
6. Concrete slabs - span horizontally between supports, used as floors and sometimes as roof systems.
7. Footings - transfer load from the structure to the foundations.

Simplistically, the three main structural load bearing elements are:

1. Structural frames.
2. Floors (note: roofs, unless they serve the function of a floor, are not treated as elements of a support structure).
3. Load bearing walls.

#### 13.8.3 Standard structural efficiencies

There are three standard ways of optimizing efficiency in structural design:

1. Resources used (in unit quantity).
2. Energy used (in kWh) in transportation.
3. Energy used (in kWh) in construction.
4. Fabrication data (from pre-fab to localized).

# 14 Architecture surface sub-system

*A.k.a., Surfacing, coating, etc.*

In most buildings, there are additional surfaces and/or specialized surface processing added to base architectural surfaces.

## *14.1 Surface standards*

Just like other subsystem services (e.g., plumbing, electrical, etc.), there are surface standards.

### 14.1.1 Standard surface documentation

Surface systems are documented via specifications and drawings.

1. Surface drawings (a.k.a., surface schematics, surface drawings) illustrate the system that will support illumination.
2. Surface specifications include all written content, reasoning for decisions, and calculations.

Buildings may have the following architectural surface diagrams:

1. Surface tiling diagram.
2. Painting diagram.
3. Baseboard and crowning diagram.
4. Trim diagram.
5. Surface processing diagram (e.g., polishing concrete).

> **NOTE:** *Surface diagrams are generally applicable to all structures, including but not limited to walls, floors, ceilings, roofs, doors, windows, etc.*

### 14.1.2 Standard surface requirements

What is required for a viable surface system is:

1. **For architecture** - Surfaces appropriate for:
    A. Aesthetics (surface for aesthetics).
    B. Function (surface for function).
        1. Impermeability (surface for impermeability to elements, such as: mold, fire, light, earth, etc.).
2. **For walking and transportation** - Surfaces designed proportionate to motion and surface composition, including the maintenance (cleaning) of the surface.
    A. **For transport** - Surfaces proportionate to motion and safety.
    B. **For walking** - Surfaces proportionate to motion and safety.
3. **For economic calculation** - Data sheet about

surface composition, usage, and safety to produce optimization calculation.

4. **For life support demand** - Surfaces proportionate to human demand.
5. **For technology and exploratory demand** - Surfaces proportionate to human demand.
6. **For dwellings** - Surfaces proportionate to human demand.
7. **For working areas** - Surfaces proportionate to human and production demand.

#### *14.1.2.1 Standard surface efficiencies*

Surfaces can be made more efficient by reducing:

1. The amount of materials used.
2. The labor associated with the production of the surface.
3. The labor associated with the installation of the surface.
4. The necessity to maintain/clean the surface.

### 14.1.3 Hazards with the surface system

Common hazards with the surface system include, but may not be limited to:

1. Off-gassing (a.k.a., out-gassing) of harmful chemicals.
2. Abrasion or chemical reaction (e.g., lacquer).
3. Cleaning.
4. Contamination (as the surface degrades and falls off).
5. Slip (when surfaces are not designed appropriate to speed of motion).

## *14.2 Objects in the surface system: fixtures, fittings, and appliances*

Surface fixtures and fittings are equipment that interface with the electrical-illumination in a building:

1. **Surface fixtures** - systems and material layers for producing [physical] surfaces. The most common fixtures include, but may not be limited to:
   A. **Windows:** window surfaces are a light permittance surfaces, and can be part of construction and/or installation. These surfaces can be more or less insulated. These surfaces can let different amounts of frequencies of light through.
   B. **Shades (blinds):** are light permittance surfaces that reduce or eliminate light (and possibly, rain). Blinds and other shades are part of the surfacing system, except where they also act as structural barriers to physical force, wherein they are also classified as part of the structure.
   C. **Screens (mesh covering openings):** are object permittance surfaces that reduces the permittance of insects and animals from outside to in (or reverse), and also, restrict the movement of pets through openings. Screens allow atmosphere to transfer, and will reduce light transfer to some relative degree (because, the physical areas of the screen will block out light). Screens can be used to protect the indoor occupants from insects.
   D. **Tile and plank flooring:** an added material layer of flooring usually shaped into a tile and/or plank formation. These may be added by several means:
      1. Surface added by gravity and interconnection. The tiles and/or planks are interconnected and kept on the surface by gravity.
      2. Surface added by physical connectors and interconnection. The tiles and planks are interconnected and kept on the surface by physical interconnectors (and not, adhesive). Of course, adhesive and physical connectors can be combined.
      3. Surfaces are added by means of an adhesive. Adhesive is the "glue" that secures the tiles to another surface (e.g., floor, wall, ceiling, etc.). The added, individual tiles and planks come together with some space between them wherein the adhesive is only present. These gaps (spaces) are known as grout lines. Larger tiles and more effective adhesive (e.g., cement, paste, mucilage, etc.) allows for smaller exposure of adhesive in the form of "grout lines" per area. Note that degree of parallelity of individual tiles and planks also affects the exposure of adhesive; wherein, more parallelity reduces the presence of exposure if non-exposure (i.e., less "grout") is an objective.
   E. **Facade cladding:** an added material layer to a surface.
   F. **Paint:** an added material layer of thin material by hydrodynamic, adhesive, and chemical mechanisms.
   G. **Baseboards and crowns:** are fixtures attached to floors, walls, and ceilings. These are usually fixed to the surface, and can be decorative and/functional *(see "surface appliances" below)*.
   H. **Water membranes:** are waterproofing impermeable membrane and moisture/vapor membranes (e.g.., house waterproofing membrane, rubberized roofing, ice-dam) protect the building from water damage.

2. **Surface fittings** - a device designed to attach in some way one surface to another. The most common fittings include, but may not be limited to:
   A. Attaching connectors (i.e., hooks).
   B. Winds (e.g., winding up and down blinds).
   C. Locks.
      1. Physical.
      2. Digital magnetic.
3. **Surface appliances** - appliances and objects that change the surface, the most common of which include:
   A. Decor.
      1. Paintings.
      2. Limited area added textural materials.
      3. Decorative trim.
      4. Baseboards(and crowns as decorative trim.
   B. Functional.
      1. Televisions.
      2. White board.
      3. Baseboards and crowns as functional wall (or, other surface) protectors.
      4. Mirrors.

**IMPORTANT:** *All fixtures, fittings, and appliances must be specified with the right connection type for their placement.*

### 14.2.1 Facade cladding

Facade cladding maintains the following characteristics:

1. Appropriately selected texture can make an area more aesthetic.
   - The following critical question must always be asked, why does the area need facade cladding to make it look more aesthetic?
   - Note that many structures have an exterior and interior facade to improve insulation, improve impermeability, provide surface protection, provide aesthetics, improve surface usage characteristics (e.g., hanging, outleting, etc.).
2. Uses more material.
   - Why are more materials necessary?
3. Some facade is impossible to effectively clean without pressure washing and pressure washing can sometimes damage the facade.
   - How will the facade be cleaned, and will it ever need cleaning?
4. Some facades, particularly those outdoors can create breeding grounds for insects, especially spiders.
   - Is a breeding ground for insects a concern in context?
5. Facades can serve a dual purpose, as texture and protection and/or conduiting for cables and pipes.
   - Is the facade only necessary to aesthetically cover infrastructure (Read: cables and pipes), if so, why?
6. Buildings and other architectural surfaces can be designed with and without facade, some designs are likely to make façades more, and others less, necessary.
   - Is the facade a necessary use of materials for the given time period?

## *14.3 Installation of surface system*

There are many ways to install surfaces. Surfaces are generally installed over top of (Read: on top of) structure.

## *14.4 Operation of surface system*

In concern to surfaces, most significant operational activities are associated with cleaning.

### 14.4.1 Surface load demands

*A.ka., Surface loading.*

Surface loads are measured in several ways::

1. Gravity: When individual objects compose a surface (e.g., tiles), then gravity is a surface load demand.
   A. Weight (and mass) capacity as amount of weight a surface can sustain and remain viable.
   B. Stability: Likelihood of overturning (or, becoming unstable) given accidental pressure on the surface.
2. Resistance to damage and failure from:
   A. The elements and contact with other [accounted for] materials.
   B. Repeated cleaning.
   C. Thermal bridging and thermal capacity.
3. Electricity (electrical power) to do the work of motion in dynamic surface systems.

### 14.4.1 Surface cleaning

Necessarily, buildings have surface cleaning services and procedures. Surfaces can be cleaned in a number of different ways, including but not limited to:

1. Water-based:
   A. Hand washing.
   B. Scrubbing-washing (can be by hand or machine).
   C. Pressure washing. Pressure washers are rated in terms of their PSI. More powerful pressure washers can remove paint, and less powerful ones can be used to clean paint (and other surfaces).
2. Air-based:
   A. Air pressurizers (e.g., air sprayer).
   B. Suction (e.g., vacuums).

3. Thermal temperature accounting:
    A. Steam-based (e.g., steam floor cleaners).
    B. Warmth-based (e.g., hot water).
4. Automaticity accounting:
    A. Higher manualization, lower automation.
    B. Lower manualization, higher automation.

### 14.5 Engineering calculations for surfaces

*Nothing here yet.*

## 15 Architecture water sub-system

*A.k.a., Architectural hydrological system, plumbing system, plumbing network, hydraulics system, hydraulics network, hydraulics engineering, hydronic network, hydronic system, water engineering, plumbing engineering, hydraulics engineering, hydronic engineering.*

A complete water-based service system for architecture provides adequate supply of water and removes waste, while meeting user service requirements. The principal parts of an architectural water service system are categorizable under the conception of a plumbing network (a.k.a., plumbing systems):

1. Piping throughout (piping network).
2. Water supply sub-system.
3. Water and waste removal sub-system.
4. Plumbing fixtures and fittings (integrated into plumbing network.

Plumbing is any system that conveys fluids for a wide range of applications. Plumbing uses pipes, valves, plumbing fixtures, tanks, and other apparatuses to convey fluids. Heating and cooling, waste removal, and potable water delivery are among the most common uses for plumbing, but it is not limited to these applications. Note that there are many distribution configuration methods for a plumbing network.

**TERMINOLOGICAL CLARIFICATION:**
*The word "plumbing" means lead-work. Historically, pipes that transport water were made of lead. A more accurate term for a water and drainage system/network might be, hydraulics, or just, water system. However, a plumbing network can be used to transport more than just water. There are specialized plumbing system for vacuum, gas, etc.*

All plumbing systems transport materials (most often, fluids) via pipes. Piping systems for a plumbing system/network include, but may not be limited to:

1. Water supply piping:
    A. Hot water.
    B. Hot water recirculating.
    C. Cold water.
    D. Tempered water.
2. Sanitary piping:
    A. Lipid-inclusive sanitary (oil interception).
    B. Soap inclusive sanitary (soap interception).

   C. Wastewater.
   D. Rainwater/stormwater (environmental interception).
3. Vent piping - A pipe that goes through the wall and up to the roof to vent to the outside environment.
4. Hydronics piping (hydronic piping) - Hydronics (hydro- meaning "water") is the use of liquid water or gaseous water (steam) or a water solution (usually glycol with water) as heat-transfer medium in heating and cooling systems (e.g., chiller plants, HVAC systems, etc.)
   A. Hydronic supply.
   B. Hydronic return.
5. Drainage piping:
   A. Area drainage (part of sanitary system).
   B. Landscape and foundation drainage.
   C. Storm drain.
6. Fire protection piping:
   A. Fire protection dry.
   B. Fire protection other.
   C. Fire protection pre-action.
   D. Fire protection wet.
7. Special systems piping:
   A. Vacuum.
   B. Fuel gas.
   C. Carbon dioxide.
   D. Compressed air.
   E. Natural gas.
   F. Nitrogen.
   G. Nitrous oxide.

Herein, an optimized water system is designed to account for water availability, water demand, and ecological needs.

## *15.1 Plumbing standards*

*A.k.a., Hydraulic standards, hydrologic standards.*

The design of a plumbing system is greatly influenced by your applicable codes. The most common plumbing codes are the:

1. International Plumbing Code (IPC) [codes.iccsafe.org]
2. Uniform Plumbing Code (UPC)
3. Unified Facilities Criteria Plumbing Systems (UFC) 3-420-01 Plumbing Systems.

National standards include, but may not be limited to.

- National plumbing standard (NPS) is the North American standard today.

There are many different plumbing related water sub-system standards, such as:

1. Supply standards require and facilitate that adequate supply is provided.
2. Drainage standards requires that adequate drainage is provided. Often, these standards also deals with pollution prevention, sewage infrastructure, and maintenance. Technical design standards for drainage cover sanitary pipework, foul drainage, rainwater drainage and disposal, wastewater treatment, discharges, and cesspools.

### 15.1.1 Standard plumbing documentation

*A.k.a., Plumbing system specification and drawings, plumbing and pipe drawings, plumbing and pipe diagram, plumbing schematics, hydraulics schematics.*

Plumbing is documented via specifications and drawings:

1. Plumbing drawings illustrate the system that will bring water in, transfer water around the building, and take waste out. It typically includes water supply lines, drains, vent pipes, valves, and fixtures (e.g., toilets and sinks). Some diagrams also show fittings. There are diagrams for every sub-system in the plumbing system, including but not limited to:
   A. Riser diagrams are used as supplementary details on working drawings in order to show more clearly how the plumbing system is to be installed. Riser diagrams of plumbing systems can be shown in both orthographic and isometric views. A riser diagram is generally not drawn to scale, but should be correctly proportioned.
   B. Drain diagrams.
   C. Supply diagrams.
   D. Sanitary piping diagrams.
   E. Etc.
2. Plumbing specifications include all written content, reasoning for decisions, and calculations.

#### *15.1.1.1 Plumbing system plan*

The plumbing plan is a plan view that shows the complete plumbing system. The plumbing plan shows the following parameters for all units of plumbing equipment:

1. Source of supply.
2. Transportation of supply.
3. Location of process and/or use.
4. Size of usage system.
5. Type of equipment for de-/construction.

The plumbing plan should include the following (where applicable):

1. Water supply lines.
2. Drains.

3. Vent pipes.
4. Waste lines and vent stacks.
5. Valves.
6. Plumbing fixture.
7. Size and type of pipe to be used.
8. A plumbing fixture schedule.
9. Symbols legend.
10. General notes.

The plumbing plan includes standards for safety and water quality for all buildings. It also covers requirements for the prevention of floods and other hazards.

## 15.1.2 Standard plumbing requirements

What is required for a viable plumbing production-distribution system is:

1. **For architecture** - plumbing production proportionate to water-usage electrical power and liquid (water) demand [via a load].
   - Herein, a load means the amount of water at a specific temperature required by a building.
2. **For economic calculation** - Data sheet about loads (water fixtures) to produce optimization calculation.
3. **For life support demand** - water proportionate to human demand.
4. **For technology and exploratory demand** - water proportionate to human demand.

## 15.1.3 Hazards with the water system

*A.k.a., Plumbing risks, hydraulics risks.*

The primary plumbing risks include, but may not be limited to:

1. **Blockages** - the partial or complete blockage of some element in the system.
2. **Leaks** - a leak from one or more elements in the system. Water leak testing consists of capping all system openings and filling the system with water, and pumping a static head into the system at around 100 psi for at least 2 hours. This test is often conducted prior to sterilization.
3. **Frozen pipes** - liquids freezing within the pipe due to extreme cold.
4. **Thermal expansion and contraction** - as pipes expand and contract due to changes in temperature they can weaken and/or become loose.
5. **Water vapor and humidity** - the presence of water in the atmosphere.
6. **Noise ("banging")** - water moving through pipes, particularly pipes that are too large and pipes that change diameter, can create unwanted noise and vibration. Most noise comes from pipes going through holes that are not large enough so that when the pipe expands from the [hot] water there is creaking.
7. **Sterility** - the water system should be cleaned and disinfected. Disinfection is usually conducted with chlorine. It is injected into the system through a service cock, near the entrance into the building. Once the disinfectant is injected into the system at the correct concentration, it is then held in the system for a set period of time. After the retention, the concentrations are checked and if they are satisfactory, the system is flushed.
8. **Hydraulic shock (water hammer)** - is the term used to describe the pounding noise and vibrations in a piping system when a volume of liquid flowing is abruptly stopped. A pressure wave is started at the point of fluid stoppage and is reflected back and forth from this point to a point downstream. This wave is slowly dissipated after a period of time. Water hammer arrestors can be provided at every branch to multiple fixtures and on every floor for both hot and cold water.
9. **Rupture** - due to the buildup of energy. For example, most boilers have heat-purge controls.

#### *15.1.3.1 Water vapor and humidity*

Water vapor is a colorless, odorless gas that is always present in the air. Water vapor can create problems if it condenses on interfaces with unintended building components. Condensation occurs when moist air is cooled below its dew point temperature, by either mixing with colder air or contacting cold surfaces. Condensation can cause frosting and fogging of the surfaces of materials altering the function and/or components. It can saturate insulating materials in structure, and render them ineffective. It can create drips, puddles, water stains, fungal growth, and corrosion inside a building. When water penetrates building materials, it can cause some materials to weaken and disintegrate. It can blister and rupture paint coatings and membranes on the outside of a building.

There are many potential sources of water vapor within a building, including the unique category of and human metabolic activity such as respiration and sweating. In a new building, water vapor may also come from wood, concrete, plaster, and other materials that are still giving off excess moisture. For standard human occupation, a good optimum interior relative humidity is between 40 and 60 percent. In warm, humid locations, interior air pressure should be slightly higher than outside to reduce the inflow of humid air. A building's atmospheric mechanical system (e.g., HVAC) is often designed to reduce the amount of water vapor inside a building by ventilation, by dehumidifying the air with an air-conditioning system, or both.

#### *15.1.3.1 Vapor/humidity control*

Whether or not mechanical systems are installed, there are four precautions we take in detailing to avoid water vapor problems in a building (Allen, 2016):

1. Use thermal insulation, multiple glazing, and thermal breaks to keep interior surfaces at temperatures above the dew point of the air.
2. Use a warm-side vapor/moisture retarder (object or surface coat/alteration) to keep air and water vapor from reaching surfaces and spaces that are cool enough to cause condensation to occur.
3. During assembly, ventilate the portion that lies on the cold side of a vapor retarder, to be sure that no moisture is trapped there.
4. Where condensation is likely to occur despite any such precautions, we provide a gravity-driven system to catch and remove condensate before it can create problems.

## *15.2 Conception of the plumbing service system*

There are plumbing systems that are, and are not, water based. All water-based plumbing systems use two separate subsystem networks made of pipes. One brings freshwater inside, and the other transports wastewater/ sanitary away. The following are the most common types of water systems/networks associated with most architecture:

1. **Water supply (inflow)** - water supplied to the architecture from a specific source (i.e., water entering the architecture).
   A. **By source:**
      1. Municipal sourced.
      2. Well or nature sourced (other than rainwater).
      3. Rain sourced.
   B. **By temperature:**
      1. Cold water.
      2. Hot water.
   C. **By purity:**
      1. Municipal water (from the municipal source).
      2. Fresh water (freshwater) from nature.
      3. Drinkable (purified) water.
2. **Sanitary water (outflow)** - water leaving the architecture (i.e., water exiting the architecture).
   A. Rainwater (but, may also be a supply source).
   B. Gray water.
      1. Water with fat.
      2. Water with soap.
   C. Blackwater.

The three basic (normally used, considered fundamental) types of pipe systems for a water-based plumbing system/network are:

1. **Cold water piping (water supply cold)** - has pressure. Pressurized water pipes can go in a straight horizontal line. To supply clean cold water.
2. **Hot water piping (water supply hot)** - has pressure. Pressurized water pipes can go in a straight horizontal line. To supply clean hot water.
3. **Sanitary piping** - has no pressure, and requires a downward sloping pipe at a country specific graded angle (often, 2%). Non-pressurized pipes require a gravity slope to move. These remove black and grey water.

A refrigerant hydronic system may be considered a type of plumbing system that is not water-based. There are also plumbing systems for other types of liquid materials.

## *15.3 Conception of the water supply sub-system*

*A.k.a., Water supply infrastructure.*

Water supply is the provision of water by utilities organisations, typically using a pump and pipe system. The main components of a water supply system for an architectural construction are:

1. **Plumbing network (a.k.a., water network, hydraulics network)** - the interconnect of pipes through which water flows within and without an architectural structure.
2. **Building supply** or **water service** – a large water supply pipe that carries potable water from the water district or city water system or other water source to the building.
   A. **Cold water supply line** - a supply line that provides cold water. All municipalities supply architectural constructions with a cold water supply.
   B. **Hot water supply line** - some municipalities supply architectural constructions with a hot water supply also. These municipalities supply hot water from a series of water heating plants throughout the city, not from basement boilers.
3. **Building main line** – a large pipe that serves as the principal artery of the water supply system. It carries water through the building to the furthest riser. The building main is typically run (located) in a basement, in a ceiling, in a crawl space, or below the concrete floor slab.
   A. **Cold water building main line** - all buildings supplied with water have a cold water building main line. The cold water building main line often maintains a branch point where water splits off into the cold water supply and hot water heating system.

   B. **Hot water building main line** - a main line for hot water.
4. **Riser** - a water supply pipe that extends vertically in the building at least one story and carries water to fixture branches. It is typically connected to the building main and runs vertically in the walls or pipe chases.
5. **Fixture branch** – a water supply pipe that runs from the riser or main to the fixture being connected. In a water supply system, it is any part of a piping system other than a riser or main pipe. Fixture branch pipes supply the individual plumbing fixtures. A fixture branch is usually run in the floor or in the wall behind the fixtures.
6. **Fixture connection** - a fixture connection runs from the fixture branch to the fixture, the terminal point of use in a plumbing system.
7. **Shut-off valve** - for the entire system, as well as for specific areas, let people turn off the water flow while they fix problems. These are typically located in the hot and cold-water supply at the fixture connection.
   A. **Main water shut-off valve** - shuts off [main line] water to the whole building.
   B. **Fixture specific shut-off valves** - shuts off water to specific areas and/or fixtures.
8. **Water meter** – used to measure and record the amount of water used. It may be placed in a meter box located in the ground near the street or inside the building. In the market-State, this device allows a local water district to calculate the bill for water usage for a building.

### 15.3.1 Water supply equipment

General water supply equipment includes, but is not limited to, the following equipment:

1. Pipes.
2. Water heaters.
3. Pressure booster systems.
4. Pressure regulating valves.
5. Circulating pumps.
6. Back flow preventers.
7. Balancing valves Isolation valves.
8. Hangers and supports.
9. Thermal insulation.

### 15.3.2 Water supply for different categories of building

All plumbing systems must use equipment to maintain adequate pressure and flow in all parts of the system. Different categories of buildings have different arrangements of plumbing:

1. House system - derive pressure from either, or some combination of the following:
   A. Municipal pressure.
   B. Water tank on top floor or roof.
   C. Separate pump.
2. Apartment systems:
   A. Multi-story systems (high-rise systems) - refers to those buildings that are too tall to use pressure from the municipal water supply to reach the entire building. These taller, vertical buildings need systems that can reach each unit. The pressure options include:
      1. Gravity-based roof tanks - wherein, water is pump up from storage tanks on the ground floor or in the basement. The water reaches the roof tank, where gravity helps it flow down to every unit.
      2. Booster pumps - that adds the pressure needed to move water from the storage tanks or straight up from the municipal water supply. These pumps add to the system's existing pressure.
      3. Hydro-pneumatic storage tanks - water moves from the municipal supply or the storage tanks into these hydro-pneumatic storage tanks, where air pressure helps push the water to where it is needed.
      4. Note that these systems need control valves for each unit. This reduces the risk of cross-contamination between units. It also lets the water supply to an individual unit be shut off if repairs are needed or the unit isn't occupied.
   B. Multiple dwellings - have separate units but don't have the same water pressure issues. Multiple dwelling apartments can use plumbing systems like those in a house system, except that the pipes branch out more to provide water to each unit. As the water comes into a multiple dwelling apartment from the municipal supply, a system of pipes, faucets and valves makes sure water gets where it's needed. The drain-waste-vent (DWV) system carries wastewater out of each unit in the apartment building.

### 15.3.3 Hot water supply specifics

The US General Services Administration maintains the following guidelines in concern to domestic hot water supply (Plumbing systems, 2021):

1. Domestic hot water supply temperature is often generated at 60°C (140°F), and is tempered to 49°C (120°F) using a three-way mixing valve, before supplying to all plumbing fixtures.

2. Hot water supply to dishwashers shall be at 82°C (180°F), and the temperature shall be boosted from 60°C (140ºF) to 82°C (180°F).
3. Circulation systems or temperature maintenance systems may need to be included.
4. Hot water shall be available at the furthest fixture from the heating source within 15 seconds of the time of operation.

## 15.4 Conception of the water piping sub-system

*A.k.a., The piping network, water piping infrastructure.*

Water distribution uses a piping system/network. Piping is the process of selecting and routing a piping network. The process of piping involves:

1. **Pipes (piping types)** - pipe material based (may include function; e.g., PVC cold water; copper hot water, etc.).
   A. Material based (i.e., the physical/material composition of the pipes).
   B. May also include system-type (e.g., water). But, this is not necessary; all that is necessary (often appropriate) is material type.
   C. Contains routing preferences.
2. **Piping systems** - piping system categories (a system of classification by piping system function; e.g., hot water, cold water, oxygen, vacuum, etc.).
   A. Customizable potentially by:
      1. Materials.
      2. Mechanical calculations.
      3. Fluid type.
      4. Temperature.
      5. Fluid viscosity.
      6. Fluid density.
      7. Flow conversion method (references International Plumbing Code by applying a demand factor to the plumbing fixtures).
   B. Reference to system classification.
3. **Plumbing fixtures (or, piping fixtures)** - endpoint or processing points for the contents transported in the piping system (e.g., lavatory, sink, etc.).

### 15.4.1 Piping routing rules and parameters

*A.k.a., Plumbing pipe running rules, pipe layout and design rules.*

Routing preferences (a.k.a., piping interconnection rules) refers to the rules ("preferences") for connecting (routing) pipes over distance.

Pipe routing preferences/rules are based on one or a combination of the following:

1. Pipe material (material types).
2. Pipe connection type (pipe geometry, geometry types).
3. Flange types

The parameters to consider when creating pipes in software include:

1. Pipe type (generally, material composition)
2. System type (generally, function)
3. Diameter type
4. Slope

Common pipe routing best practices include, but may not be limited to:

1. In general, pipes do not pass vertically directly through floors; instead, they pass through the space between a floor, wall, and ceiling.

### 15.4.2 Plumbing pipes

**NOTE:** *Pipes are made of materials (and they conduit the transportation of materials).*

Pipes may be classified by (note: this content is usually defined in a set of piping standards):

1. Type of material (i.e., material composition of pipe).
2. Function of pipe network (e.g., to provide cold water, hot water, etc.)
3. Specific pipe elements:
   A. Types of physical interconnection between pipe elements (e.g., glue, screw, etc.).
   B. Geometric function of pipe elements (e.g., segment, curve, etc.).
   C. Conduit shape (e.g., square, round, oval.)
4. Sizes (relative to region)
   A. United States, Canada, and Brazil
   B. Europe
   C. Australia
   D. Russia
   E. China
   F. Others

Categories of connection for piping include, but may not be limited to:

1. By geometric function of element:
   A. Straight connector
   B. 90 degree bend
   C. Other degree bends.
   D. T connector
   E. Cross connector
   F. Size adapter
2. By physical interconnection type:

   A. Compression connection
   B. Welded (solder connection)
   C. Threaded (screw connection)
      1. With plumbing this often necessitates another tape like material that is first twisted around the part to be screwed.
   D. Flanged connection
   E. Glued connection
3. By conduit shape:
   A. Round

### *15.4.2.1 Types of pipes by function*

Other piping elements include, but may not be limited to:

1. Supply pipes.
   A. Water supply line pipes.
   B. Cold water pipes
   C. Hot water pipes
2. Drain pipes.
   A. Drop pipes (drop tubes, plumbing drops) - sanitary pipes that drop sanitary water down an elevation(s).
   B. Soil sack - vertical pipe that carries waste away from sanitary units (blackwater).
   C. Waste sack - a vertical pipe that carries graywater.
3. Vent pipes:
   A. Stack vent.
   B. Loop vent.
   C. Roof vent.
4. Trap pipes.

### *15.4.2.1 Types of pipes by geometry*

*A.k.a., Types of pipe interconnections.*

Piping elements include:

**NOTE:** *Pipe connectors are sometimes called pipe fittings.*

1. **Pipe segment** - straight, horizontal segment of pipe.
2. **Elbow** - curved piece that joins two pipes.
   A. 90 degree.
   B. 45 degree.
   C. Etc.
3. **Junction**
   A. Tee - shaped like a T; connects 3 pipe segments.
   B. Tap.
4. **Cross** - connects 4 pipe segments.
5. **Transition** - adapter element for changing pipe sizes.
6. **Union** - connector of 2 pipe segments.
7. **Flange** - connects piping and components in a piping system by use of bolted connections and gaskets.
8. **Cap** - closes (seals off) end of a pipe.

*Note: The above types of [pipe] fittings (unions, interconnections) can be set for routing a pipe.*

### *15.4.2.2 Types of pipe fittings and connectors*

**NOTE:** *All pipe connectors are also called fittings. Hence, the term 'fitting' can be appended onto the end of each of these connectors (e.g., Tee fitting, mini ball fitting, etc.*

Piping connectors include, but may not be limited to:

1. Connectors and couplings
   A. Tee
   B. 90 degree
   C. 45 degree
   D. Compression
   E. QickTight
   F. Insert
   G. Small tube push fit
   H. Sharkbite
   I. Bulkhead
   J. Flare
   K. Radiant heat
   L. Cleanout plugs
   M. ABS
   N. Hose adapters
   O. Barbed
   P. QwikRepair
   Q. Full flow quick
   R. Left/right
2. Couplings
   A. No-hub coupling
   B. Flexible pipe connector
3. Valves
   A. Sharkbite
   B. Push to fit
   C. Kitz
   D. Aquamix tempering
   E. Blackwater
   F. Slice gate
   G. Add-A-Line
   H. PVC check
   I. PVC ball
   J. Straight and angle style
   K. Needle
   L. Gas ball
   M. Mini ball
   N. Isolation
   O. Zone
   P. Purge
4. Adapters

   A. Quick Tee
   B. Quick connect
5. Flanges
6. Supply hoses
   A. Flexible water connectors
   B. High-flow water connectors
   C. Gas connectors
   D. Commercial gas connectors
   E. Gas connectors with valves

**NOTE:** *Some pipe connectors are for potable water, and others are not. In other words, some fittings on these pages may be suitable for use in potable water systems, while others may not.*

#### *15.4.2.3 Types of piping tools*

The most common types of piping tools include, but may not be limited to:

1. Pipe and tubing index.
2. Thread seal tape (PTFE tape, teflon tape, plumbers tape).
3. Pipe freeze kits.
4. Pipe threaders.
5. PVC/ABS reamers.
6. Pip fitting removers.
7. Nipple extractors.
8. Pip repair clamps.
9. Pipe hangers.
10. J-hook hangers.
11. Pipe brackets.
12. Pipe taps.
13. Hose clamps.
14. "Bunny box" nipple case.
15. Plumbers saw.
16. Pipe wrench.
17. Pipe cleanout brush.

#### *15.4.2.4 Pipe categorization specifics*

In general, pipes are categorized by the following specifics:

1. Material(s).
2. Purity of material(s).
3. Pipe diameter (pipe bore).
4. Wall thickness (pipe schedule).
5. Rigidity.

Hence, different pipe networks will need different:

1. Types of material.
2. Sizes of pipe.
3. Rigidities of pipe.

#### *15.4.2.5 Types of piping materials*

The most common materials for pipes are:

1. **Metal**
   A. **Cast iron** - mostly in use before 1960; used for drain/waste/vent (DWV) lines.
   B. **Steel (galvanized pipe)** - common in older homes; lasts only about 50 years.
   C. **Stainless steel**
   D. **Chrome** (note: chrome plated brass fittings can contain lead)
   E. **Brass** (note: must be lead free. Older brass fittings, valves, and faucets can contain lead).
   F. **Copper** - commonly used in water lines and some drain lines; resists corrosion, lasts a long time. Not that some types of copper piping are available in both rigid and flexible varieties. Copper pipes are categorized by their purity, size (wall thickness and diameter), and rigidity:
      1. **Flexible copper tubing (a.k.a., soft copper tubing, coil tubing)** - often used with appliances lines (e.g., dishwasher, refrigerator, icemaker) and rolled out for under slab installations. These are generally called, type K copper plumbing pipes.
      2. **Rigid copper.**
         i. **Rigid copper distribution pipe** — comes in three thickness's: type M (thinnest), type L (thicker), type K (thickest).
         ii. **Rigid copper drain pipe** — comes in one thickness marked drain-waste-vent (DWV) and is thinner walled than type M.
2. **Plastic** - used since mid-1970s; two types:
   A. **ABS (acrylonitrile-butadiene-styrene)** - black color; first to be used in residential homes, though some areas restrict their use in new construction.
   B. **PVC (polyvinyl-chloride)** - white or cream color; rating and diameter are stamped on the pipe. PVC is commonly used for drains. The two most common forms of PVC are:
      1. **Schedule 40 PVC** is strong enough for drain lines and cold-water lines, but local code will determine applicability. When used for cold-water lines, it is generally not allowed for use inside a building.
      2. **Schedule 80 PVC** is often used for cold water lines, but isn't allowed for use inside a building in some areas because it isn't suitable for hot water.
   C. **CPVC (chlorinated polyvinyl chloride)** - as strong as PVC but is heat-resistant, which makes it acceptable in most areas for interior [hot water] supply lines. It is most commonly measured with CTS standards (which is important when considering fittings for existing pipe; for example, a 2" fitting will not always

fit on a 2" CTS pipe, but it will always fit on a 2" nominal size PVC pipe).

1. Schedule 40 and 80 CPVC pipe and schedule 80 CPVC fittings are available and generally used in industrial applications.

3. **PEX (cross-linked polyethylene)** - newest pipe for residential water supply (cold and hot supply lines) use. In general, PEX is primarily used for supply lines. However, PEX can also sometimes be used for cold and hot water drains. PEX is also sometimes used in radiant hot water heating. PEX is an option for plumbing as well as radiant and hydronic systems in both residential and larger plumbing applications. Note that PEX is not intended for compressed air applications. PEX type piping can use compression fittings or push on fittings, more permanent connections require crimp style fittings and a crimping tool (Read: PEX pipes can use crimp, clamp, and press connectors -- necessitating these types of tools). PEX pipes do not require glue or cement, and can simply be joined with push-to-connect fittings, metal insert fittings, or plastic insert fittings for a watertight seal. PEX pipe is not approved for outdoor applications and is not approved for continuous UV exposure. PEX pipe should not be stored in direct sunlight.
   A. The disadvantages of PEX piping include:
      1. Almost all PEX used for pipe and tubing is made from high-density polyethylene (HDPE). PEX will likely leach toxic chemicals (e.g., VOCs). Different brands cause different odors and leach different chemicals. There are 3 types of PEX (A, B, and C); the type B is claimed to have the least significant leaching problem (note, this needs to be confirmed). The pipes may either have to be outgased through flushing over an extended prior of time, or a sufficiently capable water filter may need to be installed at usage endpoints
      2. PEX is extremely sensitive to all sources of UV light. Most manufacturers recommend a limited amount of sunlight exposure, which is important to note during the installation process, and others recommend total darkness.
      3. PEX can be damaged by chlorine and other oxidizing chemicals. PEX pipe is vulnerable in concern to contact with such solutions as petroleum products and oxygen.
      4. PEX can be damaged by pests. Some pest control companies argue against installing PEX because it is highly susceptible to pest damage. Since PEX is plastic, it's more sensitive than copper and other metal pipes. Rodents can chew threw the pipe. Note here that this is more of a rodent problem than a PEX problem.
      5. PEX can't be installed in extremely high heat areas. The max temperature a PEX pipe can hold before damage is approximately 82C (180F).
      6. PEX is semi-permeable, which means liquid can enter the pipe. When it comes to safety, PEX isn't antibacterial. This is one reason people don't choose PEX in the PEX vs. copper decision. The plastic material also allows water to enter the tube, which could cause contamination.
      7. PEX should not be used if there are hot water lines that are pinched by small holes. This situation can result in squeaking when hot water flows cause the line to expand slightly.
   B. The benefits of PEX piping include:
      1. Easy to install (Read: easier install than rigid pipe).
      2. Cuts easily.
      3. Is flexible and can be navigated around obstacles.
      4. Available in long coils that can eliminate the need for extra fittings.
      5. Freeze damage resistant. PEX pipe will expand if frozen and contract to its original shape when thawed. PEX pipe is not freeze-proof. Normal standard insulation precautions should be taken PEX piping to help prevent freezing.
      6. When installed correctly, PEX is generally not associated with noise complaints.

#### *15.4.2.6 Drain-waste-vent piping*

*A.k.a., Plumbing vent pipe, vent stack.*

In modern plumbing, a drain-waste-vent (or DWV) is part of a system that allows air to enter a plumbing system to maintain proper air pressure to enable the removal of sewage and greywater from a dwelling. The plumbing vent, also known as a vent stack, helps regulate the air pressure in your plumbing system. The plumbing vent pipe removes gas and odors. It also allows fresh air into the plumbing system to help water flow smoothly through the drain pipes. However, no water runs through the plumbing vent pipe. It is a vertical pipe attached to a drain line and runs through the roof of your home. The vent stack is the pipe leading to the main roof vent. It channels the exhaust gases to the vent and helps maintain proper atmospheric pressure in the waste system.

#### *15.4.2.7 Piping insulation*

Domestic cold and hot water distribution systems should be insulated per ASHRAE 90. and all exposed piping should have PVC jacketing.

#### *15.4.2.8 Vertical and sloped piping*

Types of sloped and vertical pipes include, but may not be limited to:

1. Vent pipes - might run level, although some codes call for a slight slope toward the main drain.
2. Drain pipes - all drain lines must be sloped.
3. Riser pipes - A pipe that extends vertically from one floor level (or, elevation) to the next for the purpose of carrying or distributing water, steam, etc. Generally made from durable metal or plastic. Metal risers last longer than plastic ones.
    A. Vent riser - a riser that vents. Vent risers often start from the last plumbing fixture on the top most level of the plumbing network.
    B. Wet riser- The pipes are kept permanently charged with water.
    C. Dry risers - A pipe is maintained empty of water is called a dry riser. This is found in fire suppression equipment. Dry risers have pipes that are dry. These pipes are capable of being charged with water to extinguish fire.
    D. Sprinkling riser - This riser used in the garden or in commercial buildings and kitchens to sprinkle water on detection of smoke. For proper functioning of the riser pipes it is important to get a servicing done for the riser pipes because:

**WARNING:** *Leaking from a wet riser could cause substantial damage.*

### 15.4.3 Hot water piping

There are two types of hot water piping:

1. **Domestic hot water (DHW) piping** - is hot water piping for a building.
2. **District hot water piping (a.k.a., municipal hot water piping, heat networks, teleheating, etc.)** - is a piping system that distributes generates and distributes heated water from a centralized location through a system of insulated pipes. This heated water is produced centrally and distributed to many buildings.

Hot water distribution networks can be made to recirculate the hot water with a hot water recirculation system. Using a recirculating pump, the hot water from your furthest plumbing fixture will circulate back to the water heater through the domestic hot water piping. Installing such a system is likely to save energy. These circulation systems come in two types:

1. Constant (continuous) circulation.
2. On-demand circulation. This system is optimal because the pump is not overused and distribution losses are decreased drastically, leading to more energy conservation.

It is important to note that material selection and pipe insulation play a significant role in the efficacy of a hot water distribution system. Cold water supply lines dot not have to withstand maximum water temperature and can be made out of different types of material. Hot water supply lines are generally composed one of the following types of material: copper, polybutylene (PB), chlorinated polyvinylchloride (CPVC), random polypropylene (PP-R) and cross-linked polyethylene (PEX).

## *15.5 Conception of the sanitary water sub-system*

*A.k.a., The water sanitation subsystem, sanitary septic subsystem, water and waste removal subsystem, water sanitary infrastructure.*

Used water and other wastes are carried to the sanitary sewer or septic tank/biodigester through a waste removal system. The sanitary drainage system is not under pressure and depends on gravity (and pre-existing water pressure) to carry the waste.

### 15.5.1 Sanitary piping

The sanitary system is isolated from the water supply system and must be sized for sufficient capacity, have proper slope and venting, and have provisions for cleanout (and inspection).

- Typically, it is practical to drain as many fixtures as possible into a single drain.
- Sanitary pipes never go 90 deg into a [main] pipe, they always have to be attached at 135 or 45 deg. Bends at 90 degrees can easily result in blockages. A 45 degree bend between two sanitary pipes is optimal. Blockages in sanitary pipes can easily occur be because of lack of pressure within the pipe; such pipes mostly use gravity to move the water.

Sanitary piping network generally includes:

1. **Stack pipes** - vertical drain pipes. All stacks extend into ground and empty into a house drain.
    A. **Soil stack pipe** - a vertical drain pipe that collects waste from one or more fixtures (Read: sanitary units; e.g., toilets). Soil stacks move water away from fixtures like urinals or toilets.
    B. **Waste stack pipe** - a vertical drain that doesn't carry soil from a sanitary fixture (e.g., sink). Waste stacks move water away from "clean

water fixtures" like showers and sinks.

   C. **Main stack pipe** - a soil stacks that drain water closets. Every multi-story building must have at least one main stack. And, every bathroom must have a main stack.
   D. **Secondary stack pipe** - stacks that do not drain water closets. These are usually a smaller diameter than the diameter of main stacks.
   E. **Vent stacks** (*see: vent stack pipe*) - only support the system with airflow – they don't actually move water.
2. **Cleanout fitting** - is a pipe with a removable plug that is found a waste system. It is designed to help keep the pipe clear of any debris that could cause any type of stoppage in the water drain lines. Cleanouts are usually placed at the connection point between the sewer lines and the drain lines where the base is located of a vertical stack and at all places where the pipe direction changes at 90 degrees. Cleanouts are required at the base of all stacks.
3. **Branch main pipe** - pipes that connect fixtures to the stack.
4. **House drain pipe** - receives all waste and water discharged by the soil stacks and waste lines. It drains waste water toward the outside of the house and is directly connected to the house sewer. The house drain is laid from a point just outside the building foundation wall, where it connects to the house sewer.
5. **House sewer pipe** - the house drain becomes the house sewer once it is outside the house. The house sewer empties into the city sanitary sewer or private septic/biodigester system.
6. **Vent stack pipe (vent pipe)** - gases from the system dissipate through the vent stack, which rises above the roof. To prevent the siphonage of a trap seal in fixture traps and allow gravity flow of drainage, it is essential to let atmospheric air from outside the building into the piping system to the outlet (or discharge) end of the trap. The air is supplied through pipes called 'vents'. This air provides pressure on the outlet end of the seal equal to pressure on the inlet end. Since the air supplied by the vent to the outlet end provides a pressure equal to that at the inlet end of the trap, the trap seal cannot escape through siphonage. Note that the term main soil vent, wast vent, and soil stack vent, refer to the portion of the stack pipe extending above the highest fixture branch; these vent pipes are an extension of the main soil and waste stack.
   A. **Main vent (vent stack)** - the principal pipe of the venting system
   B. **Vent branches** - pipes connected to the main vent and run undiminished in size as directly as possible from the building drain to the open air above the roof.
   C. **Individual vent** - a vent that connects the main vent with the individual trap underneath or behind a fixture.
7. **Trap pipes** - installed bellow each fixture to prevent gases from entering the house. The trap is always filled with water. Water closets have a built-in trap.
   A. **Fixture trap pipes** - most, if not all, fixtures have their own trap.
   B. **House trap pipe** - should be provided with a cleanout and a relief vent or fresh air intake on the inlet side of the trap. Relief vents or fresh air intakes shall be carried above grade and shall be terminated in a screened outlet located outside the building. The size of the relief vent or fresh air intake shall not be less than one-half the diameter of the drain to which the relief vent or air intake connects.
8. **Drain fixtures** - fixtures, generally on the floor, into which waste water flows.
9. **Sewage ejector fixtures** - should only be used where gravity drainage is not possible. If they are required, only the lowest floors of the building should be connected to the sewage ejector; fixtures on upper floors should use gravity flow to the public sewer. Sewage ejectors should generally be non-clog, screenless duplex pumps, with each discharge not less than 100 mm (4 inches) in diameter. They should be connected to the emergency power system.

#### *15.5.1.1 Vents*

Vents in the wastewater system let air in so the water more easily flows out.

#### *15.5.1.2 Sealing valves and pipes*

*A.k.a., Trap pipes, trap seal valves, trap seal pipes, unwanted flow pipes, p pipes, hepvo valves, hepvo trap, etc.*

Traps seal the drainage system so nothing can move back up once it drains away. Traps are required because they prevent sewer gases from entering the building and causing serious illness or death. The term 'trap seal' refers to the water being held in the bent portion of the fixture trap. The trap seal forms a seal against the passage of sewer gases through the trap and into the building. There are several types of sealing traps:

1. The trap most commonly used with plumbing fixtures is the P-trap. The P-trap gets its name because of it is shaped similar to the letter P. P-traps trap a bit of water, thus prevent gas flow. In

very cold conditions, the water in these valves can freeze, possibly causing the trap housing to break. Certainly, the trap will not work when the water inside is frozen. P-pipes need space beneath the drain to contain the water trap.
2. Alternatively, a hepvo valve incorporates a self-sealing silicone valve that allows water flow one way and seals the tube shape when there is no water flow. Hepvo traps work in very cold conditions and do not need so much depth of volume beneath the drain because they can extend off quickly at a near 90 degree, horizontal, angle from the drain.

#### *15.5.1.3 Floor drains*

The following are best practices for floor drains:

1. Floor drains should be provided in multitoilet fixture restrooms, kitchen areas, mechanical equipment rooms, locations where condensate from equipment collects, and parking garages and ramps.
   A. Floor drains shall be cast iron body type with 6 inch diameter nickel-bronze strainers for public toilets, kitchen areas and other public areas.
   B. Equipment room areas will require large diameter cast iron strainers and parking garages will require large diameter tractor grates.
   C. Drainage for ramps will require either trench drains or roadway inlets when exposed to rainfall.
2. Single fixture toilet rooms do not require floor drains.
3. Trap primers shall be provided for all floor drains where drainage is not routinely expected from spillage, cleaning, or rainwater.
4. Specific drains in kitchen areas shall discharge into a grease interceptor before connecting into the sanitary sewer.
5. Floor drains and/or trench drains in garage locations are to discharge into sand/oil interceptors.

### 15.5.2 Drain fixture units

Drain fixture unit (DFU) is a relative measure of the drain wastewater flow or load for various plumbing fixtures. A drain fixture unit is a unit of measure, based on the rate of discharge, time of operation and frequency of use of a fixture, that expresses the hydraulic load imposed by that fixture on the sanitary plumbing installation. A fixture unit is equal to 0.028m$^3$ (1 cubic foot) of water drained in an 32mm (1+1⁄4 inches) diameter pipe over one minute.

### 15.5.3 Water-based biotreatment

*A.k.a., Water-based bio-management (biomanagement).*

The biotreatment system is a process for conversion of water-based organic waste and its transformation into energy (gas), fertilizer, and aquifer directed water .

The elements in a water-based biotreatment system are:

1. Supply tank.
2. Pre-treatment.
3. Biodigester.
4. Stabilized organic matter storage tank.
5. Biogas purification unit (filters).
6. Motor and generator set.

Processes responsible for the degradation of organic matter include:

1. Anaerobic microorganisms.
2. Anaerobic degradation:
   A. Hydrolysis.
   B. Acidogenesis.
   C. Acetogenesis.
   D. Methanogenesis.

Waste characterization factors include, but may not be limited to:

1. Composition of each waste.
2. Hydraulic detention time (TDH).
3. Only biodegradable organic waste.

Other parameters for the proper functioning of the biodigesters:

1. Inflow into the system
2. Organic load applied
3. PH
4. Temperature
5. Carbon Nitrogen Ratio
6. Chemical Oxygen Demand Ratio (COD)
7. Biochemical Oxygen Demand (BOD)
8. Monitoring

### 15.5.4 Septic system elements

A septic system elements (specification) include, but may not be limited to:

1. Septic design diagram.
   A. Local sewage system.
   B. Septic tank.
      1. Septic filtration - In places where there is no public network, sanitary sewage must be retained and the residual water must be

treated before being discharged back into nature. ?? The septic tank is a tank capable of retaining the waste coming from bathrooms and kitchens, transforming them into less aggressive material to nature. By retaining this waste at the bottom of the tank, odorless liquids called effluents are formed. A septic tank consists of a tank. Sewage remains for a few hours inside, which allows the sedimentation of solid particles on its bottom that form a slime rich in microorganisms. This biomass is responsible for the decomposition of organic matter present in the liquid.

C. Septic filtration with anaerobic filter.
D. Fat box (a.k.a., fat trap) - Water fat separator by decanting process. Water from the kitchen cannot be directly discharged into the pit (nor can it be discharged directly into the public sewer system), as the fat on contact with the water solidifies and can obstruct the pipes.
E. Soap box - soap is separate from the water.
F. Graded box - Block solid waste. Solid residues can also clog the pipes and must be retained in the grid.
G. Septic tank - 1st stage of the Bio-digestive process. Waste is retained at the bottom of the tank.
H. Anaerobic filter - 2nd stage of the Bio-Digestive process with a false bottom and Gneiss gravel, which provides the ideal environment for the formation of Zogleias (bacterial colonies), the final stage of the Bio-Digestive process. The efficiency of the system is increased by directing the effluent to the biodigestion zone, located at the bottom of the tanks, where the process of self - destruction of the bacteria causes all the sludge deposited at the bottom to be in constant motion.

2. Biodigestive septic tank (biodigester).
   A. Sptetic tank.
   B. Anaerobic filter.
   C. Sinkhole (sink-hole)

#### *15.5.4.1 Biodigester location*

As a general rule, the biodigester should be located near the source of material. The direct advantage of this is that the waste can then be easily mixed and fed to the biodigester unit without having to travel long distances, which might require pressure and increase the likelihood over time of blockages.

The following three main factors for site selection should be taken into consideration:

1. Proximity to source of materials.
2. Areas prone to flooding should be avoided.
3. The pit should be located on the lower side of the site (source of material) for easy flow (by gravity) into the biodigester.

## *15.6 Conception of the rainwater sub-system*

*A.k.a., Water rainwater infrastructure, gutters, rainwater conduits.*

A rainwater design diagram for an architectural object and the surrounding site includes, but may not be limited to:

1. Rainwater directing.
   A. Rainwater gutters, pipes, and conduits (a.k.a., rainwater continuous guttering.)
   B. Guttering covers.
   C. Guttering cleaning.
2. Rainwater catchment.
3. Rainwater storage tank.
   A. Tank.
   B. Purification (e.g., ozonation).
4. Rainwater filter/filtration.
5. Rainwater drains in architecture.
6. Rainwater drainage around architecture.
7. Rainwater pool overflow.

### 15.6.1 Rainwater drainage

Proper drainage around all architectural structures is essential. The more surface area covered by architecture, the larger the amount of water the ground must absorb or be channelled away for storage, evaporation, ground drainage. Paths can be built that actually allow water to drain through them as opposed to “pool” off to the side. For paths that do not allow for immediate drainage there must be conduits for channelling the water to locations where it could either be:

1. Used.
2. Stored for usage or evaporation.
3. Drained.

Pipes and fittings for rainwater drainage should be sized based upon local rainfall intensity.

#### *15.6.1.1 Roof drainage*

Adequate provision must be made for rainwater to be carried from the roof of buildings and away from the buildings' foundation. To achieve this, roofs must be designed with a suitable fall towards either a surface water collection channel or gutter that conveys surface water to vertical rainwater pipes, which in turn connect the discharge to the drainage system.

Drainage from roofs is generally provided by internal rainwater outlets and downpipes, or by external guttering systems or hoppers. It is recommended that there are at least two drainage points, even if the roof is small, to mitigate against one of them becoming blocked.

The type of roof covering used determines the required fall of the roof. Minimum recommended falls are typically (Designing Buildings: Drainage, 2021):

- Aluminium - 1:60.
- Lead - 1:120.
- Copper - 1:60.
- Roofing felts - 1:60.
- Mastic asphalt - 1:80.
- Flat roofs - should have a designed minimum fall of 1:40 (2.5cm), so that an actual finished fall of 1:80 (1.25cm) is achieved, allowing some room for error in the construction.

The discharge from a building downpipe can be:

1. Directed some distance away from the building and allowed to soak into the ground.
2. Directly connected to a drain discharging and into a soakaway.
3. Directly connected to a drain discharging and into a surface water sewer.
4. Indirectly connected to a drain via a trapped gully if the drain discharges into a combined sewer.

Roof drain can have a separate overflow drain located adjacent to it. Overflow drains will be the same drains as the roof drains except that a damming weir extension will be included.

#### *15.6.1.2 Pathway drainage*

Pathway areas on and around architecture are provided with some method of surface water drainage, including but not limited to (Designing Buildings: Drainage, 2021):

1. **Drains and gutters** - channel the water away from the architecture.
2. **Permeable pavement** - allows the water to percolate downward into the ground.
3. **Other methods detailed** in Transportation Service System: Drainage subsystem.

### 15.6.2 Rainwater gutter

*A.k.a., Rain gutter, rain conduit, rain channel, eavestrough, eaves-shoot, eaves channel, surface water collection channel.*

A rain gutter is a component of a water collection and discharge system for a building. Gutters can be separate conduits or embedded within the structure of a building. Fundamentally, gutters prevent water ingress into a the building by channelling the rainwater away from the exterior walls and foundations.

It is necessary to prevent water standing as well as dripping or flowing off roofs in an uncontrolled manner for several reasons:

1. To prevent standing water. In the case of a flat roof, removal of water is essential to prevent water ingress and to prevent a build-up of excessive weight.
2. To prevent it damaging the walls, drenching persons standing below or entering the building.
3. To direct the water to a suitable disposal site where it will not damage the foundations of the building.

Note that a roof must be designed with a suitable fall to allow the rainwater to discharge.

A rain gutter may be a:

1. Integrated roof profile - make the external surface profile of the building behave like a water gutter, directing water to flow in specific ways.
2. Roof trough - trough positioned along the lower edge of the roof slope which is fashioned from the roof covering and flashing materials.
3. Discrete trough of metal, or other material that is suspended beyond the roof edge and below the projected slope of the roof.
4. Wall integral structure beneath the roof edge, traditionally constructed of masonry, fashioned as the crowning element of a wall.[

### 15.6.3 Concrete profiling for a rainwater distribution system

The roof of the welling surface shall have a water distribution network integrated into its surface profile. The top of the building should channel water to distribution points along the veranda that channel water to hung pots (with plants), or runoff water appropriately if no plants.

Requirements for guttering a roof include:

1. Allow for distribution to hanging (or otherwise located) plants.
2. Allow for excess water to be transported appropriately.
3. Leaves and other natural material should not easily block the flow of water.
4. Excess water should be transported down the remaining structure and away from the structure of the house.
    1. Transport of water not connected to plants.
    2. Transport of water connected to plants.
        i. Could use lightweight chains to direct the water and those chains could have vines growing on them.

5. The veranda must drain water or allow water to flow off the veranda evenly.
6. The ground foundation should have appropriate drainage around the foundation and building pad.

### 15.6.4 Rainwater reservoir

A rainwater reservoir is often exclusively for rainwater; however, in limited cases this reservoir may also be connected to other water sources.

There are several ways to implement a rainwater reservoir system:

1. Each architectural structure can have its own reservoir.
2. A number of architectural structures can share a reservoir system.

Placement of rainwater reservoir systems:

1. Above ground-level - use gravity to access the water. May require a pump to pump water up to the reservoir. Can have an electrical generator attached to the plumbing to produce electricity as the water falls.
2. At ground-level - requires a pump to access the water.
3. Below ground-level - requires a pump to access the water.

## *15.7 Conception of the drainage water sub-system*

*A.k.a., Water drainage infrastructure.*

Drainage is the directed removal of water, both surface and sub-surface water. Drained water may either be:

1. Recycled for reuse in (or around/on) the architecture.
2. Used on the landscape.
3. Discharged into a body of water (Read: effluent).

Herein, 'effluent' is an outflowing of water or gas to a natural body of water, from a structure. Typically, effluent is conveyed by drains to sewers, and from sewers to a suitable outfall or treatment plant, before being discharged to a water body.

In architectural drainage terms, drained water can refer to the following:

1. **Subsoil water (ground water)** - This is water collected from the earth to lower the subsoil's water table. Subsoil water is considered to be clean and can be discharged into an approved watercourse (e.g. river or lake), or soakaway without treatment.
2. **Surface water** - This is collected from surfaces such as roofs and paved areas. Surface water is considered to be clean and can be discharged into an approved watercourse (e.g. river or lake), or soakaway without treatment. Surface water is a type of sanitary water.
   A. Roof drainage.
   B. Paved area drainage (path drainage).
   C. Road drainage.
3. **Greywater (foul water) and blackwater (soil water)** - This is effluent contaminated by domestic or manufacturing waste. Foul and soil water must be conveyed, often by sewer, to a treatment location before being discharged into a watercourse. Foul and soil water are a type of sanitary water. Surface water is a type of sanitary water.
   A. **Greywater (a.k.a., foul water, waste water)** - effluent from sinks and basins which does not contain excreta.
   B. **Blackwater (a.k.a., soil water)** - effluent from water closets, toilets and urinals which does.

### 15.7.5 Groundwater control

*A.k.a. Groundwater drainage control.*

Groundwater control encompasses the range of temporary works techniques used to allow below-ground construction projects to be carried out in dry and stable conditions. The most common groundwater control methods are:

1. Subsoil drainage.
2. Groundwater pumping.
3. Low permeable cut-off walls.
4. Grout barriers.
5. Artificial ground freezing.

#### *15.7.5.1 Subsoil drainage*

Subsoil drainage can be used to improve ground stability, to lower the moisture content of a site, to enhance horticultural properties for landscaping and so on. It can be required to drain the whole site or to protect a particular part. Subsoil drainage generally involves the use of pipes that are porous to allow subsoil water to pass through the pipe body, or pipes that are perforated with a series of holes in the lower half to allow subsoil water to rise into the pipe. This type of groundwater control is only feasible up to a depth of 1.5 m, and any further lowering of the water table should be achieved by other methods.

When subsoil drainage is used to protect an architectural substructure, a cut off drain is generally installed that intercepts the flow of water and diverts it away from the site.

#### *15.7.5.2 Groundwater pumping (dewatering)*

Groundwater pumping is a groundwater control method that involves pumping groundwater from an array of wells or sumps around a site. The objective is to lower groundwater levels. Examples of this group of techniques include sump pumping, wellpoints, deepwells and ejector wells.

#### *15.7.5.3 Low permeable cut-off walls*

Low permeable cut-off walls are installed into the ground around the perimeter of the site. These walls act as barriers to groundwater flow, and effectively exclude groundwater from the site. The requirement to pump groundwater is limited to pumping out water trapped within the area enclosed by the cut-off walls. Examples of the techniques used to form cut-off walls include steel sheet-piling, concrete diaphragm walls, concrete bored piles and bentonite slurry walls.

#### *15.7.5.4 Grout barriers*

Grout barriers are formed after fluid grouts are injected into the ground and set or solidify in soil pores and rock fissures. The solidified grout blocks the pathways for groundwater flow and can produce a continuous zone of treated soil or rock around the site that is of lower permeability than the native material. This reduces groundwater inflow in a similar way to cut-off walls. The most commonly used grouts are based on suspensions of cement in water.

#### *15.7.5.5 Artificial ground freezing*

Artificial ground freezing uses a very low temperature refrigerant (either calcium chloride brine or liquid nitrogen) that is circulated through a series of closely-spaced boreholes drilled into the ground. The ground around the boreholes is chilled and ultimately frozen. Frozen soil or rock has a very low permeability, and will significantly reduce groundwater inflow into the site.

## *15.8 Objects in the water system: fixtures, fittings, and appliances*

*A.k.a., Water-based technologies, including appliances.*

Plumbing fixtures and fittings are equipment that interface with the water in a building:

1. **Plumbing fixture** - A device for receiving water and/or waste matter that directs these substances into a sanitary drainage system. Note that the term is used erroneously in common vernacular to describe "fittings". The most common fixtures include, but may not be limited to:
   A. Toilets.
   B. Sinks.
   C. Bathtubs.
   D. Shower receptors.
   E. Toilets (water closets).
   F. Filters and inceptors (e.g., chemical feeder).
   G. Inspection chambers.
   H. Drain fixtures:
      1. Static open drain fixtures.
      2. Open/closed drain fixtures.
   I. Heat recovery systems
   J. Gutters.
   K. Pumps.
   L. Water meters.
   M. Water sensors.
   N. Hot water fixtures:
      1. Water heaters.
      2. Radiators (hot water radiators).
2. **Plumbing fitting** - a device designed to control and guide the flow of water. Note that some people call these "fixtures," but that term means something different in plumbing. The differing usage of "fitting vs. fixtures" can lead to unintended consequences, such as when legislation calls for changes in fixtures, although the true intent involves changes in fittings. The most common fittings include, but may not be limited to:
   A. Faucets (hot, cold, or mixed).
   B. Shower heads.
   C. Shutoff valves.
   D. Shower valves.
   E. Drinking fountain spouts.
   F. Pipe fittings (note: all pipe connectors are also called pipe fittings).
3. **Plumbing appliances** - appliance devices that use water, the most common of which include:
   A. Refrigerators (only those with a water hookup).
   B. Washing machines.
      1. Fabric washing (e.g., clothes washer).
      2. Ceramics washing (e.g., dish washer).
   C. Dish washing machine (including, instrument washing machine).
   D. Waste disposal unit (under kitchen sink).

**IMPORTANT:** *All fixtures, fittings, and appliances must be specified with the right capacity for their placement.*

### 15.8.1 Pump fixtures

Building installations do not have a constant demand for water, and the flow provided by pumping systems must be adjusted to match demand. There are three main ways to achieve demand matching:

1. **Flow restriction [control]** - uses a control valve at

the pump outlet to restrict flow.

2. **Flow recirculation [control]** - uses a recirculation valve to send the unused water flow back to the pump inlet.
3. **Variable speed [control]** - uses a variable speed pump (with a variable speed impeller) to adjust flow and match usage demand.

Variable speed control is the most efficient option because the other two waste pumping power:

1. Flow restriction [control] wastes power because the pump consumes power to compensate the pressure loss across the control valve.
2. Flow recirculation [control] wastes power since the unused water flow represents wasted power.

#### *15.8.1.1 Variable speed pumps*

Variable speed pumping systems are often used to boost the pressure of the local water supply, especially in high multi-story constructions. Variable speed pumping systems can adjust the rotating speed of the impeller to modulate water flow. This method is significantly more efficient than using valves. Flow restriction and flow recirculation both represent a waste of pumping power, driving up electricity expenses. Only variable speed pumping systems can optimize their operating efficiency, consuming just the necessary power to establish the required water flow. (Variable speed, 2021)

Here, speed control is achieved by designing the pump's motor system with a variable frequency drive (VFD). A VFD modulates the voltage and frequency of the power supply, and the rotational speed of the pump changes accordingly. If the demand for water is below the rated flow of the pump, the VFD slows it down until the flow provided matches demand. (Variable speed, 2021)

Note that when variable speed pumping systems are deployed as part of an HVAC installation, the design process must consider the entire installation and not only the hydronic piping. To take advantage of a variable speed pumping system, HVAC installations must also be capable of adjusting the air supplied by ventilation systems, and the cooling output of chillers and boilers.

Variable speed pumping systems provide an excellent opportunity to save energy in applications where large amounts of water are used. However, the benefits can only be achieved if the system is designed correctly and compliant with local codes. Professional design services from MEP engineers are strongly recommended.

> **NOTE:** *When deploying speed controls for a pumping systems, it is important to have reliable electrical protections.*

#### *15.8.1.2 Well pumps*

*A.k.a., Water pumps.*

A well pump is installed after drilling or digging a well. Its purpose is to pump water from the well into a plumbing system. An electric motor drives an impeller or centrifugal pump, which pushes water from the well through a jet or pipe. Well/water pumps supply the pressure needed to pressurize a plumbing system or fill a water tank with water from an underground (Read: well) source. (Ultimate guide, 2021)

There are three primary types of well pumps:

1. **Centrifugal pumps** - rotate an internal fan to create suction. Unlike other well pumps, centrifugal pumps sit in a mechanical housing next to the well instead of inside it, making maintenance less of a hassle. Centrifugal pumps are generally used for shallow wells as they do not have enough power for deep wells.
2. **Submersible pumps** - are practical for virtually any well, no matter how shallow or deep it is. Submersible pumps are placed underwater, inside the well. The motor powers impellers that push water up the pipe. Turning on the pressure switch causes the impellers to spin, which will push water to the surface. These pumps are watertight, generally last a long time and rarely need repairs. However, repairs involve pulling the pump out of the well and up to the surface. These pumps will not function unless they are entirely submerged under water. A submersible pump has a cylindrical shape, and the bottom half consists of a sealed pump motor that attaches to an aboveground power source. The motor powers impellers, which in turn drive the water upward. Turning on the pressure switch causes impellers to spin, thereby sucking water into the pump. The water gets pushed through the body of the pump, then (typically) into a storage tank on the ground's surface. Even though a submersible pump can deliver water more efficiently than a jet pump with a similarly sized motor, any motor issues could require removing the entire unit from the well casing. Fortunately, most submersible pumps tends to be highly reliable and can operate at peak performance for as long as 25 years before needing maintenance.
3. **Jet pumps** - provide the most power and can deliver more water faster than other type of pump. Jet pumps work in wells at all depths. Jet pumps create pressure via impellers. The impellers move water (drive water), through a small orifice mounted in the housing located in front of the impeller. Doing so increases the water's speed. When the water leaves the jet, a vacuum will suck more water from the well. This water will combine

with the drive water and discharge into the plumbing at high pressures. There are two types of jet pump:

A. **Single-drop** - best for shallow wells. These are placed inside a building or in an outbuilding.
B. **Double-drop** - suitable for deep wells. These require a split installation. The jet assembly is in the well, and the motor must stay above ground.

**NOTE:** *That the upfront costs for submersible pumps are often higher, they are generally lower maintenance, and often a lower cost long-term investment. Unlike aboveground well pumps, which are vulnerable to mechanical failure, submersible pumps tend to have fewer problems. Because submersible pumps are underwater, they don't lose prime, an issue commonly experienced by aboveground pumps. Cavitation, an occurrence when gas or air makes its way into a pump's mechanical parts, is generally not an issue for a submersible pump because the pump sits far below the water's surface and can always access water.*

When choosing the right pump for a well sourced system, the most important factor is the well's depth (i.e., how far the water must travel to get to the surface of the ground):

1. If the well is less than 8 meters (25ft) deep (Read: shallow well), use a shallow well jet pump. A submersible pump can be used for wells as shallow as 8 meters.
2. If the depth of the well is between 8 to 33 meters (25ft to 110ft), use a deep well jet pump. Alternatively, a submersible pump can be used here.
3. If the depth of the well is between 33 to 121 meters (110ft to 400ft), use an appropriately sized submersible pump. Remember, you can also use a submersible pump for wells as shallow as 25 feet.

If the well is a shallow (up to 8m), then a single-drop jet pump is recommended. These pumps come with one-way check valves, which serve to keep the pumps primed. The single-drop jet pump sits aboveground and draws water up through one inlet pipe. This pump sits over the well and draws up water via suction. The distance it can suck up the water depends on the air pressure. While air pressure changes with elevation, jet pumps generally are not ideal for wells more than 25 feet deep. A jet pump generates pressure via its impeller, which pushes the drive water through a small orifice or a jet inside housing located in front of the impeller. The jet's constriction increases the moving water's speed. As the water exits the jet, a vacuum will then suck more water out of the well. When this extra water comes together with the drive water, it will discharge into the plumbing at high pressure.

If the well is up to 33m deep, then a double-drop jet pump is recommended. Deep-well jet pumps are positioned above ground. They draw water by using two pipes. One pipe draws water out of the well, while the other pushes the water up. A deep well jet pump sucks up water from depths as great as 33m, and hence, uses a foot valve for priming the pipe as well as prevents water drainage from the pipes. The impeller is responsible for driving water into the body of the jet, whereas the jet delivers the water back to the pump. A deep well jet pump uses suction at the jet for bringing water into the system. It also uses pressure to lift water up the well and deliver it. Some models come with a tailpipe, which prevents users from pumping the well dry (Read: overpumping). When the water level dips below the jet's housing, the tailpipe will ensure nobody can pump the well dry. The higher the jet sits above the level of the water, the more efficiently it will pump. Just like with a shallow-well system, a deep-well system also requires priming with water.

If the well is up to 121m deep, then a submersible pump is recommended. Deep-well submersible pumps use pressure tanks to suction water via one pipe that connects to the plumbing system. While a jet pump can work with wells several hundred feet deep, they are generally not as effective for deeper wells as submersible pumps.

#### *15.8.1.3 Pool pumps*

Pool pumps are the source of water circulation for a pool system. Pool pumps primarily pull water from the pool through a skimmer and main drain, pushing it through a filter, and returning it to the pool through the main returns. This allows chemicals (if present) to circulate evenly throughout the pool, as well as filter out debris by circulating water through a filter system. Without the water moving around regularly, algae may start to form in your pool water. Some pool pumps can also add and/or remove water from the pool -- add in the case of water shortage and remove in the case of excess water, such as from excess rain. These pumps use electricity.

There are three common types of pool pumps:

1. **Single-speed pumps** - pump the swimming pool's water through the system at one constant speed. The pump runs at the same speed all the time and can increase power usage.
2. **Two-speed pumps** - run at two fixed speeds – high and low. The higher speed is equipped to handle pool cleaners while lower speeds are best for general circulation.
3. **Variable-speed pumps** - adjust their speed based on the task they are performing.

#### *15.8.1.4 Pool system fixtures*

Most pool systems consist of the following elements:

1. A basin.
2. A motorized pump.
3. A water filter.
4. A chemical feeder.
5. Drains.
6. Returns.
7. PVC plastic plumbing connecting all of these elements.

Every pool system has two general sides to the system (as well as a filtration system):

1. **The suction side** - draws water from the pool to the pump. This is the part that begins the circulation process. This side generally consists of the following elements:
    A. **Skimmer outlet** - pulls water from the pool's surface into the filtration system. These are usually positioned on the side of the pool. Debris goes through a flapping door ("weir") and goes into the skimmer basket that traps the material. The skimmer basket will need to be emptied periodically to keep it from clogging.
    B. **Main drain outlet** - located at the bottom of the pool and pulls debris that has fallen to the base.
    C. **Suction lines** - run to the pump. These lines are generally a flexible or rigid set of PVC pipes that run from the skimmer to the pump system. Depending on the type of pool, the suction lines can be found above ground or underground. Suction lines can leak, causing problems with the system. If the suction lines are above ground, the leak is easier to find and therefore fix.
2. **The pressure side** - provides pressure to move water through various pool fixtures and back into the pool basin.
    A. Pump - pushes the water through the filter, heater, and chemical feeder.
    B. Filter - filter debris and particle matter from the pool. Note that the 'filter system' consists of the pump and the filter. Filters include, but may not be limited to:
        1. Sand filters.
        2. Cartridge filters.
        3. Diatomaceous earth filters.
        4. Biological filter (for natural pools).
    C. Heater (heat exchanger).
    D. Chemical feeder - introduction and circulation element for chemicals. Chemicals may include, but are not limited to:
        1. Ozonator.
        2. Chlorinator.
        3. Salt.
        4. Etc.
    E. Return lines - carry the water from the circulation system to the return jets.
    F. Return jets - are positioned in the pool basin (generally), and return water into the pool. Some return jets are movable to control the circulation of the water. Pointing them down helps with better chemical and temperature distribution as well as overall filtration.

**NOTE:** *The only difference between a standard chlorine pools and a salt water pool is that in the salt pool the chlorine is not poured into the water, but is produced by electrolysis from common salt dissolved in the pool. The effect is the same - it is still a chlorine pool.*

In 'natural pools' no additional chemicals are required due to biological self-cleaning processes. Technology is used to support and enhance the natural processes. A natural pool will function as it should if the regeneration area is designed correctly and the underwater plants are used properly. The pool is fortified with zooplankton (including: water fleas, rotifers, paramecia, etc.), which play an important role in keeping the water clean on a continual basis. In natural pools, the separation of the pool into two water circuits allows the system to operate economically and with minimal use of space. The first circuit is responsible for cleaning the surface of the water and removing floating particles. Its pump runs throughout the day. The purpose of the second circuit is to eliminate organic compounds. Its pump runs continually during the swimming season. Features like rock fountains, waterfalls or curtain fountains can be integrated into either or both of the circuits.

Note that some pools also contain a pool cover to protect the pool and/or nearby persons. Pool cover types include, but may not be limited to:

1. Winter cover - is the most common and least expensive of the pool covers. It is usually made of a tarp-like material but does the job of keeping debris out of the pool. Note that these covers usually only lasts two winters.
2. Security cover - is a sturdier and more costly cover than the standard winter cover. The security cover is made to keep debris, children and pets out of the pool when covered.

3. Automatic pool cover - rolls out over the pool with the touch of a button.
4. Solar pool cover – is intended to extend the pool's usage season. It can warm up the water earlier in spring and keep it warmer longer later in the fall.

## 15.8.2 Mixed cold and hot water fixtures

The most common dual water fixtures are:

1. Sinks.
2. Showers.

## 15.8.3 Cold water fixtures

The most common cold water fixtures are:

1. Toilets.
2. Bidet spray (is a small shower head with a relatively short hose often connected to the wall near the toilet).

#### *15.8.3.1 Toilets*

Toilets are a collection receptacle for human urine and faeces. Some toilets use water. The size and type of toilet receptacle can vary from place to place, depending on culture, availability, and purpose. Water-using toilets can differ in the following ways:

1. Size, shape, and purpose:
    A. The squat floor toilet.
    B. The standard sitting bowl toilet.
    C. The urinal.
    D. The handicapped toilet.
    E. The bidet.
    F. The standard sitting toilet with integrated bidet.
2. Trigger mechanism for flushing:
    A. Some toilets have a single handle for flushing.
    B. Some have a pull chain.
    C. Some have a push button (Read: flush valve).
    D. Hands-free automatic flushing.
3. Flushing quantity type:
    A. Single flush system - In a single flush system, the toilet user can only use the same amount of water whether flushing liquids or solids. These toilet systems mostly use a trip lever handle mounted on the side or the front of the tank. The toilet handle is connected to a lift chain which is in turn connected to a flapper. When you push the toilet handle down, the chain lifts the flapper off the flush valve opening allowing water to flow down to the bowl for flushing to happen.
    B. Dual flush system (a.k.a., flush valve systems) - has two different buttons/handles that offer lower and higher water pressure, depending on the amount of waste. This conserves water. A dual flush valve assembly is mounted on top of the flush valve. When any of the buttons are pressed, the valve seal lifts off allowing water to flow down to the bowl. The amount of water depends on the button you pressed. These systems can be designed to let users push a handle/button in one direction for liquid waste and another direction/button for solid waste.
4. Flushing hydrodynamics type:
    A. Gravity flush system (a.k.a., gravity-powered flush, tank-based, cistern-based) - water flows from the tank which is mounted on top of the bowl and move to the bowl via gravity creating a force inside the bowl that causes the toilet trap to siphon out the waste. These toilets have a cistern that fills and stores water until flushing occurs solely by gravity. After flushing, the water supply once again fills the cistern for the next flush. Water that sits in the toilet tank for long periods of time can become unsanitary.
    B. Pressure-assisted flush system (a.k.a., gravity with compressed air flush) - combines the gravity flushing system with compressed air. This system is used to create a powerful flush in toilets where gravity flush system on its own would not be sufficient like in rear-discharge and upflush toilets. A pressure-assisted toilet has secondary plastic tank inside the main tank called a pressure vessel. Incoming water from the water supply line mixes with the air in the pressure vessel therefore becoming pressurized. When you flush the tank, the water leaves the tank forcefully and powerfully flushes the toilet. Pressure-assisted flushing systems are louder than gravity flush systems which might be uncomfortable for some people. Because of this gravity-powered flush assistance, tank toilets can function on a water pressure as low as 10 pounds per square inch (psi).
    C. Tankless flush system (a.k.a., flushometer, fully pressurized flush) - are connected directly to the pressurized plumbing network without an in-between tank. Some plumbing networks have enough water pressure to power the flush of a tankless toilet without any sort of mechanical assistance. Tankless toilets use approximately the same amount of water as a tank-type toilet, but the water enters the fixture at a greater pressure. Tankless flush systems usually need at least 15 to 20 psi of water pressure to function properly, sometimes more. Urinals are an exception. Urinals generally operate using the

same basic principles as regular flush valve toilets, but they require less water pressure because of the nature of the material being flushed (liquid versus solid waste). For this reason, urinals can run on much smaller water supply lines. They also require much less water to complete a flush.

D. "Tornado" and "double-cyclone" system: The double cyclone system uses tank that passes water into bowl through 2 nozzles located at the top of the bowl facing sideways. As a result, the water swirls in the bowl like cyclone which is very effective in cleaning, rinsing and flushing the toilet. The "cyclone" is created due to the direction in which the water enters the bowl. The nozzles which face sideways allow the water to strike the surface of the bowl thereby creating a vortex which is what cleans the bowl. The tornado system is an improved version of the double-cyclone flush system. Instead of 2 nozzles, the tornado flush system lets the water in to the bowl through 3 jets positioned sideways around the top of the bowl. As the water enters the bowl, it swirls around the like a "tornado" which is very effective in cleaning the bowl. It also has more quiet flush. With a tornado flush system, the toilet bowl does have a rim which eliminates bleeding ground for germs. It is also easier to clean.

E. Tower style flush system (a.k.a., canister flush system) - uses a canister toilet flapper which is normally mounted in the middle of the tank and connected to the flush handle.

F. Double vortex flush system - Water enters the bowl via 2 nozzles at the top of the bowl which face sideways which creates a whirlpool in the bowl. Although most of the water comes through the 2 nozzles, some of the water is directed straight to the trapway simultaneously with the double-vortex action.

Most flush toilets operate using a siphon, which is a tube at the bottom of the bowl fixture. Water coming into the toilet must do so fast enough to fill the siphon tube, allowing the water and whatever else is in the bowl to be sucked through and pulled down the drain. Some water supply lines don't allow water to enter a toilet fast enough to trigger the siphon effect.

**NOTE:** *In many places on the central and south American continent, plumbing/sewage systems are not capable, due to their design, to handle large amounts (or, any at all) of toilet paper. Flushing toilet paper causes clogs and plumbing issues. That said, toilet paper is designed to be flushed; it breaks apart in the water and can form a movable sludge. Pipe networks must have enough pressure and appropriate pipes to move such sludge effectively. Municipal water pressure in some areas of the world isn't strong enough (or, the pipes are not designed) to handle the sludge. Most spetic systems can handle toilet paper.*

### 15.8.4 Hot water fixtures

Common hot water fixtures include:

1. **Fixtures that produce hot water (water heating fixtures):** Normally, cold water comes out of the taps automatically. To get hot water, cold water moves through a heater to raise its temperature. Hot water can be generated by heaters utilizing natural gas, electricity or steam as an energy source. 'Water heater' is a generic term for a device that heats water.
   A. **Instantaneous hot water (a.k.a., on-demand water heaters, demand-type water heaters, tankless water heaters)** - make hot water on demand without the presence of a tank.
      1. Powered by natural gas.
      2. Powered by electricity.
   B. **Boiler (a.k.a., boiler, tank storage water heater, hot water tank)** - make and hold hot water inside a tank. This type uses hot water storage.
      1. Powered by natural gas.
      2. Powered by electricity.
2. **Fixtures that use hot water:**
   A. **Heat radiating fixtures (a.k.a., hot water radiators)** - radiate heat from pre-heated water.
   B. **Heat recovery fixtures (a.k.a., power pipes)** - recover heat from heated water in drains.

There are many different sub-types of water heater, which can be electric or gas, and can be tank-based or tankless. These include, but are not limited to:

1. Whole house water heaters.
2. Bathroom water heaters.
3. Under sink and over sink water heaters.
4. Shower head water heaters.

Hot water heaters are generally powered by either:

1. Electricity.
2. Natural gas.
3. Propane.

#### *15.8.4.1 On-demand water heater*

*A.k.a., Tankless water heater, instantaneous water heater, instant hot water heater.*

On-demand water heaters provide hot water only as it is needed (i.e., on-demand). In other words, these systems work from demand, not from [tank] capacity. These systems use high-powered heaters (or burners) to rapidly heat water as it runs through a heat exchanger, and is then, delivered directly to endpoints without storing it in a tank. These systems usually take a minute or less to heat the water and distribute to the usage point, after a hot water tap has been turned on.

The advantages and disadvantages include, but are not necessarily limited to:

1. On-demand water heaters occupy less space than boilers.
2. On-demand water heaters need to be selected to provide sufficient hot water for all expected endpoint uses when providing hot water simultaneously.
3. Save energy over time.
4. Cannot be used to supply radiators with hot water.

#### 15.8.4.2 Tankless coil (furnace and boiler) water heater

A tankless coil water heater provides hot water on demand without a tank. When a hot water faucet is turned on, water is heated as it flows through a heating coil or heat exchanger installed in a main furnace or boiler. Tankless coil water heaters are most efficient during cold months when the heating system is used regularly but can be an inefficient choice for many homes, especially for those in warmer climates.

#### 15.8.4.3 Tank-based water heater

*A.k.a., Boiler, reservoir water heater, hot water tank, conventional water storage water heaters.*

Boilers provide hot water by heating the water in a tank (reservoir), either through electricity or gas. These systems use an insulated tank with a fixed storage capacity that heats and stores the water until it is needed. These systems continuously use energy to maintain a hot water supply [in a tank]. A pipe emerges from the top to deliver hot water to endpoints.

Natural gas storage-tank water heaters use almost 50 percent less energy to operate than the electric variety. However, they cost more than electric models. Natural gas systems also feature a temperature and pressure-release valve that opens when either temperature or pressure exceeds preset levels.

The advantages and disadvantages include, but are not necessarily limited to:

1. Boilers occupy more space than on-demand water heaters.
2. Smaller boilers (relative) can run out of water prior to the user desiring the water running out.
3. Can be used to supply radiators with hot water.

The greater the demand for water, the higher the requirement for capacity (tank size).

#### 15.8.4.4 Indirect (furnace and boiler) water heaters

Indirect water heaters require a storage tank. An indirect water heater uses the main furnace or boiler to heat a fluid that's circulated through a heat exchanger in the storage tank. The system is "indirect", because the furnace or boiler is the location where a separate fluid is heated, which passes through a heat exchange coil [hot] water tank. It is the heat exchange coil in the tank that makes the water therein hot. The boiler/furnace that heats the coil is separated from the hot water tank. The energy stored by the water tank allows the furnace to turn on and off less often, which saves energy. An indirect water heater, if used with a high-efficiency boiler and well-insulated tank, can be the least expensive means of providing hot water, particularly if the heat source boiler is set to "cold start."

#### 15.8.4.5 Heat pump water heater

Heat pump water heaters use electricity to move heat from one place to another instead of generating heat directly. To move the heat, heat pumps work like a refrigerator in reverse. Heat pump water heaters require installation in locations that remain in the 4.4º–32.2ºC (40º–90ºF) range year-round and provide at least 28.3 cubic meters (1,000 cubic feet) of air space around the water heater. Air passing over the evaporator can be exhausted to the room or outdoors. Heat pump water heaters will not operate efficiently in a cold space since they tend to cool the space they are in. Installing them in a space with excess heat, such as a furnace room, will increase their efficiency.

**NOTE:** *Heat pumps can be used to transfer thermal energy between different materials. There are heat pumps that combine heating, cooling, and water heating.*

#### 15.8.4.6 Solar boiler (a.k.a., solar water heater)

A solar boiler is a type of tank-based water heater. Solar boilers use sunlight to heat. Light from the sun strikes a solar collector and heats the black metal sunstrip absorber underneath the glass cover. This heat is transferred to a non-toxic anti-freeze solution (e.g., propylene glycol and water) that is pumped through the collector and returns to the solar boiler. In many cases, a solar boiler is paired with a conventional heating system. In this case, cold water enters the solar boiler for initial heating, and is then delivered to the backup or conventional heating system for final heating as required. Conventional energy requirements can be reduced substantially by using the Solar Boiler, and on many days the Solar Boiler will provide ample hot water without the backup (conventional) heater turning on.

#### *15.8.4.7 Drain water heat recovery (DWHR) unit*

*A.k.a., Hot water heat recovery system, power-pipes.*

A hot water heat recovery unit works by using outgoing warm drain water to pre-heat cold water going to the water heater. A DWHR is generally a double-wall, vented heat exchanger system can be used to supply fresh, pre-heated water to the water heater. The system features multiple coils wrapped in parallel around a central drainpipe. DWHR systems are based on a fundamental physical principle called the “falling film” effect. This means water falling down a vertical pipe does not run down the center of that pipe, but clings to its inside wall.

#### *15.8.4.8 Hot water radiator*

*A.k.a., Hydronic radiator.*

Hot water radiators work by drawing heat from water or steam and use that heat to warm up surrounding air. Hydronic heat is one of the most effective ways to warm a building. It is highly controllable, silent and maintains a much steadier ambient temperature than central air systems. Hot water radiators can be positioned either within a room itself, or under the floor.

Area-base hot water radiators have piping that allows hot water to enter the radiator through a control valve and exits through a lockshield. On initial fill, air is vented through the bleed valve to ensure the radiator is completely full of water. The control valve allows water into the radiator. It can be manual or thermostatic. A thermostatic radiator valve (TRV) adds control and increased energy efficiency.

### 15.8.5 Inspection chambers

Inspection chambers are part of a drainage system. They are locations where inspection of the water and piping can occur, and blockages can be removed. Inspection-type chambers include, but may not be limited to:

1. **Manholes** - allows the physical whole-human access to the blockage in the underground pipes.
2. **Inspection chambers** - small boxes/chambers, which allow only hands, arms, and cameras (and other devices) to inspect and test the drainage and flow of water through the pipes. Note that any type of water network can have one or more inspection chambers, such as
   A. **Sewer inspection chambers (caixa de inspecao de esgoto)** - allows for inspection of sewer water.
   B. **Soap water chambers (caixa de sabao)** - this is a box/chamber where water with soap enters can be inspected.

### 15.8.6 Plumbing filtration and inceptor fixtures

Plumbing filtration fixtures include:

1. **Water supply filtration** - a filter that purifies the source of water so it is fit for various purposes, most often, drinking.
   A. Carbon-type filters.
   B. Reverse osmosis filters.
   C. Etc.
2. **Sanitary water filtration** - a filter that filters out material from the sanitary water system so it doesn't contaminate its final destination.
   A. **Lipids (FOG) filters (a.k.a., fat interceptors, lipid interceptors, caixa de gordura)** - FOG refers specifically to fats, oils and grease entering the sewer system when poured down drains in homes, apartments, restaurants, industry and public facilities. FOG is generally a product of cooking. When poured down the drain (sink or floor), FOG can build up, blocking sanitary sewer lines. This accumulation not only reduces the capacity of the wastewater collection system, but it also alters its effectiveness, and can lead to complete blockages. In severe cases, blockage can lead to: Sewage backups into homes and businesses and Sewers that overflow onto roadways and property, eventually flow into local waterways, causing contamination. The easiest way to solve the grease problem and help prevent overflows of raw sewage is to keep this material out of the sewer system. Through education and by adopting certain habits, it is easy to minimize FOG sources at home. FOG buildup also increases the cost and resources usage of maintaining a wastewater treatment system. Grease traps and interceptors are devices designed to keep fats, oils and grease (FOG) from entering building and public sewer lines. They can be located inside or outside of your kitchen, depending on the application. In general, they are designed to retain FOG-laden discharge long enough for grease in the water to cool, solidify and separate from the remaining waste. Once the grease has separated, it can be disposed of properly.
   B. **Sand/oil interceptors** - generally contain one to four compartments (basins) where oil separates and floats to the surface, while sand and grit settle to the bottom sludge.

## *15.9 Installation of plumbing system*

*A.k.a., Plumbing installation.*

There are many ways to install plumbing. These systems are usually embedded into structure.

## *15.10 Operation of plumbing system*

*A.k.a., Plumbing operation.*

Most significant operational activities are located on the supply side because of the requirement for static pressure given dynamic demand. Some demand-side specialized water systems, such as pools and ponds, may have significant operational activities.

### 15.10.1 Plumbing load demands

*A.ka., Water loading.*

Water loads are measured in several ways, most notably, energy consumed to produce:

1. Conditioned water flow, and
2. Surface temperature.

In order to do work, plumbing systems are split into a power usage system and an water flow and temperature changing service system:

1. **A power usage system:**
    - A. **Energy consumed** may be by electricity or combustion of fuel.
        1. Most plumbing electrical loads are measured in watts [of electrical] power. Often, the kilowatt hour (kW.h)
        2. Heating and cooling systems can be measured in BTU [of heating or cooling] power
2. **A water-flow conditioning (production and distribution) system:**
    - A. **Water flow volume** is water flow rate, or quantity of water being moved, which is measured in:
        1. $L^3$/sec (cubic liters per second) or
        2. cubic gallons per minute (CGPM).
    - B. **Water flow velocity** (Read: distance travelled per unit of time) is measured by sensing the pressure that is produced through the movement of the water. Velocity is also related to water density with assumed constants of 70° F and 29.92 in Hg. Water velocity is generally measured using flow meters, which are one of the most effective instruments for measuring water flow, or the speed of the water. It is possible to measure the velocity at different points in a pipe and find the average velocity in the pipe. The most common measuring units for velocity are:
        1. Meters per second (m/s, m/sec)
        2. Feet per minute (FPM)
    - C. **Temperature** production is measured in kelvins or Celsius (or Fahrenheit in imperial).
    - D. **Static pressure**, as it applies to water, is the water pressure within a system when no faucet or valve is on, i.e. the water is static or not flowing. Static and dynamic pressure can be tested for with a standard water pressure test gauge for a outlet. By connecting the gauge to a spigot and turning the valve on while nothing is on within the plumbing system. Readings need to be taken at the proximal and distal a mains. It is an important design consideration to have these openings built into the design so that post installation construction to drill holes is not required. The most common measuring units for pressure are:
        1. kPa
        2. psi
        3. H2O
3. **The conduit pipes** (piping, transmission lines) and filters are another type of load.
    - Friction causes losses in conduit lines and filters.
4. **Non-usage**, but presence, will still equate to system service usage.
    - If a usage circuit has no load in the form of a power factor of zero the user would consume NO liters per minute (i.e., no usage), but the supplier would still have to send static pressure to them and incur real energy losses in lines, pumps, and filters. Power factor is the relationship (phase) of volume and velocity in a water production-distribution system.

## *15.11 Engineering calculations for plumbing*

In order to achieve optimally configured plumbing systems, the selection of sub-systems be must account for:

1. Identify demand requirements (load).
    - A. Identify demand fixture units.
2. Identify supply parameters for demand requirements.
    - A. Identify supply fixture sizes and first hour rating.
        1. Tankless-based water heaters: Flow rating in liters/minute at specific temperatures.
        2. Tank-based water storage: volume of stored fluid possible.
3. Identify thermal heating and cooling requirements.
4. Identify fuel/power type.
5. Identify fuel/power availability.
6. Identify fuel/power financial cost (market only).
7. Calculate energy efficiency (energy factor, EF).
8. Overall resource and financial costs (budget).
    - A. Acquisition.

B. Installation.
C. Operation.
D. Maintenance.
E. Replacement.
F. State tax.

#### *15.11.1.1 Water heating sub-system calculations*

It is possible to calculate the energy efficiency of water heating systems, including storage tanks, tankless or demand-type water heater, or heat pump water heater. The energy factor (EF) indicates a water heater's overall energy efficiency based on the amount of hot water produced per unit of fuel/power consumed over a typical day. This includes the following:

1. **Recovery efficiency** – how efficiently the heat from the energy source is transferred to the water
2. **Standby losses** – the percentage of heat loss per hour from the stored water compared to the heat content of the water (water heaters with storage tanks)
3. **Cycling losses** – the loss of heat as the water circulates through a water heater tank, and/or inlet and outlet pipes.

The higher the energy factor, the more efficient the water heater. However, higher energy factor values don't always mean lower annual operating costs, especially when you compare fuel sources. Product literature from a manufacturer usually provides a water heater model's energy factor. Don't choose a water heater model based solely on its energy factor. When selecting a water heater, it's also important to consider size and first hour rating, fuel type, and overall cost.

#### *15.11.1.2 Water supply calculations*

The proper design of a water distribution system within and between buildings necessitates calculations on the supply side.

The water is system is calculated in the following ways:

1. Estimate demand (water supply fixture units, WSFU).
2. Calculating pipe sizes for the whole building supply (cold and hot water) system.
3. Calculating pipe sizes for the whole building drainage system
4. Calculating friction pressure drops or losses in cold and hot water pipes, as well as drainage pipes.

#### *15.11.1.1 Estimate demand with water supply fixture units (WSFU)*

*A.k.a., Water supply units.*

Water supply fixture units (WSFU) is the standard method for estimating the water demand for a building. WSFU is is defined by the American Uniform Plumbing Code (UPC) and is used to calculate the demand in water supply systems. This system assigns an value called a WSFU to each fixture in a building, based on the amount of water required and the frequency of use. The water supply fixture units are distinguished between cold, hot or both. If a plumbing line serves only the cold water side of a fixture, then the corresponding value should be used. For example, a main line may serve the both cold and hot water, but then a branch line may go to the hot water heater. The branch line would only use the hot water value.

The international plumbing code (IPC) maintains a water supply fixture unit table. If a plumbing fixture is not available in the table, then a fixture unit value can be assigned by the designer or engineer. Typically, a similar plumbing fixture that has a similar maximum flow rate and frequency of use will be selected. If the plumbing fixture will be on for long periods of time, then the volumetric flow rate can be inserted into the domestic water piping calculator.

Note that a fixture unit (FU) is used in plumbing design for both water supply and waste water. Different fixtures have different flow requirements.

One WSFU is equal to one gallon per minute = 3.785 L/m = 1 WSFU. The relationship between liters per minute (LPM; or gallons per minute, gpm) and fixture units is not constant, but varies with the number of fixture units. Fixture units are used in order to determine the required size of pipe. Fixture unit values can be determined using charts from the International Plumbing Code or similar codes in local jurisdictions.

Additionally, there are situations where a design provides for more FUs being discharged than being supplied. This occurs in situations where liquids may infiltrate or are added to a draining system, such as might happen in a large sports venue. Examples of how this could occur include rain water infiltration.

**Table 7.** *Example table of water-supply fixture units for common plumbing fixtures.*

| Type of fixture or group of fixtures | Water-supply fixture unit value | | |
|---|---|---|---|
| | Hot | Cold | Combined |
| Bathtub | 1.0 | 1.0 | 1.4 |
| Lavatory | 0.5 | 0.5 | 0.7 |
| Kitchen sink | .8 | .8 | 1.2 |

**Table 8.** *Example table of water-supply fixture units for common plumbing fixtures. Not that for SI: 1 gallon per minute = 3.785 L/m, 1 cubic foot per minute = 0.4719 L/s.*

| Supply systems predominantly for flush tanks | | Supply systems predominantly for flushometer valves | |
|---|---|---|---|
| **Load** | **Demand** | **Load** | **Demand** |

| Water supply fixture units | Gallons per minute | Cubic feet per minute | Water supply fixture units | Gallons per minute | Cubic feet per minute |
|---|---|---|---|---|---|
| 1 | 4.0 | 0.051 | - | - | - |
| 2 | 4.0 | 0.0485 | — | — | — |
| 3 | 3.2 | 0.58730 | — | — | — |
| 4 | 7.0 | 1.0494 | — | — | — |
| 5 | 3.1 | .73653 | 5 | 15.0 | 2.00 |
| ... | | | | | |

**Table 9.** *Example of fixture units for fixture models in relation to community access-types.*

| Appliance or fixture | Fixture unit value | | | Number of fixtures and appliances | Total (Col 1, 2, or 3) x 4 = Total) |
|---|---|---|---|---|---|
| | Personal | Common | Team | | |
| Model 389 | 1 | 1 | 1 | 25 | 2 |
| Model 49 | x | x | x | x | x |
| Model 342 | x | x | x | x | x |
| Model 45 | x | x | x | x | x |
| Model 53 | x | x | x | x | x |

**Table 10.** *Table estimating peak hour demand/first hour rating for a set of plumbing fixtures. Example values given.*

| Fixture use *(machine specific)* | Average liters per usage | x | Times used during one hour | = | Liters used in one hour (or, gallons) |
|---|---|---|---|---|---|
| Shower | 20 | x | 3 | = | 60 |
| Dish washing | 1 | x | 1 | = | 1 |
| Manual dish washing | 2 | x | 1 | = | 2 |
| Automatic dish washing | 3 | x | 1 | = | 3 |
| Clothes washing | 25 | x | 1 | = | 25 |
| Drinking | .5 | x | 2 | = | 1 |
| | | | Total peak hour demand | = | 92 |

## 15.11.2 Standard plumbing efficiencies

*A.k.a., Plumbing control and automation.*

It is possible to attach meters to fixtures to measure incoming and outgoing water. Some plumbing system context lend themselves easier to automation, such as pool plumbing. In a pool, for example, plumbing can be automated in the following ways:

1. Refill the pool when the fill is low.
2. Automatically overflow the pool when over filled.
3. Automatically filter pool.
4. Automatically clean and replace filter.
5. Etc.

In non-industrial situations, plumbing is considered pre-automated. In other words, it is a static system that is designed to meet a demand, and there isn't significant need for dynamic motion on the usage side. Conversely, at the size of a utility providing water pressure to many buildings and/or storeys, there are degrees of automation. Sensors, which may not need to be on continuously, can provide a valuable source of information on the status of the system. Monitoring instruments can be continuous or temporary.

# 16 Architecture atmospheric sub-system

*A.k.a., Atmospherics engineering, HVAC engineering, refrigeration engineering.*

Atmospheric thermal conditions can be changed with energy from several sources, including:

1. Natural ventilation.
2. Electrical ventilation.
3. Electricity (refrigeration or direct heating).
4. Combustion (hydrocarbons or carbon).
5. The underground earth.

## *16.1 Atmospheric standards*

Atmospheric/HVAC standards include, but are not limited to:

1. ANSI/ASHRAE Standard 180-2018 - Standard Practice for Inspection and Maintenance of Commercial Building HVAC Systems
   - American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE)
2. Air Conditioning Contractors of America (ACCA)
3. Air Conditioning and Refrigeration Institute (ARI)
4. National Fire Protection Association (NFPA)
5. Sheet Metal & Air Conditioning Contractors National Association (SMACNA)

### 16.1.1 Standard atmospheric documentation

*A.k.a., Atmospheric system specification and drawings.*

Atmospheric systems are documented via specifications and drawings.

1. Atmospheric drawings (a.k.a., HVAC schematics, atmospheric schematics) illustrate the system that will support airflow and transfer thermal energy. Atmospheric (HVAC) drawings illustrates the atmospheric system.
2. Atmospheric specifications include all written content, reasoning for decisions, and calculations.

#### *16.1.1.1 Atmospheric system plan*

An atmospheric plan covers the following elements:

1. System concept.
2. Load calculation.
3. System zoning.
4. Air distribution.
5. Equipment selection.
6. Duct size calculation.
7. Adjustment, testing and balance.

The atmospheric plan includes standards for ventilation and air quality for all buildings. It also covers requirements for the prevention of condensation and other hazards.

### 16.1.2 Standard atmospheric requirements

What is required for a viable atmospheric production-distribution system is:

1. **For architecture** - heating, ventilation, and air cooling (HVAC) production proportionate to electrical/combustion power and air demand [via a load].
   - Herein, a load means the amount of heating or cooling required by a building.].
2. **For economic calculation** - Data sheet about loads (HVAC appliances) to produce optimization calculation.
3. **For life support demand** - HVAC proportionate to human demand.
4. **For technology and exploratory demand** - HVAC proportionate to human demand.

#### *16.1.2.1 Circulation best practices*

The following atmospheric circulation best practices should be followed:

1. The air circulation should not blow air on people positioned normally in a module. This is especially true where people sleep; air should not blow onto a bed (or in the specific area where a person is sleeping or working).
2. In general, air needs to be conditioned prior to entering a building, otherwise moisture will increase in the building (leading to a higher potential for mold growth).
3. One of the most effective ways to economize resources, power, and human labor, is to "centralize" the production of cold and/or warm air for atmospheric thermal regulation for several blocks and/or buildings. Duct energy loss over distance ought to be accounted for when taking this decision. It must be remembered that there may be return vents for circulation of large areas. Recirculated air will need higher quality filtration and/or sterilization than proximal usage-distribution systems.
4. Fans and heat exchange systems should have space between them and other surfaces (e.g., walls).

### 16.1.3 Hazards with the atmospheric system

The following are some common issues and risks with HVAC systems:

1. HVAC systems normally create noise and vibration due to the fans and compressors.
2. Duct leakage refers to the leakage of air from the air distribution system ductwork.
   A. Ducts that actually leak atmosphere.
   B. Ducts that are not sufficiently insulated and pass near thermal bridges or areas where temperature is not controlled.
3. Water leakage, which is particularly possible case with the inside unit of a split heat exchange system. Sometimes the drain gets clogged, and sometimes the machine malfunctions and begins leaking water.
4. Humidification of the indoor environment leading to mold and rot. In order to prevent this the following best practices can be followed:
   A. Do not set the thermostat to “fan on” position. In this position the fan blows air all the time whether the cooling system is running or not. When this happens a lot of the moisture the system just took out of the air will be blown back into the house before it can drain way.
   B. Use exhaust fans during moisture-producing activities. Cooking, bathing, washing, and similar activities produce a lot of moisture inside the home. Exhaust that moisture directly outdoors using a fan. Similarly, avoid drying clothes indoors except with a clothes dryer that is exhausted directly outdoors.
   C. Do not open windows or use ventilative cooling when it is too humid outside.

The following are potentially hazardous atmospheres:

1. Fog - tiny water droplets suspended in the air near the earth's surface.
2. Steam - water in the gas phase, due to boiling. Steam is very hot and can harm or kill someone.
3. Vapor - substance in the gas phase at a temperature lower than its critical temperature, which means that the vapor can be condensed to a liquid by increasing the pressure on it without reducing the temperature. Most vapors are dangerous to some degree. Water vapor (humidity) can cause mold and other water-damage issues in specific environments.
4. Aerosol - suspension of fine solid particles or liquid droplets in air or another gas, usually refers to an aerosal spray that delivers a consumer product from a can. Most areosols are dangerous to human health.
5. Mist - a phenomenon caused by small droplets of water suspended in the air, an example of a dispersion, where warm, moist air meets sudden cooling, such as in exhaled air in the winder, or when throwing water onto the hot stove of a sauna. Like water vapor, mist can cause water-related damage.
6. Smoke - a collection of airborne particulates and gases emitted when a material undergoes combustion. Most smoke is dangerous to humans.
7. Cloud - an aerosal consisting of a visible mass of minute liquid droplets, frozen crystals, or other particles suspended in the atmosphere of a planetary body or similar space.
8. Fire - oxidation of a material in the exothermic chemical process of combustion.
9. Flame - gaseous part of a fire.

**ASSOCIATION:** *For gas and fuel risks, see the associated gas and fuel section of the architectural subsystem and power subsystem.*

## 16.2 Conception of the atmospheric service system

An atmospheric system specification may include:

1. Ventilation system:
   A. Ventilation points.
   B. Conduits.
   C. Fans.
   D. Filtration.
2. Types of ventilation:
   A. Mechanical ventilation.
   B. Natural ventilation.
3. Types of atmospheric movement (atmospheric pressure-driven conduit types):
   A. Positive pressure conduits and vents.
      1. Outlet vents.
   B. Negative pressure conduits and vents.
      1. Inlet vents
      2. Suction (vacuum) conduits and vents.
4. Types of air processing:
   A. Temperature:
      1. Heat removers (coolers).
      2. Heat adders (heaters).
   B. Mechanical:
      1. Particulate modifiers.
         i. Mechanical filters (e.g., HEPA).
   C. Electrical:
      1. Ionic filters (using negatively charged metal plates).
   D. Chemical:
      1. Electrical ozone production (a type of electrical modification).
      2. Other chemical types (e.g., added oxygen or $CO_2$).
5. Types of piping:

   A. Hydronic water piping.
   B. Refrigerant fluid piping.
   C. Water drain piping.
   D. Ducting for atmosphere transfer.
6. Temperature adjustment:
   A. Types of heating:
      1. Centralized.
         i. Vented atmospheric heating (by means of centralized ducting).
         ii. Centralized under-floor heating (centralized by means of heated water or electricity).
         iii. Centralized wall-attached heating (centralized by means of heated water or electricity).
      2. Distributed.
         i. Localized under-floor heating (by means of one water heater or one electric distribution point).
         ii. Localized wall-attached heating (by means of one water heater or one electric distribution point).
         iii. Localized air circulation heating (e.g., mini-split heat pumps).
   B. Types of cooling:
      1. Centralized.
         i. Vented atmospheric cooling (by means of centralized ducting).
      2. Distributed.
         i. Localized circulation cooling (e.g.. mini-split heat pumps and air conditioners).

## *16.3 Conception of the atmospheric control sub-system*

An atmospheric control system is the system of controls that change atmospheric and surface (thermal) parameters over time. Such a system incorporates communication between various system inputs and outputs related to the atmosphere and surface temperatures. Atmospheric control may be more automated ("intelligent") or more manual.

An atmospheric control system may have any of the following functions:

1. <u>On/Off switch</u> that turns the atmospheric system (and sub-systems) on and off.
2. <u>Volume and velocity control</u> that makes the system cycle or output more air.
3. <u>Thermal control (a.k.a., temperature control)</u> that makes the system change the output temperature.

Atmospherics can be regulated through the following methods:

1. Atmospheric processing and cycling can be set with timers.
2. Heaters and coolers can be put on timers.
3. Atmospherics can be connected to motion sensors.
4. Atmospherics can be connected to electromagnetic sensors (i.e., sensors that detect sunlight).
5. Atmospherics can be connected to particle sensors (i.e., presence of dust, contaminant, etc.).
6. Atmospherics can be connected to alarms.

### 16.3.1 Thermostat

*A.k.a.,, Thermostatic regulator, thermostatic controller.*

A thermostat is a device that turns the HVAC unit on and off to maintain the temperature at the thermostat close to the specified setting. Simplistically, it is a device that monitors the indoor temperature and automatically adjusts the heating and/or cooling system to maintain the desired level. A thermostat is wired to a heating and/or cooling unit and acts as a thermometer, switch, and temperature controller. It is typically mounted on an interior wall and, alone, cannot measure temperature throughout the house – only near the thermostat.

Most thermostat modules should be placed:

1. So that it is easily accessible.
2. Possibly in a central location in the structure.
3. At eye-level for adults, or possibly lower for children.
4. Away from sunlight (and other temperature extremes.

Thermostats have a basic task - to maintain the temperature of an area (as in, some configuration of floor, wall, ceiling, room volume area. If the temperature falls below the set-point, or desired temperature, the thermostat enable the heating system, or cooling system in the sense of rising above the set-point. Once the temperature reaches the setpoint, the system either disable the heating/cooling system or maintains the area with less power. A programmable thermostat has [at least] two inputs: the setpoint and the current temperature. In most cases, the user programs the setpoint at various activities and/or times of day for each day of some calendar cycle (e.g., week). The thermostat then monitors and compares the current temperature to the desired setpoint and acts accordingly. The Nest learning thermostat also allows the user to set a schedule, but has a few more inputs, such as occupancy and manual overrides. If the schedule says 23 Celsius, but the thermostatic system doesn't sense anyone is in the area (e.g., home), then it will lower the temperature automatically. These systems can be designed to "learn" users' atmospheric habits. For example, imagine a case where every morning someone set the thermostat to 20 Celsius, the intelligent thermostat would remember and predict, and thus, adjust the schedule over time to mirror your preferences.

## 16.4 Conception of the atmospheric processing sub-system

*A.k.a., Atmospheric processing and distribution systems.*

An atmospheric processing system is a machine or technology that is used to change the material characteristics of the atmosphere, and/or its direction of flow.

Atmospheric processing systems can perform the following functions:

1. Temperature control - regulated by a thermostat (Read: temperature controller):
   A. Cooling of interior area:
      1. Central cooling.
      2. Space cooling.
   B. Cooling of limited interior space:
      1. Refrigerator (cooling without freezing).
      2. Freezer (deep refrigeration).
   C. Heating of interior area:
      1. Central heating.
      2. Space heating.
2. Air direction control:
   A. Air circulation (fans and ducts; e.g., air handler).
3. Area air-water control:
   A. Humidification (humidificator).
   B. Dehumidification (de-humidificator).
4. Localized drying control:
   A. Dryer (for drying of fabrics).
5. Air purity control:
   A. Purification (purificator).

## 16.5 Conception of the heating, ventilation, and air conditioning (HVAC) sub-systems

*A.k.a., Heating and cooling atmospheric processing systems, heating and cooling atmospheric fixtures.*

Heating, ventilation, and air conditioning (HVAC) systems can be classified according to:

1. Atmospheric processing type.
2. Distribution type.

The required atmospheric processes for an HVAC system include:

1. The heating process.
2. The cooling process.
3. The ventilation process.

Other atmospheric processes can be added, such as:

1. Ventilation fans.
2. Humidification.
3. Dehumidification.
4. Filtration.

In concern to distribution type, HVAC systems come in two general types depending upon whether they have venting to the exterior environment as well as venting throughout the interior environment (Seyam, 2018):

1. Exterior environmental venting?
   A. Has venting to the exterior environment.
      1. Ducted (vented, central, centralized).
   B. Does not have venting to the exterior environment
      1. Ductless (non-vented, local, mini-split, minisplit).
2. Interior area venting?
   A. Has venting throughout the interior environment.
      1. Ducted (vented, central, centralized).
   B. Does not have venting throughout the interior environment.
      1. Ductless (non-vented, local, mini-split, minisplit).

The same information could alternatively be displayed as follows:

1. Ducted (vented, central, centralized):
   A. Has venting to the exterior environment.
   B. Has venting throughout the interior environment.
2. Ductless (non-vented, local, mini-split, minisplit):
   A. Does not have venting to the exterior environment
   B. Does not have venting throughout the interior environment.

Central HVAC systems (ducted HVAC systems) are located in a central equipment room and deliver the air by a delivery ductwork system. Central HVAC systems can be all-air, air-water, or all-water systems. Numerous air quality products integrate easily with whole-building, ducted systems. These include humidifiers, dehumidifiers, and air purifiers.

A ductless indoor unit blows conditioned air and/or heats directly into one living space without ducts. Ductless systems can be configured with either one or multiple indoor units.

### 16.5.1 HVAC components

Basic (generalized) components of an HVAC system include, but are not limited to:

1. Mixed-air plenum and outdoor air control.
2. Air filter.
3. Supply fan.
4. Exhaust or relief fans and an air outlet.
5. Outdoor air intake.
6. Ducts (ventilation conduits)
7. Terminal devices.
8. Return air system.
9. Heating and cooling coils.
10. Self-contained heating or cooling unit.
11. Cooling tower.
12. Boiler.
13. Water chiller.
14. Humidification and dehumidification equipment.
15. Control.

HVAC systems commonly include the following equipment:

1. Primary equipment:
   A. Heating equipment.
   B. Cooling equipment.
   C. Air delivery equipment (i.e., air handlers).
2. Space requirements:
   A. Equipment rooms.
   B. HVAC systems.
   C. Fan rooms.
   D. Conduits.
   E. Equipment access.
3. Atmospheric distribution:
   A. Terminal units.
   B. Ductwork.
4. Hydronic piping (fluid conduiting):
   A. System piping (supply and return).
   B. Delivery piping.

Horizontal hierarchy representation of the main types of central HVAC systems:

1. All air systems:
   A. Single zone.
   B. Multi zone.
   C. Terminal reheat.
   D. Dual duct.
   E. Variable air volume.
2. Air-Water systems:
   A. Fan coil units.
   B. Induction units.
3. All water systems.
   A. Fan-coil units.
4. Water-source heat pumps.
5. Ground-source heat pumps (geothermal).
6. Heating and cooling panels.

**Table 11.** *Table shows the difference between central and decentralized HVAC systems based upon a set of criteria.*

| Criteria | Central system | Decentralized system |
|---|---|---|
| Temperature, humidity, and space pressure requirements | Fulfilling any or all of the design parameters | Fulfilling any or all of the design parameters |
| Capacity requirements | Considering HVAC diversity factors to reduce the installed equipment capacity<br><br>Significant first cost and operating cost | Maximum capacity is required for each equipment<br><br>Equipment sizing diversity is limited |
| Redundancy | Standby equipment is accommodated for troubleshooting and maintenance | No backup or standby equipment |
| Special requirements | An equipment room is located outside the conditioned area, or adjacent to or remote from the building<br><br>Installing secondary equipment for the air and water distribution which requires additional cost | Possible of no equipment room is needed<br><br>Equipment may be located on the roof and the ground adjacent to the building |
| First cost | High capital cost<br><br>Considering longer equipment services life to compensate the high capital cost | Affordable capital cost |
| Operating cost | More significant energy efficient primary equipment<br><br>A proposed operating system which saves operating cost | Less energy efficient primary equipment<br><br>Various energy peaks due to occupants' preference<br><br>Higher operating cost |
| Maintenance cost | Accessible to the equipment room for maintenance and saving equipment in excellent condition, which saves maintenance cost | Accessible to equipment to be located in the basement or the living space. However, it is difficult for roof location due to bad weather |
| Reliability | Central system equipment can be an attractive benefit when considering its long service life | Reliable equipment, although the estimated equipment service life may be less |
| Flexibility | Selecting standby equipment to provide an alternative source of HVAC or backup | Placed in numerous locations to be more flexible |

## 16.5.2 HVAC Zoning

Zoning allows for the creation of customized temperature zones throughout a building, which allows for greater temperature preference control and efficiency. This process allows the user(s) to set the conditions independently for each section of a building. Depending upon the specific type of HVAC machine, both split-type systems and central ducted systems have the capacity for single and multi-zoning.

#### *16.5.2.1 Ducted HVAC zoning*

Here, a zoned system is a single HVAC system serving two or more zones, rather than two separate HVAC systems. A ducted zoning system (a.k.a., zoned HVAC) is a system that uses dampers in the ductwork to regulate and redirect processed air to specific areas of a building. In this case, HVAC zoning utilizes a series of dampers that are installed either in the ducts or at the air vents. These dampers can open or close mechanically as needed to deliver airflow.

Ducted systems can be zoned in two ways. First, these systems can be zoned manually with each zone having its own thermostat. Secondly, these systems can be zoned centrally by an intelligent central controller that allows for adjustment of all zones from one central location.

If multiple ducts or air registers serve a particular part of the building, multiple dampers will move at once. Note that an air register is the same thing as a grille (vent), but with adjustable dampers in it. In other words, a register is a grille with moving parts, capable of being opened and closed and the air flow directed

#### *16.5.2.2 Ductless HVAC zoning*

Ductless zoning, unlike ducted zoning, requires more than one air handling unit. Ductless systems can be zoned in two ways. Firstly, these systems can be zoned manually, wherein multiple thermostats are located in various areas of the building to turn on/off and set the temperature of specific units in those areas. Secondly, these systems can be zoned centrally by an intelligent central controller that turns individual units on/off and sets their temperature.

## *16.6 Conception of the admospheric ducting sub-system*

*A.k.a., HVAC ducting.*

Ducting is the process of selecting and routing a ducting network. The process of ducting involves:

1. **Ducts (ducting types)** - duct material based (may include function):
   A. Material based (i.e., the physical/material composition of the ducts).
   B. May also include system-type (e.g., atmosphere type). But, this is not necessary; all that is necessary (often appropriate) is material type).
   C. Contains routing preferences.
2. **Ducting systems** - ducting system categories (a system of classification by ducting system function; e.g., hot air, cold air, purified air, vacuum, etc.).
   A. Customizable potentially by:
      1. Materials.
      2. Mechanical calculations.
      3. Atmosphere/gas type.
      4. Temperature.
      5. Atmospheric density.
      6. Flow conversion method.

**TERMINOLOGICAL CLARIFICATION:** *A forced air system is essentially any HVAC system that delivers temperature-controlled air into your home via ducts and vents. Hence, a central air conditioning system uses the forced-air system to deliver cooled air, making use of the vents, plenums, and ducts to provide conditioned air. A central heating system does the same.*

It is important to note that having a ductless system may be more efficient, in that there is usually energy lost in duct work. The length, size, texture, configuration of ductwork can dramatically reduce energy efficiency.

### 16.6.1 Ducting system types by function

Ducting system types by function include:

1. Type of materials the that travel through ducts:
   A. Used in ducting and connectors.
2. Type of atmosphere, including, but not necessary limited to:
   A. Hot air.
   B. Cool air.
   C. Vented air.
   D. Moist/humid air.
   E. Special systems:
      1. Vacuum.
      2. Toxic and/or other gases.

### 16.6.2 Ducting routing rules and parameters

The following measurement characteristics are used to design a ducting system to meet requirements (Bhatia, 2021):

1. Duct size
2. Fan size.
3. Duct shape.
4. Airflow volume.
5. Airflow pressure.
6. Air intake ducting.
7. Air outlet ducting.

#### *16.6.2.1 The measurement of airflow through ducts*

Air pressure is understood in the following ways:

1. **Mass:** Air has mass. The density of dry air is:

   A. 1.225 kg/m^3
   B. 0.0765 lb/ft^3.
2. **Atmospheric pressure** - Pressure of the atmosphere at the earth's surface NIST standard atmospheric pressure = 1.01325 bar.
   A. **BAR** - unit of pressure (or stress).
      1. 1 bar = 750.07 mm of mercury at 0°C, at 45°.
3. **Gauge pressure** - is pressure measured relative to ambient atmospheric pressure. Quantified in pounds per square inch-gauge (PSI-G).
4. **Absolute pressure** - is the total of the indicated gauge pressure plus atmospheric pressure. The zero reference in absolute pressure is a perfect vacuum, which has no atmospheric pressure at all. Pressure measured relative to full vacuum. Referred to as pounds per square inch-absolute (PSI-A).
   A. Absolute pressure = gauge pressure + atmospheric pressure

The pressure of airflow through ducts maintains three possible measurement values:

1. **Static pressure** - is the air pressure in the duct, which is used for fan selection. It is the pressure that causes air in the duct to flow. Static pressure is the outward push of air against duct surfaces and is a measure of resistance when air moves through an object like duct work. Measured in pascals per meters or inches of water column (in-wc). It acts equally in all directions and is independent of velocity.
   A. **External static pressure (ESP)** - is the static pressure created downstream of the AHU and it includes all the duct losses from the fan until it reaches the discharge point. This could include a negative static pressure on the pull side of the fan and a positive pressure on the push side, or any combination of pressures the fan must overcome. It is estimated by the HVAC design engineer as he lays out the ductwork, diffusers, and terminal devices.
   B. **Internal static pressure (ISP)** - is pressure as it pertains to the HVAC AHU, is the static pressure loss across the filters, coils, louvers, dampers, and twists and turns inside the AHU casing. ISP is usually provided by the supplier, but for custom designs, the HVAC design engineer estimates the pressure loss across the various components of the AHU
   C. **Total static pressure (TSP)** - is the sum of the external static pressure (ESP) and internal static pressure (ISP).
      1. TSP = ESP + ISP
2. **Velocity pressure** - is the pressure generated by the velocity and weight of the air, which is used for measuring the flow ($m^3$/s or cfm) in a system. Velocity pressure is the pressure caused by air in motion. It is equal to the product of air density and the square of the velocity divided by 2.
   A. VP = 0.5 x ρ x v2
   B. Using standard air, the relationship between V and VP is given by:
      1. $VP = (v / 4005)^2$
      2. VP will only be exerted in the direction of air flow and is always positive.
3. **Total pressure** - is used to find velocity pressure. Total Pressure determines the actual mechanical energy that must be supplied to the system. Total pressure equals static pressure plus velocity pressure. In other words, total pressure is the algebraic sum of velocity pressure and static pressure:
   A. TP = VP + SP
   B. TP = Total Pressure
   C. VP = Velocity Pressure
   D. SP = Static Pressure

Air flow is measured in the following ways and by the following units:

1. **Air volume of air flow (volumetric flow rate)** - determined by how many metric cubes per second (or, cubic feet per minute) of air pass by a stationary point.
   A. $m^3$/s - meters cubed / second.
   B. cfm - cubic feet/minute.
   - Air volume in cfm can be calculated by multiplying the air velocity by the cross-sectional area of the duct in square feet or cubed millimeters:
     - cfm = fpm x area
     - Area = cfm/fpm
2. **Air velocity of air flow:**
   A. m/s - meters / second.
   B. fpm - feet / minute.
      - fpm = cfm/area
      - Area = cfm/fpm
3. **Duct shape size:**
   A. Diameter in metric or imperial.
   B. Length x height in metric or imperial.
4. **Friction loss.**
   A. Pa/100m - pascals / 100 meters
   B. H2O/100 ft - water / 100 feet

System capacity is directly affected by changes in air flow. As air is heated or humidified, its specific volume increases and its density decreases. If the air density is low, more air volume (in $m^3$/s or cfm) is required to keep the mass flow rate the same.

#### *16.6.2.1 Best practice ducting routing rules*

Some best practice ducting routing rules include, buy are not limited to (Bhatia, 2021):

1. **Configure the network appropriately:** Ducts should be designed so that the length of each run (each section of ductwork) is short enough to provide proper control of air flow and stability of construction. Radial or trunk-and-branch configurations have shorter runs and generally work best. Wherever possible, ducts should be located within the conditioned space. Do not twist or block ducts and do not position them so they may collapse in the future.
2. **Straightness is optimal:** this is the most important rule of all; reduce the number of bends and turns to an absolute minimum. From an energy perspective, air wants to go straight and will lose energy if it bends. From a cost perspective, straight ducts costs less than fittings. Fittings are more costly because they must be hand assembled even if the pieces are automatically cut by plasma cutters.
3. **Appropriately size the ducts:** Ductwork that's too small won't be able to carry enough air to heat or cool a building. Ducts that are too large can lose both air and energy, cutting system efficiency. Use industry standards and procedures, such as those published by ASHRAE, to size ducts.
4. **Calculate for sufficiency for sufficiency of return ducts:** Supply ducts carry conditioned air to the building, but the system also requires enough return ducts to bring expended air back to the HVAC unit to be conditioned again. Each room that receives heating or cooling should have at least one return duct (in a centralized system). As a rule of thumb, use 2 cfm for each sq.-inch of return air opening; for example, 20" x 20" grille equals 400 sq.-in. gross area of grille, which means 800 cfm of recommended air flow.
5. **Preferentially pass ducts through conditioned spaces:** Ducts placed in conditioned spaces are more efficient than those placed in unconditioned spaces. If located within conditioned space, conductive and radiative losses, leakage losses, and equipment cabinet losses are reduced or regained into the building space. If it is not feasible to locate ductwork within conditioned spaces, the ducts should be properly sealed and insulated. The trunk ducts are usually located above corridors in the cavity above the ceiling to minimize noise transmission to the conditioned zones and allow easy access without disturbing the building occupants.
6. **Appropriately design for thermal zoning:** Zoning is a practice of dividing a building into distinct thermal zones, which have similar heating and cooling requirements. In practice the corner rooms and the perimetric spaces of the building have variations in load as compared to the interior core areas. If zones have special temperature and/or humidity requirements, they should be served by independent air distribution systems separate from variable zones. The idea is to permit independent control of temperature and humidity in similar zones. Where it is not possible, consider use of VAV systems and/or supplementary controls. Some locations will have highly variable occupancy loads that must be accounted for so as not to waste energy and provide sufficient HVAC when occupied (e.g., conference rooms). Building are usually divided into two major zones:
   A. **Exterior zone:** This is the area inward from the outside wall (usually 12 to 18 feet, if rooms do not line the outside wall). The exterior zone is directly affected by outdoor conditions during summer and winter and has variable thermal loads.
   B. **Interior zone:** This is the area contained by the external zone. The interior zone is only slightly affected by outdoor conditions and usually has a uniform and steady cooling load throughout.
7. **Seal and insulate sufficiently:** Make sure all ductwork sections fit together tightly. Connections can be mechanically sealed with sheet metal screws or other fasteners to improve connection strength. Seal connections with mastic or metal tape. Cover the ductwork with insulation, such as rigid fiber board or standard blanket-type insulation.
8. **Efficiency and effectiveness accounting rules:**
   A. **Account for attenuation over distance:** For supply ducts longer than 10 feet, the air is reduced in that run by 10% for every 5 feet over 10 feet. For example, a 30 foot run yields a reduction of 40% (30-10=20, 20÷5=4, 4×10=40%). Minimize length and restrictions. Keep the supply duct length as close to 10 feet as possible but never less than 6 feet. Use the fewest number of bends as possible.
   B. **Account for structural rigidity:** Use at least 24 inches of straight plenum before any fitting, such as an elbow, tee, or takeoff. Electric duct heaters require 48 inches. Avoid elbows directly off units. The maximum total plenum length should be restricted to 150 ft. For the plenum, maximize length and minimize restrictions.
   C. **Account for the degree of split of a tee connector:** When using a tee, split the flow as close to 50/50 as possible, no more than 60/40.

Here, always use a turning vane.

D. **Account for the degree of branch off a tee connector:** Turn the tee 90° to make a side branch with no more than 30 percent of the air. Do not use a turning vane.
E. **Account for distance between takeoffs:** Maintain distance between takeoffs as evenly as possible. Space the takeoffs at least 6 inches apart and 12 inches from the end cap.
F. **Use radiused over mitered fittings:** Use long and radiused duct fittings instead of short or mitered fittings wherever possible. Mitered (edged) fittings are less efficient (due to friction loss) than radiused (rounded) fittings.

#### *16.6.2.1 Air flow characteristics in ducts*

Air flow in ducts has the following characteristics (Bhatia, 2021, p.9-10):

1. At any point, the total pressure is equal to the sum of the static and velocity pressures.
2. The exertion of pressure is different for static pressure and velocity pressure.
   A. Static pressure (SP) is exerted equally in all directions. Static pressure is typically used for fan selection.
   B. Velocity pressure (VP) is exerted only in the direction of air flow. Velocity pressure is used for measuring cfm in a system.
   - This makes it difficult to directly measure velocity pressure in a duct; because, static pressure is also pushing in the direction of air flow, you can never measure just velocity pressure. Practically, velocity pressure is calculated by measuring pressure perpendicular to the air flow (Static Pressure) and also measuring pressure parallel to the air flow (Total Pressure). Once values for the two pressures are available, it is possible to subtract static pressure from the total pressure and derive the velocity pressure.
     - VP = TP - SP
3. Static and velocity pressure are mutually convertible. The magnitude of each is dependent on the local duct cross-section which determines the flow velocity. The following pressure changes are affected in the ducts:
   A. Constant cross-sectional areas: Total and static losses are equal.
   B. Diverging sections (increase in duct size): Velocity pressure decreases, total pressure decreases, and static pressure may increase (static regain).
   C. Converging sections (decrease in duct size): Velocity pressure increases in the direction of flow, total and static pressure decrease.
4. The total pressure generally drops along the air flow because of frictional and turbulence losses.

#### *16.6.2.2 Types of ducting*

*A.k.a., HVAC ducts, duct fittings.*

Ducts may be classified by (note: this content is usually defined in a set of piping standards):

1. Type of material (i.e., material composition of duct).
2. Function of duct network (e.g., to provide filtered air, cool and/or hot air, etc.)
3. Specific duct elements:
   A. Types of physical interconnection between duct elements (e.g., glue, screw, flange, etc.).
   B. Geometric function of duct elements (e.g., segment, curve, flexible, etc.).
   C. Conduit shape (e.g., square, round, oval.)
4. Sizes
   A. United States, Canada, and Brazil
   B. Europe
   C. Australia
   D. Russia
   E. China
   F. Others

#### *16.6.2.3 Types of duct by function*

The air distribution system will have a designation depending on the function of the duct. There are five general designations of ducts by function:

1. **Supply air ductwork** - supplies conditioned air from the air handling unit to the conditioned area.
2. **Return air ductwork** - removes air from the conditioned building spaces and returns the air to the air handling unit, which reconditions the air. In some cases, part of the return air in this ductwork is exhausted to the building exterior.
3. **Fresh air ductwork** - supplies outdoor air to the air handling unit. Outdoor air is used for ventilating the occupied building space.
4. **Exhaust (relief) air ductwork** - carries and discharges air to the outdoors. Exhaust air is taken from toilets, kitchen, laboratories and other areas requiring ventilation.
5. **Mixed air ductwork** - mixes air from the outdoor air and the return air then supplies this mixed air to the air handling unit.

#### *16.6.2.4 Components of a ducting system*

The primary components of ducting system are:

1. **Plenum or Main Trunk** - is the main part of the supply and return duct system that goes directly from the air handler to the “Trunk Duct”.

2. **Trunk duct** - when a duct is split into more than one duct, it is called a "trunk". Ducts that are on the end of a trunk and terminate in a register are called branches.
3. **Take off** - Branch ducts are fastened to the main trunk by a takeoff-fitting. The takeoff encourages the air moving the duct to enter the takeoff to the branch duct.
4. **Air terminals** - are the supply air outlets and return or exhaust air inlets. For supply, diffusers are most common, but grilles and registers are also used.
   A. **A diffuser** - is an outlet device discharging supply air in a direction radially to the axis of entry.
   B. **A register** - is a grille equipped with a volume control damper.
   C. **A grille** - is a register without a damper.

#### *16.6.2.5 Types of ducting material*

The primary types of metal material used in ducting include, but may not be limited to (Bhatia, 2021):

1. **Galvanized steel** - is used commonly for heat pumps and air conditioners.
   - The specifications for galvanized steel sheet are ASTM A653, coating G90.
2. **Aluminium** - is widely used in clean room applications. These are also preferred systems for moisture laden air, special exhaust systems and ornamental duct systems.
   - The specifications for Aluminium sheet are ASTM B209, alloy 1100, 3003 or 5052.
3. **Stainless steel** - is used in duct systems for kitchen exhaust, moisture laden air, and fume exhaust.
   - The specifications for stainless steel sheet are ASTM A167, Class 302 or 304, Condition A (annealed) Finish No. 4 for exposed ducts and Finish No. 2B for concealed duct.
4. **Carbon steel (black iron)** - is widely used in applications involving flues, stacks, hoods, other high temperature and special coating requirements for industrial use.
5. **Copper** - is mainly used for certain chemical exhaust and ornamental ductwork.

The primary types of non-metal material used in ducting include, but may not be limited to (Bhatia, 2021):

1. **Fibreglass reinforced plastic (FRP)** - is used mainly for chemical exhaust, scrubbers, and underground duct systems. Advantages are resistance to corrosion, self-insulation, excellent sound attenuation and high quality sealing. Limiting characteristics include cost, weight, range of chemical and physical properties, and code acceptance.
2. **Polyvinyl chloride (PVC)** - is used for exhaust systems for chemical fumes and underground duct systems. Advantages include resistance to corrosion, light weight, and ease of modification. Limiting characteristics include cost, fabrication, code acceptance, thermal shock, and weight.
3. **Fabric (a.k.a., textile ducts)** - is usually made of special permeable polyester material and is normally used where even air distribution is essential. Due to the nature or the air distribution, textile ducts are not usually concealed within false ceilings. Condensation is not a concern with fabric ducts and therefore these can be used where air is to be supplied below the dew point without insulation.
4. **Flex duct** - consists of a duct inner liner supported on the inside by a helix wire coil and covered by blanket insulation with a flexible vapor barrier jacket on the outside. Flex ducts are often used for runouts, as wellas with metal collars used to connect the flexible ducts to supply plenums, trunks and branches constructed from sheet metal or duct board. Flex ducts provide convenience of installation as these can be easily adapted to avoid clashes but has certain disadvantages. These have more friction loss inside them than metal ducting. Flex duct runs should be as short as possible (1.5-1.8m or 5-6ft max.), and should be stretched as tight as possible.

**NOTE:** *Pressure in the air conditioning ducts is small, so materials with a great deal of strength are not needed. The thickness of the material depends on the dimensions of the duct, the length of the individual sections, and the cross-sectional area of the duct.*

#### *16.6.2.6 Ducts classified by velocity and pressure*

Ducts are classified into 3 basic categories in terms of velocity (Bhatia, 2021):

1. **Low velocity systems** - are characterized by air velocities up to 2000 fpm.
2. **Medium velocity systems** - are characterized by air velocities in the range of 2,000 to 2,500 fpm.
3. **High velocity systems** - are characterized by air velocities greater than 2,500 fpm.

**DESIGN RELATIONSHIP CONSIDERATION:**
*Duct velocity influences noise, vibration, friction losses and fan power.*

High duct velocities result in lower initial costs but require increased fan static pressures; therefore, resulting in increased energy usage. Often these need additional noise attenuation (use of noise silencers) and are not suitable for comfort applications. Generally, high-velocity systems are applicable to large multi-story buildings, primarily because the advantage of savings in duct shafts and floor-to-floor heights is more substantial. Small two- and three-story buildings are normally low velocity. A velocity of 1,000 to 1,500 fpm for main ducts and a velocity of 700 to 1,000 fpm for the branch take offs are recommended.

Ducts are classified into 3 basic categories in terms of pressure (Bhatia, 2021):

1. **Low pressure** - applies to systems with fan static pressures less than 3 inches WC. Generally, duct velocities are less than 1,500 fpm.
2. **Medium pressure** - applies to systems with fan static pressures between 3 to 6 inches WC. Generally, duct velocities are less than or equal to 2,500 fpm.
3. **High pressure** - applies to systems with fan static pressures between 6 to 10 inches WC. Usually the static pressure is limited to a maximum of 7 inches WC, and duct velocities are limited to 4,000 fpm. Systems requiring pressures more than 7 inches WC are normally unwarranted and could result in very high operating costs.

**DESIGN RELATIONSHIP CONSIDERATION:** *Duct pressure influences the duct strength, deflection and air leakage.*

Good engineering practices for duct pressurization are:

1. Use of medium pressure classification for primary air ductwork (fan connections, risers, and main distribution ducts).
2. Use of low pressure classification for secondary air ductwork (runouts/branches from main to terminal boxes and distribution devices).

### *16.6.2.7 Types of duct sizes*

Different ducting networks will need different sizes of duct.

The current practice is to determine duct size through the following:

1. Nominal diameter.
2. Outside diameter.
3. Inside diameter.
4. The duct schedule (or wall thickness).

### *16.6.2.8 Types of duct shape*

Different ducting networks will need different shapes of duct.

Ducts typically come in three types, each with advantages and disadvantages:

1. **Round** - is the most efficient (offers the least resistance) in conveying moving air is a round duct, because it has the greatest cross-sectional area and a minimum contact surface. In other words, it uses less material compared to square or rectangular ducts for the same volume of air handled. Some of the advantages of round ductwork include:
   A. Round shape results in lower pressure drops, thereby requiring less fan horsepower to move the air and, consequently, smaller equipment.
   B. Round shape also has less surface area and requires less insulation when externally wrapped.
   C. Round ducts are available in longer lengths than rectangular ducts, thereby eliminating costly field joints. Spiral lock-seams add rigidity; therefore, spiral ducts can be fabricated using lighter gauges than longitudinal seam ducts. Spiral ducts leak less and can be more easily sealed compared to rectangular ducts.
   D. The acoustic performance of round and oval ducts is superior because their curved surfaces allow less breakout noise. The low-frequency sound is well contained in round ducts.
   E. Round ducts can help promote healthier indoor environments. Less surface area, no corners and better air flow reduce the chance of dirt and grime accumulating inside the duct and, therefore, becoming a breeding ground for bacterial growth.
2. **Rectangular** - fit above ceilings and into walls, and they are often easier to install between joists and studs. Disadvantages of rectangular ducts are as follows:
   A. They create higher pressure drop.
   B. They use more pounds of material for the same air-flow rate as round ducts.
   C. Their joint length is limited to the sheet widths stocked by the contractor.
   D. Their joints are more difficult to seal.
   E. Ducts with a high aspect ratio can transmit

excessive noise if not properly supported.

3. **Oval** - have smaller height requirements than round ducts and retain most of the advantages of the round ducts. However, fittings for flat oval ducts are difficult to fabricate or modify in the field. Other disadvantages include:
   A. Difficulty of handling and shipping larger sizes.
   B. Tendency of these ducts to become more round under pressure.
   C. In large aspect ratios, difficulties of assembling oval slip joints.

#### *16.6.2.9 Types of ducting interconnections*

Connectors for ducting include, but may not be limited to:

1. By geometric function of element:
   A. Straight connector.
   B. 90 degree bend.
   C. Other degree bends.
   D. T connector.
   E. Cross connector.
   F. Size adapter.
2. By physical interconnection:
   A. Compression connection.
   B. Welded (solder connection).
   C. Threaded (screw connection).
      1. With plumbing this often necessitates another tape like material that is first twisted around the part to be screwed.
   D. Flanged connection.
   E. Glued connection.
3. By conduit shape:
   A. Rectangular.
   B. Round.
   C. Oval.

#### *16.6.2.10 Types of ducting elements*

Ducting elements include:

1. **Pipe segment** - straight, horizontal segment of pipe.
2. **Elbow** - curved piece that joins two pipes.
   A. 90 degree.
   B. 45 degree.
   C. Etc.
3. **Junction**
   A. Tee - shaped like a T; connects 3 pipe segments.
   B. Tap.
4. **Cross** - connects 4 pipe segments.
5. **Transition** - adapter element for changing pipe sizes.
6. **Union** - connector of 2 pipe segments.
7. **Flange** - connects piping and components in a piping system by use of bolted connections and gaskets.
8. **Cap** - closes (seals off) end of a pipe.

*Note: The above types of [duct] fittings (unions, interconnections) can be set for routing a duct.*

#### *16.6.2.11 Fan selection*

The fan must be selected to deliver a specific volumetric flow rate and generate static pressure to overcome the pressure losses due to ducts (length and dimensions), fitting, and the components of an air handling unit (AHU).

## *16.7 Objects in the atmospheric system: fixtures, fittings, and appliances*

Atmospheric fixtures and fittings are equipment that interface with the atmosphere in a building:

1. **Atmospheric fixtures** - a device for processing air. The most common fixtures include, but may not be limited to:
   A. Heating, ventilation, and air conditioning (HVAC) systems.
   B. Exhaust fans:
      1. Humidity exhaust fans.
      2. Kitchen exhaust fans.
      3. Hazardous chemical exhaust fans.
2. **Atmospheric fittings** - a device designed to control and guide the flow of atmosphere. The most common fittings include, but may not be limited to:
   A. Vents.
   B. Air intakes.
   C. Thermostats.
   D. Duct airflow monitoring devices (e.g., anemometer and manometer).
   E. Drain (e.g., for heat pumps and air conditioners).
   F. Etc.
3. **Atmospheric appliances** - appliance devices that change the atmosphere, the most common of which include:
   A. Drying machine.
   B. Air purifier (portable).
   C. De-/humidifier (portable).
   D. Refrigerator
   E. Freezer
   F. Vacuum (a type of atmospheric filter; can be central or portable)

**IMPORTANT:** *All fixtures, fittings, and appliances must be specified with the right capacity for their placement.*

### 16.7.1 Air handling systems

*A.k.a., Air circulation systems, air handling* *fixtures, air circulation fixtures, air handling unit (AHU).*

Air handlers are a complementary component of space heating and air conditioning equipment that distribute air within building interiors. Air handlers also provide filtering, and they ensure a constant supply of outdoor air. Air handlers sustain the airflow required to deliver heating or cooling for indoor areas. In the air handler, the air supply is blown through a heating and/or cooling element before circulating through the indoor area. Air handlers are generally equipped with filters. The filter is normally placed at the air handler intake to protect internal components from dust and other polluting particles. Filtering requirements change depending on the application; for example, medical facilities and some manufacturing processes require highly purified air quality. (Air Handlers, 2021)

There are two general types of air handlers:

1. Localized air handler - are included in small air conditioners and packaged units within which air handlers are built-in.
2. Central air handlers - are used in large HVAC systems where hydronic piping connects to air handlers with chillers and/or boilers.

Based on their connection two a duct system, there are two types of air handlers:

1. Air handling units designed for connection to a duct system, where the airflow in each area is controlled with dampers. Central air handlers generally use ducts.
2. Air handler units that discharge air directly into indoor spaces, without ducts. Localized air handlers generally do not use ducting.

Based on their physical construction and applications, air handlers may be classified as follows:

1. Fan coil units - compact air handlers with a simple construction. Their basic components are a fan, a filter, and a heating or cooling coil.
2. Make-up air units - larger air handlers designed to condition outdoor air and deliver it to indoor spaces. These air handlers do not recirculate indoor air.
3. Rooftop package units - are used in larger HVAC systems and designed for exterior installation within a rooftop HVAC system configuration.

Heat exchangers are a fundamental component of air handlers. Depending on how heat is delivered or removed, these heat exchangers are classified as:

1. Direct heat exchange air handlers - move air directly through heating or cooling elements. For example, air is blown through electrical resistance units or gas burners in heating applications, or through AC evaporator units when cooling is required. Air handlers can also be integrated with heat pumps to provide heating and cooling with the same device.
2. Indirect heat exchange air handlers - do not move air through the heating or cooling unit. Instead, another substance is used to supply or remove heat. Water is the most common option, since it can be used for either heating or cooling, by circulating it through a boiler or chiller. Steam and refrigerant fluids are other options.

Air handlers with separate heating and cooling coils can provide dehumidification. Air is cooled below the required temperature to remove humidity by condensation. Since this process cools the air excessively, the heating coil is then used to raise temperature back to a comfortable level. (Air Handlers, 2021)

Air handlers are applied to provide sufficient airflow when the building is at full occupancy. Demand-controlled ventilation (DCV) involves the adjustment of airflow according to occupancy, with the purpose of conserving power. It is possible to monitor occupancy, and this information is used to decrease airflow when the full capacity is not required. When deploying demand-controlled ventilation, the speed of fans can be adjusted with variable frequency drives (VFD), which reduce fan power in cubic proportion to fan speed. For example, if a VFD reduces fan speed to some lower percentage of its rated RPM, then power consumption is also reduced by some percentage. The performance of air handlers can also be increased with heat recovery systems, which exchange heat between the outdoor air supply and the exhaust of a ventilation system. During summer, a heat recovery system uses the exhaust air to remove heat from the outdoor air supply. Since the outdoor air reaches air handlers at a lower temperature, the cooling load is reduced. The opposite process applies during winter, where the exhaust air is used to preheat the outdoor air supply. In this case, the heating load is reduced. (Air Handlers, 2021)

Noise and vibration are common issues when air handlers are not designed or installed properly, or when maintenance has been lacking. Oversized fans and inadequate air handler supports are two common causes of noise and vibration issues.

The internal mechanical components will wear down over time, and rotating elements of motors and fans can start experiencing unbalance and misalignment, producing more noise and vibration. A certain degree of noise and vibration is unavoidable when using air handlers, especially when dealing with a large unit. (Air Handlers, 2021)

##### *16.7.1.1 Positioning of interior air handlers*

Interior air handlers are generally placed on the wall near the ceiling and oriented in a manner that is unlikely to blow air on occupants.

### 16.7.2 Heat pump atmospheric processing systems

*A.k.a., Combined heating and cooling atmospheric processing systems.*

A heat pump is a device that transfers heat between the inside of a building space and the outside environment. It is an atmospheric processing system that transfers thermal energy from a cooler location to a warmer location using the refrigeration cycle, being the opposite direction in which heat transfer would take place without the application of external power. A heat pump works similarly to a refrigerator or air conditioner -- it uses electricity and a refrigerant to "pump" or move heat from one location to another by using a compressor and a circulating structure of liquid or gas refrigerant. In a heat pump, electricity is used by the compressor to send refrigerant around the system, capturing heat from outside, or inside, and bringing it to the opposite side of the split system. A pure heat pump does not generate heat by electrifying metal (e.g., light bulb) or oxidizing organics (e.g., furnace).

**NOTE:** *Heat pumps can be used to transfer thermal energy between different materials. There are heat pumps that combine heating, cooling, and water heating.*

There are two general variants of heat pumps categorized by the direction of thermal energy transfer:

1. **Reversible heat pumps (two-way heat pumps)** - work in both directions to keep both the heat and the cold-regulated. A reversible heat pump is essentially an all-in-one air conditioning and heating system that works year-round. These systems conduct heat from the outdoors to the indoors during times of cold (i.e., in winter). When it is hot outside (i.e., in summer), these pumps convect heat out from inside a building, keeping the inside cool. Reversible simply means that the flow of refrigerant can be reversed, and is therefore able to draw ambient heat from outside to provide indoor heating. By means of a reversing valve in the outdoor unit, a heat pump can absorb heat energy from outside air, even in cold temperatures, and transfer the heat inside the building. In other words, these systems use a reversing valve to reverse the flow of refrigerant from the compressor through the condenser and evaporation coils. Reversible heat pumps are more effective throughout the whole year than irreversible heat pumps.
    A. In heating mode, a heat pump collects heat from the air, water, or ground outside a structure, then concentrates it and transfers it for use inside. During the heating cycle, the outdoor coil is the evaporator, and the indoor one functionings as the condenser. Here, heat pumps are three to four times more effective at heating than simple electrical resistance heaters using the same amount of electricity; they can have coefficient of performance (COP) = 4.
    B. In cooling mode, the heat pump collects thermal energy from air inside the structure and transfers it outside. In other words, they use a refrigerant to absorb heat from the air inside a building and transport it outside. During the cooling cycle, the outdoor coil is the condenser, and the inside one the evaporator. The COP for cooling mode is less than for heating mode, because the work done by compressor is utilized only during the heating mode.
2. **Irreversible heat pumps (one way heat pumps)** - heat pumps that can only transfer heat one way.
    A. **Heating mode only irreversible heat pumps** - can only transfer heat from outside to the inside and will have no effect in the summer (when it is hot outside). A separate cooling system will need to be installed for when it is hot outside.
    B. **Cooling mode only irreversible heat pumps** - can only transfer heat from the inside to the outside. An air conditioner (AC) is basically a one way heat pump; an irreversable heap pump is generally called and air conditioner. It can cool but not heat. All air conditioners work on the heat pump principle that they draw heat out of an area.

Reversible heat pumps are machines that are capable of producing both heating and cooling [within a single device] for an environment. A reversible heat pump can heat and cool. It is important to note here that although a reversible heat pump can heat a structure, when outside temperatures drop below freezing, the efficiency of a heat pump is significantly affected. Typical reversible heat pump systems have an auxiliary heater added to the indoor unit to add supplemental heat when outdoor temperatures drop below freezing.

**TERMINOLOGICAL CLARIFICATION:** *The term heat pump is usually reserved for a device that transfers heat from outside to inside to heat a building. However, in the United States, the term, heat pump, generally refers to the reversible version of the heat pump (i.e., a two-way heat transfer heat pump that can cool and heat).*

There are three main types of heat pumps (note: all three of these operate on the same principles, except they gather heat from different sources:

> **NOTE:** *These are all split atmospheric processing machine with a part of the machine interior to the building and another part of the machine exterior to the building.*

1. **Air source heat pump (a.k.a., air-to-air heat pump):**
   A. Air source heat pumps extracts heat from outdoor air and transfers it into the building. The system is comprised of an indoor and outdoor unit and works by extracting heat from the outdoor air and transferring it into the building. This is one of the easiest and cheapest heat pumps to install and takes up little space. It is also the most common type of heat pump.
2. **Ground source heat pump (a.k.a., geothermal):**
   A. A ground source heat pump extracts the heat energy from the ground and soil around a building's foundation and transfers it into the building. Ground source heat pumps move heat through a series of pipes that are buried in loops outdoors
   B. The ground temperature is almost always warmer than the air in the winter, which is why ground source heat pumps are more efficient than air source heat pumps, especially in the winter months. In other words, ground-sourced heat pumps are typically more efficient than air-sourced because the ground has a higher density and heat capacity compared to air.
   C. A geothermal heat pump is also more reliable and quieter than an air source system. The main reason geothermal heat pumps haven't become more widespread is due to the high cost of installation. For the system to work correctly, excavation is needed to insert long runs of tubing underneath or near the building. A newer system called "direct-injection" aims to make this process more affordable, but still requires more time, effort and money than air source.
   D. This type of heat pump requires earthwork excavation. For new builds, the cost can be incorporated within construction. The underground pipes that form the exterior part of the system extract some number of Watts per meter of pipe underground.
3. **Water source heat pump** (note: sometimes considered a sub-classification of geothermal heat pumps)**:**
   A. Water sourced heat pumps are only viable if there is a body of water close to the building, such as a pond or river. Water sourced heat pumps can be of two types related to the water source they are connected to: closed loop (lake) or open loop (river). A water source heat pump extracts heat energy from water by pumping the water from the source directly through the heat pump. This method provides a more constant input temperature than an air source pump and is much cheaper to install than a ground source pump. Water source heat pumps require a constant flow of water and during the heart of the winter months, a second heat source may be needed as back-up.
   B. If the refrigerant in the heat pump system leaks into a closed source water environment (and even into an open sourced water environment) it could kill fish and other aquatic life therein.
   C. A non-reversing water source heat pump is one without a reversing valve, but where the flow of water can change direction instead of the refrigerant.
4. **Exhaust air heat pump (EAHP):**
   A. An exhaust air heat pump (EAHP) extracts heat from the exhaust air of a building and transfers the heat to the supply air, hot tap water and/or hydronic heating system (underfloor heating, radiators).
5. **Grey water heat recovery heat pump:**
   A. This type of heat pump is rare and is designed to recover heat from grey water plumbing.

Heat pumps can also be categorized based on how they heat and cool building interiors. The classification above describes where they exchange heat with the, but not how the heating or cooling effect reaches indoor spaces:

1. **Liquid-to-air heat pumps** - that heat or cool indoor air directly (similar to rooftop air conditioners). After being cooled or warmed, the air is circulated through indoor spaces using air-handling units and ductwork.
2. **Liquid-to-water** - heat pumps are similar to chilled water systems, wherein the heat pump is used to heat or cool water, which is then circulated through the building. The water then heats or cools indoor air as it circulates through fan-coils.

#### *16.7.2.1 Geothermal systems (a.k.a., ground-source heat pumps, GSHP)*

Geothermal heat pumps draw heat from the ground during the winter and transfer it indoors, and from the indoor air during the summer and transfer it into the ground. Geothermal systems can deliver atmospheric heating and cooling (as well as water heating). For water heating, it is possible to add a desuperheater to a geothermal heat pump system. A desuperheater is a small, auxiliary heat exchanger that uses superheated gases from the heat pump's compressor to heat water. Desuperheaters are also available for tankless or demand-type water heaters. Desuperheaters operate best in summer, when the compressor has more frequent operation. During the fall, winter, and spring, when the desuperheater isn't producing as much excess heat, the building will rely more on its storage or demand water heater.

Depending on region, the underground environment is an effective heat source during winter and an effective heat sink during summer. These systems pump heat between a building interior and the underground. Heat is extracted from the building and released underground during summer, and the opposite process is carried out during winter. A geothermal heat pump exchanges heat with the ground at relatively low depth in comparison to a geothermal power plant.

Geothermal systems can be classified into three main types, based on how they exchange heat with the underground:

1. **Direct exchange (DX)** - exchange heat using refrigerant lines that are buried in direct contact with the ground or groundwater, as implied by their name. This is the oldest type of geothermal system. Because heat is exchanged directly with the ground as refrigerant travels through buried piping, these systems have a higher efficiency and a lower installation cost than other geothermal heat pumps. Direct exchange heat exchangers are susceptible to refrigerant leakage and pipe corrosion, and they must be designed to withstand both conditions. Even a slight opening in refrigerant lines can cause a serious refrigerant leak and lead to groundwater contamination.
2. **Closed loop systems** - use water to exchange heat between the refrigerant and underground. Refrigerant never travels underground as a result. Water circulates through a series of buried loops before returning to the heat pump, releasing or gathering heat depending on the operating mode. Closed loop geothermal systems use a mixture of water and antifreeze in the underground piping loop. Leaks in closed loop systems are less serious because the refrigerant evaporates rapidly when exposed to the atmosphere.
3. **Open loop systems** - use water to exchange heat with the underground, but groundwater is pumped directly to the heat pump. The main drawback of open loop systems is that groundwater cannot be treated easily before circulating through the heat pump, exposing the system to corrosive substances or abrasive particles. Open loop geothermal systems are a viable option when groundwater conditions are suitable.

When a geothermal system is installed closed to a large body of water such as a lake, the piping that normally travels underwater can simply be submerged. This provides a simpler and less expensive installation, but it is only possible if the property has access to a large body of water.

Geothermal systems can be configured in either a liquid-to-air or liquid-to-water configuration. In the liquid-to-water configuration with a closed-loop or open-loop geothermal system, it is important to remember that the water circulating underground is completely isolated from the water circulating through the building.

### *16.7.2.2 Variable refrigerant flow systems*

Variable refrigerant flow (VRF), also known as variable refrigerant volume (VRV), is an HVAC technology characterized by using refrigerant lines directly to move heat, similar to how a mini-split air conditioner works, but without the use of air ducts or hydronic piping. In general, VRF systems have a large outdoor unit connected to several indoor units with refrigerant lines. The outdoor unit has one or more variable speed condensers, adjusting its continuous output according to the total heating or cooling demand of indoor units. This continuous configuration is significantly more efficient than using an ON/OFF control to run the condenser intermittently; and, equipment lasts longer by avoiding the mechanical wear of frequent starts and stops. (Variable Refrigerant, 2021) A variable refrigerant system allows for the usage of zones, allowing the system to turn off at times when certain zones do not require heating or cooling. Additionally, these systems can be designed for simultaneous heating and cooling in different zones, and heat recovery from one zone to another.

Variable refrigerant flow systems may be designed to operate as heat pumps, allowing reversible operation between heating and cooling modes. Some VRF designs are designed for cooling only; these systems are best suited for tropical weather.

Variable refrigerant flow systems are available in two-pipe and three-pipe configurations, and each option offers different performance features:

1. **Two-pipe VRF systems** - have a supply line and a return line between the outdoor unit and the multiple indoor units. This layout is simpler and less expensive than a three-pipe configuration, but it also comes with a limitation: the system cannot deliver simultaneous heating and cooling for different building, and all indoor units must operate in the same mode.
    A. Branch controllers: Some devices include branch controllers that allow simultaneous heating and cooling with a two-pipe VRF system. A branch controller uses the heat removed by units in cooling mode and delivers it to areas that require heating. The outdoor unit only provides balancing between heating and cooling loads.

2. **Three-pipe VRF systems** - involve two supply lines, one for heating and one for cooling, and a common return line. Indoor units are connected to all three refrigerant lines, and they have a branch selector that switches between the heating and cooling lines as needed.

Each option has advantages and disadvantages, and the best selection depends on project conditions:

1. Two-pipe VRF systems with branch controllers offer the most flexible configuration for future expansions. All refrigerant lines are connected to a common hub, and you can simply add more as required by new indoor units.
2. Three-pipe VRF systems allow a higher energy efficiency. However, they are less flexible for future expansions, since it is necessary to modify the existing refrigerant lines.

#### *16.7.2.3 Heat pump operation*

To provide cooling inside when it is hot outside, heat pumps have the following stages (note that the exact same steps occur in reverse to provide heat inside when it is cold outside):

1. Refrigerant enters the compressor (outdoor unit) of the heat pump system as a hot low-pressure gas and is compressed into a high-pressure gas.
2. Next a hot high-pressure gas, the refrigerant enters the condenser where it is condensed into a liquid. During the condensation process, the liquid refrigerant gives up its heat, which is radiated to the outside air.
3. Next a cold, pressurized liquid, the refrigerant moves into the expansion valve, which restricts the flow of the liquid. Upon exiting the expansion valve, the pressure lets up.
4. The cold, low-pressure liquid now moves into the evaporator, where it absorbs heat from air blown over the evaporator coils and turns into a gas.
5. Next a hot low-pressure gas once again, the cycle starts over. The cycle repeats until the temperature of the air in your home matches that set by the thermostat.

In colder temperatures a heat pump will run almost all the time to maintain warmer internal temperatures. A heat pump that runs all year round (HVAC system) will have more wear and tear. However, in contrast to a conventional furnace, the heat pump will generally heat more evenly. In extremely cold temperatures, heat pumps are not highly efficient. Also, the outdoor units should never be covered in snow. Although a heat pump can heat a home, when outside temperatures drop below freezing, the efficiency of a heat pump is affected as the unit requires more energy to maintain warm temperatures inside the home. Typical heat pump systems have an auxiliary electric heater added to the indoor or outdoor unit to add supplemental heat when outdoor temperatures drop below a specifically set degree. In specific setups, if outside heat is insufficient, the heat pump may have an attached electric heater that will supplement the outdoor environment with additional heat to meet the inside heat requirements. However, because electric auxiliary heating Is not very efficient, the addition of a furnace can be a solution to this problem, creating a system that relies on the heat pump as the primary heat source but automatically switches to the furnace when appropriate. The discharge temperatures of a heat pump will be significantly less than that of a furnace. However, during non-extreme temperatures, an efficient heat pump may use four times less electricity than a resistance heater.

Note that some heat pumps have a defrost mode. Different heat pumps have different ways of determining when to go into defrost. On a call for defrost, the reversing valve is energized, switching the system into the air conditioning mode. The outdoor evaporator becomes the condenser but at the same time the outdoor fan shuts off. This allows the high pressure refrigerant circulating through the outdoor coil to get very warm, melting the ice.

#### *16.7.2.4 Heat pumps combined with other atmospheric and water processing systems*

In addition to the main types of heat pumps (i.e., air, water, and geothermal), there are also several sub-types, including but not limited to:

1. **Hybrid heat pumps (a.k.a., dual fuel heat pump** or **add-on heat pump)** - uses both an electric heat pump and/or a fossil fuel gas furnace (natural or propane gas). In other words, a dual fuel system is a system with the ability to heat with a gas furnace and/or heat pump. Herein, the air-source heat pump uses a gas furnace for auxiliary or backup heating rather than the electric heating element (within the heat pump system). When the outside temperature drops too low (typically below the -1C to -3C (30F to 25F) the furnace will do most of the heating. Additionally, if the economic conditions change and either electricity or gas becomes more expensive or more abundant, then the least expensive option within the system can be chosen for a period of time.
2. **Solar heat pumps** - uses a solar powered boiler to increase the initial temperature of the water. This warm water then feeds into the heat pump evaporator for final processing, thereby reducing the overall amount of electricity consumed to produce hot water.
3. **Absorption heat pumps (AHP)** - is an air-source

heat pump driven not by electricity, but by a thermal energy (heat) source, such as combustion of natural gas, steam solar-heated water, air, or geothermal-heated water. These heat pumps are driven by heat as opposed to normal heat pumps that use electricity and mechanical energy. Absorption heat pumps can be used in situations where both heating and cooling is required. The principle of operation of an absorption heat pump is based on absorption and evaporation of a refrigerant.

4. **Gas-fired absorption heat pumps (a.k.a., gas engine heat pump)** - uses a generator, and an absorber, which combined is called a thermal compressor. This replaces the electric compressor, which is standard in air conditioning and heat pump systems. Note that there are also absorption (or gas-fired) coolers available that work on the same principle.

**NOTE:** *The heat transfer from a heat pump (or, heat pump combination) can heat water for radiators, or even circulate it under floors for heating.*

Most air conditioning units have a heat pump version. In other words, there are air conditioners that put out heat (i.e., they are heat pumps), however, they are sold on the market as air conditioning systems (even though they are heat pumps). In warm weather, a heat pump and an air conditioner are the exact same thing (i.e., perform the same function similarly). During the phase where the heat pump is cooling the interior environment it is using the same mechanisms as an air conditioner to do so. They both equally cool the interior environment. The difference is that an air conditioner can't heat the interior air significantly during winter. And, a heat pump can be used to create and/or support interior heating. In the case of cold temperatures outside, the external part of the heat pump absorbs heat from outside and brings the heat to the inside. However, the heat provided by a heat pump is less than that provided by conventional combustion furnaces and burners. An air conditioner and air-sourced heat pump look identical from inside and outside the building.

#### *16.7.2.5 Heat pump installation configuration options*

There are a few different ways to install heat pump systems based on the positioning of the system and whether or not it uses ducts:

1. **Ductless heat pump (a.k.a., split-ductless** or **mini-split)** - is used in buildings without ducts. They include two units: an outdoor compressor and indoor handlers (usually, a maximum of four). These systems do not require ductwork. These systems circulate refrigerant through the tubing that connects the indoor and outdoor units.
   A. **Single zone ductless heat pump** - consist of one outdoor unit and one indoor unit.
   B. **Multi-zone ductless heat pumps** - consist of one outdoor unit and two or more indoor units. Multi-zone units can be more cost-effective, because they have a cheaper upfront cost compared to installing multiple single zone heat pumps.
2. **Package ducted heat pump (a.k.a., packaged heat pump)** - wherein, all the mechanical components are housed in a relatively large, single, outdoor unit. Only the ductwork is found inside the building. This outdoor unit may be mounted on a concrete pad outside or even on the roof. Sometimes, a packaged unit also includes electric heating coils or a gas furnace, which supplements the heat pump to deliver warm air indoors during extremely cold weather conditions.
3. **Split ducted heat pump (a.k.a., ducted mini split)** - wherein, an indoor evaporative unit is placed in the attic, basement, or closet, while the condenser and compressor unit is located outside in a large metal box. Ducting is connected to the indoor unit and transfers air throughout the building.

#### *16.7.2.6 Decisioning selection of a heat pump*

Generally, heat pumps range from 1.2kW to over 10kW. Here are some factors to consider when choosing the size and type of a heat pump:

1. Does the system need to provide hot air, cool air, hot water, or some combination?
2. Will it need to be combined with other atmospheric and/or water processing systems?
3. What is the local climate, including the average seasonal high and low temperatures?
4. What is the level of insulation in the building?
5. What is the size of the building(s) and the number of occupants?
6. Is there ducting, or will there be ducting? If not then a ductless system is necessary.
7. Is there access to a lake or river? If not, then a water-sourced heat-pump is unavailable.
8. Is an air-sourced, ground-sourced, or water sourced heat pump the best option given the conditions and constraints?

### 16.7.3 Heating only atmospheric processing systems

*A.k.a., Heating machines, heating specific atmospheric fixtures, environmental heating mechanisms, heaters, heating fixtures.*

Heaters are machines that produce significant heat for an environment. A heater is really just a catch all term for a device that heats up an environment. There are several types of machines used to generate heat for an environment. The following systems only produce heat.

Firstly, heat for a building can either be produced centrally or by area:

1. **Central heating units** - have a central location for the heating device, be it in a machine room or attic or basement, where the heat is created and distributed throughout the building. These systems are generally part of an HVAC system. These systems are quite common in most houses, apartment complexes, and commercial buildings. Modern central heating systems are efficient enough that they typically won't require additional energy-wasting localized or space heaters. A furnace or boiler is the mechanism that produces the heat that a central heating system will then distribute to keep the internal environment warm. Modern central heating units, produce high amounts of heat, which is then distributed, generally, by forced-air through ductwork, by hot water circulating through pipes, or by steam fed through pipes. A central heating system uses some form of energy combustion (e.g., gas) and/or electricity.
2. **Space heaters (a.k.a., portable heaters, panel heaters, area heaters, etc.)** - are portable units that lack the ability to transfer heat to another location. These heaters heat a limited area. These systems are generally electric. If they use any form of combustion, then [generally] they should only be used outdoors.

Area heaters are generally installed under windows and on perimeter walls of the building. This allows them to counteract the cold air radiating off the window glass, as well as the areas where the building's greatest heat loss tends to happen.

### *16.7.3.1 Combustion furnace ("fire box")*

Furnaces get their name from the Greek word "fornax," which means oven. A furnace generates heat by burning a fuel source (gas, oil, or biomass). Sometimes furnaces are designed to only heat the local environment, but more often, furnaces produce hot air and force it throughout a building via a series of ducts.

> **NOTE:** *Many furnaces share the same interior cabinet space, ductwork and thermostat with the central air conditioner.*

The first furnaces were stone or clay structures that used coal and/or wood to create intense heat. The combustion source for a modern furnace could be:

1. Biomass (e.g., wood, wood chips, or wood pellets).
2. Bio and/or natural gas (most common).
3. Coal hydrocarbon.
4. Oil hydrocarbon.

The combustion chamber is the part of the furnace where some combustible element (fuel) is burnt to create the heat that enters into a heat exchanger. There are many types of combustion furnace.

Natural gas furnaces are environmentally friendlier and more energy efficient than oil furnaces. Natural gas also costs less than oil. Not all locations have access to all fuel sources. There are many similarities, but each type has its own unique features, as well as pros and cons for different buildings. Natural gas furnaces are environmentally friendlier and more energy efficient than oil furnaces. Natural gas also costs less than oil. There must be a supply of natural gas in the area for this type of furnace to be installed. Oil furnaces are less expensive up front than natural gas, but the fuel costs will depend on the highly volatile oil market. Oil is also less eco-friendly than natural gas. Oil furnaces require more cleaning due to the buildup of soot and debris. However, oil furnaces can be installed in areas where there is no natural gas.

One of the biggest benefits of a furnace is its reliability. Though modern heat pumps work pretty well in temperatures that dip below freezing, they still have to source heat from somewhere. If a region experiences long, cold winters, it's generally best to choose a furnace, which generates its own heat. Another benefit is that furnaces tend to last longer than heat pumps. Since they are used only during the heating season, they generally require less maintenance and sustain less wear and tear. While the average useful life of a heat pump is just 10 to 15 years, both gas and oil furnaces can easily last 20 to 30 years with proper care.

There are several types of furnaces used in HVAC systems, including but not limited to:

1. **A sealed combustion furnace (a.k.a., sealed combustion heater)** - draws on air from outside the house to use for burning fuel (i.e. combusting fuel). The jets of the burners in a gas furnace must have air to mix with the gas. A sealed combustion furnace, however, isn't open to the house. It's closed-off and draws air through a plastic PVC pipe that connects it to the outside. A second pipe attached to the combustion chamber sends out the exhaust. The combustion process is entirely isolated from the air in a house. Sealed combustion furnaces do not remove air from indoors, and this can be help in keeping humidity balanced inside in winter.
2. **An atmospheric furnace** - uses air from within the

building. The combustion chamber in the furnace is exposed to the space around it so the furnace can draw air directly inside. An atmospheric combustion chamber draws air from inside the house as it runs, causing an air deficit. Air from the outside,. which is usually drier in the winter, then rushes in to replace it; thus, creating a drier atmosphere.

#### 16.7.3.2 Electric furnace heater

*A.k.a., Electric furnace, electric resistance heater.*

Electric furnaces are a type of furnace that runs off electricity producing heat by heating metals. The source of power for an electric furnace is electricity. A fan is used to circulate the heated air.

#### 16.7.3.3 Steam water heaters

Steam heat is created by converting water from a boiler into steam. Steam is an efficient source of heat for large buildings; because, on the basis of unit mass, steam can hold a significant amount of energy. It ranges from approximately 2326 to 2908 kJ/kg (1000 to 1250 BTU/lb), which can be converted into mechanical operations as heat or using a turbine. In other words, steam-based heaters can be used for more than one purpose; they can be used for heating [water] (to provide thermal warmth) as well as generating electricity.

Most of the heat content in steam is latent heat; therefore, it can be transported at the same temperature. Some of the major advantages associated with using steam systems include the high capacity for heat, low toxicity, high efficiency, and low cost as compared to other alternatives.

Note here that steam heaters can be very dangerous. If a steam pipes breaks around animal occupants, the steam can seriously harm and even kill. Steam systems need to be inspected regularly (often, annually).

#### 16.7.3.4 Boilers (boiler plants)

A boiler is a device that heats water. Most boilers supply hot water below the boiling point, which is then distributed through hydronic piping to provide space heating. Some boilers use a steam-based heating and distribution system. Here, water is turned into steam, which is denser than air and lighter than water. Air doesn't hold heat well, and water is difficult to move, so steam is a good medium for transferring heat to where it is needed. In most instances, a furnace or other heating device is attached to the boiler. The hot water or steam is distributed through a series of hot water pipes and/or ducts that make up a central heating system.

Some boilers provide both hot water and hot water atmospheric heating, which can eliminate the need to have a separated central heating system and hot water heater. This does, however, require hot water piping throughout the architecture in a closed loop (primarily) cycle that recycles back into water to be heated again. These systems generally use hydrocarbon combustion to provide sufficient heat, however, smaller systems may use electricity only. The source of power for a boiler could be:

1. Fuel combustion - tends to be the most economic option.
   A. Wood (biomass).
   B. Natural gas (most common).
   C. Propane.
   D. Coal.
2. Electricity - these boilers have a much higher operating cost than combustion-based boilers, which limits their usefulness in buildings.

The boiler plant must be designed so that building occupants are not exposed to components at high temperature, and it must be properly vented to prevent the accumulation of combustion gases. Steam-based hot water distribution systems can be very dangerous if a pipe bursts. In such case, they are likely to kill occupants in rooms where the steam (or very hot water) enters.

#### 16.7.3.5 Water-based space heater

Integrated or combination water and space heating systems usually cost more than a separate water heater and furnace or boiler, but installation and maintenance costs may be less. For example, you won't need multiple utility hook-ups since there's one source of heat. There also aren't as many moving parts to maintain or service. Some of these high efficiency systems may also provide power savings, and hence, lower utility costs (market only). The sizing of a combination system involves several different calculations than those used for sizing a separate water heating or space heating system.

To determine the energy efficiency of a combination water and space heating system, use its combined appliance efficiency rating (CAE). The higher the number, the more energy efficient. Combination appliance efficiency ratings vary from 0.59 to 0.90. The higher the number, the more energy efficient model.

#### 16.7.3.6 Water-based radiant floor heater

Water-based radiant floor heating systems are fuelled by either natural gas, propane gas, or oil. These system do not “boil” the water, rather they heat it to below boiling. This hot water is then pumped to radiant floor tubes, to radiators, or it is run through a heat exchanger.

#### 16.7.3.7 Furnace and boiler combination

A system that produces hot air and produces hot water. These systems are generally gas, but may be electric. The water from a boiler system can be circulated, like an air ducted vent system, to heat the interior.

#### 16.7.3.8 Electricity-based radiant floor heater

Electricity-based radiant floor heating systems use electricity to heat metal under the floor.

#### 16.7.3.9 Portable electric space heaters

*A.k.a., Electric space heater, portable space heater, portable electric heater, portable heater.*

Electric heaters use electricity to heat metals, and include a fan to blow and circulate the heated air.

### 16.7.4 Cooling only atmospheric processing systems

*A.k.a., Cooling machines, cooling specific atmospheric fixtures.*

The following systems only provide cooling (i.e., reduce heat).

#### 16.7.4.1 Air conditioning machines

*A.k.a., AirCon, AC, A/C, air cooling machine.*

It is important to note here that an air conditioning system cannot provide significant heating to an interior environment; an air conditioner is only capable of cooling. This means that it extracts heat from the indoor air and transfers the heat outside. Note that some air conditioning systems are sold as air conditioners, but are actually reversible heat pumps (i.e., because they are actually heat pumps, they can provide heating). An air conditioner is typically paired with a heating system (e.g., electric heater or furnace) to provide heat when it is cold outside. The components used in an air conditioner are also similar to a heat pump, consisting of an outdoor unit housing a condenser, compressor, and fan. The indoor unit includes an evaporator coil (a.k.a., evaporator core) and a fan. The evaporator coil is the part of the system where the refrigerant absorbs heat. That is, it's where the cold air comes from. The evaporator coil is located inside or near the air handler where the blower fan is. Evaporator coils are made from copper, steel, or aluminum because these metals conduct heat easily. A refrigerant circulates through the condenser and evaporator, absorbing heat from indoor air and transferring it outdoors. While the evaporator coil picks up heat from indoor air, the condenser coil releases heat into outdoor air. The resulting cold air moves through the ducts using the fan and cools the indoors. Functionally, an air conditioner has two connected coils with continuous flowing refrigerant fluid inside of them. The two coils form the two primary processes the machine performs. The coil inside the build is called the evaporator. The coil exterior the building is called the condenser (condenser). The fundamental engineering principle is to keep the evaporator (inside part) colder than the room temperature, and the condenser hotter than the surroundings. With this material configurations making this conditions where the continuously flowing fluid absorbs hear from the room and ejects it out to the exterior surroundings. To achieve this engineering objective, the machine also requires a compressor (mechanism) and an expansion value (mechanism). The compressor mechanism sits near to the condenser, and the expansion valve sits near to the evaporator. The compressor increases the pressure on the refrigerant fluid. By compressing the fluid, the compressor dramatically increases its temperature. Turning it into a hot gas that can be ejected exterior coil (condenser coil). A fan in the condenser unit makes this task more efficient. During the heat ejection phase, the gas turns back into a liquid. An expansion valve fitted at the exit of the condenser coil restricts the refrigeration flow, thus reducing the pressure on the refrigerant fluid. The low pressure refrigerant should be at a temperature lower than the interior's temperature.

By passing the air of the interior environment the machines cools (reduces the temperature) of the interior atmospheric (and possibly, the whole interior material) environment. The refrigerant gets converted to vapor during this heat absorption process. There is one significant issue with this design - near to the evaporator coils, the air temperature will be low, which will lead to water condensation on the evaporator coils. Therefore, a pipe is required to remove this water condensate.

Note that compressors can be damaged if the input refrigerant is not in gaseous form. A more advanced expansion mechanism (which may also use its own internal refrigerant) may be used to tightly control the output of the compressor system. These more complex compression mechanisms have a variable/dynamic restriction flow system. These mechanisms ensure that the compressor receives the refrigerant in pure vapor form. Herein, the refrigerant flow rate and the room temperature are actually controlled by the speed of the compressor.

Modern air conditioners dehumidify as they cool; this can be seen by the water that drains away from the machine. However, this dehumidification is incidental to their main job of controlling temperature. In general, they cannot independently control both temperature and humidity.

The refrigeration cycle in a typical AC works as follows:

1. Using electricity as its power source, the refrigerant flows through a closed system of refrigeration lines between the indoor unit and the outside unit.
2. Warm air from the inside of the building is pulled into ductwork by a motorized fan.
3. The refrigerant is pumped from the exterior compressor coil to the interior evaporator coil, where it absorbs the heat from the air.
4. This cooled air is then pushed through connecting ducts to vents throughout the home, lowering the interior temperature.

There are two primary types of air conditioning systems as categorized by the presence of ducting as well as installation configuration:

*Note: These are all split atmospheric processing machine with a part of the machine interior to the structure and another part of the machine exterior to the structure. Both the interior and exterior parts need ambient air (i.e., do not box or close them in). If they are confined, then recirculation will occur and lead to high inefficiency.*

1. **Ducted (vented, central, centralized) air conditioner systems** - a centralized air conditioning system uses one centrally located indoor unit, with an exterior fanned compressor (a.k.a., condenser unit, heat pump), that delivers cool air throughout the building through a series of ducts and vents. In other words, a central A/C system generates cold air at a single point inside the building and distributes it via ducts throughout the building. This unit is generally placed on the roof, or on a concrete slab next to the building. The unit is connected with the supply and return ducts installed along the walls of a building. The inside part of the machine is heat absorbing when cooling (or, heat emitting if a heat pump in heating mode). The outside unit will release heat to the exterior environment. In a cooling arrangement, a condensing unit is located outside and contains the condenser coils, a compressor, and the compressor fan motor. The evaporator coils (cooling coils) are located inside the building. Note that in a heating and cooling configuration with an air handling furnace, the inside evaporator coils are located on top of an air handling furnace. The air handling furnace uses a blower fan motor to draw air through the return vent, blow it past the evaporator coils, and force the air through the structure's venting network. The return air is then drawn back through the return vents, cycling the air. Once the room has reached a set temperature, the thermostat turns the condensing unit off until the room temperature moves outside set parameters. Central air conditioners usually include a large particle filter (not small particle filter, such as, HEPA filter). These filters should be checked monthly and replaced ever couple of months (as needed). A typical central air conditioning system is a two-part or split system that includes:
   A. The outdoor unit contains the condenser coil, compressor, electrical components and a fan.
   B. The evaporator coil, which is usually installed on top of the gas furnace inside the home.
   C. A series of pipes, or refrigeration lines, connecting the inside and outside equipment.
   D. Refrigerant, the substance in the refrigeration lines that circulates through the indoor and outdoor unit.
   E. Ducts that serve as air tunnels to the various spaces inside your home.
2. **Ductless (non-vented, local, mini-split, minisplit) air conditioner systems** - do not require ductwork for air supply. The cold air blows through a slim indoor unit mounted on the wall. These units are powered by a single exterior compressor, and connected by refrigerant tubing and electrical wiring. Using electricity as its power source, the refrigerant flows through a closed loop system of refrigeration lines between the indoor unit and the outside unit. Ductless mini-splits offer zoned temperature controls, meaning that it is possible to set each zone to a different temperature. These systems generally have lower quality air filtration. The following are types of ductless systems (which apply to heat pumps as well as an air conditioner).
   A. **Single-split ductless system** - uses refrigeration technology to transfer thermal energy from one outdoor unit to one indoor unit.
   B. **Multi-split ductless system** - uses refrigeration technology to transfer thermal energy from one outdoor unit to many indoor units.
   C. **Window air conditioner systems** - are devices that fit within a window port.
   D. **Portable air conditioner systems** - are portable air conditioning devices.

There are two primary types of air conditioning systems as categorized by the presence of motor speed controller:

*Note: These are all split atmospheric processing machine with a part of the machine interior to the structure and another part of the machine exterior to the structure.*

1. **Inverter** - An inverter is energy saving technology that eliminates wasted operation in air conditioners by efficiently controlling motor speed. In inverter type air conditioners, temperature is adjusted by changing motor speed without turning the motor 'on' and 'off'; instead, the compressor runs on different power modes. An inverter air conditioner can regulate the speed of its compressor motor. This type of system will reduce temperature fluctuations in the environment. With inverter technology, both the temperature and the humidity will remain constant. Simply by adjusting the speed of the motor(s), the compressor speed, flow rate, cooling capacity, and temperature can all be controlled accurately. The advantages of inverter systems include:
   A. Less electricity consumption.

   B. Constant air temperature.
2. **Non-inverter** - A non-inverter air conditioner cannot regulate the speed of its compressor motor. The motor runs at full speed, but turns off once room temperature drops to the desired level. Non-inverter systems cycle off the [exterior] compressor once the set temperature is 1-2 degrees approximate the temperature set by the user. The compressor turns back on once the temperature is 1-2 degrees outside the set temperature. This change will cause an ~4 degree continuous temperature and humidity fluctuations in the  environment. The disadvantages of an non-inverter system include:
   A. More electricity consumption.
   B. Environmental variable fluctuations (e.g., fluctuations in temperature and humidity).

Air conditioners (of the type: wall units, cassettes, ducted units) are generally fitted at higher levels on the walls of a room in order to produce quick cooling in the room. As air is cooled, it contracts, become denser and sinking. Warmer air at the bottom is displaced, and due to it being less dense, it rises. This process continues and sets up a convection current that will allow thermal transfer to occur, wherein warmer air rises, is taken in by air conditioner, and cooler air is output in a horizontal or downward direction. Since cold air is emitted from the A/C unit blowers, the unit has to be placed at the top of a room to allow a convection current to form. Note that there are some A/C units that "throw" the cool air upwards to generate this convection current; however, the bulk of A/Cs available are situated at the top

#### *16.7.4.2 Chiller plants (water-based)*

*A.k.a., Water-based and centralized air cooling system, water-based and centralized air conditioning system.*

Chiller plants use chilled (Read: cooled) water to remove heat from a building. Chiller plants are commonly used for air conditioning in large and/or integrated facilities. In manufacturing applications, they also play an important role in process cooling. Chiller plants use chilled (cold) water to remove heat from indoor spaces. Chiller plant systems cool large amounts of water in a central location, and then pump the cool water to distal air handlers that circulate and cool the local air. The temperature of chilled water increases as it captures building heat within each air handler, and is then returned to the chiller plant to be cooled again. Chiller plants provide a high cooling output and have a much higher efficiency than unitary air conditioners. Additionally, hydronic piping requires less space than air ducts, since water can hold more heat than air in a given volume. (Chiller Plants, 2021)

A chiller plant systems consists of the following primary elements:

1. **Large refrigeration condenser:** Chillers are larger versions of air conditioning condensers, with cooling capacities often reaching several hundred tons of refrigeration.
2. **Pump and hydronic piping:** A pump system that distributes chilled water throughout the building, and the piping used for this purpose is called hydronic piping.
3. **Cooling coils and fans (air handlers):** Chilled water is delivered to cooling coils in air-handling units, where fans blow air through the coil to reduce its temperature.

All chiller systems use water to remove heat from buildings, but they differ in the method used to release the heat to the exterior environment:

1. **Air-cooled chillers** - are exposed directly to outdoor air, just like the condenser units of smaller air conditioning systems. A fan is used to establish airflow through the chiller, and the condenser is constantly releasing heat outdoors.
2. **Water-cooled chillers** - are not in contact with outdoor air, and instead they use a secondary water loop reject heat. This water loop connects to an outdoor cooling tower where heat is released, and water is then returned to the chiller to remove more heat.

Note that air-cooled chillers have a simpler configuration because they are only connected to one hydronic piping circuit, while water-cooled chillers use another loop to reject their own heat. However, water-cooled chillers typically offer a higher efficiency than their air-cooled counterparts.

Most chiller compressors can be classified in the following ways:

1. **Reciprocating compressors** - use pistons to compress refrigerant. These resemble the engine of a car. Depending on how the chiller is designed, the compressor and its motor may share the same housing, or they can have separate housings. Reciprocating compressors are the most affordable, and it is possible to use multiple units together to serve variable loads. However, reciprocating compressors are disadvantaged by their low efficiency. Additionally, their piston mechanisms require more maintenance.
2. **Centrifugal compressors** - are similar to centrifugal pumps, since a rotating impeller is used to increase pressure. Their cooling output is controlled with inlet valves that regulate the flow of refrigerant in to the compressor. Centrifugal compressors are the most efficient type when

operating at rated capacity. They are also very compact, and available in a wide range of sizes. The main disadvantage of centrifugal compressors is their sharp drop in efficiency when operating under part-load conditions.

3. **Rotary-screw compressors** - have two matching helical screws that rotate at high speed, and refrigerant is compressed in the space between them. The cooling output is controlled with a special valve that adjusts the volume ratio.

Although a centrifugal compressor is more efficient at full load, rotary-screw compressors offer the highest efficiency under part-load conditions. Since buildings do not require the full cooling output all the time, these compressors normally have the lowest running costs. The main disadvantage of rotary-screw compressors is their higher price, compared with reciprocating and centrifugal units of the same capacity. They are only recommended in applications that benefit from their high efficiency at part load.

Note that chiller plants can be equipped with ice storage tanks to increase their energy performance.

#### *16.7.4.3 Water-based cooling towers*

Water can absorb large amounts of heat when it evaporates; hence, cooling towers normally use that physical principle to expel heat from a building. Cooling tower systems that use water evaporation to achieve their cooling effect are classified as either (Cooling Towers, 2021):

1. **Open circuit cooling towers** - discharge water carrying the building's heat directly on the upper side of the unit. Water falls against an upward flow of air, which is established by a fan above the cooling tower. With the combination of forced airflow and water evaporation, the unit releases a large amount of heat in a relatively compact volume.
    - The water is exposed directly to the atmosphere before it returns to the chiller, heat pump or process being cooled. Therefore, it must be treated constantly to prevent contamination with particles or bacteria.
    - Since some water evaporates as it falls through the cooling tower, it must be replenished constantly to sustain the required flow through the HVAC unit or process being cooled.
2. **Open circuit contamination prevention cooling towers** - this system operate similarly to the prior system, but In this case, the water stream from the chiller or process does not reach the cooling tower directly, and instead it cools down in a heat exchanger connected to the cooling tower.
    - This configuration requires an extra water loop and pump, but it prevents contamination with bacteria or particles.
3. **Closed circuit cooling towers (adiabatic cooling towers)** - operate similarly to open circuits, but do not expose water to the atmosphere, and instead, circulate it through a coil inside the unit.
    - This system uses a fan to establish an upward airflow, but water is sprinkled from a separate source. As a result, the water that flows through the chiller plant or cooled processes is never exposed to the atmosphere.
    - These systems save water.
    - Also, by deactivating the sprinklers when airflow from the fan can provide enough cooling by itself.

Cooling towers normally complement a major air conditioning system such as a chiller or a large heat pump in the following three ways:

1. While the compressor units in heat pumps and chiller plants gather heat from indoor spaces, cooling towers are used to remove the heat from the compressors themselves.
2. Since large HVAC units are often found indoors, while cooling towers are installed outdoors, both devices are normally connected with a water loop. The piping loop is equipped with a pump to keep the water in circulation.
3. There are special applications where a cooling tower can provide direct heat removal, without being connected to a chiller or heat pump.

There are two methods to increase the energy efficiency of a cooling tower:

1. By using high-efficiency motors to drive the pump and fan in the cooling tower system.
2. By adding speed control capabilities to these motors. These speech control mechanisms use variable frequency drives (VFD). A VFD can lower the speed of a fan or motor under partial load conditions, achieving a drastic reduction in energy expenses.

**NOTE:** *Under some climate conditions, it is possible to use a waterside economizer to increase the efficiency of a chiller or heat pump. When weather conditions are adequate, a waterside economizer can assume a portion of the space cooling load, reducing the electricity consumed by chillers or heat pumps.*

#### *16.7.4.4 Refrigeration and freezing machines*

Refrigerators and freezers use electricity and refrigeration technology to reduce the temperature of an enclosed space. These systems are considered appliances that provide cold storage space for food, liquids, lab samples, and other heat-sensitive items. The purpose of the refrigerator is to keep food fresh for a longer duration of time. In general, food kept in an environment around 6 degrees celsius will remain fresher for a longer duration of time. Hence, the task of a refrigerator is to maintain a low temperature.

Refrigeration and freezing machines have the following parameters:

1. Size of machine in liters as total gross capacity.
2. Size of refrigeration in liters.
3. Size of freezer in liters.
4. Degree of coldness.
   A. Freezerless refrigerator (no-freezer refrigerator).
   B. Freezer.
   C. Combination refrigerator and freezer.

Refrigeration-type appliances, like many HVAC systems, requires clearance space behind, to the sides, in front, and at the top. This clearance space ensures the relative free flow of air around the appliance.

## 16.7.5 Purification atmospheric processing systems

*A.k.a., Purification specific atmospheric fixtures.*

Atmospheric filtration systems can be integrated into architecture in two ways:

1. In-line filters integrated into HVAC systems, or
2. Portable filtration systems that are separated, individual items (i.e., portable air filters).

Household air filters are available in two basic types:

1. Media filters create a physical barrier that traps minute particles.
2. Electronic filters (electrostatic precipitators) use a high-voltage charge to attract and capture contaminants.

However, more completely, there are four types of whole house filters:

1. Flat filters (normal for central HVAC systems).
2. Extended media filters (HEPA type filters).
3. Electronic filters (electrostatic precipitators) - these systems produce some ozone ($O^3$) as a byproduct.
4. Ultraviolet filters.
5. Portable room filters.
6. Ozone ($O^3$) systems

### 16.7.5.1 *Ozone generators*

Ozone generators introduce ozone gas into the environment to purify the air of pathogenic organisms and statically charge airborne particles so they more easily stick to surfaces. Ozone generators take in oxygen from the air ($O^2$) and give it a strong electrical charge. This electrical charge forces the oxygen molecules to rearrange themselves and form $O^3$. Ozone generators have several primary uses:

1. Killing airborne mold and mildew
2. Preventing the growth of mold and mildew.
3. Killing bacteria and viruses.
4. Removing odors.

It is important to note here that high concentrations of ozone can damage materials and harm human lungs. Other types of air purifiers generally do not release pollution into the air. While ozone generators release a gas that is considered a pollutant to clean and sanitize.

## 16.7.6 De-/humidifying specific atmospheric processing systems

*A.k.a., De-/humidification specific atmospheric fixtures.*

It is possible to control the humidity of the general indoor environment and localized indoor spaces to:

1. Provide greater comfort.
2. Protect materials.
3. Dry wet textiles.

Within the indoor environment, low and high air humidity can causes discomfort for humans, it can also lead to several health issues, and can be damaging to buildings, technologies and other indoor objects. Humidity control is important in all indoor environments.

The most common material concerns for humidification in a building include, but are not limited to:

1. Low humid air can cause dryness in wooden floors, surfaces and furniture making them more prone to deformation and cracking.
2. Low humid air can cause dryness in paint and plaster causing it to crack and fall off.
3. Especially humid air can precipitate water within an enclosed environment and lead to mold growth.

Humidification systems can also protect sensitive electronic equipment from electrostatic discharge.

### 16.7.6.1 *Humidification systems (humidifiers)*

Outdoor air tends to have the lowest humidity during winter, and it becomes even drier as it passes through heating systems. As a result, indoor air can easily reach a relative humidity value below human comfort.

The following are the most common types of humidification systems:

1. **Steam humidifiers** - increase indoor air humidity with a controlled dispersion of steam, often with the assistance of ventilation systems. Steam-based humidification is the most expensive method but also the cleanest, and for this reason it is preferred in healthcare applications.
2. **Atomizing humidifiers** - spray water at high pressure to increase indoor air humidity, and they have the lowest operating cost among humidification systems. Atomizing humidifiers are also characterized by their flexible design, and adaptability to serve a wide variety of humidification loads.
3. **Ultrasonic humidifiers** - produce a cool mist to humidify indoor spaces. They are less efficient than atomizing humidifiers, but still much more efficient than steam humidifiers. The mist produced by ultrasonic humidifiers is quickly absorbed into the air, preventing the accumulation of droplets on surfaces.

Humidification is measured in kilograms per hour (kg/h).

#### *16.7.6.2 De-humidification systems (dehumidifiers)*

Outdoor air tends to have the highest humidity during summer. As a result, indoor air can easily reach a relative humidity value higher than human comfort and appropriate conditions for indoor technologies and other objects.

De-humidification is measured in kilograms per hour (kg/h).

#### *16.7.6.1 Drying machines*

Drying machines are used to dry textile materials and remove separated fibers (Read: lint). Lint sticks to clothes that have not been dried in a drier and often enters the atmosphere when the textiles are moved. Lint is a common source of indoor and outdoor air pollution and can be harmful (particularly over time) to human respiratory health. Additionally, without a drying machine, if the clothes are dried indoors, then the humidity in the local environment will increase.

All dryers use heat, air, and motion to catalyze the process of drying textiles while using electricity. To perform the drying function, drying machines create warm/hot air within which wet textiles are tumbled within a rotating drum. There are two categories of drying machine based upon the different ways they produce heat:

1. Electric heating coils.
2. Gas burners.
   A. Natural gas (most common).
   B. Propane (least common).

Gas and electric dryers work similarly, but gas models typically cost less to operate because they dry clothes faster. Hence, gas dryers are more energy efficient than electric only dryers. Gas drying machines also dry clothes more quickly because they heat up more quickly. Most electric dryers require a 240V outlet to provide enough power to produce heat and tumble the clothes. Most new gas dryers use 120 volts of electricity.

Drying machines come in two general types depending upon whether they have a vent to the exterior environment:

1. **Ventless dryers** - dryers that do not require a vent to the outside. These dryers are used when there is no vent to the outdoor, or venting to the exterior is not possible. When using a ventless dryer there is no need to cut holes in the walls or run ducting. In Europe, ventless dryers are more common than vented dryers. The two major types of ventless dryers are:
   A. Condensation dryers.
   B. Heat pump dryers. Heat pump dryers are a newer type of ventless dryer.
2. **Vented** - dryers that have require a vent to the outside. In the United States, vented dryers are the most common.
   In general, ventless dryers are more expensive than vented options. Additionally, ventless heat pump dryers are more costly up-front than condensation ventless dryers. However, the operating costs for ventless heat pump dryers are lower - half or more the cost per load of a traditional vented dryer in gas or electric.

## *16.8 Installation of atmospheric system*

There are many ways to install atmospherics. These systems are usually embedded into structure.

## *16.9 Operation of atmospheric system*

This system is more split in terms of operational characteristics on the supply and demand sides, and depends on installed configuration. With ducts, there is the need for supply side dynamic air pressure. On the demand side, the user will operate a thermostat and possibly airflow volume and/or direction control system in order to adjust temperature of the air, the amount of air, and the direction of air.

### 16.9.1 Atmospheric load demands

*A.ka., Electrical loading.*

HVAC loads are measured in several ways, most notably, energy consumed to produce:

1. Conditioned air flow, and
2. Surface temperature.

In order to do work, HVAC systems are split into a power usage system and an airflow and surface temperature changing service system:

1. A power usage system:
   A. Energy consumed may be by electricity or combustion of fuel.
      1. Most HVAC electrical loads are measured in watts [of electrical] power. Often, the kilowatt hour (kW.h)
      2. Heating and cooling systems can be measured in BTU [of heating or cooling] power
2. An airflow conditioning (production and distribution) system:
   A. Airflow volume is air flow rate, or quantity of air being moved, which is measured in:
      1. m3/sec (cubic meters per second) or
      2. cubic feet per minute (CFM).
   B. Airflow velocity (Read: distance travelled per unit of time) is measured by sensing the pressure that is produced through the movement of the air. Velocity is also related to air density with assumed constants of 70° F and 29.92 in Hg. Air velocity is generally measured using anemometers, which are one of the most effective instruments for measuring air flow, or the speed of the air, and are available in vane and hot-wire technologies. The vane anemometer is in essence a small fan driven by the movement of air across the fan blades. The hot wire anemometer uses a heated wire that is cooled by the movement of air across the wire. It is possible to measure the velocity at different points in a duct and find the average velocity in the duct. The most common measuring units for velocity are:
      1. Meters per second (m/s, m/sec)
      2. Feet per minute (FPM)
   C. Temperature production is measured in kelvins or Celsius (or Fahrenheit in imperial).
   D. Static pressure is measured using a manometer with pressure probes. Early manometers used a column of water to reflect system pressure. A manometer is an instrument used to measure and indicate pressure. The air pressure physically elevated the water in a measured in inches, which is why static pressure is expressed today in inches. Readings need to be taken at the supply side and return side of the system. It is an important design consideration to have these openings built into the design so that post installation construction to drill holes is not required. The most common measuring units for pressure are:
      1. kPa
      2. psi
      3. H2O
3. The conduit lines (ducting, transmission lines) and filters are another type of load.
   - Friction causes losses in conduit lines and filters.
4. Non-usage, but presence, may still equate to system service usage.
   - If a usage circuit has no load in the form of a power factor of zero the user would consume NO watt.hours, but the supplier may still have to send static pressure to them and incur real energy losses in conduits, fans, and filters. Power factor is the relationship (phase) of volume and velocity in HVAC production-distribution system.

## *16.10 Engineering calculations for atmospherics*

Factually, heat will flow spontaneously from a region of higher temperature to a region of lower temperature. Heat will not flow spontaneously from lower temperature to higher, but it can be made to flow in this direction if work is performed. The work required to transfer a given amount of heat is usually much less than the amount of heat present. The amount of work required to drive an amount of heat Q from a lower-temperature reservoir (e.g., ambient air) to a higher-temperature reservoir (e.g., the interior of a building) is:

- W = Q / COP
- Wherein,
  - W is the work performed on the working fluid by the heat pump's compressor.
  - Q is the heat transferred from the lower-temperature reservoir to the higher-temperature reservoir.
  - COP is the instantaneous coefficient of performance for the heat pump at the temperatures prevailing in the reservoirs at one instant.

### 16.10.1 Calculated engineering performance of HVAC systems

The following are terms used in measuring the performance of a HVAC system:

1. **COP rating (coefficient of performance)** - indicates the ratio of heating or cooling provided by a unit relative to the amount of electrical input required to generate it. The higher the number, the more efficient a heat pump is and the less energy it

consumes. COP is not a good indicator of efficiency because it only gives a snapshot of performance at very specific good conditions.
- COP = heating/cooling output (kW) / electricity input (kW).
    - For example, if an air conditioner creates 5kW of heat from a 1kW electrical input, its COP is 5.0.

2. **SCOP rating (seasonal coefficient of efficiency)** - the manufacturer has to test the units at different outside air temperatures. Units are expected to operate for a certain number of hours per temperature, which simulates the hot season.
    - The higher the number, the more efficient a heat pump is and the less energy it consumes.
3. **AFUE rating (annualized fuel utilization efficiency)** - is a measure of how efficiently a unit uses fuel. All combustion furnaces have an energy efficiency rating known as the AFUE. This is a percentage that shows how much of the energy consumed by the furnace becomes heat rather than escaping as energy loss. The higher the AFUE percentage, the more efficient the furnace is. This measure is for oil or gas (not electric) fired heaters and boilers. This rating compares the heater's annual heat (energy) output to its annual energy input in Btu. The calculation includes expected pilot flame losses and heater use during a typical year at an "average" location. The higher the rating, the more efficient a unit is.
    - In the U.S.A. the minimum allowed AFUE rating for a non-condensing (typical home heater) fossil-fueled, warm-air furnace is 78 percent; the minimum rating for a fossil-fueled boiler is 80 percent; and the minimum rating for a gas-fueled steam boiler is 75 percent. However, there are some systems capable of very high AFUE's of around 97 percent.
4. **SEER rating (seasonal energy efficiency ratio)** - is the total cooling capacity of an air conditioner or heat pump in Btus during its normal annual usage, divided by the total electric input in watt-hours during the same time period. In other words, SEER is calculated by dividing the cooling output of the unit in a given season by the energy it used during that period. It measures a heat exchange efficiency in cooling mode. The higher the SEER number, the more efficiently the unit is at converting electricity into cooling
    - High efficiency units must have a SEER of at least 14. In the U.S.A., at present, the minimum standard SEER for newly manufactured air conditioning and heat pump units (other than window units) is 13 SEER.
    - It should be note that a unit's actual SEER rating will decline over time as coils get dirty, motors and compressors age, and the refrigerant degrades. The SEER rating also declines as the outside temperature rises. If the unit is installed incorrectly or the ductwork is leaky and not well made, the actual overall SEER rating can be much lower as well.
5. **HSPF (heat season performance factor)** - is a measure of a heat pump's efficiency in heating mode. It measures the total heating output of the heat pump during its normal annual usage in BTUs divided by the total electric input in watt-hours during the same time period. It is used to measure a heat pump's efficiency when it is in heating mode (note: similar to how the SEER rating measures efficiency in cooling mode). It is only used with heat pumps. The higher the HSPF, the more efficient the heat pump. In other words, the higher the HSPF, the less the unit costs to heat a space during one year. A heat pump system with a high HSPF score will perform better during cold snaps.
    - Split system heat pumps that are considered high-efficiency have at least an HSPF of 8.2 (some units currently go as high as 9.35). Ground source heat pumps ("geothermal") tend to have high HSPF's because the heat source (ground temperature) is very stable and predictable, therefore the equipment can be designed very specifically.
6. **EER ratings (energy-efficiency ratio)** - is the ratio of the cooling output in Btu's divided by the unit's power consumption in Watts at a specific temperature (usually 95 degrees Fahrenheit). This rating is only useful for hot climates. The higher the EER, the more efficient the model.
    - For example, if an air conditioner generates 5kW of cooling from a 1kW electrical input its EER is also 5.0.
7. **BTU rating (British thermal unit)** - measures the amount of heat energy needed to raise one pound of water to one degree Fahrenheit at sea level. The higher the BTU, the faster the unit can cool a space.
8. **Ton** - is used for air conditioning and heat pumps as a measure of energy usage in british thermal units (Btu). The common rating term for air conditioning size is the "ton," which is 12,000 Btu per hour of cooling. Before refrigeration air conditioning was invented, cooling was done by saving big blocks of ice. When cooling machines started to get used, they rated their capacity by the equivalent amount of ice melted in a day, which is where the term "ton" came from sizing air conditioning. Relatedly, a Btu is the amount of heat energy required to

raise the temperature of one pound of water (about a pint) one degree Fahrenheit in one hour. This is also about the amount of energy given off by completely burning a wooden kitchen match. A heating unit is used to identify air conditioners, because air conditioners are just moving heat – not producing “cold.” There is no such thing as a unit of cold, just units of heat moving out of one environment and into another.

- For instance, a 4 ton air conditioner is one that can remove 48,000 BTUs of heat per hour from the house.
- TON = $Q_{ABSORBED}$
- 1 TON = # of Watts

9. **Metric units use:** Watts of cooling / Watts of electricity.
10. **Imperial units use:** BTU of cooling / Watts of electricity.

#### *16.10.1.1 Ton rating*

There are 12,000 BTUs per ton, a two-ton heat pump has a capacity of 24,000 BTUs of heating or cooling, meaning that it would be rated at 24,000 BTU per hour. Compared to larger heat pumps, a two-ton unit will be less expensive and likely occupy less space. These units are more suited for heating and cooling smaller spaces or enhancing comfort in areas with moderate heating and cooling needs.

A capacity of 24,000 BTUs will heat or cool areas of up to 1,000 square feet. But it’s important to confirm that a two-ton unit is suitable for your home and climate before investing in one. Picking the right unit ensures you save on energy consumption, reduce wear and tear and maximize comfort.

A ton of heat pump capacity is equivalent to 12,000 BTU per hour, and a three-ton heat pump is rated at 36,000 BTUs per hour. This rating means that it has a higher heating and cooling capacity than a two-ton unit and a lower capacity compared to a 4-ton heat pump. It will also consume more energy that a 2-ton unit to maintain indoor air at the desired temperatures. While it’s not necessarily heavier than smaller-capacity pumps, it will likely cost more to buy and install. A quality three-ton heat pump can effectively heat or cool an average area of 1,500 square feet, but will be too large for smaller spaces.

#### *16.10.1.2 Standard atmospheric efficiencies*

HVAC systems run at different efficiencies. To provide 10,000 kWh of heating from a device that runs at 85% efficiency, the system needs to provide the device 11,765 kWh of heat from some source, for example, gas:

- 10,000 kWh / 0.85 = 11,765
- Inevitably, some thermal output will go to waste, which is where the 85% efficiency comes in.

If an electric heater is 100% efficient. Hence, to provide 10,000 kwH of heating, the system needs to provide 10,000 kWh of heat from electricity.

# 17 Architecture gas and fuel sub-system

Note that an architectural gas and fuel service system is similar to a water service system in the plumbing networks/systems are used to access and distribute the materials to endpoints.

## *17.1 Natural gas sub-systems*

Natural gas and propane are common resources used in many different home appliances, specifically in cooking and heating systems.

### 17.1.1 Hazards with the natural gas system

The primary natural gas risks include, but may not be limited to:

1. Leakage.
2. Explosion.
3. Buildup of dangerous combustion by-products.

### 17.1.2 Natural gas piping

Gas enters the building through a gas-based plumbing/piping network. There are several best practices that ought to be followed when creating a piping network for gas (Plumbing systems, 2021):

1. Gas piping entering the building must be protected from accidental damage by vehicles, foundation settlement or vibration. Where practical, the entrance should be above grade and provided with a self tightening swing joint prior to entering the building.
2. Gas piping shall not be placed in unventilated spaces, such as trenches or unventilated shafts, where leaking gas could accumulate and explode.
3. Gas shall not be piped through confined spaces, such as trenches or unventilated shafts.
4. All spaces containing gas-fired equipment, such as boilers, chillers and generators, shall be mechanically ventilated.
5. Vertical shafts carrying gas piping shall be ventilated.
6. Gas meters shall be located in a gas meter room, thus avoiding leakage concerns and providing direct access to the local gas utility.
7. Gas detectors should be placed on the ceiling where gas is used.
8. All gas piping inside ceiling spaces shall have plenum rated fittings.
9. Diaphragms and regulators in gas piping must be vented to the outside.

Vents to the outside environment must be installed wherever natural gas is burned; because the combustion creates by-products (e.g., carbon monoxide) that are dangerous to humans and other animals.

### 17.1.3 Objects in the gas system: fixtures, fittings, and appliances

Natural gas fixtures and fittings are equipment that interface with the natural gas in a building:

1. **Natural gas fixture** - A device for receiving natural gas. The most common fixtures include, but may not be limited to:
   A. Gas meters.
   B. Natural gas sensors.
2. **Natural gas fitting** - a device designed to control and guide the flow of natural gas. The most common fittings include, but may not be limited to:
   A. Hoses.
   B. Connectors.
3. **Natural gas appliances** - appliance devices that use natural gas, the most common of which include:
   A. Gas ovens.
   B. Gas burners.
   C. Gas grills.
   D. Tankless water heaters.
   E. Tank-based water heaters.
   F. Fireplaces.
   G. Dryers.
   H. Furnaces.
   I. Boilers.
   J. Outdoor gas lights.

## *17.2 Fuel oil sub-systems*

Fuel oil systems require tanks of oil to be delivered to the architecture, which are then connected to fuel oil fittings and appliances. Fuel oils are all petroleum-based (hydrocarbons), and most commonly include kerosene , diesel, and gasoline.

### 17.2.1 Hazards with the fuel oil system

The primary natural gas risks include, but may not be limited to:

1. Oil discharge when connecting.
2. Leakage.
3. Fire.
4. Frequent maintenance.
5. Oil deliveries.
6. Buildup of dangerous combustion by-products.

### 17.2.2 Fuel oil piping

Fuel oil enters the building through a gas-based plumbing/piping network. There are several best practices that ought to be followed when creating a piping network for gas (Plumbing systems, 2021):

1. Fuel oil piping system shall use at least Schedule 40 black steel or black iron piping.
2. Fittings shall be of the same grade as the pipe material. Valves shall be bronze, steel or iron and may be screwed, welded, flanged or grooved.
3. Double-wall piping with a leak detection system shall be used for buried fuel piping.
4. Duplex fuel-oil pumps with basket strainers and exterior enclosures shall be used for pumping the oil to the fuel burning equipment.
5. Underground fuel oil storage tanks shall be of double wall, non-metallic construction or contained in lined vaults to prevent environmental contamination.
6. Tanks shall be sized for sufficient capacity to provide 48 hours of system operation under emergency conditions (72 hours for remote locations such as border stations). For underground tanks and piping a leak detection system, with monitors and alarms for both, is required. The installation must comply with local, State and Federal requirements, as well as EPA 40 CFR 280 and 281.

Vents to the outside environment must be installed wherever natural gas is burned; because the combustion creates by-products (e.g., carbon monoxide) that are dangerous to humans and other animals.

### 17.2.3 Objects in the fuel oil system: fixtures, fittings, and appliances

Fuel oil fixtures and fittings are equipment that interface with the fuel oil in a building:

1. **Fuel oil fixture** - A device for receiving fuel oil. The most common fixtures include, but may not be limited to:
   A. Not applicable.
2. **Fuel oil fitting** - a device designed to control and guide the flow of fuel oil. The most common fittings include, but may not be limited to:
   A. Tanks.
   B. Hoses.
   C. Connectors.
3. **Fuel oil appliances** - appliance devices that use fuel oil, the most common of which include:
   A. Oil-fired burners.
   B. Oil-fired furnaces.
   C. Electrical generators.

# 18 Architecture electrical sub-system

*A.k.a., Electrical service engineering, electrical power system.*

Electrical systems either use electricity to function or are involved in the production and/or transmission of electricity.

The most common electrical sub-systems in a building are:

1. Electrical production systems; electrical supply.
2. Electrical distribution systems.
3. Lighting.
4. Heating, ventilation and air conditioning.
5. Automated control.
6. Operation of machines (e.g., motors and appliances).
7. Data processing, transmission/telecommunications.

Within architecture, there are three types of equipment:

1. **Electrical demand equipment** - equipment that uses electricity, such as motors, computers, lighting, HVAC, etc.
2. **Electrical production / supply equipment** - equipment that produces electricity, such as solar panels and generators.
3. **Electrical distribution and sub-processing equipment** - equipment that allows for the transmitted distribution of electricity and the sub-processing to ensure compatibility with end devices. Such as wires and transformers before endpoint electrical devices.

In relation to electricity in buildings, the term electrical power is usually associated with:

1. Electrical demand.
2. Electrical rating.
3. Electrical supply capacity.

In this context, electrical power is concerned with how much power a building or a circuit may require, which in turn will relate to capacity of supply, size and rating of conductors, type and rating of protective equipment as well as functional switching capacity.

Power calculation variables include, but are not limited to:

1. **The watt** - is the SI unit of electrical power that measures energy transfer at a rate of 1 joule per second. Herein, one watt is defined as the energy consumption rate of one joule per second (J/s).

One watt is also defined as the current flow of one ampere with a voltage of one volt.

2. **The circuit-watt** - is the power consumed in lighting circuits by lamps, and where applicable, their associated control gear (including transformers and drivers) and power factor correction equipment.
    A. **Lamp lumens per circuit-watt** - is the total lamp lumens summed for all luminaires in the relevant areas of the building, divided by the total circuit-watts for all the luminaires.
    B. **Luminaire lumens per circuit-watt** - is the (lamp lumens x LOR) summed for all luminaires in the relevant areas of the building, divided by the total circuit-watts for all the luminaires.

## *18.1 Electrical standards*

Significant electrical standards include, but are not limited to:

1. U.S. Occupational Safety and Health Administration (OSHA; or its equivalent) - is part of the United States Department of Labor and was created to ensure safe and healthful working conditions for working men and women by setting and enforcing standards and by providing training, outreach, education and assistance.
2. Institute of Electrical and Electronics Engineers (IEEE) - is the world's largest technical professional organization dedicated to advancing technology for the benefit of humanity. The IEEE has developed standards for over a century using technical experts from all over the world. The IEEE has over 1100 active standards.
    - IEEE 1547 - Standard for Interconnection and Interoperability of Distributed Energy Resources with Associated Electric Power Systems Interfaces. This is the standard that describes the interconnection of PV and other distributed energy resources (DERs) to the utility grid.
3. International Electrotechnical Commission (IEC) - is an international standards organization that prepares and publishes international standards for all electrical, electronic and related technologies.
4. American National Standards Institute (ANSI) - is a private, not-for-profit organization dedicated to supporting voluntary standards. ANSI accredits many different standards developers, including those familiar to the electrical industry like NFPA, UL, and IEEE. ANSI has over 11,500 active standards.
    - ANSI /IEEE Standard C37.2 - Standard for Electrical Power System Device Function Numbers, Acronyms, and Contact Designations. Identifies the features and function number of a protective device such as a relay or circuit breaker.
5. National Electrical Manufacturers Association (NEMA) - develops performance standards and promotes product interoperability to increase market demand while improving safety to mitigate risks.
6. North American Electric Reliability Corporation (NERC) - is a not-for-profit international regulatory authority whose mission is to assure the effective and efficient reduction of risks to the reliability and security of the grid.

Significant electrical codes include, but are not limited to:

1. The International Code Council (ICC) has a chapter in its international building code (IBC) related to electricity, chapter 13 (2018). [codes.iccsafe.org]
2. U.S. National Fire Protection Association (NFPA)
3. U.S. National Electrical Code (NEC)
4. Institute of Electrical and Electronics Engineers (IEEE)
5. National Electrical Safety Code (NESC)
6. International Code Council (ICC)
7. International Building Code (IBC)
8. International Fire Code (IFC)
9. International Energy Conservation Code (IECC)
10. Energy Market Authroity (EMA) Codes of Practice
11. Etc.

**NOTE:** *In some jurisdictions, there are also testing agencies, that test and then certify the building as meeting a set of criteria.*

### 18.1.1 Standard electrical documentation

*A.k.a., Atmospheric system specification and drawings.*

Electrical systems are documented via specifications and drawings.

1. **Electrical drawings (a.k.a., electrical schematics, electrical schematics):** illustrate the system that will support airflow and transfer thermal energy. Atmospheric (HVAC) drawings illustrates the atmospheric system.
2. **Electrical specifications:** include all written content, reasoning for decisions, and calculations.

#### *18.1.1.1 Electrical load data tables*

Electrical system equipment includes two primary categories:

1. **Electrical usage equipment [data] table (a.k.a.,**

**electrical usage equipment list)** - is appliances, devices and other equipment that uses electricity to meet human technical needs. All endpoint equipment that uses electricity.
2. **Electrical equipment [data] table (a.k.a., electrical equipment list)** - is equipment that relates specifically to the electrical system (e.g., solar power equipment, transformers, circuit breakers, etc.). All electrical system specific equipment.
3. **Load calculation table (a.k.a., demand calculation table)** - this table shows electrical load calculations for each family. The calculations in this table are often separated first by family, and then, totals.
4. **Load forecast table** - this table shows

#### *18.1.1.2 Electrical production drawings and specifications*

*A.k.a., Electrical system diagrams, electrical system schematics.*

An electrical drawing illustrates the electrical circuit system.

1. Circuit diagram (a.k.a., wiring diagram, wiring circuit diagram).
2. One-line electrical wiring diagram.

An electrical specification includes a materials list:

1. Schedule for a power panel.
2. Schedule for electrical circuit.
3. Schedule for solar system.

#### *18.1.1.3 Electrical system plan*

An electrical plan covers the following elements:

1. System concept.
2. Load calculation.
3. System zoning.
4. Electricity distribution.
5. Equipment selection.
6. Wiring size calculation.
7. Adjustment, testing and balance.

The electrical plan includes standards for safety and electricity quality for all buildings. It also covers requirements for the prevention of fires and other hazards.

#### *18.1.1.4 Electrical efficiency plan*

The analysis to determine the best system to meet the energy/power requirements for a habitat service system, and may be produced through the following steps:

1. **Step 1:** Determine the following [for the whole HSS, individual buildings and combined buildings]:
   A. Hourly electrical load for the whole HSS
      1. Demand loads.
   B. Hourly thermal loads for the HSS.
   C. Hourly heating loads for the HSS
   D. Hourly cooling loads for the HSS.
   E. The final estimation, which can be based on measured data or simulation analysis.
2. **Step 2:** Identify the main energy resources available within or close to the site where the HSS is located. These resources typically include solar, wind, geothermal, hydroelectric, fossil fuel, and biomass.
3. **Step 3:** Collect specific analysis data including market-economic parameters such as fuel costs and electricity prices from the grid as well as the capital and operation and maintenance (O&M) costs for various power-generating technologies.
4. **Step 4:** Carry out optimal analysis for various technically feasible options for power generation technologies, including fuel-based as well as renewable energy technologies. Calculation formulas within tables, as well as simulation tools, are typically used in the analysis.
5. **Step 5:** Rank and select the most [cost-]effective system, including the optimal capacities.

### 18.1.2 Standard electrical requirements

What is required for a viable electrical production-distribution system is:

1. **For architecture** - Electrical production proportionate to electrical demand [via a load, motion].
2. **For economic calculation** - Data sheet about loads (electrical appliances) to produce optimization calculation.
3. **For life support demand** - electricity proportionate to human demand.
4. **For technology and exploratory demand** - electricity proportionate to human demand.
5. **For buildings** - Appropriated localized electrical production proportionate to a mains supply (Read: supply from a distance).

### 18.1.3 Hazards with the electrical system

The most common hazards with an electrical system are:

1. Outage.
2. Load growth.
3. Electrical shocks.
4. Fires.
5. Lightning.

6. Damage to devices. Some electrical equipment and devices are sensitive to changes in supply frequency and voltage levels. In most cases, electrical systems are designed to operate within certain ranges of tolerances of specific values of frequencies and voltages.
7. Over or under parameter electricity (e.g., over voltage, under current, etc.).
8. Short-circuiting. Occurs when electrical wires that are not intended to touch come into contact with one another.

#### *18.1.3.1 Electrical safety*

Electrical safety covers the design, installation, inspection and testing, and operation of electrical installations in order to prevent injuries from electrical shocks and burns, and to prevent injuries arising from fires due to electrical components overheating or arcing. To ensure safety, all electrical equipment should be able to handle, control and dissipate electrical power safely, to avoid the risk of fire or electric shock.

#### *18.1.3.2 Power quality disturbance protection elements*

In order to protect against power quality disturbances, the following are some preventive and corrective devices and strategies that can be considered:

1. **Pulsed rectifiers** - are utilized to improve the shape of voltage and current sinusoidal waveforms, especially when operating motors
2. **Power harmonic filters** - are commonly used to reduce the effects of harmonic distortions
3. **Dynamic voltage compensators** - installed between power sources and loads to protect electrical systems against voltage sags
4. **Capacitor banks** - are specified to provide several benefits to the electrical distribu-tion systems, including increase in the power factor, improvement of voltage regu-lation, reduction in energy losses, and prevention of harmonic resonances
5. **Special transformers** - are utilized to control harmonic currents and mitigate voltage sags
6. **Uninterruptible power supply (UPS) systems** - are commonly specified as backup power sources for critical loads that require stable voltage levels. For several buildings, UPS systems consist typically of battery-powered devices that are charged from the utility power source using inverters and rectifiers. When the source voltage level is reduced due to any disturbances, a bypass switch is activated and power is supplied from the battery. The battery continues to provide steady power to the critical loads until the main power source returns to its normal operating condition, unless the battery is totally discharged. Generally, battery-powered UPS systems come in a variety of sizes from 100 W to 500 kW. It should be noted that these standard sizes of batteries can only maintain the necessary voltage level for short periods. For large critical building loads, such as data centers or operating rooms in hospitals, UPS systems include, standby engine generators. The generators are connected to the critical load through transfer switches and can provide power for extended periods of time.

#### *18.1.3.3 Electrical grounding*

It is important to properly ground electrical systems to minimize fire hazards, electrical shocks and injuries to occupants, and damage to equipment. Grounding systems are passive systems used to establish an electrical potential reference point in an electrical system for the proper dissipation of electrical energy in case of abnormal or transient conditions.

Design documents for grounding systems shall indicate at a minimum the following:

1. Type and location of grounding electrodes.
2. Bonding requirements.
3. Testing requirements.
4. Conductor material type, size and protection requirements.
5. Separate grounding systems, properly bonded, per code and use requirements.

The following types of grounded systems may be used in a building:

1. **Electrical system grounding:** Electrical systems that are grounded shall be connected to earth in a manner that will limit the voltage imposed by lightning, line surges, or unintentional contact with higher-voltage lines and that will stabilize the voltage to earth during normal operation.
2. **Grounding of electrical equipment:** Normally non-current-carrying conductive materials enclosing electrical conductors or equipment, or forming part of such equipment, shall be connected to earth so as to limit the voltage to ground on these materials.
3. **Bonding of electrical equipment:** Normally non-current-carrying conductive materials enclosing electrical conductors or equipment, or forming part of such equipment, shall be connected together and to the electrical supply source in a manner that establishes an effective ground-fault current path.
4. **Bonding of electrically conductive materials and other equipment:** Normally non-current-carrying

electrically conductive materials that are likely to become energized shall be connected together and to the electrical supply source in a manner that establishes an effective ground-fault current path. Figure 5.26 illustrates the application of a bonding jumper system to connect the panel enclosure to the neutral wires.

5. **Effective ground-fault current path:** Electrical equipment and wiring and other electrically conductive material likely to become energized shall be installed in a manner that creates a permanent, low-impedance circuit facilitating the operation of the protection device or ground detector for high-impedance grounded systems. It shall be capable of safely carrying the maximum ground-fault current likely to be imposed on it from any point in the wiring system where a ground fault may occur to the electrical supply source. The earth shall not be considered as an effective ground-fault current path.

The following grounding electrodes are possible for use in a grounding system:

1. Metal underground water pipe.
2. Metal frame of the building or structure.
3. Concrete-encased electrode.
4. Ground ring.
5. Rod and pipe electrodes.
6. Other listed electrodes.
7. Plate electrodes.
8. Other local metal underground systems or structures.

Some building standards do not allow for the following types of grounding electrodes:

1. Metal underground gas piping system.
2. Aluminum electrodes.

There are several basic rules for specifying grounding electrodes to protect building electrical systems from fault currents:

1. Each [circuit] system has to be grounded.
2. Grounding location needs to be as close to the power source of the derived. The grounding connection should be inside tripping protection device. If the tripping device trips, then the circuit would become ungrounded.
3. There should be only one grounding connection per derived system. When two or more locations are connected to the earth may result in return flow of ground-fault current back to the system.
4. In order to facilitate the flow of fault currents into the ground, low resistance path for the grounding conductor is needed. The ground electrode system connecting a building electrical system to ground will often have an electrical resistance lower than 25 Ω. Several parameters and factors can affect the resistance of the ground electrode system (e.g., oxidation, earth movement, and moisture).
5. In order to ensure that all non-electrical conductive parts of equipment are safe to touch under normal operation, equipment grounding is required. The frames, enclosures, or structural supports of electrical equipment and distribution systems such as transformers, switchboards, panels, motor controllers, motors, generators, cabinets, lighting equipment, and outlet boxes have to be connected to earth through permanent and continuous paths that may include raceways, cable trays, armors of cables, and equipment grounding buses.

#### *18.1.3.4 Lightning protection*

Lightning protection systems are passive systems used to protect building and structures from damage caused by lightning and static discharges. Direct lightning strikes can be neutralized by a structural lightning protection system (a structural LPS). This interception establishes a circuit, allowing the structural LPS to conduct the lightning current to the earth, bypassing the building structure while equalizing the potential between the cloud and the earth. Roof lightning protection systems are essential to protect buildings, persons, and equipment from lightning. The lightning protection system intercepts lightning strikes and safely passing their extremely high currents to ground.

Electrical engineering documents for lightning protection systems shall indicate:

1. Air terminals height and spacing.
2. Arrangement of main and down conductors.
3. Grounding points and spacing.
4. Legend.
5. Testing requirements of grounds.

## *18.2 Conception of the electrical service system*

*A.k.a., Electrical supply sub-system.*

In a habitat, power is produced for buildings as endpoints. Power production system are often differently configured around the world depending on their earth geo-position and the local jurisdiction (market-State). Buildings are connected to electrical supplies from either proximal or distal locations. When distal, a transmission network exists to supply multiple locations. The specific voltages distributed and served to buildings vary significantly worldwide and depend on the building types. Note that in most design cases, electrical systems are designed to operate within certain ranges of tolerances of specific values of frequencies and voltages.

Different jurisdictions in the world use different power system specifications:

1. Frequencies (Hz).
2. Number of phases.
3. Low voltages.
4. Medium voltages.

For example, as of 2017, the following jurisdictions maintain the following specifics for their power systems (Krarti, 2017):

| Country | Frequency (Hz) | Number of phases | Low voltages (V) | Medium voltages (kV) |
|---|---|---|---|---|
| Argentina | 50 | 1.3 | 230/400 | 6.6, 13.2, 33 |
| Brazil | 60 | 1.3 | 110/220, 125/216, 127/220, 220/380 120/240 | 6, 11.4, 13.8, 22, 25, 34.5 |
| France | 50 | 1.3 | 115/220, 127/220, 220/380 | 3.3, 5.5, 10, 15, 20, 30 |
| Japan | 50 | 1.3 | 100/200 | 3, 6, 6.6, 11, 20, 22, 60 |
| United States | 60 | 1.3 | 120/240, 120/208, 227/480 | 2.4, 4.16, 4.8, 6.9, 8.32, 12, 12.47 |
| Venezuela | 60 | 1.3 | 120/240 | 2.4, 4.16, 4.8, 12.47, 13.8 |

Some systems are more affected by current and voltage levels, and others more by frequency levels. A larger current flow can result in higher heat to be dissipated in the device. Specifically, the dissipated heat is proportional to the square of the current flow. For instance, doubling the voltage will typically double the current, resulting in the device dissipating four times the heat. Most devices cannot tolerate large increases in heat generation and may be significantly damaged. Most electrical devices cannot operate reliably with supply voltage levels that are higher than 10% of their rated voltage. Alternatively, some devices depend on magnetic fields to transfer and convert electrical energy to operate (such as motors and transformers) and are thus affected by any changes in frequency levels. For example, a pump driven by a 60 Hz electrical motor transfers less fluid when operated with 50 Hz source voltage. The electrical motor shaft speed is reduced by the ratio 5/6. Therefore, the output of direct-driven systems (such as HVAC equipment including pumps and fans) should be derated, typically by a factor of 5/6. It should be noted, however, that a 60 Hz motor can be operated to deliver the same mechanical power even when operated from a 50 Hz source, by increasing the torque has to be increased when operated at 50 Hz since the mechanical power is the product of the torque and the shaft speed (i.e., if shaft speed is 50Hz then the torque must be increased over a motor shaft speed of 60Hz. Similarly, operating a 60 Hz transformer using a 50 Hz source may cause saturation of its core resulting in overheating conditions. Other electrical systems can be sensitive to changes in frequencies from 60 to 50 Hz. For instance, circuit breakers have different tripping curves depending on the frequency level. It is important to ensure that adequate trip curves with the proper frequency value are utilized when coordinating protection devices. Moreover, reading meters may lose their accuracy when operating at different frequency systems.

High voltage levels are not safe to human life and require special safety precautions. For safe utilization, low voltages are typically used in buildings. High voltages are sometimes used in specialized manufacturing operations.

## *18.3 Conception of the electrical distribution sub-system*

Power distribution systems are often differently configured for:

1. Dwellings,
2. Units of dwellings (apartments), and
3. Commercial buildings.

A typical electrical distribution system for a building consists of:

1. A supply line from some source.
2. If the supply line is from the market-State, then there is a meter (to measure usage for payment).
3. The line continues through the meter to a circuit breaker panel that serves a set of branch circuits with fuses.
4. The branch circuits provide electricity to various loads (lighting and receptacles) located within the building.
5. In the United States, small buildings are served using 240/120 V system (dwellings and detached homes) or 208Y/120-V system (small commercial buildings or apartment buildings). These voltages are obtained directly from a utility transformer that is served by a 13.8 kV distribution voltage.

Electrical distribution systems can include, but are not limited to the following additional elements:

1. A step-down transformer(s).
2. Power panels.
3. Protection devices.

4. Grounding systems.
5. Wiring methods.

Residential buildings generally include the following base elements (in order from endpoint to production source):

1. **Loads:** usage sub-systems.
2. **Branch circuits:** to many endpoints. Electricity feeds a panel that then feeds a branch-like connection of loads (Read: demands...for electricity).
3. **Panel-board circuitry**: connects branches with a main (or, mains) sources. This type of panel can house:
   A. A connected main and branch distribution panel (a.k.a., main distribution panel, MDP). Herein, the main panel supply is served by the main feeder from some step-down transformer.
   B. A branch to branch distribution panel.
4. **Panel-board protection device:** with breakers or fuses, or even uninterpatible connections between a mains the branches.
5. **Grounding elements:** are often connected to the panel-board and ground the whole electrical system into the earth.
6. **Electricity usage meter** : used by market entities to "profit" and "big data", or used in community to monitor and adjust production.
7. **Proximal feeder:** service entrance feeder.
8. **Transformer:** to ensure safe voltage and current enter architecture.
9. **Mains feeder and entrance of electricity:** from the (Intersystem team or market-State entity) utility production organization.

A typical electrical distribution system consists of a meter connected to one panel that serves a set of branch circuits to provide electricity to various loads (lighting and receptacles) located within the building. The production of electricity comes from one or more sources.

The electrical power distribution systems for commercial buildings is more complex than those of residential buildings, but utilizes the same basic component configuration, including: a network of step-down transformers, lighting and power panels, protection devices, grounding systems, monitoring systems, and wiring methods. In production and/or high occupancy buildings (a.k.a., commercial buildings in the market-State), the electricity is supplied at a high voltage of, for example, 13.8 kV and is distributed to the building at lower levels of 480Y/277-V and/or 208Y/120-V. Herein, the main feeder supplies electricity from the utility, which moves through a transformer served by the main feeder and transforms it into a safer and more usable for electricity using loads (Read: demands) within the building. Here, a main distribution panel (MDP), served by the main feeder from the main step-down transformer (13.8-kV–480Y/277-V), provides electricity safely to various loads through subfeeders, low-voltage step-down transformers (480Y/277-V–208Y/120-V), and panels. While the MDP is protected by power circuit breakers as well as a grounding system, the panels include several molded-case breakers that protect branch circuits serving building end-use loads such as plug-loads (receptacles) and lighting fixtures, or motors.

The complexity of power distribution in a larger building, versus individual residences, includes the following base elements (in order from endpoint to production source):

1. Loads connected to end-point distribution branch circuits. The building will be divided into electrical areas, each connecting loads directly with the endpoint branch circuit.
2. Endpoint branch panels house the branch circuitry, and connect loads to transformers.
3. These transformers step-down current from the interior sub-feeder. In other words, the interior sub-feeder feeds many transformers that subsequently feed safer electricity into as many branch panels as there are branch areas (and branch circuitry).
4. The main distribution panel (MDP) connects the buildings electrical sub-feeder to the main electrical supply coming from outside the building (generally).
5. The main feeder from outside the building connects to the main distribution panel (MDP).
6. The main feeder is in turn connected to another transformer for stepping down electricity from the utility to the interior of the building.
7. A meter may exist between the building (from the point of the transformer forward) to measure electricity usage by the building and its interior occupation. In the market-State, this meter is used to tax (State behavior) and profit (market behavior).

## *18.4 Conception of the electrical wiring sub-system*

The laying of electrical wire can be optimized by the following best practices:

1. Use a conduit (or, raceway) with pre-placed "pull wire" to pull a new wire and/or replace an old.
2. Use a metal conduit to reduce attenuation of the wire's electromagnetic field, as well as reduce shocks and the potential for damage by insects and/or rodents.
3. Never permanently staple wires (any type of wire,

including power and data).

Electrical wire conductors transport electricity. These wire conductors include:

1. Different materials.
2. Different configuration of wiring (e.g., flat, twisted, etc.).
3. Different number of wires (most homes have three-wire service - two hot wires and one neutral).
4. Different sizes.
5. Different coverings (Read: insulation).

**NOTE:** *There are also different wiring methods.*

#### *18.4.3.1 Primary electrical circuits*

There are two primary electrical circuits in a building, which are generally rated differently:

1. **Main circuit** - is a conductor that attaches to the primary outside source of electricity (often coming from a municipal electric utility fed from an electrical grid). The main circuit is generally rated on the amapcity of the conductors.
   - The question is, how much amperage can the main circuit [into the building] handle?
2. **Branch circuit(s)** - is a conductor or a set of conductors that extends typically from a panel (such as a circuit power panel or a lighting panel) to the utilization equipment (e.g., a electrical outlet, receptacle, a motor, or a lighting fixture). A building can have many branch circuits. Branch circuits are generally not rated based on the ampacity of the conductors, but by the size of the overcurrent protection devices connected to them with ratings of 15, 20, 30, 40, and 50 A.
   - The main safety question is, how much overcurrent protection does the branch have?
   - The main design question is, what is the demand load associated with the panel to determine the best circuit breaker size (Read: amperage rating) of each circuit breaker in the panel.

### 18.4.1 Electrical loading specification

In order to specify the components for electrical distribution systems for a building, it is necessary to determine:

1. **All the end-use loads** that need to be served by electricity as well as their:
   A. Rated voltages.
   B. Rated frequencies.

The procedure is generally as follows:

1. The loads are estimated
2. The branch circuits are selected
3. The panels as well as the feeders and subfeeders are specified.
4. If required, transformers are added as needed to supply voltages throughout the building.

Design objectives include, but are not limited to:

1. Safety should be the most important objective for specifying various components of the power distribution systems for buildings.
2. When any problem occurs, such as a fire due to short-circuiting, arcing, or melting within a power unit, any person located near has access to a fire extinguisher device and can have a safe pathway to the exit.
3. Electrical production and distribution systems should be designed to ensure that they operate reliably without interruption under normal loading conditions.
4. The design specifications of any electrical production and distribution system should allow for some flexibility. In particular, the system should be able to handle additional electrical loads due to future expansion and/or change of end-use equipment or loads (i.e., lighting, appliances, or motor loads).
5. The components of the power production and distribution systems should be designed to be easily accessible in order to facilitate their maintenance, repair, and replacement.
6. Selecting a rating of 20Amp for a circuit breaker provides more reliability (and safety) than using a 15Amp circuit breaker.

## *18.5 Objects in the electrical system: fixtures, fittings, and appliances*

Electrical fixtures and fittings are equipment that interface with the electricity in a building:

1. **Electrical fixtures** - a device for producing and/or processing electricity. The most common fixtures include, but may not be limited to:
   A. Circuit breaker.
   B. Solar panels.
   C. Backup batteries.
   D. Transformers.
   E. Generators.
   F. Grounding elements and electrodes.
   G. Lightning protection elements.
   H. Feeders.
2. **Electrical fittings** - a device designed to control and guide the flow of electricity. The most common fittings include, but may not be limited to:

   A. Switches.
   B. Sockets.
   C. Light fittings.
   D. Fans (etc.)
   E. Electrical wiring (note that this could also be considered a fixture. Additionally, some buildings make is so wiring cannot be replaced without demolishing walls -- in this case, builders sometimes staple the wiring to the studs).
3. **Electrical appliances** - most appliances require electricity.
   A. Motors.
   B. Robots.

**IMPORTANT:** *All fixtures, fittings, and appliances must be specified with the right capacity for their placement.*

### 18.5.1 Outlets

Outlet receptacles in an electrical system can be of many types , including but not limited to:

1. Duplex receptacle.
2. Ground fault current interrupter.
3. Weatherproof duplex receptacle.
4. Duplex receptacle served by an emergency branch circuit.

### 18.5.2 Switches

Switches in an electrical system can be of many types, including but not limited to:

1. Simple switch.
2. Three way switch.
3. Switch with built-in dimmer.

### 18.5.3 Electrical processing equipment

Electrical processing equipment in an electrical system can be of many types, including but not limited to:

1. Power panels.
2. Junction boxes.
3. Transformers - are electrical components designed to do one of three things:
   A. Decouple one circuit from another,
   B. Increase voltage from one value to a higher potential, or
   C. Decrease voltage to a lower potential.
4. Electrical meters (instrument transformers).

#### *18.5.3.1 Electrical transformers*

Common types of transformers used in building include, but may not be limited to:

1. **Power transformers** - change power parameters, of which there are two usages:
   A. Used for electricity transmission and distribution. Electrical power is transmitted long distances at very high voltages. This power must be stepped down for most buildings. A transformer may be installed to step-down transmission voltages to voltages expected for individual buildings.
   B. Used within buildings In particular, power transformers are cost-effective devices to make available voltages needed for lighting and other specialized applications.
2. **Electrical instrument meters (instrument transformers)** - are often instrument transformers that monitor (and "meter") electricity use. These instrument transformers allow the measurement of high voltage and current with low-scale voltmeters and ammeters. There are two basic types of instrument transformers: voltage transformers (a.k.a., potential transformers, PT) and current transformers (CT).
3. **Autotransformers** - are small and relatively inexpensive transformers used to that step down voltages to low voltage.

There are basically two types of connections for electrical transformers used for building systems:

1. Single-phase transformers.
2. Three-phase transformers.

There are basically two types of transformers for building applications:

1. Liquid-filled transformers - wherein the liquid acts as a coolant and an insulation dielectric. Oil-filled transformers can create a severe fire and explosion hazard and therefore have to be mounted outdoors unless fireproof and explosion-proof vaults are used for indoor installations.
2. Dry-type transformers - are constructed so that the core and coils are open to allow cooling by the free movement of air. In some cases, fans may be installed to increase the cooling effect. The dry-type transformers are widely used because of their lighter weight and simpler installation method compared to the liquid-filled transformers. Dry-type transformers are more expensive, typically by more than 200%, than the oil-filled transformers.

There are several potential hazards that need to be considered in the case of transformers:

1. Noise problems: To reduce noise problems, it is recommended to specify transformers with minimum sound level (50 dB or lower). Moreover, it is desirable to place the transformer in the least valuable space of the building away from any quiet areas. In some cases, the electrical room where the transformer is located may need to be soundproofed using adequate acoustical materials.
2. Vibration problems: To reduce the vibration associated with the operation of transformers, isolators should be placed beneath the transformer mounting pads. Moreover, flexible conduits should be installed to house the secondary and primary feeders of the transformer. Without these measures, vibration may be transferred to other building parts and cause structural damages.
3. Heat problems: Heat is dissipates by transformers as part of the copper conduit losses. This heat can represent 0.5%–2% of the total transformer power rating depending on the transformer efficiency. To avoid overheating of the transformer and the room housing the transformer, ventilation should be provided or adjustable louver should be installed in the wall or the door adjacent to the transformer.
4. Electromagnetic field problems: Transformers should not be placed near normal human occupied locations because of their strong electromagnetic fields (e.g., a transformer should not be on the other side of the wall of a couch, bed, or any potentially normally occupied location).

## 18.5.4 Electrical protection equipment

Types of electrical panel protection devices include, but are not limited to, all of which are designed to interrupt the power to a circuit when the current flow exceeds safe levels:

1. **Fuses ("fuse box")** - are an over-current protective device with a circuit opening fusible part that is heated and severed by the passage of current through it. A fuse box is a place where one or more fuses may be installed into a system. A fuse should not be used in situations that require a GFCI.
2. **Circuit breakers ("breaker box")** - are a device designed to open and close a circuit by non-automatic means (i.e., manually) and to open the circuit automatically on a predetermined matter without damage to itself when properly applied within its rating. A circuit breaker is a trip mechanism for shutting of the electricity in cases of potential danger. The circuit trip mechanism itself can wear out over time and may/will need to be replaced. A typical circuit breaker consists of a main breaker handle and multiple branch circuit breakers. The main breaker handle mechanism is the most often replaced part due to failure. The branch breakers and the main breaker are, basically the same thing. They function in the same way, but the branch breakers are smaller. The main breaker is designed to interrupt a larger amperage load. Circuit breakers are available for various voltages and continuous current ratings as well as interrupting current ratings, response characteristics, and methods of operation. A branch circuit is a conductor (or a set of conductors) that extend from a panel to the utilization equipment (e.g., receptacles, motors, and lighting fixtures). Branch circuits are generally not rated based on the ampacity of the conductors but by the size of the overcurrent protection devices connected to them with ratings of 15, 20, 30, 40, and 50 A. The mechanism of opening the contacts may involve solid-state, thermal, magnetic, or thermal-magnetic trip units. In general, circuit breakers have two different ways of working: the first is through the use of an electromagnet and the other is through the use of a bi-metal strip. In both instances, when turned on, the breaker allows electrical current to pass from a bottom to an upper terminal across the strip. Once the current reaches any unsafe levels, the magnetic force of the solenoid or strip becomes strong enough to throw a metal lever in the switch mechanism, breaking the current. The other option that can happen is that the metal strip can bend, throwing the switch and breaking the connection. In order to reset the flow of electricity, the switch can just be turned back on (generally, manually). This movement of the switch reconnects the circuit. Circuit breakers have other applications, such as using for ground-fault circuit interrupter, or GFCI. The function of GFCI is to prevent electric shock, rather than just overheating. It breaks the circuit in an outlet if the current gets unbalanced. To reduce and even eliminate the potential damages associated with ground faults, addi-tional protection systems are needed. In particular, the use of ground-fault current inter-rupters (GFCIs) is required for several locations within buildings. GFCIs allow the detection of small ground faults (as low as 6 mA) and to quickly open the circuit to avoid any harm to humans and damages to electrical equipment. The GFCI can generally be reset by the touch of a button. GFCI technology is widely found in kitchens or bathrooms, where electrocution is a risk from the use of electrical appliances near water sources such as sinks or faucets. GFCI circuit breakers are commonly

installed in panels and provide ground-fault protection to all the loads served by the branch circuits connecting the breakers. There are also portable in-line GFCI units that go in between an outlet and the power cable to an electrical device. Circuit breakers can be installed either in single pole or multipole. Multipole breakers are generally gang operated so that all the poles are closed and opened simultaneously by one common operating mechanism (such as a handle). Therefore, circuit breakers cannot cause single phasing in three-phase systems as can be the case when using fuses as protection devices. Circuit breakers do not contain fuses, instead electrical circuitry are used. Circuit breakers have several advantages compared to fuse only systems:

A. Can serve as means of both protecting and switching an electrical circuit.
B. Does not cause single phasing.
C. Can be remotely operated.
D. Can easily incorporate ground-fault protection.

Non-panel fault protection types include, but may not be limited to:

- Grounding (earthing).

### 18.5.5 Feeders

Electrical feeders are the power lines through which electricity is transmitted in power systems. These electrically conductive lines (Read: feeders) transmit power from a generating station or substation to the distribution points. In power engineering, a feeder line is part of an electric distribution network, usually a radial circuit of intermediate voltage. For sizing the feeders and subfeeders, demand loads rather than the actual connected loads should be considered to account for the fact that not all the loads would be utilized simultaneously.

In small buildings there is just one main feeder supplying a branch circuit breaker panel. In larger buildings there are two feeders, one that supplies the mains circuit breaker panel and a sub-feeder that feeds

### 18.5.6 Motors

Motors convert electrical energy to mechanical energy and are typically used to drive machines. The driven machines can serve a myriad of purposes in buildings, including moving air (supply and exhaust fans), moving liquids (pumps), moving physical objects (gates), and compressing gases (refrigerators). To select the type of motor to be used for a particular application, several factors have to be considered, which include the following (Krarti, 2017):

1. The form of the electrical energy that can be delivered to the motor:
   A. Direct current (DC), or
   B. Alternating current (AC), single phase or three phases.
2. The requirements of the driven machine, such as motor speed and load cycles.
3. The environment in which the motor is to operate:
   A. Normal (where a motor with an open-type ventilated enclosure can be used).
   B. Hostile (where a totally enclosed motor must be used to prevent outdoor air from infiltrating inside the motor).
   C. Hazardous (where a motor with an explosion-proof enclosure must be used to prevent fires and explosions).
4. Depending on materials and configurations, motors can be more or less efficient. In the market, more efficient motors cost more.

The difference in electrical efficiency between two motors can be calculated by (Krarti, 2017):

- $\Delta P_R = P_M \left( (1/\eta_S) - (1/\eta_E) \right)$
  - Wherein,
  - PM is the mechanical power output of the motor. $\eta_S$ is the design (i.e., full-load) efficiency of the standard motor. $\eta_E$ is the design (i.e., full-load) efficiency of the energy-efficient motor.

Hence, the electric energy savings incurred from the motor replacement is thus:

- $\Delta kWh = \Delta PN_R * N_h \times LF_M$
  - Wherein,
    - $\Delta P_R$ is the reduction in motor real power demand estimated using the equation for the difference in electrical efficiency between two motors *(see above)*.
    - $N_h$ is the number of hours per year during which the motor is operating.
    - LFM is the load factor of the motor's operation during 1 year.

## *18.6 Installation of electrical system*

*A.k.a., Wiring installation.*

There are many ways to install electrics. These systems are usually embedded into structure.

## *18.7 Operation of electrical system*

*A.k.a., Wiring operation.*

Most significant operational activities are located on the supply side because of the requirement for static pressure given dynamic demand. Some demand-side specialized electrical systems, such as solar panels, may have significant operational activities.

## 18.7.1 Electrical load demands

*A.ka., Electrical loading.*

In order to do work, electrical systems are split into an electrical power production, distribution, and usage service system. Herein, electrical loads are measured in several ways, most notably, energy consumed:

1. Most electrical loads are measured in watts [of electrical] power. Watts is a unit of power.
   - Kilowatt hour (kW.h or kWh) is a unit of energy equal to one kilowatt of power sustained for one hour or 3600 kilojoules (3.6 megajoules).
     - How many kWh does a load use? A 60-watt load uses 60 watts of energy/power; if energy usage is accounted in hours of usage, then power usage for loads may be expressed in some scaled unit of the watt hour (e.g., kilowatt hours). One kilowatt hour is equal to 1,000 watts continuously for 1 hour. Therefore, a 60-watt bulb uses 60 watts hours or . 06 kilowatt hours of energy for each hour it's on.
2. Volt-ampere hour (V.A.h, VAh, or VA) which are the same as W.h or Wh when power factor =1.
   - As power factor drops (current & voltage increasingly are out of phase) the user gets increasingly-less Watts for the same VA.
3. The transmission lines and transforms are another type of load.
   - Current causes losses in transmission lines and transformers.
4. Non-usage, but presence, will still equate to system service usage.
   - If a usage circuit has no load in the form of a power factor of zero the user would consume NO watt.hours, but the supplier would still have to send current to them and incur real energy losses in lines and transformers. Power factor is the relationship (phase) of current and voltage in AC electrical distribution systems.

**NOTE:** *It is important to note that when calculating usage of electricity by a device, measuring amperes don't provide sufficient information about energy transfer from a source to a load. If a load took 100 amperes at 1 volt, the power consumption (joules of energy per second) is 100 watts. If a different load took 100 amperes at 100 volts, the energy transfer per second is 10,000 watts.*

Electrical load evaluation includes the following calculable variables:

1. **Load** - demand.
   - **Connected load** - is the total electric power-consuming rating of all devices connected to an electrical distribution system, the total demand.
2. **Demand load** - is calculated in a certain time interval by measuring the greatest load demand during this time interval.

Demand loads can be calculated using demand factors as summarized for lighting loads *(generalized examples shown)*:

| Occupancy type | Connected loads range (VA) | Demand factors (%) |
|---|---|---|
| Dwelling units | 0-3,000 | 100 |
| | 3,001-120,000 | 35 |
| | Over 120,000 | 25 |
| Hospitals | 0-50,000 | 40 |
| Warehouses for storage | 0-12,500 | 100 |
| | Over 12,500 | 50 |

Demand factors for non-dwelling receptacle loads *(generalized examples shown)*:

| Connected loads range (VA) | Demand factors (%) |
|---|---|
| 0-10,000 | 100 |
| Over 10,000 | 50 |

3. **Maximum demand** - the integrated demand for a specified time interval (i.e., 5 minutes, 15 minutes, 30 minutes, or other appropriate time intervals, rather than the instantaneous demand or peak demand).
   - **Maximum load demand** - is defined as the sum of ratings of all electrical equipments that are connected at the supply point regardless of their status of operation It is calculated depending on the installed equipment without measuring or testing their actual demand The connected load, which is independent of time, is greater than the maximum load demand.
4. **Instantaneous demand (a.k.a., instantaneous load)** - the power that something is using (or generating) at any one moment in time.
5. **Peak demand (a.k.a., peak load)** - the power that everything is using at some peak time(s).
6. **Demand factor (a.k.a., power factor) -** is the ratio of the sum of the maximum demand of a system (or part of a system) to the total connected load on the system (or part of the system). Demand factor is always less than one. The ratio of the maximum coincident demand of a system, or part of a system, to the total connected load of the system. Demand

factor is express as a percentage (%) or in a ratio (less than 1). Demand factor is always < =1. The lower the demand factor, the less system capacity required to serve the connected load. The term demand factor is used to refer to the fractional amount of some quantity being used relative to the maximum amount that could be used by the same system. The word "demand" itself says the meaning of Demand Factor. The ratio of the maximum coincident demand of a system, or part of a system, to the total connected load of the system. The demand factor is always less than or equal to one. As the amount of demand is a time dependent quantity so is the demand factor. Demand factor is the ratio of the maximum (peak) demand to the full load of a device in a specific period of time.

The demand factor is the ratio of the maximum demand on a system to the total connected load of the system or

*EQUATION: Demand factor = Maximum demand load / Total load connected*

*Demand Factor = Maximum demand / Total connected load*

A. To calculate demand for a part of a system:

- $f_{Demand}(t)$ = demand / maximum demand
  - Wherein,
  - $f_{Demand}$ = demand for load in a given time period / maximum possible demand for load

B. To calculate demand for a whole system:

*DF = Maximum demand of a system (M.D) / Total connected load (TL) on the system*

- DF = M.D / TL
- Wherein (i.e., this formula uses 2 variables):

1. Maximum demand - Maximum coincident demand is the maximum of all the demands that have occurred during a given period.
   - Measured in Watt.
2. Total connected load - Total Connected Load is the load connected across the system.
   - Measured in Kilowatt.

**EXAMPLE:** *If a residence having 6000W equipment connected has a maximum demand of 300W, then demand factor = 6000W / 3300W = 55%. Or, for example, an over sized motor 20 Kw drives a constant 15 Kw load whenever it is ON. The motor demand factor is then 15/20 = 0.75= 75 %.*

7. **Coincidence factor** - is the ratio of the maximum demand of a system, or part under consideration, to the sum of the individual maximum demands of the subdivisions.

   *EQUATION: Coincidence factor = Maximum system demand / Sum of individual maximum demands*

8. **The load factor ($f_{load}$)**- Is defined as the average load divided by the peak load in a specified time period. It is a measure of the utilization rate, or efficiency of electrical energy usage; a high load factor indicates that load is using the electric system more efficiently, whereas consumers or generators that underutilize the electric distribution will have a low load factor. The load factor is the ratio of the average load over a designated period of time, usually 1 year, to the maximum load occurring in that period.

   *EQUATION: Load factor = Average load / Maximum load*

   $f_{load}$ = *average load (or, demand) / maximum load (or demand) in a given time period*

9. **Diversity factor** - is the ratio of the sum of the individual maximum demands of the various subdivisions of a system (or part of a system) to the maximum demand of the whole system (or part of the system) under consideration. The diversity factor is the reciprocal of the coincidence factor. Diversity is usually more than one. Consider two buildings with the same maximum demand, but that demand occurs at different intervals of time. When supplied by the same feeder, the demand on such a system is less the sum of the two demands. In electrical design, this condition is known as diversity. Diversity factors have been developed for main feeders supplying a number of feeders, and typically, they are 1.10 to 1.50 for lighting loads and 1.50 to 2.00 for power and lighting loads. Feeder conductors should have sufficient Ampere Capacity to carry the load. For example, consider that a feeder supplies five users with the following load conditions: On Monday, user one reaches a maximum demand of 100 amps; on Tuesday, two reaches 95 amps; on Wednesday, three reaches 85 amps; on Thursday, four reaches 75 amps; on Friday, five reaches 65 amps. The feeder's maximum demand is 250 amps.

   *EQUATION: Diversity factor = Sum of individual maximum demands / Maximum system demand*

   Hence, in this example, the diversity factor can be determined as follows:

*Diversity factor = Sum of total demands ÷ Maximum demand on feeder = 420 ÷ 250 = 1.68 × 100 = 168%*

*Diversity Factor = (Sum of individual maximum demand) / (Maximum demand of power station)*

*Diversity Factor = Installed load / running load.*

The demand load for a panel:

| | Connected Load | | | Demand Load | |
|---|---|---|---|---|---|
| Load type | $P_R$ (kW) | $P_X$ (kVAR) | DF | $P_R$ (kW) | $P_X$ (kVAR) |
| Lighting | 14 | 1 | 1.00 | 15 | 4.2 |
| Appliances | 4.1 | 2.1 | 0.5 | 4.1 | 2.1 |
| Heatpump | 14.8 | 4.9 | 1.1 | 15 | 8.8 |
| Total | | | | 34.1 | 15.1 |

To determine true load and compare between loads, the following factors are required:

1. Idling/standby losses.
2. Raw electrical transformation efficiency.
3. Raw power output supply potential.

## 18.8 Engineering calculations electricity

To determine electrical power usage ("consumption") for a building, a control system may have an instrument transformer (utility "meter") installed in the high-voltage side of the service transformer. In particular, potential transformers (PTs) and current transformers (CTs) are installed to form wattmeters. One method that is commonly used to measure energy use in buildings (kWh) consists of using three wattmeters (one per phase). A wattmeter is made of a PT and a CT with a common turns ratio of 100. Estimate the actual current supply to a building supplied by 208Y/120 voltage system if a phase.

Optimization of an electrical system can occur on both the production and demand side of the system. Effective power systems need planning and demand forecasting to ensure that power supply meets power demand.

Here, it is essential to calculate the power factor of every system. The power factor is defined as the ratio of actual power used by the consumer (expressed in kW) to the total power supplied by the utility (expressed in kVA).

#### *18.8.1.1 Power generation cost*

*A.k.a., Power generation cost, energy cost.*

It is possible to determine the cost effectiveness of local power production systems and transported power (Read: utility grid power) systems, which can then be compared and combined. In general, the cost of energy is calculated as the cost of generating one kWh by the power production system/technology; while, accounting for its capital costs, financing costs, fuel costs, and fixed and variable operating and maintenance (O&M) costs over an assumed lifetime. Typically, the term levelized cost of energy (LCOE) is utilized when the present worth of all costs are considered. The specific calculations for LCOE depend on the power generating technology, but a general method is provided:

$$LCOE = ( \sum^{N}_{K=0} Ck * SPPW (d,k)) / \sum^{N}_{K=0} E_k$$

- Wherein,
  - $C_k$ are the total costs incurrent in year k and include investment expenditures, operations and maintenance (O&M) expenditures, and fuel costs.
  - $E_k$ is the total electrical energy produced at year k.

**NOTE:** *In the market, for a power generating technology to be economically competitive, LCOE should be lower than the baseline (typically from the grid) prices.*

#### *18.8.1.1 Life cycle financial cost*

The life cycle analysis method is the most commonly accepted method to assess the financial costs of energy efficiency or distributed generation technology applications over their lifetime. For instance, it is possible to decide between two alternatives for the same project: install an energy-efficient transformer or consider premium efficiency motors), or both.

The basic procedure of the method is relatively simple, since it seeks to determine the total cost incurred by various alternatives over the lifetime of the system. The total costs are estimated over the system lifetime including installation, operation, replacement, and maintenance costs. The cost is commonly determined using:

1. The current cost [to legally acquire and legally install the capital/technology]. There word "legal" is used here because there are often legal and/or State taxes related to the acquisition of assets.
2. The annualized cost [to continue to legally own, operate, replace, and maintain the capital/ technology].

In the market-State, the system alternative with the lowest total cost is typically selected.

#### *18.8.1.2 Electricity production resources and costs*

There are resources and costs (market only) associated with electricity production, including but not limited to:

1. Generation plant: The cost of acquisition and operation of the power plant to generate electricity represents typically the highest cost category. The power generation plants have to meet several

regulatory and safety requirements.

2. Transmission/distribution systems: To deliver the electricity from the generation plant, where it is produced, to areas where it is utilized, transmissions lines, sub-stations, and distribution networks have to be used. The cost of the transmission/distribution systems depends on the distances to be covered as well as transformers, capacitors, and meters to be used. Moreover, the delivery energy losses can be a significant part of the transmission/distribution costs.
3. Fuel systems: The electricity is generated using a primary fuel source depending on the power plant. The fuel cost can be small as in the case of hydroelectric plants or significant as in conventional fuel oil or coal power plants. The cost of fuel may fluctuate depending on the world markets.
4. Administrative costs: In the market, these are the salaries of management, technical, and office staff as well as insurance.
5. Maintenance costs: In the market there are maintenance costs for the power plant equipment.

# 19 Architecture illumination sub-system

*A.k.a., Lighting, illumination engineering, lighting engineering.*

Lighting systems convert electrical energy or fuel into light. Herein, light and illumination are one thing. Principle and attribute. Principle refers to what something is (e.g., light), and attribute is what something does (e.g., illumination).The illumination of buildings is a design process aimed at generating light for the user's well-being. The layering and patterning of light is considered successful when complex physiological and psychological requirements are satisfied. Such requirements arise from vision: the medium through which information and perceptions about a given space are received by photosensitive organs and processed by the brain. The illumination of an architectural space is simply the result of transmitted or reflected light emanating from proximal and distal surrounding surfaces. Only with a proper understanding of physiological and psychological factors, and a familiarity with available technologies, can lighting decisions be made for proper effect.

When available and well controlled, daylight is by far the preferred source of illumination. Today, the common design approach combines the contribution of both electric and natural lights.

Architectural illumination has several significant design elements:

1. Illumination within the building.
   A. Natural sunlight.
   B. Artificial (by means of electrical power).
2. Illumination surrounding the building.
   A. Natural sunlight.
   B. Artificial (by means of electrical power).

The most significant characteristics of an illumination system are:

1. Volume of area consumed by technology.
2. Connector type.
3. Power type.
4. Lumen output (measured in lumens or luminous flux).
5. Color rendering index.
6. Color temperature.
7. Thermal output (note that some lighting adds relevant heat to a building).
8. Electrical load.
9. Total wattage.
10. Nominal wattage.
11. Lifetime.

## *19.1 Illumination standards*

Just like other subsystem services (e.g., plumbing, electrical), there are illuminance standards, produced with different objectives.

## 19.1.1 Standard illumination documentation

Illumination systems are documented via specifications and drawings.

1. Illumination drawings (a.k.a., illumination schematics, light drawings) illustrate the system that will support illumination.
2. Illumination specifications include all written content, reasoning for decisions, and calculations.

An illumination drawing (illumination system schematic) illustrates the illumination system, including its wiring and electrical subsystem, and its lighted surface values. Note that an electrical diagram may/will include a circuit diagram for lighting.

There are two primary lighting diagrams:

1. An electrical lighting circuit diagram - shows the wiring of a lighting circuit(s) and the endpoints. In some cases, the main electric lighting circuits are separate from the power ring main circuit.
2. An illuminance diagram - shows the illuminance values of all surfaces, including time-of-day and illumination programming.

#### *19.1.1.1 Illumination system plan*

> **NOTE:** *An illumination plan may be a sub-section of the electrical plan.*

An illumination (lighting and shading) plan necessarily involves:

1. Illuminance design diagram includes location and orientation of illumination:
    A. Light transportation surfaces (e.g., windows and mirrors).
    B. Illumination points.
        1. Natural.
        2. Artificial.
    C. Shading from view.
        1. Privacy.
    D. Shading from local illumination:
        1. Functional and desired.
        2. Function and not desired (i.e., light pollution).
    E. Shading from sun.
2. Electrical [lighting] design diagram for the circuitry that provides electricity and control to the illumination (and sensor) points.

## 19.1.2 Standard illumination requirements

What is required for a viable illumination system is:

1. **For architecture** - Illumination production proportionate to user demand.
2. **For economic calculation** - Data sheeting about demand (lighting) to produce optimization calculation.
3. **For life support demand** - illumination proportionate to human demand.
4. **For technology and exploratory demand** - illumination proportionate to human demand.
5. **For transport** - Lighting proportionate to motion and safety.
6. **For walking** - Lighting proportionate to motion and human biorhythms.
7. **For dwellings** - Appropriate space lighting with a human circadian light proportionate setting.
8. **For working areas** - Appropriate space lighting for safety, motion, and/or human biorhythms.

#### *19.1.2.1 Bio-compatibility requirements*

When designing an illumination system, circadian compliant environmental lighting is preferred. Designs have a requirement to account for light [artificial production] in relationship to natural restoration cycles, both in existence, illuminance power, and frequency duration. In particular, a general rule for outdoor human compliance outdoor lighting is designed to protect eyes from higher frequency blue light and to increase contrast. The best choice is for specific tints of:

- Red.
- Orange.
- Red-orange = 100% protection (no visible blue).
- Yellow
- Amber
- Gold
- Brown = moderate protection (some visible blue).

It is noted that some areas may be specifically light with tints of higher frequency blue for a specific localized reason (e.g., event or recreational landscape, possibly including buildings). It is also important to remember here that the farther into full red the color filter (in the form of glasses, or emitted in the form of a red bulb/led) the more other colors will be distorted and blend together. This can have consequences in situations where high visual precision in a complex environment requires contrast awareness between objects.

The most biocompatible light bulbs are those that are capable of emitting a full-spectrum of light during the day (capable of matching sky blue also) while dimming and emitting more red-type wavelengths when electrically dimmed.

To protect the eyes from the wrong frequencies of light at night, and to increase contrast over pure red, it is relevant to select specific tints:

1. 100% protection (no visible blue)
   A. Orange
   B. Red-orange
2. Moderate protection (some visible view, but more contrast.
   A. Yellow
   B. Amber
   C. Gold
   D. Brown

**NOTE:** I*t is important to be aware, for safety, that 100% blue blocking (Read: only red light) will distort other colors. And, the closer to all red, the more colors will lose contrast between one another. For this reason, some tasks that require high physical precision should likely not be performed with them on. Of additional note, after someone removes blue-blocking glasses, for example, their color perception will be temporarily altered so that specific colors appear to be other colors.*

#### *19.1.2.2 Efficiency possibilities*

In general, the most energy efficient lights are LEDs (light emitting diodes).

### 19.1.3 Hazards with the illumination system

There are several hazards associated with an illumination system, including but no necessarily limited to:

1. **Light pollution** - refers to outdoor or indoor artificial light that is considered excessive or obtrusive - artificial light which shines where it is neither wanted, nor needed. Light pollution has the potential to disrupt breeding patterns of nocturnal animals, insects and the migration of birds. It can also have an adverse impact on the health and wellbeing of people, disrupting natural body cycles regulated by darkness and light. Light after dusk, when people are attempting to sleep, can trigger daytime physiology, telling the brain to become more alert, increasing the heart rate and body temperature, and suppressing the production of melatonin. It is thought that sleep disorders, increased stress and certain types of cancer can be developed if sleep is disturbed by artificial lighting. Light pollution can also be a significant waste of energy. The main categories of light pollution are (Light pollution, 2021):
   A. **Glare** - is a discomforting or disabling brightness that causes a loss in visibility as stray light scatters within the eyes.
   B. **Sky glow** - occurs from both natural and artificial sources of lighting that increase night sky brightness. Light can be emitted directly or reflected into the atmosphere to produce a luminous background. Here, the ability of ground observers to view the stars at night is hindered.
   C. **Light trespass** - occurs when light enters into areas in which it is unwanted (or, unneeded). An example of this would be the light from an exterior street light entering a bedroom window and illuminating the interior.
   D. **Over-illumination** - simply refers to the excessive use of lights.
   E. **Light clutter** - occurs when an area where there are large group of lights that may cause distraction or confusion. Clutter can be found in particular in parts of cities or on busy roads.
2. **Shadow** - refers to places blocked by light (either at night by artificial lights, or during the day with sunlight). Shaded areas with a lot of decomposing organic matter, and/or high humidity, are likely to develop mold and bacterial growth.
3. **Fires.**
4. **Electrical shocks**.

## *19.2 Conception of the illumination system*

**NOTE:** *Sometimes the illumination system is considered a sub-system of the electrical system.*

Illumination is the attribute (quality) of 'light'. Light is a physical process measured by means of electromagnetism, and illumination is measured by the quality of the light in meeting fulfillment and the quantity of the light in lux (illuminance) and kelvin (color temperature). Fundamentally, a light source is a controlled loss of energy emitter.

### 19.2.1 Natural illumination

*A.k.a., Natural lighting.*

Natural light, as opposed to artificial light, refers to light produced by sunlight.

### 19.2.2 Artificial illumination

*A.k.a., Artificial lighting.*

Artificial light, as opposed to natural light, refers to any light source that is produced by electrical means.

The most common forms of artificial illumination are:

1. **Incandescent** - uses a wire or filament being heated to incandescence (emitting light) by a flow of current through it. It can be run directly on line current and therefore does not require a ballast. It can also be dimmed using relatively simple equipment. Produces light in a well accepted warm

tone.

2. **Fluorescent** - produces light by activating selected phosphors on the inner surface of the bulb with ultraviolet energy, which is generated by a mercury arc. Because of the characteristics of a gaseous arc, a ballast is needed to start and operate fluorescent lamps. Produces bluer light and has a flicker rate that can be draining to human energy levels.
   A. **Induction** - Induction lamps are electrodeless fluorescent lamps driven by high-frequency current, typically between 250kHz and 2.65mHz, usually via an external generator. They are available in limited wattages and are known for exceptionally long service life: up to 100,000 hours. Lamp efficacies typically range from 64 to 88 lumens per watt. Color rendition with induction lamps is very good.
3. **High intensity discharge (HID)** - Light is produced in HID and low pressure sodium (LPS) sources through a gaseous arc discharge using a variety of elements. Each HID lamp consists of an arc tube which contains certain elements or mixtures of elements which, when an arc is created between the electrodes at each end, gasify and generate visible radiation.
   A. Metal halide (MH).
   B. Mercury vapor (MV).
   C. High pressure sodium (HPS).
   D. Low pressure sodium (LPS) - similar to high pressure sodium.
4. **Light-emitting diode (LED**) - a semiconductor light source that emits light when current flows through it. LEDs have a flicker rate. LEDs require a separate power supply. LEDs come in to types:
   A. LED bulbs.
   B. LED strips.

Artificial lighting in an illumination system can be of many types, including but not limited to:

1. Lighting panel.
2. Recessed light.
3. Recessed light served by an emergency branch circuit.
4. Recessed linear light.
5. Recessed linear light served by an emergency branch circuit.
6. Track light.
7. Recessed can light.
8. Wall-mounted light.
9. Recessed wall wash light.
10. Battery-powered emergency light.
11. Ceiling-mounted exit sign - arrow for direction.
12. Wall-mounted exit sign - arrow for direction.

### 19.2.3 Shadows (deprivation of illumination)

The shadow of each building needs to be accounted for. Large buildings have been blamed for casting a shadow over public areas. In other cases, the design of highly reflective buildings can creating a "death ray" type beam of sunlight capable of melting cars on the street.

In most common areas, unless intended for specialized reasons, dark spaces should be avoided.

### 19.2.4 Redirecting light (reflecting illumination)

Objects redirect light to varying degrees. Some objects can be designed to absorb near all light.

Light can be redirected in several ways.

1. Redirected sunlight using an inside mirror.
2. Redirecting light using non-mirrored surfaces.
3. Redirecting light using buildings. Architects can now designed buildings which don’t block out the light by diffusing light from one building onto a wide area (possibly, including other buildings). Such building designs and configurations work together to disperse and refract sunlight. They are designed so that when one building creates shade, the other can act as a huge curved mirror, allowing the light to be reflected downwards into its shadow.

### 19.2.5 Affects of illumination

Illumination has affects on its environment, both for the object(s) reflecting the illumination and the organisms inhabiting that environment. The most notable affect of illumination on objects is that of heat and appearance to organisms. Blue light is an indicator of sunlight and daytime, under normal conditions. Additionally, under natural conditions the near infrared is always present, and the human body has evolved and adapted to its presence.

#### *19.2.5.1 Illumination and heat*

Two components to the heat of the light are:

1. The way the light is generated.
2. The power consumed.

#### *19.2.5.2 Illumination and human biorhythms*

*A.k.a., Light and biological cycles.*

**INSIGHT:** *Humans (and some other organisms) are designed to live under light, to take in light, and to use it for bio-cellular processes.*

Both sunlight and artificial light are likely to have an affect upon human biorhythms. Both daytime light and night time light ought to be compatible with human biorhythms. Technology can facilitate human connection or disconnection from oneself and the natural environment. Humans and other animals react to light cycles. Humans are designed to live under light, to take in light, and to use it for bio-cellular processes.

Humans evolved under the presence of natural high blue light during the day and the absence of that type of light at night. Through evolution humans have had a very predictable day and night, light and dark pattern. With the advent of modern technology, humans can now simulate day-time during the night-time, which leads to the disregulation of natural circadian and cortisol rhythms. Daylight during night-time is often is a detrimental influence, because it stops (or at least hinders) the human body's ability to regenerate itself during sleep mode. It is possible that If you the use of the wrong kind of light at night can reduce the effectiveness of the regeneration phase, opening the door for degenerative diseases. Potentially, it is in human DNA to have reduced brightness and color temperature after sunset. Fundamentally, light influences biological timings.

It is important to note here that the brightness and frequency of light at night can affect other organisms, including plants and other mammals (e.g., owls).

> *"We need to realize that it's in our DNA to have darkness after sunset, before we go to sleep. That gives us access to our intuition, our creativity. I would put it right up there with survival."*
> *- Pam Morriss, Lighting Expert, San Francisco Magazine October 2009*

#### *19.2.5.3 Illumination flicker and humans*

Flicker refers to the on and off pulsing of a light source. LEDs and other sources of light have some degree of flicker (a stroboscopic effect). The lower the flicker rate, the more perceptible it is to human physiology, and the higher the likelihood of causing stress (or even, distress) to human physiology. In order to not negatively affect human biophysiology, an LED pulse width modulation of 10000hz or higher is considered optimal for human safety. This means the light turns on and off 10000 times per second, and the flicker will not be visible to human sight.

When flicker is present, the brain has to eliminate these pulses, and this is what makes people exceedingly tired after being its presence for relative durations of time. When significant flicker is present the body has to significantly adapt to it.

#### *19.2.5.4 Illumination and performance*

Some technology can make it more difficult to perform and function. For example, working under flourscent light tinted toward the blue spectrum, with high contrast, and with relative flicker is likely to stress the human brain and reduce performance on work with a focused task. Light can reduce or improve performance in relation to both:

1. **Visual sight accuracy.** This element is associated with a color rendering index and contrast index. Herein, visual contrast sensitivity (VCS), is the ability to distinguish between an object and its background or detect differences between objects. Note that color depends on frequency presence in conjunction with how something absorbs and reflects light.
2. **Visual physiological performance.** This is a subjective element and relative to the individual, the context, and the illumination configuration. There are a variety of known causes of in concern to light, including:
   A. Brightness at the wrong time.
   B. Color at the wrong time.
   C. Frequency (flicker) at the wrong time.
   D. Electrical-magnetic fields that power electrical lights.

#### *19.2.5.5 Biocompatible light bulb technology*

Commercial products in this category include, but may not be limited to:

1. TrueLight Luna Red™ Sunset Light - is an adjustable wavelength emitting lightbulb by TrueDark [truedark.com]. These are a 4-way adjustable light bulb emitting wavelengths from 1000K to 3000K with the ability to dim or brighten to customize the illumination of the environment.
   A. The characteristics of the bulb include:
      1. Standard A19 size with E26 base
      2. AC 85V–265V / 50Hz – 60Hz
      3. Flicker-Free LED Bulb
      4. Lumens: 121lm – 447lm (1000K = 121lm / 2000K = 264lm / 3000K = 447lm)
      5. CRI: 1000K Ra=51.4 / 2000K Ra=92.1 / 3000K Ra=81.8
   B. The costs of the bulb include:
      1. Monetary acquisition cost: 22.5 USD per unit (or, 4 bulbs = 90 USD).
      2. Power requirement cost per bulb: 7 watts (per hour).
      3. Replacement life span: 30,000 hours / 27.4 years (based on 3 hrs/day).

## *19.3 Conception of the electrical illumination circuit sub-system*

Electrical illumination circuits come in both types of electricity:

1. AC electrical illumination circuits.
2. DC electrical illumination circuits.

## *19.4 Conception of the illumination*

### *control sub-system*

A lighting control system is the system of controls that change lighting parameters over time. Such a system incorporates communication between various system inputs and outputs related to lighting. Lighting control may be more automated ("intelligent") or more manual. Lighting control systems are used on both indoor and outdoor lighting. Lighting control systems serve to provide the right amount of light where and when it is needed.

An illumination control system may have any of the following functions:

1. On/Off switch that turns the illumination on and off.
2. Dimmer switch that makes the illumination brighter or dimmer.
3. Color spectrum control:
   A. By means of control built into the bulb (such that when the power changes, the color temperature changes).
   B. By means of a light panel that allows for controlling the color temperature of LEDs.

Lights can be regulated through the following methods:

1. Lights can be put on timers.
2. Shades can be put on timers.
3. Lights can be connected to motion sensors.
4. Lights can be connected to electromagnetic sensors (i.e., sensors that detect sunlight).
5. Lights can be connected to alarms.
6. Lights can be dimmed (so as to reduce power input, for example, at night).

Automated control of an illumination system can account for the following factors:

1. Chronological time - schedules incorporate specific times of the day, week, month or year.
2. Solar time - schedules incorporate sunrise and sunset times, often used to switch outdoor lighting. Solar time scheduling requires that the location of the building be set. This is accomplished using the building's geographic location via either latitude and longitude or by picking the nearest city in a given database giving the approximate location and corresponding solar times.
3. Occupancy - is primarily determined with occupancy sensors.
4. Alarm conditions - typically include inputs from other building systems such as the fire alarm or HVAC system, which may trigger an emergency 'all lights on' or ' all lights flashing' command for example.
5. Program logic - specialized logic set by a user(s).

### 19.4.1 Shading control

Shading is the term used when illumination from non-controllable sources are to be reduced or blocked (i.e., to be controlled).

Shading control involves:

1. Shading requirements:
   A. Shading of light during day.
      1. Shading from sun.
      2. Shading from sources of light exterior to architecture.
   B. Shading of light during night.
      1. Shading from moon.
      2. Shading from sources of light exterior to architecture.
2. Architectural shading with exterior blinds.
   A. Attachments at top and bottom of exterior (veranda) at edge and surrounding walkway.
      1. Allows for customization of shades in appearance and materials.
3. Architectural shading with interior blinds, curtains, or other.
   A. Attachments at top and possibly bottom of interior edge near the exterior surface (wall or window).

### 19.4.2 Safety control

Within a habitat, lights may be used as signals in the case of emergency. Also, at night and when there is presence they come on to illuminate the surroundings, but importantly, at night the color temperature of their illumination remains low so as not to disrupt our bodies production of melatonin and its other restoration cycles.

## *19.5 Objects in the illumination system: fixtures, fittings, and appliances*

Illumination fixtures and fittings are equipment that interface with the electrical-illumination in a building:

1. **Illumination fixtures** - a device for producing light. The most common fixtures include, but may not be limited to:
   A. Light fixtures - hold light bulbs.
   B. Shade fixtures (e.g., blinds, screens) - allows for control of illumination.
   C. Curtains - allows for control of illumination.
   D. Windows (*also classified as* 'structural' and 'surface') - window surfaces are a light permittance surfaces, and can be part of construction and/or installation. These surfaces can let different amounts of frequencies of light

through.
E. Light controllers - provide electrical control of some light sources.
F. Lighting electrical ballasts - provide appropriate electrical power for some light sources.
G. Electrical transformers - provide appropriate electrical power for some light sources.
H. Mirror - light redirecting surface fixture (*also classified as* 'surface').

2. **Illumination fittings** - a device designed to control and guide the flow of electricity and illumination. The most common fittings include, but may not be limited to:
   A. Switches - control points for lights and shades.
   B. Light bulbs - come in many different types and can be categorized according to their energy usage and emission wavelength and brightness
3. **Illumination appliances** - appliance devices that change the atmosphere, the most common of which include:
   A. Portable lamps with light bulbs.

**IMPORTANT:** *All fixtures, fittings, and appliances must be specified with the right capacity for their placement.*

### 19.5.3 Light switches

*A.k.a., Illumination switches.*

A light switch is an electrically wired switch most commonly used to operate electric lights, permanently connected equipment, or electrical outlets. External to the architectural wiring of a building, portable lamps such as table lamps may have a light switch mounted on the socket, base, or in-line with the cord.

**NOTE:** *In many architectural constructions, buildings are a mess of light switches. Light switch placement can be confusing to users and use materials unnecessarily given available wireless technologies. Light switch wiring diagrams are some of the most complex diagrams for an architectural construction.*

There are several types of light switch:

1. Manually operated on/off switches.
2. Dimmer switches that allow control of the brightness of lights as well as turning them on or off.
3. Time-controlled switches (some of which are integrated into the wiring and others are separate external items that fit into an electrical socket and into which the cord of a lamp is placed). This may be a type of smart home system.
4. Occupancy-sensing switches (motion sensors). This is a type of smart home system.
5. Daylight-sensing switches. This is a type of smart home system.
6. Remote controlled physical switches and dimmers (a.k.a., physical smart switches, physical wifi switches). This is a type of smart home system.
7. Remote controlled software-only switches and dimmers (no-touch switches). This is a type of smart home system.

**NOTE:** *Light switches are also found in flashlights, vehicles, and other devices.*

There are two general types of illumination control for a building; illumination control:

1. **With light switches** - the use of physical light switches placed [generally on walls] within the building.
2. **Without light switches** - the use of digital controllers, and possibly, physical [motion] sensors. Of course, a hidden “switch” or circuit breaker must still exist, but there’s no need to have a visible switch on the wall surface. This method uses software-only switches and dimmers (no-touch switches).

### 19.5.4 Panelized light switches

*A.k.a., Panelized illumination switches.*

In the case of a panelized lighting solutions, switches are replaced with keypads and motion sensors that trigger scene lighting. All lights are run to a panel and the panel circuits are smart.

## *19.6 Installation of illumination system*

*A.k.a., Illumination circuit installation.*

There are many ways to install illumination circuitry. These systems are usually embedded into structure.

### 19.6.1 Illumination point placement

Lights can be placed on all allowable surfaces. The placement of lights depends on context.

#### *19.6.1.1 Interior lighting*

There are four general types of interior lighting:

1. **Accent** - lighting aimed at areas of interest.
2. **Ambient** - appropriate lighting that fills an area with an appropriate brightness and color temperature.
3. **Decorative** - lighting that provides for a type of festivity (e.g., christmas lighting) or fixture-based beauty (e.g., chandelier lighting).

4. **Task** - lighting for an activity that facilitates performance and reduces unwanted stress.

### 19.6.2 LED strip placement

There are a series of best practices that should be followed when placing LED strips:

1. LED strips should never be directly exposed (i.e., visible to users). They should be mounted out of sight and projected toward another surface.
2. With long led strips, the voltage will decrease along the strip. Hence, there will be very bright lights at the beginning of the strip where the voltage is high, and dim lights at the end where the voltage is less. If many light strips are combined in series, then the voltage and brightness decrease over distance.
3. LED strips should be placed inside of a channel with a diffuser where appropriate. This isn't of high importance when the LED strip is hidden from view. In instances where there is nothing for the light to be projected onto, LED strips should be installed inside of a channel with a diffuser. These channels hide the led strips, but they are also much easier to mount and keep straight than the bare LED strip. Typically, these channels are made out of aluminum or silica gel. Aluminum channels come in two options: a corner mount option or a flat surface option. There are also silica gel covered channels. Silica gel channels are bendable, while the aluminum ones are not (note: bends are up and down, and not left and right). Some of these channels are waterproof while others are not. Note here that surface attachable mounting clips can be used in place of channels to attach LED strips to surfaces. If there is adhesive on the back of the strip, these mounting clips will reinforce that adhesive.
4. Installations should keep a uniform distance and angle to the surface they are projecting onto. Not doing so can cause Hotspot in the illumination. These Hotspot can also be cause by turns in the led strip themselves (creating more illumination in one area versus others). Loops at corners will create a hotspot because the number of LEDs in that area will increase. A better option is to use solderless corner connectors. Here, the number of copper connects on the strip are matched to a corner connecter with the same amount of pins.
5. LED strips do not need to be RGB. There are at least three types of LED strips in relation to color:
   A. RGB strips - each channel can be turned on or off.
   B. RGB + W (white) strips - each channel can be turned on or off.
   C. White strips (or, another single color).
6. Choose the right power for the application, including voltage and watts. Note that watts will add up when LED strips are connected. The voltage needs to match exactly, but it is OK to go over in concern to watts.
7. Choose the right number of LEDs per meter (density). The greater the LED density, the more expensive the strip will be, but it will also provide greater color accuracy and brightness. Note here that a higher density equates to higher power consumption and higher heat. Additionally, heat will lower the lifespan on the strip.
8. Select the right waterproofing type. Note here that as waterproofing increases, heat dissipation decreases. There are three types of waterproofing for LED strips:
   A. IP 20/30 - no water protection.
   B. IP 65 (silicone coating) - the top of the strip is coated in a waterproof silicone layer. This is sufficient for LEDs that will occasionally be splashed or exposed to high humidity.
   C. IP 67 (silicone sleeve) - the strips are sealed in a silicone sleeve that provides a completely water-tight seal.
9. Individually addressable LEDs include microchips connected to each LED that takes instructions, allowing for each LED to take different actions. Note here that in some cases, a single dead addressable LED can cause the rest of the strip to start working.

## *19.7 Operation of illumination system*

In concern to electrics, most significant operational activities are located on the supply side because of the requirement for static pressure given dynamic demand. In concern to illuminance, most significant operational activities are located on the demand side because of needed changes (e.g., occupancy and time of day) in the illuminance of areas.

### 19.7.1 Illumination load demands

*A.ka., Illumination loading.*

Illumination loads are measured in several ways, most notably, energy consumed to produce:

1. Energy consumed,
2. Illumination produced, and
3. Thermal temperature.

In order to do work, illumination systems are split into a power usage system and an illuminance changing service system:

1. A power usage system:
   A. Energy consumed may be by electricity or combustion of fuel.
      1. Most electrical illumination loads are measured in watts [of electrical] power. Often, the kilowatt hour (kW.h)
      2. Illumination systems can be measured in BTU [of heating or cooling] power.
2. An illumination-flow conditioning (production and distribution) system:
   A. Light flow illuminance is light flow rate, or quantity of light being moved, which is measured in:
      1. Light intensity emitted [from a source]: Lumen (lm) is the unit for luminous flux. It measures the total amount of light emitted by a light source in all directions. Luminous flux takes into account the sensitivity of the eye to the visible part of the electromagnetic radiation. Lumen is therefore the unit to measure the brightness of a light source independently of the direction of the light beam. Luminous flux is a measure of the total amount of light in a light beam. Light intensity is a measure of the light density.
      2. Light intensity received [to a surface]: Lux (lx) is a unit of illumination: 1 lux is the illuminance produced by 1 candela on a surface perpendicular to the light rays at a distance of 1 meter from the source. Lux corresponds to the illuminance that is obtained by an observer when each square meter of the considered surface receives a luminous flux of one lumen. Lux can be measured from different distances. With a light meter it is possible to measure the lux value of any surface or space.
      3. Light intensity observed [by someone]: Candela (cd) is the unit for brightness. The word candela means candle in Latin. One candela corresponds approximately to the light intensity of a normal candle. The candela is related to the lumen and lux units. The unit lumen is used for the total luminous flux in a light beam. A light beam with a strength of 1 candela and a space angle of 1 steradian (for a cone-shaped beam corresponds to an opening angle of 65.5 °) has a total luminous flux of 1 lumen. 1 candela is thus equal to 1 lumen per steradian. When a beam with a strength of 1 lumen illuminates a surface of 1 square meter, this gives an illuminance of 1 lux. 1 lux is therefore equal to 1 lumen per square meter.
   B. Light temperature is frequency of the light (tint).It is possible to measure the color of light at different points on a surface and find the average frequency of the light. The most common measuring unit for temperature:
      1. Kelvin
   C. Thermal temperature production is measured in kelvins or Celsius (or Fahrenheit in imperial).
3. The conduits and circuitry connected to electrical illumination loads are another type of load.
   - Current causes losses in transmission lines, transformers, and circuitry.
4. Non-usage, but presence, will still equate to system service usage.
   - If a usage circuit has no load in the form of a power factor of zero the user would consume NO illumination (i.e., no usage), but the supplier would still have to send static illumination to them and incur real energy losses in electrical lines, circuitry, and filters. Power factor is the relationship (phase) of light and timing in an illumination production-distribution system.

## *19.8 Engineering calculations for illumination*

Illuminance area calculations for different configurations of lighting and different types of day, with different configurable shading configurations.

To provide appropriate light and/or other desirable elements (e.g., heat), an illumination system must be designed to account for:

1. Electrical service illumination object name.
2. Electrical service illumination object identifier.
3. Table of technical electrical specifics of illumination object.
4. Table of electrical usage specifics of illumination object.
5. Table of applicable access categories (person to common to InterSystem).
6. Time of day (t) of usage(s).
7. For each task and activity of usage [of illumination object], calculate:
   A. $E_m$ (Lx)
   B. $U_0$
   C. $UGR_L$
   D. $R_a$

Illuminance is the level of light on a surface; measured in lux (lx, illumination value). It can be used as a reference measurement of the performance of a lighting system as related to the activity.

Lux is a measure of the amount of light on a surface.

- One lux is equal to one lumen per square metre (lm/m^2).
  - Wherein, a lumen (lm) is the SI unit of luminous flux, describing the quantity of light emitted by a lamp or received at a surface.

Average illuminance is the illuminance averaged over a specific area. This may be derived from either:

1. An average of the illuminances at a representative number of points on the surface.
2. From the total luminous flux falling on the surface divided by the total area of the surface.

Characteristics of illuminance include, but may not be limited to:

1. **Correlated colour temperature (CCT; a.k.a., color temperature and color appearance)** - refers to the visual sensation correlated with the 'warmth' or 'coolness' of light. The metric used to characterise the colour appearance of the light emitted by a light source is the, expressed in Kelvin (K).
   - Warm white light is produced by light having a colour temperature below 3,000 K (reddish hues), whereas 4,000 K and above (bluish) is cool and cold white light.
2. **Colour rendering index (CRI)** - refers to the ability of a light source to show surface colours as they should be, usually in comparison with a tungsten or daylight source. Measured on the colour rendering index (CRI) scale.
   - A value of 0 means it is impossible to discern colours at all, and a score of 100 means no colour distortion. For most indoor lighting applications a value of at least 80 is recommended.

Items to be included in lighting design and analysis engineering are:

1. Average illuminance.
2. Equivalent spherical illuminance.
3. Uniformity ratios.
4. Visual comfort probability.
5. Visual bio-compatibility probability.
6. Special purpose lighting characteristics.

Electrical engineering documents for lighting systems shall, at a minimum, indicate the following:

1. Lighting fixture performance specifications and arrangements
2. Emergency Lighting
3. Exit Lighting
4. Lighting Control and circuiting

### 19.8.1 Standard illumination efficiencies

*A.k.a., Illumination control and automation, smart lighting, intelligent lighting control.*

Often, the greatest three efficiencies achievable in an illumination system are:

1. Identifying and eliminating (or significantly reducing) light pollution.
2. On when needed only, and off when needed only. (i.e., not leaving lights on when not needed, which can be achieved easily through automation).
3. Using natural sunlight. Daylight availability can be used to reduce artificial illumination. Reducing the amount of artificial lighting used when daylight is available is known as, daylight harvesting.

Given current technology, it is possible to construct buildings without the need or presence for physical light switches. Switches are gradually being replaced by touch panels or directly operated via apps on smartphones/ tablets.

**NOTE:** *It is reasonable to consider how it may always be important to have a manual backup of the system.*

Instead of physical switches, illumination control works by means of:

1. **Presence sensors (not necessarily required)** - these sensors are installed strategically to detect human movement that in turn, triggers the systems to be activated or deactivated and at different intensities as per the specific programming of different zones in the building. The following sensors detect motion and presence:
   A. **Passive infrared sensor (PIR) sensors** - detect changes in the levels of energy around the area. PIR sensors don't actually emit the infrared; objects give the sensor infrared rays.
   B. **Active infrared sensors (AIR, sometimes just IR)** - will detect motion and presence by emitting infrared rays and then recording and measuring the result over time to detect changes that indicate the presence of motion and presence.
2. **Control software** - computer programs running on a computing system with a display and can effect digital and mechanical control devices.
   A. Tablet - a device for interfacing with the software program.
   B. OpenHAB to control the illumination.

**INSIGHT:** *In an optimized scenario, users simply walk from room to room and the lights adjust accordingly.*

In the following cases, having no light switches may be preferable:

1. Turning on the light should be as easy or easier than flipping a wall switch.
2. Guests, children, and occupants who currently can't find their phone must be able to control those aspects of the system that do require human interaction. In these cases, a dedicated mounted tablet or a remote control may be suitable.

Alternatively, in certain building cases it is not feasible to have no light switches (i.e., complete automation of illumination):

1. The building may not be to meet jurisdictional code.
2. The building may be difficult to resell.
3. The lights won't work if your central controller goes down.
4. Locations where it is easier to flip a switch, rather than access a phone.
5. Locations where a near instantaneous control of illumination is critical in cases of emergencies.
6. Locations where it is not possible to access a phone.
7. Locations where any downtime of the server is a serious issue for illumination considerations (i.e., emergency-type environments).
8. A location where possible future switch control may be necessary. Similarly, a location where running wires while building is easy, but doing so after is much more difficult.

Some factors to consider in concern to illumination automation include:

1. Check for bulbs that can restore last state when power fails. Right now most bulbs will turn on after power failure. If a power failure happens when the user is out of town, they may return to their building to find the bulbs have been continuously on since the power failure. Herein, it is also possible to use motion sensors to remedy bulbs turning on after a power outage when the occupant(s) are not in the building.
2. Add a whole house battery backup or generator.

# 20 Architecture communication sub-system

*A.k.a., Communications, telecommunications, electrical signaling.*

Communications systems convert electrical power into data-communications signals. These signals are sent, processed, transmitted, and received.

Architectural communication has several significant design elements:

1. Communication within the building.
   A. Support service systems.
   B. Automated control systems.
2. Communication outside the building.
   A. Local person-to-person communications.
   B. Internet communications.

The most significant characteristics of a communications system are:

1. Electrical power.
2. Electrical wiring.
3. Network switching.
4. Data transport.
5. Transmitting and receiving.

## *20.1 Communications standards*

Just like other subsystem services (e.g., plumbing, electrical), there are communications standards, produced with different objectives.

### 20.1.1 Standard communications documentation

Communications systems are documented via specifications and drawings.

1. Communications drawings (a.k.a., communications schematics, light drawings) illustrate the system that will support illumination.
2. Communications specifications include all written content, reasoning for decisions, and calculations.

A communication drawing (communication system schematic) illustrates the communication system, including its wiring, powering, and distribution subsystem, and its qualities therein. Note that an electrical diagram may/will include a circuit diagram for communications.

There are two primary communications diagrams:

1. A wired communications circuit diagram - shows the powering, process, and wiring of a communications

circuit(s) and the endpoints. In some cases, the main electric communications circuits are separate from the power ring main circuit.

2. An access distribution diagram - shows the location of communications endpoints (including outlets) and/or wireless network area of coverage.

##### *20.1.1.1 Communications system plan*

> **NOTE:** *A communications plan may be a sub-section of the electrical plan.*

A communication plan necessarily involves:

1. Communication design diagram includes location wiring of sub-systems:
   A. Areas of wired coverage.
   B. Areas of wireless coverage.
   C. Electrical communications circuits.
   D. Electrical power wiring (e.g., ac/dc).
   E. Electrical communications wiring (e.g., ethernet).
   F. Communications computational processors (e.g., switches and routers).
   G. Architectural plug-in ports (e.g., RJ45 plug).

### 20.1.2 Standard communications requirements

What is required for a viable communications system is:

1. **For architecture** - Communications transmission proportionate to user demand.
2. **For economic calculation** - Data sheeting about demand (communications) to produce optimization calculation.
3. **For life support demand** - communications proportionate to human demand.
4. **For technology and exploratory demand** - communications proportionate to human demand.
5. **For transport** - communications proportionate to motion and safety.
6. **For walking** - communications proportionate to motion.
7. **For dwellings** - Appropriate communications systems for user-to-user and user-to-building communications.
8. **For working areas** - Appropriate communications infrastructure for safety, motion, and coordination.

### 20.1.3 Hazards with the illumination system

There are several hazards associated with an communication system, including but no necessarily limited to:

1. **Electrical hazards** - the communications system is powered by electricity, and thus, has the same hazards as other electrically powered systems.

## *20.2 Objects in the communications system: fixtures, fittings, and appliances*

Furniture fixtures and fittings are equipment that sit on or are otherwise attached to the architectural surfaces of a building for the specific purpose of resting objects:

1. **Communication fixtures** - furniture objects that are classified as fixtures are affixed to or through the architecture. The most common fixtures include, but may not be limited to:
   A. **Electrical power wiring.**
   B. **Electrical signals wiring.**
   C. **Graphical user interfaces.**
   D. **Data ports.**
2. **Communication fittings** - communications objects that are classified as fittings are not affixed to the architecture and are more immediately mobile. The most common fixtures include, but may not be limited to:
   A. **Routers.**
   B. **Switches.**
   C. **Graphical user interfaces.**

## *20.3 Installation of communications system*

Communications objects are physically built and moved into place. Sometimes installation can be done by one or more people, and other times installation requires special mechanical and/or human assisted equipment.

## *20.4 Operation of communications system*

Communications systems operate in a variety of ways, including:

1. Machine-to-machine
2. Machine-to-human
3. Human-to-machine
4. Human-to-human

Communications with and between humans requires a physical interface that the human sends and receives signals (data/information) through.

## *20.5 Engineering calculations for communications*

> *Data and computer communications calculations go here.*

# 21 Architecture furniture sub-system

*A.k.a., Joinery, woodwork, millwork, casework, etc.*

In most buildings, there are additional objects that provide surfaces for the storage and/or placement of other animate (e.g., human) and inanimate (e.g., toaster) objects. Furniture provides stationary surfaces for the placement of objects (including humans). Furniture can be made out of many different substances. Furniture has aesthetic shape and surface properties to individuals, within which there are cultural and functional preferences.

**Terminological clarification:**
*Typically, "millwork" refers to custom built items, whereas "casework" refers to pre-fabricated items.*

## *21.1 Furniture standards*

Just like other subsystem services (e.g., plumbing, electrical, etc.), there are surface standards.

### 21.1.1 Standard furniture documentation

Furniture systems are documented via specifications and drawings.

1. Furniture drawings (a.k.a., surface schematics, surface drawings) illustrate the system that will support illumination.
2. Furniture specifications include all written content, reasoning for decisions, and calculations.

Furniture may have the following diagrams:

1. Object construction diagram.
2. Object usage diagram.
3. Object placement diagram.
4. Object maintenance diagram.

### 21.1.2 Standard furniture requirements

What is required for a viable furniture system is:

1. **For architecture** - Furniture appropriate for:
   A. Aesthetics.
   B. Function.
2. **For walking and transportation** - Surfaces designed proportionate to motion and surface composition, including the maintenance (cleaning) of the surface.
   A. **For transport** - Furniture proportionate to motion and safety.
   B. **For walking** - Furniture proportionate to disability.
3. **For economic calculation** - Data sheet about furniture composition, usage, and safety to produce optimization calculation.
4. **For life support demand** - Furniture proportionate to human demand.
5. **For technology and exploratory demand** - Furniture proportionate to human demand.
6. **For dwellings** - Furniture proportionate to human demand.
7. **For working areas** - Furniture proportionate to human and production demand.

#### ***21.1.2.1 Standard furniture efficiencies***

Furniture can be made more efficient by reducing:

1. The amount of materials used.
2. The labor associated with production
3. The labor associated with installation.
4. The necessity to maintain/clean the furniture.

### 21.1.3 Hazards with the furniture system

Common hazards with the furniture system include, but may not be limited to:

1. Off-gassing (a.k.a., out-gassing) of harmful chemicals.
2. Falling over (for tall furniture; including, dropping).
3. Cleaning issues.
4. Sharpness of edges.
5. Pinching (for furniture that moves).

## *21.2 Objects in the furniture system: fixtures, fittings, and appliances*

Furniture fixtures and fittings are equipment that sit on or are otherwise attached to the architectural surfaces of a building for the specific purpose of resting objects:

1. **Furniture fixtures** - furniture objects that are classified as fixtures are affixed to the ground and not immediately mobile without unattaching. The most common fixtures include, but may not be limited to:
   A. **Storage furniture:** These are areas that hold or otherwise store objects. Some of these fixtures store objects inside of themselves (e.g., cabinet), and some store objects on top of themselves (e.g., table).
      1. **Shelving (architecturally attached)** - are individualized planks (generally, horizontal) that store objects.
      2. **Cabinets (with and without shelving)** - are objects that store objects within themselves.

i. Permanently open cabinets - cabinets with no doors).
    1. Cabinets with connected appliances inside (e.g., oven or dishwasher inside a cabinet space).
    2. Cabinets without connected appliances.

ii. Open-close cabinets - cabinets with doors. The doors to a cabinet can be mesh and some degree of opaque to transparent (glass).

3. **Tables (architecturally attached)** - are objects that store other objects on top of themselves for direct access and/or observation via humans. Tables can have shelving within them (i.e., table with shelves). When a table allows for storage inside (i.e., table with cabinet).

B. **Animal furniture:** These are objects that allow humans to sit or be in a non-upright form.
1. **Chairs (architecturally attached).**
    i. One person chair.
    ii. Multi-person chair.
2. **Lying furniture (i.e., sleeping furniture, beds):** These are objects that allow humans to lie down and are attached to the architecture. Wall folding beds are an example of architecturally attached lying furniture.

2. **Furniture fittings** - furniture objects that are classified as fittings are not affixed to the ground and are more immediately mobile. The most common fixtures include, but may not be limited to:

A. **Object storage furniture:** These are objects that store other objects.
1. **Shelving (freestanding).**
    i. With and/or without wheels.
2. **Cabinets (freestanding).**
    i. With and/or without wheels.
3. **Tables (freestanding).**
    i. With and/or without wheels.
4. **Boxes (or cans)** can be used to store objects and/or waste.

B. **Animal furniture:** These are objects that allow humans to sit to sit or be in a non-upright form.
1. **Chairs (architecturally attached).**
    i. One person chair.
    ii. Multi-person chair.
2. **Lying furniture (i.e., sleeping furniture, beds):** These are objects that allow humans to lie down and are attached to the architecture. Wall folding beds are an example of architecturally attached lying furniture.

3. **Furniture appliances** - appliances and objects that change the surface, the most common of which include:

A. **Connectors** - mechanical devices (sometimes magnetic) that connect furniture to furniture and furniture to architecture. An example of a connecting device is a cabinet door hinge.
1. **Mechanisms** - mechanical (and sometimes, magnetic) systems that connect objects in a dynamic way.
2. **Hooks** - mechanical (and sometimes magnetic) objects that statically connect (Read: hook) mobile objects to architecture or other freestanding objects.

B. **Locks** - mechanical (and sometimes magnetic) devices that lock objects to other objects.

## *21.3 Installation of furniture system*

Furniture objects are physically built and moved into place. Sometimes installation can be done by one or more people, and other times installation requires special mechanical and/or human assisted lifting equipment (e.g., crane in the mechanical sense, and lift ropes in the case of human assisted).

## *21.4 Operation of furniture system*

In general, furniture systems require little specialized operation. Doors (drawers, etc.) are opened and closed by either humans or automated mechanisms. Most furniture is operated in the sense that elements of it are opened and closed, as needed, by the user(s).

### 21.4.1 Furniture load demands

*A.ka., Furniture loading.*

Furniture loads are measured primarily in the following ways:

1. Gravity:
    A. Weight (and mass) capacity as amount of weight a furniture object can sustain and remain a viable structure (and not, break).
    B. Stability: Likelihood of overturning (or, becoming unstable) given accidental pressure.
2. Resistance to damage and failure from:
    A. The elements and contact with other [accounted for] materials.
    B. Repeated cleaning.
3. Electricity (electrical power) to do the work of motion in dynamic furniture systems.

## *21.5 Engineering calculations for furniture*

*Furniture construction and usage calculations go here.*

### *21.6 Common furniture materials*

Most furniture is made out of some combination of wood, fabric, metal, plastics, adhesives, or glass. Some furniture also has stone as part of its composition.

## 22 Thermal energy design optimization

*A.k.a., Thermal control engineering.*

It is essential to consider energy saving techniques and materials when designing buildings. Consideration is given to the placement of windows, doors, and even to where a structure is located on a property. Buildings and their subsystems can be designed and integrated to better account for and use thermal energy. Whole-building energy simulations can optimize the thermal design of a building. Thermal energy design is necessary for both:

1. Energy sustainability (a.k.a., energy savings).
2. Human comfort.

Human thermal comfort has been defined as the condition of the psycho-physiology that expresses satisfaction with the surrounding environmental temperature.

The are factors that affect thermal sensation include, but may not be limited to:

1. Air temperature.
2. Humidity.
3. Air velocity.
4. Mean radiant temperature.
5. Clothing levels.
6. Human metabolic rate.

Thermal energy standards include the construction, installation and use of boilers, chimneys, flues, hearths and fuel storage installations.

### *22.1 Thermal energy factors*

Thermal considerations for the design of structures include:

1. Building architecture specific factors:
   A. Shading.
   B. Openings.
   C. Ventilation.
   D. Materials and surface finishes.
2. Site specific factors:
   A. Location on site.
   B. Shading on site.
   C. Direction on site.

**NOTE:** *These energy factors are all interrelated. Any mention of one factor will necessary include a mentioning of the other(s).*

The three primary thermal considerations are:

1. Sunlight.
2. Exterior environmental temperature.
3. Interior temperature changes (e.g., heaters).

Sunlight is electromagnetic radiation that will pass through glass windows to varying degrees due to composition, and can make a building (its interior and exterior) hot.

## 22.1.1 Thermal bridging

A thermal bridge is a localised area of the building envelope where the heat flow is different (usually increased) in comparison with adjacent areas (if there is a difference in temperature between the inside and the outside). In other words, a thermal bridge results when the inside and the outside of the building are directly connected through elements that are more thermally conductive than the surrounding areas of the structure (e.g., screws penetrating, beams penetrating, joists passing through an insulation layer). Thermal bridging is a major cause of poor energy performance, durability, and indoor air quality of buildings. Thermal bridging results in condensation, and a high (or, higher) potential for mold. One of the most regular locations of thermal bridging is at window framing points.

To prevent thermal bridging, the following options are available for window installation:

1. Glass glazing (glass panes): Use double, triple, or quad glazing.
   A. Gas glazing (gas filled panes): Gas filled glazing. Argon gas is cost effective and provides a good boost in performance over air-filled units. Krypton gas, while more costly, provides an increase to performance.
   B. Frames: Select frames made of low conductive materials. Aluminum frames without thermal breaks are a complete no-no for energy efficiency and comfort. Aluminum is a high conductor of heat. Note, thermally broken aluminum is a good option depending on how good the thermal break is.
   C. Spacers: Spacers are the material attached to the surface structure of the windows between each glazed window pane. Selecting windows with better spacers can help prevent thermal bridging in the windows as well. These spacers separate the panes of glass and appear where there are divided lights. Avoiding spacers made of aluminum and steel, and selecting stainless steel and various composite materials are much better options.
   D. Installation: Proper window installation including air sealing and insulation around the windows will significantly reduce the amount of energy loss.

## 22.1.2 Shading (in the context of thermal energy)

Shading can be used to reduce the amount of transmitted radiation into a closed space. Traditional shading devices have included overhangs, venetian blinds, and trees or bushes. Shading is very beneficial during seasons of overheating due largely to the positioning of the sun. Determining the exact periods of overheating in an area is obviously important to builders. Decisions on where and when to include shading can greatly affect the comfort level inside a closed space.

## 22.1.3 Openings and ventilation (in the context of thermal energy)

Openings in the building provide ventilation. Ventilation is the intentional introduction of outside air into a building to ensure the health and well-being of the occupants that inhabit it (Hill). The function of ventilation can be arranged in three categories:

1. Health comfort ventilation
2. Thermal comfort ventilation
3. Structural ventilation

Health comfort ventilation helps ensure the quality of indoor air by replacing it with outdoor air. Thermal comfort ventilation prevents bodily discomfort by removing excess skin moisture that ordinarily would decrease the dissipation of heat. Health ventilation replenishes oxygen supplies and prevents the toxic build up of carbon monoxide.

In general, windows are considered separately from regular walls, because they behave like holes in the wall. Windows (Read: windowed openings) can quickly affect the overall comfort level of the structure. Glass windows or openings transfer heat by either conduction or direct transmission.

### *22.1.3.1 The material composition of openings*

Like all materials the ability of glass to conduct heat is measured by its insulation value. Even though insulated glass will reduce heat flow considerably, the heat transfer rate through glass is still several times greater than through a well-insulated wall. Regardless of glass' poor resistance to heat flow, solar radiation can be transmitted through it instantly. This gives glass areas a much greater influence on the heating and cooling potential within a building. When solar radiation strikes a window some of it will be reflected, some of it will be absorbed and some will be transmitted. The proportion of solar radiation that will be absorbed, reflected, or transmitted depends on the angle of the sun's rays that strike the glass. For instance, when the sun strikes the glass in a perpendicular direction, the transmitted component is large and the reflected component is small. At incidence angles greater than 60 degrees, the reflected proportion increases, and the transmitted proportion or component decreases. It is the transmitted component that influences the thermal conditions of space inside a structure.

### 22.1.4 Insulation (in the context of thermal energy)

Today insulation is one of the most efficient ways in which builders can protect the inside space of structures against fluctuations in outside temperatures. Thermal insulators are those materials that restrict the flow of heat.

Thermal insulation materials have a low thermal conductivity which serves to limit the flow of heat energy between one side of the insulation and the other. In the build environment thermal insulation is typically used to reduce the passage of heat between the inside of a building and the outside.

In architectural science, heat is transferred through:

1. **Radiation** - heat transfer mechanism because heat energy is transmitted as electromagnetic waves.
2. **Convection** - heat moves through liquid or gas molecule mediums.
3. **Conduction** - heat energy is transferred between bodies in direct contact.
4. **Evaporation** - heat in this mechanism is transferred through water vapor where by heat is lost to the atmosphere through vapor.

Insulation provides for a passive restriction of heat by either of the above-mentioned methods. Insulators act as sieves, holding back some of the heat but not completely blocking all of it. The amount of heat that would pass through a material depends on the type of material. The ability of any material conduct heat is measured by its insulation value.

The insulation values used to evaluate the amount of heat flow/transferred through a material are:

1. **U-value** - represents the amount of heat that flows through a square foot of material in one hour.
2. **k-value** - the conductivity value of a material. It reflects the amount of heat that can pass through one inch of thickness of a material.
3. **R-value** - the number of square feet it takes for one BTU to pass through a material. BTU is the amount of heat it takes to raise the temperature of one pound of water one degree Fahrenheit.

Insulation is the basic feature in a building's structure necessary to protect it from the changes in outside temperature. If properly designed, insulation can greatly increase the comfort level within a structure. Thermal insulators are those materials, which block or decrease the flow of heat. These insulation materials can drastically decrease the flow of heat through all three modes of transfer: radiation, convection and conduction. Insulation serves three purposes as it relates to the three modes of heat transfer. First, insulation may act as a reflection material that reflects electromagnetic waves of radiation. Secondly, it acts to trap air and other gases preventing these gases from transferring heat through convection. Thirdly, it acts to sieve out heat by providing a material that has a high resistance to heat transfer through conduction.

All insulation is rated according to its "U" or "R" value, but it is also classified according to its physical characteristics. These classifications are largely determined by the physical properties of the materials that make them up. Some of the physical characteristics of insulation include low or high densities, high or low compressibility, stiff or loose consistency, frothiness, and reflective ability.

### 22.1.5 Materials (in the context of thermal energy)

Certain materials are more likely to decrease heat transmission, and other materials are more likely to increase heat transmission.

The thermal behavior of a material is a function of its:

1. Density.
2. Thermal conductivity.
3. Specific heat capacity.

'Thermal mass' is an attribute that represents the best combination of these three properties of a material for:

1. Absorbing (energy acquisition).
2. Storing.
3. Slowly releasing heat (energy transfer).

Materials with thermal mass readily absorb excess heat without getting hot. This heat may be from the sun or from internal loads, such as lights and computers. Once ambient temperatures drop, the thermal mass will slowly release stored heat to the surrounding environment without getting cold. Optimal use of thermal mass can reduce a building's energy use, environmental footprint and peak-energy loads, as well as increase occupant thermal comfort.

Suitable building materials for thermal mass are those that have high specific heat, high density and low conductivity. Insulation materials, such as fiberglass and polystyrene foam, have low conductivity, but their density and specific heat are too low to provide thermal mass. Metals have high specific heat and density, but their levels of conductivity are too high. Materials like brick, stone, adobe and concrete have suitable properties for thermal mass.

#### *22.1.5.1 Fluid-based thermal energy acquisition, storage and transfer systems*

It is possible to include a fluid-based heat exchange circuit embedded in the structure of a building (Uribe, 2015).

It is possible to design a building that includes:

1. A fluid heat exchange circuit (in structure of building) that transfers heat between:
   A. A solar collector (located in the roof).
   B. A low enthalpy geothermal heat store (ground heat exchanger).
   C. A dynamic thermal barrier (walls).

These sub-systems can be interconnected by the hydraulic circuit that controls the fluid flow.

## *22.2 Energy conservation standards*

The primary standard for architectural energy conservation is:

- The International Energy Conservation Code from The International Code Council [iccsafe.org].

# 23 Insulation design optimization

*A.k.a., Insulation engineering.*

The word 'insulate' means to protect something by interposing a material between it and other elements that prevents transmission between them. The word 'insulation' refers to the material that is interposed. Insulation may be used in the construction industry for a number of different purposes:

1. **Thermal insulation** - to prevent the transmission of heat, typically between the inside and outside of a building. For more information see: Thermal insulation.
2. **Acoustic insulation (sound insulation, acoustic control)** - to prevent the transmission of sound, for example between a recording studio and a performance space. Sound insulation describes the reduction in sound across a partition. **Privacy** describes the perceived sound reduction across a wall. Privacy is a function of both sound insulation and background noise. **Background noise** is made up of services noise and environmental noise sources breaking in through the facade or open windows, vents etc. Two parameters are used to describe the sound insulation of a partition are:
   - **Dw** - represents the sound insulation between rooms on-site. Dw levels are specified by clients and Building Regulations.
   - **Rw** - represents the lab tested sound insulation of an element making up a partition wall/floor type.
3. **Fire insulation** - to prevent the passage of fire between spaces or components. Fire insulation (or more usually fire-rated or fire-resistant insulation) is a term that covers insulation materials which have insulative properties but are also non-combustible or have limited combustibility. Fire insulation is a passive fire protection element. It does not need to be activated to provide fire resistance, and hence, can help prevent the spread of flame between spaces and components within and between buildings.
4. **Electrical insulation** - to contain and separate electrical conductors and to limit the spread of electromagnetic fields.

There are many different types of insulation, which vary in terms of colour, surface finish texture, core composition and performance. Very broadly however, they tend to be open cell or closed cell.

- **Open cell insulation** - allows the passage of air through air pockets, but the route is so complex that effectively, no air will pass from one side to the other, and so heat transfer by convection is prevented.

- **Closed cell insulation** - formed by bubbles of gas whose thermal conductivity is very low.

Common types of insulation include, but are not limited to:

1. **Blanket insulation (also called matting insulation)**.
   A. **Mineral wool** - refers to fibre materials that are formed by spinning or drawing molten minerals. It can be manufactured in various thicknesses and widths and is often supplied in rolls.
   B. **Sheep's wool** - real wool from sheep that is often treated to make it more fire and insect resistant.
   C. **Glass wool (fiberglass or glass fiber)** - consists of glass fibres arranged using a binder into a wool-like texture.
2. **Foam boards** - rigid panels of insulation which are cut and fitted in place. Most commonly they are made from polystyrene, polyisocyanurate, and polyurethane
3. **Radiant barriers** - consist of a highly reflective material that reflects radiant heat rather than absorbing it.
4. **Blown-in insulation** - typically involves mineral fibres being blown into a void in the space that needs insulating.
5. **Spray foam insulation** - typically formed of polyurethane and is sprayed as a liquid which gradually expands to up to 100 times its original volume. Once set, it creates an effective thermal and noise insulating layer. Slow-curing foams can be used for cavity walls as they will flow around any obstructions before hardening. As spray foam can produce dangerous fumes and damage the structural integrity of the building if applied incorrectly
6. **Structural insulated panels (SIPs)** - a form of composite sandwich panel system that take the form of an insulating core (such as closed-cell polyurethane foam or expanded polystyrene) sandwiched between two structural facings.
7. **Aerogel insulation** - a lightweight solid derived from gel in which the liquid component of the gel has been replaced with gas. Areogel insulation comes in sheets of wrapping that are placed in a surface of the structure as insulation.
8. **Transparent insulation (versus opaque insulation)** - materials that perform a similar function to opaque insulation, but they have the ability to transmit daylight and solar energy, reducing the need for artificial light and heating. There are four common types depending on the structure of the material:
   A. Absorber perpendicular.
   B. Absorber parallel.
   C. Cavity.
   D. Quasi-homogeneous.
9. Other types of insulation.

In an architectural construction, insulation is most commonly applied to:

1. Floors (floor insulation)
2. Walls (wall cavity insulation)
3. Roofs (roof insulation)

The insulation thermal quantities can be calculated using:

1. **R-value (r-factor)** - the capacity of an insulating material to resist heat flow. The higher the R-value, the greater the insulating power.
2. **U-value (a.k.a., thermal transmittance)** - the rate of transfer of heat through a structure.

This can be a single material or a composite and the graphic below shows the relationship of U-value to R-value.

The U-value of a wall (or window) is the inverse of the sum of the R-values of that wall's (or window's) components (i.e., a low U-value is preferable). The higher the U-value, the faster heat flows through the material. The lower the U-value, the slower the heat flows through the material.

The formula is:

$$U = 1 / (R1 + R2 + R3)$$

$$U = (1 / R) = (QA / \Delta T)$$

Wherein,

- QA = Heat transfer rate
- $\Delta T$ = Temperature difference (inside versus outside)

## 23.1 *Recreational insulation design*

Some recreational facilities (exploratory service sub-systems) will produce a relatively large amount of noise and/or light pollution. These environments, when commonly accessed, need to have a sufficient insulation, either structurally, or in land area between. For example, the important consideration for a pool's placement for common access is a position (generally) that is highly sound isolated from residences, if children will frequent them. The requirement to remember about common children-accessible pools, is that they may scream loudly. This is similarly the case with sports stadiums. Insulation can come in the form of:

1. Localized structural [attenuation], and/or
2. Spatial land area and 3D objects attenuation.

In other words, requirements for optimizing insulation must account for master habitat service system strategic planning at both object and distance (object-to-object) levels.

# 24 Accessway and security design optimization

*A.k.a., Site access, building access, and accessibility engineering.*

An accessway is a path, route, opening, etc., that provides access to a specific destination or area.

There are two types of accessway:

1. Unobstructed accessway - open pathway/driveway.
2. Obstructed accessway - inclusive of a door or gate.

Buildings should be accessible to, functional for, and safe for use by their users, who may include:

1. Humans
   A. Normal functioning humans.
   B. Humans with disabilities.
2. Animals
3. Vehicles
   A. Human driven
   B. Automated

Note here that some buildings types are of an open design and do not require specialized access-ways. Other buildings are closed ("sealed") often for protection from the elements, insulation, and atmospheric conditioning efficiency. These buildings require specialized access-ways like doors and windows.

It is relevant to note here that there may be other types of access, including but not necessarily limited to:

1. Atmospheric access
   A. Doors
   B. Windows
   C. Vents and ducts
2. Non-atmospheric materials access
   A. Pipes

An access specification may include:

1. Access plan for users.
   A. Human access (walkway access)
   B. Animal access (pathway access)
   C. Vehicle access (driveway access)
2. Evacuation plan for users.
   A. Human evacuation
   B. Animal evacuation
   C. Vehicle evacuation
3. Catastrophe plan - area of refuge/safety requirements in case of catastrophe.

Access-ways for buildings include, but may not be limited to:

1. Based on direction.
   A. Bi-directional.
   B. Directional.
      1. Entraceway (a.k.a., ingress).
      2. Exit (a.k.a., egress).
2. Based on placement location.
   A. Gate - a gate is a hinged barrier used to close an opening in a wall, fence, or hedge.
   B. Door - a door is a hinged, sliding, or revolving barrier at the entrance to a building, room, or vehicle, or in the framework of a cupboard.

## 24.1 *Presence signaling*

Presence signaling devices signal an owner/occupant to the presence of someone or some thing at an accessway entrance or exit. There are two primary types of presence signaling:

1. Doorbells.
2. Motion sensors.

### 24.1.1 Doorbell

A doorbell is a signaling device typically placed near a door to a building's entrance. When a visitor presses a button a bell rings (inside the building or on a smartphone), alerting the owner/occupant to the presence of the visitor.

### 24.1.2 Motion sensor

A motion sensor is a device that senses the presence of motion and may send an alert to an owner/occupant.

## 24.2 *Access security*

*A.k.a., Secure access design*

Secure access design is intended to provide that reasonable provision must be made to resist unauthorised access to specific architectural areas (in particular, to dwellings), including any part of a building from which access can be gained to a home or secure space within the building.

### 24.2.1 Access control

Access control for a building includes both:

1. Accessway obstructions (e.g., doors and gates).
2. Locks.

#### ***24.2.1.1 Locks***

A lock is security mechanism that secures an obstructed opening from intrusion.

There are two general types of door locks:

1. **Manual locks** - require physical access (e.g., physical key) and presence.
2. **Electronic locks** - require electricity.
   A. **Manual electronic locks** - require physical presence (e.g., access card or push button pin).
   B. **Wireless electronic locks** - may be opened from anywhere.

The main parts of a door lock are:

1. **The cylinder (lock body)** - the part of the door lock where the key is inserted or where an electronic motor is housed.
2. **The bolt or latch** - a piece of metal that extends from the door into the frame and holds it closed. There are two main styles of latch (or bolt) - a spring bolt and a deadbolt. When the lock is disengaged, the bolt is inside the cylinder.
3. **The box** - the bolt extends from the cylinder into a shaped hole ("box") inside the door frame.
4. **The strike plate** - a metal plate that attaches to the frame of the door. The purpose of the strike plate is to guide the bolt from the cylinder into the box of the frame and give added reinforcement to the locking mechanism.

Electronic access control systems (ACS) include, but are not limited to:

1. PIN codes.
2. Magnetic identity cards.
3. Proximity tokens.
4. Biometric devices.

# 25 Automation design optimization

*A.k.a., Automation engineering, automation control engineering, building automation systems.*

Building control functions can be automated using automatic control, regulation, and monitoring of building functions. It is possible to integrate all building functions integrated into one automation system. It is possible to develop and operate building wide control (automation) systems, commonly known as building automation systems (BAS). In many buildings around the world, particularly newly built buildings, physical switches are being replaced by digital wireless controllers. These controllers (Read: automation or smart building technologies) can be used to control and automate:

1. The entire electrical connection system of a building.
2. Illumination.
3. HVAC.
4. Audio and video systems (AV).
5. Plumbing.
6. Curtains and blinds.
7. Doors and windows.
8. Access Control (security).
9. Pools and water features.
10. IT peripherals.

There are currently solutions that cover all aspects of building automation, including but not limited to:

1. **Intelligent lighting control** - needs based lighting control. Numerous conventional switching devices are no longer required, the optimized switching activation and deactivation of loads reduces energy consumption, and the high flexibility of the control system permits later changes with little user effort.
2. **Control of room/area parameters** - needs based area control
3. **Swimming pool and water features control** - automation of pools and ponds. These systems can monitor and adjust:
   A. The water level (Read: water quantity).
   B. The water quality.
   C. The water temperature.
   D. Other water parameters.
4. **Water pump control** - automation of water pumps. These systems may be capable of controlling at least:
   A. Irrigation.
   B. Fountains,
   C. Cisterns
   D. Lifting and pressure pumps.
   E. Etc.
5. **Doors, gates, windows and other openings** - needs based accessway controls.
6. **Access control** - needs based access control. Some access control involves the control of doors, gates, and windows.
7. **Safety and security/alarming control** - needs based safety and security automation.

Problems with smartphone and tablet based automation systems include, but may not be limited to:

1. The app continues to still exists and is supported.
2. The app is installed on the occupants smartphone/ tablet.
3. The device has a charged battery. For instance, the phone is asleep or the battery is dead and someone needs to turn on a light at 02:00.
4. The device is missing. For instance someone misplaced or broke their phone.
5. The device is properly paired with the building's network.
6. The device and app respond quickly.
7. Potential for increased wireless radiation.
8. May not be dependable in emergency situations.

A reasonably complete automation system for a dwelling-type structure may include the following:

1. Functions:
   A. What functions must the system perform?
   B. what sub-systems must the controller control?
2. Wireless solution - radio frequency solutions including wifi and bluetooth.
3. Wired solution - ethernet wired solutions.

The means of control include:

1. Mobile app[lication].
2. Computer application.
3. Voice.
4. Automatic (programmed).

## *25.1 Control sub-systems*

An architectural control system generally comprises the following sub-systems:

1. A human-machine interface (HMI).
2. Programmatic control logic.
3. Computational processing hardware.
4. Timing and sequencing hardware (e.g., swtiches).
5. Communication interfaces (e.g., wifi router) serving as the head end of a point-to-multipoint network.
6. Individual client devices.

# 26 Accessibility design optimization

*A.k.a., Disability inclusivity, disability support optimization, accessible design, accessibility engineering.*

Accessibility is the term most often used to refer to access to a building by someone with a disability. Accessible design is an approach to designing architecture that renders them easier to access and use by people with physical, sensory, or cognitive disabilities. Accesibility requires the inclusive provision of ease of access to, and circulation within, specific architecture (primarily, buildings), together with requirements for facilities for disabled people.

The following terms and factors are relevant to accessibility design:

1. **Accessible route** - A continuous and unobstructed path of travel that meets or exceeds the dimensional requirements.
2. **Visitability** - A structure that is designed intentionally with no architectural barriers in its common spaces (entrances, doors openings, hallways, bathrooms), thereby allowing persons with disabilities who have functional limitations to visit.
3. **Area requirements** - areas with additional floor space that meet or exceed the dimensional and inclusionary requirements.
4. **Ideal design for accessibility** - Design which meets, as well as exceeds, compliance with accessibility building code requirements.

Note that under some conditions it is useful to design building units (e.g., dwellings) with features that can be modified without structural change to meet the specific functional needs of an occupant with a disability.

## *26.1 Accessibility design standards*

Accessible design standards are often legislated by governments:

- In the United States of America, the Americans with Disabilities Act (ADA) is a federal law, passed in 1990, which prohibits discrimination against people with disabilities. The term "disability" means a physical or mental impairment that substantially limits one or more of the major life activities of such individuals. Among the provisions in the law are requirements that impact plumbing products in the design of accessible bathrooms and facilities. Herein, an ADA-compliant device is a device which is fully compliant, when properly installed, with the current requirements of the Americans with Disabilities Act Accessibility Guidelines (ADAAG), as legislated by the Americans with Disabilities Act of 1990.

# 27 Safe access design optimization

*A.k.a., Safe access engineering.*

Safe access design refers to the application of standards to ensure that occupants and machines are safe and protected from all of the following sources of danger:

1. Falling
2. Collision
3. Impact.

Safe access standards should be followed in order to ensure the safety of stairways, ramps and ladders, together with requirements for balustrading, windows, and vehicle barriers to prevent falling. Also included are requirements for guarding against and warning of, hazards from the use and position of doors and windows. Also included are safety requirements relating to the use and cleaning of windows.

> **NOTE:** *Some systems are static and do not require removal when they are not in use. Other systems do not need to be permanently installed and can be disassembled when not in use.*

## *27.1 Collective restraints and barriers*

Collective restraint systems protect occupants and workers. These include, but are not limited to:

1. **Guardrails** - a longitudinal barrier that prevents people from falling or straying into a dangerous or restricted zone.
2. **Barriers or guardings** - are structures that deny access to unsafe areas, and include raised rails, parapets, or walls.
3. **Purlin trolleys** - provide workers with a safety deck to walk on and protect them from exposure to edging. They are frequently used in roofing installations.
4. **Bollards** - protective posts that avoid vehicle collision on buildings and guard pedestrians at intersections.

## *27.1 Fall prevention and arrest systems*

In concern to working, fall prevention systems (or fall restraint systems) are safety systems designed to stop personnel from falling when working at height. Ideally, this type of system completely eliminates the hazard by making it impossible to fall. Fall prevention systems are active systems, which means workers have to take action in order to be protected. This aspect differentiates them from collective restraint systems, which are passive and require no action on the part of the worker. Prevention systems use individual restraints to keep workers from falling. They incorporate customised harnesses connected to an anchor and safety line to keep workers from entering areas where hazards are located. Fall prevention systems must be replaced when necessary and must be maintained. Training is required for proper use. Note that a personal fall arrest system (FAS) is a system designed to minimise injury if a worker should fall from a significant height and experience impact. The purpose of the system is not to stop the fall (that is the purpose of a fall restraint system or fall prevention system), but to limit the injuries that could happen to a worker as a result of the fall's impact.

# 28 Acoustics design optimization

*A.k.a., Sound design, acoustics control engineering, sound control engineering.*

Sound is a series of pressure vibrations that move through an elastic medium. Its alternating compressions and rarefactions may be far apart (low- pitched), close together (high- pitched), wide (loud), or narrow (soft). All perceived sound has a source, path, and receiver. Each source has a size, direction, and duration. Paths can be airborne or structure- borne. Sound has four quantifiable properties:

1. Velocity
2. Frequency,
3. Intensity
4. Diffuseness.

Regarding velocity, sound travels much faster through solids than air (and faster through warm air than cool air). Frequency is sound's vibrations per second, or hertz (Hz). This varies according to its purity and pitch. The average human pitch for hearing is about 1000 Hz. Intensity is the power level (or loudness) measured in decibels (dB). Attenuation is the loss of a sound's intensity as it travels outward from a source. Diffuse noise (blanket or background noise level) is sound emanating from a multiple of similar sound sources. Sound has four quantifiable.

Sound travels through walls and floors by causing building materials to vibrate and broadcasts in resonant locations. There are two methods of setting up the vibration (through structure-borne sound and/or air-borne sound):

1. **Structure-borne sound** - the vibration of building materials by vibrating pieces of equipment, or caused by walking on hard floors.
2. **Air-borne sound** - a pressure vibration in the air, such as wind or other moving air. When the air hits a wall, the wall materials are forced to vibrate. The vibration passes through the materials of the wall. The far side of the wall then passes the vibration back into the air.

## *28.1 Acoustic requirements*

In architecture, there are several requirements that deal specifically with acoustics:

1. Requirements for sound isolation during construction.
2. Requirements for sound insulation between buildings, including both new dwellings and the conversion of buildings to form dwellings.
3. Requirements for sound reduction between rooms

and apartments (i.e., between architectural spaces).
4. Requirements for sound reduction within a room.
5. Requirements for sound amplification in specially designated areas (e.g., theatres and concert halls).

## 28.2 The sound problem

The acoustic quality of an architectural space is related to both:

1. The ability to carry out the activities for which a space has been designed, and
2. not having noise pollution problems (such as those related to reverberation and isolation).

### 28.2.1 Sound pollution

*A.k.a., Noise pollution.*

Sound pollution occurs anywhere sound is present and is unwanted. It is important to note here that sound can be a form of pollution. Sound pollution can include exterior sources of sound, such as outside construction and landscaping noises, or interior sources, such as a washing or drying machine.

**INSIGHT:** *Noise pollution can reduce messages from nature, such as from birdsong.*

## 28.3 Cymatic science data

Constructions on a landscape convey [acoustic] frequency information [to users of the habitat-construction system]. Hence, it is interesting to consider the acoustic (3D) depiction of a landscape, which necessarily necessitates different views of the acoustic nature of the habitat. Herein, cymatics is the study of perceptible (usually visual) sound vibration, showing the transformational nature of sound and matter. Essentially, cymatics is the scientific relationship between sound and form, which relates information about acoustic (mechanical) pressure induction. The idea is that for every acoustic vibration, be it audible or not, there's a predictable, repeatable pattern that is likely to form in matter. Vibrational sound tones (i.e., audio frequencies) reveal themselves (i.e., are visibly observed) as patterns of particles in a vibratory chamber. When the physical vibratory frequency is higher, the pattern is more complex. When the frequency is turned off or removed, the matter falls out of pattern. These instruments are call cymascopes. Cymatic patterns can be scientifically observed through a cymascope. It is possible to can re-create the archetypal forms of nature as acoustic frequency through cymatic processes programmed into cymascopes.

Consider that sound has form; it can affect matter and cause form between particles matter. Now consider the structural formation of a habitat (i.e., city system), and its continuous operation. And if we ponder on that, perhaps cymatics can provide useful data on the optimal formation of that city.

## 28.4 Acoustic (sound) control

Sound of any kind emitted in a room will be absorbed or reflected off the room surfaces. Soft materials absorb sound energy. Hard materials reflect sound energy back into the space.

Note that some architectural environments are designed to be expressive of sound, such as theatres and concert halls.

Sound control uses the properties of:

1. **Isolation (a.k.a., sound isolation, noise isolation)** - Placement of sound producing equipment in isolated areas.
2. **Reflection** - Large concave surfaces concentrate sound and should usually be avoided, while convex surfaces disperse sound.
3. **Diffusion** - Providing uniform distribution. It is increased by objects and surface irregularities. Ideal diffusing surfaces neither absorb nor reflect sound but scatter it.
4. **Absorption** - Provides the most effective form of noise control.
    A. Vibration isolation padding - can be placed under the feet of machines to reduce their vibration. A dryer and washing machine are examples of machines that can often create significant vibration.
    B. Noise dampening (a.k.a., sound dampening) materials - these materials absorb sound. Examples of noise dampening materials include, but are not limited to:
        1. Noise dampening foam.
        2. Rugs and carpets.
        3. Curtains and blinds.

# 29 Fire and contaminant protection design optimization

*A.k.a., Fire and contaminant protection engineering.*

In concern to fires, this covers all precautionary measures necessary to provide safety from fires for construction and operation of architecture, including occupants, persons in the vicinity of buildings, and firefighters. Here, requirements and guidance covers:

1. Means of escape in cases of fire.
2. Fire detection and warning systems.
3. The fire resistance of structural elements.
4. Fire separation, protection, compartmentalisation isolation to prevent fire spread, control of flammable materials.
5. Access and facilities for firefighting.
6. Requirements to control fire sources and prevent burning, pollution, carbon monoxide poisoning, etc.

Fire and atmospheric danger prevention and resistance includes:

1. Fire safety/warning system (smoke alarms) - Each dwelling must have smoke detectors in each sleeping room and the corridor to sleeping rooms, at each story (close proximity to stairways), and basement.
   A. Safety and alarm requirements
      1. Fire detection and/or suppression requirements
      2. Gas hazard detection

Normal atmospheric-type of detectors found in many buildings:

1. Smoke detector
2. Gas detectors can be used to detect combustible, flammable and toxic gases, and oxygen depletion.
   A. Carbon monoxide detector - build-up of carbon monoxide is dangerous.
   B. Natural gas - leakage is dangerous (e.g., propane, butane, methane, etc.).
   C. Low oxygen - presence of low oxygen is dangerous.
3. Radon detector
4. Other site related hazardous and dangerous substances.

These detectors are connected to an alarm system that alerts occupants and others to:

1. Leakage - for example, toxic and flammable gases.
2. Build-up - for example, carbon monoxide.
3. Depletion - for example, oxygen.

It is important to have control protocols for toxic substances, during both the construction (including demolition) and operation of architecture.

## *29.1 Fire and contaminant protection requirements*

The optimization of several architectural elements can optimize the reduction and elimination of fires; optimization requirements for fire (and contaminant protection) may include, but are not limited to:

1. Optimization of infrastructural interiors, including fixtures, fitting and appliances.
2. Optimization of furniture so that they do not interfere with potential fire producing infrastructural services..
3. Optimization of illumination so that sunlight doesn't cause quick light damage.
4. Optimization of landscape to reduce the likely appearance and spread of fire.
5. Optimization of safety mechanisms to ensure that fires can be effectively resolved in a relatively short amount of time and with as little damage and harm to life as possible.

## *29.2 Optimization of a landscape to reduce the likelihood of fire and its spread*

Landscapes are areas where fires have the potential of appearing. Therein, it is important to arrange and caretake plants. Careful placement of plants can significantly reduce the impact of fire. The immediate area around buildings should be free of trees and other combustible materials. It is possible to create effective barriers to the spread of fire by means of well watered lawns, paved areas, driveways, fire breaks between trees, etc.

Fire protection principles include, but are not limited to:

1. Distances from buildings: Keep trees at least the same distance as the height of the mature tree from any buildings, for example if the height of a particular tree is 20 metres when fully grown, then it should be planted at least 20 metres away from any building (if the tree falls, then burning branches won't hit the building).
2. Consider prevailing winds: The prevailing winds will affect the way fires will travel and where ash and burning embers fall. It is important to note that prevailing winds may vary from season to season, although days of extreme fire danger are usually

characterized by hot gusty winds with southerly wind shifts later in the day.

3. Consider vehicular access: Access routes to dams, pumps, roads etc. should be kept free of trees and flammable material. This includes all routes of escape.
4. Maintenance: Points to Remember: Water trees in summer (keep moisture in the plant high)
5. Fertilize plants: Regularly fertilize. A plant that has lush green growth is less likely to burn.
6. Have water available: Have a water hose ready at all times, and ensure water is readily available.
7. Only use mulches that will not burn readily.
8. Remove dead woody material: Remove twigs, leaf litter, branches, etc. from the ground. A compact mulch of stone or even food shavings is not generally a problem, but leaves and twigs can be, in a bushfire. Leaf litter can be dug in or composted to prevent it burning.
9. Remove flaky loose bark from trees: Smooth barked trees are less likely to catch fire.
10. Prune lower branches: so that burning debris under plants can't ignite foliage.
11. Remove dead trees and fallen branches.
12. Fill hollows/cavities (hollow trunks, depressions where branches break & rot gets in) with concrete or remove the plant...fire can catch in such hollows and the tree may smoulder for some time without you knowing it.
13. Avoid large dense clumps of trees & shrubs particularly near buildings.
14. Have succulent ground cover, lawn or gravel under large trees or regularly slash or cut any underlying scrub and grass to remove potential fuel for fires.

# 30 Pest control design optimization

*A.k.a., Pest control engineering.*

A pest is either a destructive insect or animal that attacks and damages the architectural construction and/or is a nuisance to human occupants. Therein, there are two categories of pests in relation to architectural constructions:

1. Pests to the materials used to construct architectural objects.
   A. Termites.
   B. Wasps.
   C. Rodents and other mammals.
   D. Birds.
   E. Mites and silverfish
2. Pests to humans.
   A. Biting and stinging insects.
      1. Mosquitoes.
      2. Ants.
      3. Biting flies.
      4. Spiders.
      5. Wasps
   B. Non-biting insects.
      1. Flies.
   C. Rodents and other mammals.

The best method of pest prevention is prevention by design of the architectural construction itself. Pest proofing in conjunction with sanitation efforts provides the best long-term management of urban pest infestations. Building codes generally require some of the more common procedures of pest control (e.g., screening foundation vents), but often do not go far enough in facilitating the design of buildings and landscapes that sufficiently reduce or eliminate pests.

It is important to understand local pest pressures when localizing architecture. Climatic factors and bio-regions limit the distribution of many pest organisms. Generally speaking, insect pests are most troublesome in warm, humid climates. Warm temperatures speed up insects' life cycle, resulting in higher populations. (Geiger, 11, 2012)

Animals of all kinds, whether vertebrate or invertebrate, are living organisms with biological needs and behavioral preferences. All require the following in order to take up residence and become pests (Geiger, 2012):

1. Food
2. Water
3. Harborage
4. Entry

Eliminating just one of these factors can be sufficient to prevent infestations. All of the pest prevention tactics listed herein are based on minimizing these factors.

## 30.1 *Pest control design considerations*

When designing for pest control and deterrence, the following principles should be considered (Geiger, 2012):

1. Understand the local pest pressures.
2. Analyze the physical context (function and local surroundings) of the building.
3. Design for the necessary pest tolerance level.
4. Use durable pest-resistent materials.
5. Design for easy inspection.
6. Minimize moisture.
7. Seal off openings.
8. Eliminate potential harborage.
9. Engineer slabs and foundations to minimize pest entry.
10. Engineer access-ways to minimize pest entry.
11. Design buildings to be unattractive to pests.

### 30.1.1 Pest tolerance level

The tolerance to pest infestations varies by architectural function, and ideally should be considered at the design stage. An occasional trail of ants in the home may be a mere nuisance, but even a single ant in a surgical ward can have grave consequences. Institutional kitchens, health care facilities, and mission-critical manufacturing facilities demand detailed and careful design and planning to exclude potential pests. (Geiger, 13, 2012)

### 30.1.2 Pest control methods

Pest control methods for the material used in architectural constructions include, but may not be limited to:

1. Pest-resistant buildings reduce not only pest problems, but also the need for pesticide applications.
    - A. Select pest resistant materials:
        1. Using materials that pests do not consume (e.g., concrete, specific types of wood).
        2. Treating (impregnating, pressure soaking) materials that pests would otherwise consume with toxins (e.g., wood soaked in a toxin). Note here that if/when these buildings catch fire their combustion can be more toxic because of the compounds they are impregnated with (i.e., soaked in), and the toxins can leach into the local environment.
            - i. For example, chromate copper arsenate (CCA) treatments pose cancer and reproductive hazards to workers and the public, while compounds with high copper content (such as amine copper quat, ACQ) pose higher aquatic toxicity hazards. (Dickey, 2003)
            - ii. Borate treatments are viable alternatives for interior use, or situations with low exposure to moisture, which can leach the material out of the wood.
            - iii. Silicates.
    - B. Sealing off access areas:
        1. Screening of vents.
        2. Sealing all gaps.
    - C. Removing sources of intrusion, such as dense vegetation proximal the architecture, to reduce intrusion from a variety of small mammals, such as rats, mice, chipmunks, ground squirrels, raccoons, opossums, and tree squirrels.
    - D. Adding harborage disruption elements (e.g., spikes to prevent bird roosting).
2. Pesticides (insecticides).
    - A. Distributed within the building (e.g., within the attic or basement).
    - B. Distributed in the grounds around the building.

Pest control methods for rodents include, but may not be limited to:

1. Rodenticides.
2. Mechanical traps.
    - A. Capture alive traps.
    - B. Kill traps.
3. Rodent impervious constructions.

Pest control methods for insects include, but may not be limited to:

1. Repellents for airborne pests:
    - A. Repelling plants.
        1. Catnip plants.
        2. Citronella plants.
    - B. Repelling gases and odors.
        1. Citronella candles.
    - C. Repelling by means of rapid movement.
        1. Fans - rapidly moving air will deter airborne pests.
2. Mechanical dislodging of airborne pests and their nests:
    - A. Brush to rid area of a nest.
    - B. Vacuum to rid area of nest.
    - C. Pressure washing to rid area of a nest.
3. Traps for airborne pests:
    - A. Traps with gas - A machine that transforms propane into carbon dioxide, which attracts mosquitoes, and then, captures them.
    - B. Traps without gas:
        1. Glue paper.

   2. Mechanical trap.
   3. Bug lightbulbs.
4. Traps for ground-based pets:
   A. Insecticide traps for ants.
   B. Insecticide traps for cockroaches.

**NOTE:** *Ultrasonic rodent and insect "repellent" devices have generally been shown to be ineffective as deterrent agents and are not listed above.*

Techniques for pest prevention in architectural design include, but are not limited to (Geiger, 13, 2012):

1. Intrusion prevention:
   A. Screen vents, tunnels, pipes, etc., to prevent intrusion.
   B. Remove intrusion sources, such as carpet-style ground cover and vines.
   C. Fill in architectural gaps.
      1. Seal off all openings to the building exterior, as well as openings between interior rooms.
      2. Use elastomeric sealant to seal small cracks, gaps around countertops, or pipe breaks against insect entry; stainless steel wool and fire block foam can be used for larger openings.
      3. Use escutcheon plates around all pipes where they enter through walls is essential.
      4. Foundation expansion joints can be safeguarded against termites with stainless steel mesh.
   D. Install tight fitting fixtures.
      1. Install doors with minimal gaps, including functioning door sweeps where necessary.
      2. Install tight fitting windows.
2. Reduce standing water and moisture to eliminate harborage and material decay.
   A. Reduce moisture in the building. Moisture promotes building decay, moisture also promotes serious problems with insect pests such as termites, wood-boring beetles, cockroaches, flies, carpenter ants, silverfish, and millipedes, to name but a few. Perhaps even more important, excessive moisture inside buildings can lead to serious mold contamination issues—some of which can require many thousands of dollars in remediation. Multiple procedures can be used to minimize building moisture including proper guttering, downspout placement, correct ventilation of crawl spaces, one-piece countertops, humidistats, vapor barriers for crawl space flooring, appropriate slopes for patios, etc.
   B. Do not leave standing water on the architecture or surrounding landscape. Standing water is a breading habitat for mosquitoes and other insects.
3. Reduce the presence of pests on the surrounding landscape.
4. Clean refuse containers sufficiently.
5. Use durable pest-resistent materials. Selecting pest-resistant materials can exclude pests from entering a structure, or deny pests harborage once they are there. Some materials provide resistance to pests while other materials provide exclusion.

Material specifics for pest control include, but are not limited to (Geiger, 2012):

1. Pressure treated wood.
2. Stucco - resistant to insect penetration from the outside, is generally a poor choice in high termite pressure areas for two reasons:
   A. When improperly constructed, moisture can accumulate in the enclosed wood.
   B. The stucco shell makes inspection virtually impossible.
3. High-density plastic - will deter gnawing by rats and mice, and neither rodents nor insect pests are likely to penetrate high quality elastomeric sealant compounds when applied correctly.
4. Stainless steel mesh carpeting material - deters rodents from burrowing into soil to gain access.

#### *30.1.2.1 Insecticides (pesticides)*

Boric acid (borax) is most often used in pesticides, and can be found in tablet form, liquid form, powder form and in various types of traps. It is a natural salt and is one of the oldest inorganic compounds known to mankind in treating pests; it is generally considered a natural and non-toxic insecticide. It is a mined substance. Boric acid and its sodium salts can be used to control a wide variety of pests; these include: insects, spiders, mites, algae, molds, fungi, and weeds. It kills insects by absorbing into them, poisoning their stomachs, affecting their metabolism, and also, abrading their exoskeletons causing them to dehydrate (dry out). Boric acid is a white or colorless powder that can be used as an insecticide, herbicide or fungicide. Note that boric acid can also be used as an abrasive when cleaning with water. Boric acid dust should not be breathed in by humans and is dangerous to human lung tissue.

A commonly used and simple boric acid treatment for an insect infestation is as follows:

1. Ingredients:
   A. 1 tbs of boric acid.
   B. 1 tbs of sugar.

   C. 4 oz water.
   D. Cotton balls.
2. Recipe:
   A. Mix the boric acid and sugar in a bowl.
   B. This mixture can be poured over an area, or over a cotton wad.
   C. In the case of the usage of cotton, place the cotton balls in the path of the insects.

## *30.2 Architectural pest avoidance design practices*

The following architectural design practices will reduce pests. The following architectural design elements should be accounted for (Geiger, 2012):

1. Landscape
2. Foundations and slabs
3. Building exterior: siding
4. Building exterior: wall and perimeter
5. Building exterior: lighting
6. Roofs
7. Interior walls
8. Floors
9. Doors
10. Windows
11. Bedrooms
12. Bathrooms
13. Kitchens: general
14. Kitchens: institutional
15. Utilities, HVAC, and chutes
16. Refuse and recycling
17. General area

### 30.2.1 Landscape

#### *30.2.1.2 Design and maintain landscape areas near buildings to minimize the number and types of pests*

1. Tree branch maintenance.
   - Maintain at least 6 feet of clearance between exterior walls and tree limbs/branches that might provide vertebrate pest access (3.048m if tree squirrels are a problem).
2. Fruit trees that are attractive to pests.
   - Use plants that shed a minimum of seeds and fruits, since the seeds and fruit may attract and support insects, rodents, and undesired birds.
3. Landscape plants that are attractive to rats.
   - Avoid planting Algerian or English ivy, star jasmine, and honeysuckle on fences or buildings, as they provide shelter and food for rats.
4. Landscape plants that are attractive to ants.
   - Where Argentine ants are common, avoid bamboo, cherry laurel, fig, pine, and roses near buildings. These plants often have abundant scale and aphid populations, and excreta from these insects provides food for ant colonies.
5. Plants with dense canopies.
   - Separate the canopy of densely growing plants from one another and from buildings by a distance of 0.6m or more to make it more difficult for rats to move between them.
6. Wood mulch.
   - Decorative wood chips and mulch should be used sparingly in situations where termite infestation is a high probability. Wood chips should never be allowed to contact wood siding or framing of doors or windows. Crushed stone or pea gravel are alternative solutions and may also discourage ants and spiders.

### 30.2.2 Foundations and slabs

#### *30.2.2.1 Drainage design*

1. Slope of concrete and asphalt areas near buildings.
   - Provide 6.35mm slope at patio slabs, walks, and driveways away from building.
2. Backfill around foundations.
   - Tamp backfill to prevent settling and slope the final grade away from the foundation at a rate of 1.27cm per 0.3m over a minimum distance of 3.04m.

#### *30.2.2.2 Reduce moisture in crawl spaces and under concrete slabs*

1. Vents maintenance.
   - Air should flow freely (not blocked by shrubbery, mulch, or other landscape materials) through vents to reduce moisture levels. Maintain vent openings to crawl spaces.
2. Subgrade membranes under concrete slab foundations.
   - Use a continuous, durable subgrade membrane sealed at all splices, perimeters, and protrusions in order to minimize foundation moisture problems. The membrane product selected should be specifically manufactured for use as a subgrade membrane and conform to ASTM E1745, latest edition, 0.1 perm maximum. Installation should conform to ASTM E1643, latest edition.

#### *30.2.2.3 Prevent pest access to crawl spaces*

1. Corrosion resistant, pest-resistant mesh on crawl space vents.
   - For any ground-level space (e.g. raised foundation crawl space) requiring foundation vents, specify corrosion resistant vent material (e.g. bronze)

and a vent opening size smaller than the pest to be inhibited. For example, for typical ants and termites, use #50 bronze mesh between layers of 12.7mm to 25.4mm mesh for durability. Building codes generally require mesh with maximum opening of 6.35mm, which will block rodent access.

2. Clearance between crawl space ventilation and finished ground level.
    - Foundation vents should be at least 150 mm above finished ground level.

#### *30.2.2.4 Access for inspections in the design of accessory structures that abut the foundation sidewall or other structures*

1. Clearance at accessory structures.
    - Provide 45.72cm clearance beneath and 15.24cm clearance between accessory structures and exterior wall coverings at decks, fences, patios, planters, and other accessory wood structures. If this clearance is not possible, construct accessory structures so that they are easily removable to allow inspection for termites.
2. Access to foundations.
    - Provide easily removable components to allow access to foundation for inspections.
3. Concrete substructures.
    - In order to minimize entry of pests via joints, pour concrete patios as part of the main slabs.

#### *30.2.2.5 Eliminate wood and cellulose-containing material under and near structures*

1. Wood material adjacent to building.
    - No cellulose-containing material (wood scraps, form boards, vegetation, stumps, large dead roots, cardboard, trash, and foreign material) should be buried on the construction site within fifty feet of any building, especially in areas with high termite pressure.
2. Fill material.
    - Fill material used around structures should be clean and free of vegetation and cellulose material.
3. Remove wood materials from masonry
    - Prior to concrete placement, clean all cellulose-containing material from cells and cavities in masonry units to inhibit termite colonization.
4. Remove extraneous wood materials after foundation construction.
    - After all foundation work is completed, remove all loose wood and debris from the crawl space and within 0.3048m of the perimeter of the building.

#### *30.2.2.6 Consider termite susceptibility in choice of foundation materials*

1. Steel posts in post and beam foundations.
    - Use steel posts for post and beam foundations, especially in areas with high termite pressure. The ends of the posts should be sealed at both ends with welded plates and the posts should be set in concrete foundations.
2. Synthetic stucco.
    - In areas of high termite hazard, avoid Exterior Insulation and Finish Systems (EIFS, commonly referred to as synthetic stucco).
3. Foam insulation and foundation systems.
    - In areas of high termite hazard, avoid subgrade foam insulation on the exterior of the foundation, or pre-formed closed cell foam foundation systems.

#### *30.2.2.7 Minimize cracks more than 1 mm wide in concrete foundations and slabs*

1. Expansion joints.
    - Minimize need for expansion joints when designing slabs. When expansion joints are used, inspection access should be readily available and the use of termite-resistant mesh should be considered. In one study, 83% of subterranean termites entering buildings came in through expansion joints in concrete slabs.
2. Voids in concrete.
    - In order to minimize voids in concrete slabs, mechanically compact concrete with a vibrator when pouring a slab.
3. Curing of concrete slabs.
    - Cure concrete slabs slowly to reduce shrinkage and cracks. Moist curing periods should generally not be less than seven days. Consult a structural engineer for design standards.
4. Anchors in concrete slabs.
    - Embed anchor bolts in slabs as the slab is poured. If additional anchors are necessary, use adhesive anchoring systems rather than expanding fasteners to avoid causing cracks.
5. Topical curing compounds for small foundations.
    - For foundations and slabs up to about 15.24m in dimension, use liberal applications of topical curing compounds to decrease cracking.
6. Topical curing compounds or shrinkage admixtures for intermediate sized foundations.
    - For foundations about 15m to 30m in dimension, use adequate concrete reinforcing and proper concrete mix design, placement, finishing, and curing techniques. Additionally, use a shrinkage limiting concrete admixture.
7. Topical curing compounds or shrinkage admixtures for large foundations.
    - For foundations greater than about 30m in

dimension, use adequate concrete reinforcing and proper concrete mix design, placement, finishing and curing techniques. Additionally, use a properly designed, shrinkage compensating concrete admixture.

8. Integrated slabs are preferred. If joints are necessary, consider termite barriers.
   - Concrete slab foundations should be monolithic (floor slab integrated and poured simultaneously with footings). Unplanned construction joints should be minimized. In areas of high termite pressure any joints should be protected with mesh barriers or sand (graded stone) barriers. Mesh barriers should be laid on top of the vapor barrier and have a 15mm accordion fold under the joint. Edges should be turned up 25mm to be cast into the slab. The accordion fold should be protected by a strip of vapor barrier material so that the concrete does not bond to the accordion fold. Alternatively, a mesh barrier with an accordion fold can be parged to the top of the slab. Sand barriers should be confined within a void adjoining the joint that is at least 75 mm deep and at least 50 mm wide. A retainer cast into the slab should be used to confine the sand particles.

#### *30.2.2.8 Reduce opportunities for undetected termite access*

1. Visual access of upper edges of concrete slabs.
   - The upper 100mm of the edges of a slab should remain exposed at all times; it should not be concealed by masonry, timber, soil, paving, etc.
2. Avoid indentations in edges of concrete slabs.
   - The vapor barrier underneath a slab should end no higher than the level of the finished soil or paving level. Slab formwork should include 100mm of smooth faced timber around the top of the slab edge. The purpose of these construction details is to avoid indentations which allow undetected termite access.

#### *30.2.2.9 In areas of high termite hazard use shields or barriers with concrete slabs and foundations*

1. Appropriate materials and designs for termite shields.
   - If termite shields are used to reduce subterranean termite damage, they should be constructed of galvanized steel at least 0.5 mm thick; sheet copper at least 0.4mm thick; stainless steel at least 0.4mm thick; aluminum alloy at least 0.5mm thick; copper and zinc alloys at least 0.5mm thick; or woven stainless steel mesh. Joints and corners should be mitered and soldered, welded, or brazed. Shields should extend 70-80mm past the foundation or foundation component. The last 30 mm of the shield should be bent downward at a 45 degree angle to reduce injuries during inspection. In addition, corners should be rounded. The slippery metal of termite shields provides a poor footing for termites and their tubes, although there is controversy about their effectiveness. Termite shields are also useful for inspection purposes to spot signs of infestation. The shields should be constructed with no gaps for termite access, and in settings that permit inspection.
2. Mesh barriers for termite exclusion
   - When stainless steel mesh is used as a termite barrier, the mesh should be made from grade 304 or 316 wire with a minimum diameter of 0.18mm. The maximum aperture size should be 0.66mm x 0.45mm. This maximum size should be reduced if local termite species are known to be small. As necessary the mesh should be parged to concrete foundations with a grout consisting of water-dispersed copolymer, type GP Portland cement and sieved aggregate that can pass through the stainless steel mesh. The mesh should not contact dissimilar metals that will produce a corrosion reaction. If pieces of mesh need to be joined, the joint should consist of an area 10-15mm wide where the edges of the two pieces are folded together 2 1/2 times or a parged area 35mm wide where the pieces overlap. Mesh can be used as a perimeter barrier for masonry exterior walls when parged to the concrete slab, draped across the cavity, and then built into the exterior wall. It can also be used as a continuous barrier under concrete slabs, or as a barrier under joints and for utility penetrations.
3. Sand or basalt barriers for termite exclusion.
   - Where graded particles (sand or basalt) are used as a termite barrier, the particles should be graded and shaped so that a sufficient proportion of them are of a size that cannot be transported by local termite species. They also should be able to be placed so that voids between particles to not permit penetration of local termite species. They can be either igneous or metamorphic stone. The wet/dry analysis must have less than 35% variation and their specific gravity must be at least 2.52. Graded particles can be used as a perimeter barrier when installed in wall cavities or in a trench around the foundation. In either case the minimum depth of the particles should be 75 mm. Trenches should be at least 100 mm wide. Graded particles can

also be used as a continuous under-slab barrier. These barriers should be 75-100mmm deep and compacted with a vibrating plate-type tamper. Graded particles can also be used as a barrier under joints and around utility penetrations. Appropriate diameters for particles are 1.2-1.7 mm for the western subterranean termite, 1.7-2.8mm for the eastern subterranean termite, and 1.7-2.4mm for the Formosan termite.

#### *30.2.2.10 All points where utilities go through the slab should be readily accessible for inspection. Gaps between penetrations and slab should be sealed using epoxy as a sealant, mesh barriers, or sand barriers.*

1. Epoxy sealants for utility breaks.
   - Use epoxy immediately prior to pouring a slab to seal concrete around utilities.
2. Mesh barriers for utility breaks.
   - Mesh barriers should consist of a flange of mesh 50mm wide. The mesh flange should be attached to the penetrating utility with a stainless steel clamp and embedded in the slab. Alternatively, the mesh flange can be attached with a stainless steel clamp and then parged to the top surface of the slab.
3. Sand barriers for utility breaks.
   - For sand barriers, concrete should be poured in a circular area 25mm around the utility pipe. That void should then be filled with sand at least 75mm deep. The sand should be capped at the top of the slab, and a retainer cast into the slab below the sand should be used to prevent sand loss beneath the slab.

#### *30.2.2.11 Maintain adequate clearance between wood foundation components and soil.*

1. Minimum clearance.
   - There should be a minimum clearance of 45.72cm between beams or joists and soil.
2. Increased minimum clearance.
   - In areas of high termite hazard, clearance between beams or joists and soil should be 91.44cm.

#### *30.2.2.12 Use "curtain walls" around and below a foundation where necessary*

1. Effective designs for curtain walls.
   - Rats often burrow under foundations of buildings without basements. Vertical curtain walls 0.6m below the surface with an 20cm horizontal "L" or flange directed away from the building are usually effective in preventing rats from burrowing under foundations. Construct curtain walls of 29-gauge corrugated iron, concrete, or bricks.

### 30.2.1 Building exterior: siding

#### *30.2.1.1 Install and finish siding to minimize gaps, warping, and cracking*

1. Caulk and sealant for siding installation.
   - On siding, use high quality, exterior grade caulks and sealants that meet ASTM standard C-920. Caulk should be compatible with both siding materials and trim materials.
2. Areas to be caulked or sealed during siding installation.
   - Caulk or seal the following areas: wherever siding meets trim, around windows and doors, and around any penetrations (pipes, wires, etc.) that are not self-flashing.
3. Back flashing at siding butt joints.
   - Use back flashing at siding butt joints to minimize openings that might allow entry of pests.

#### *30.2.1.2 Provide sufficient clearance between siding and soil*

1. Siding or stucco installation.
   - Siding and stucco should begin at least six inches above soil level. This decreases the risk of subterranean termites reaching the wood, and makes their mud tubes more visible to inspectors.

### 30.2.2 Building exterior: wall and perimeter

#### *30.2.2.1 Direct rainwater away from walls*

1. Discharge from downspouts and gutters.
   - To minimize moisture accumulation, all downspouts and gutters should discharge at least 0.3048m away from structure wall, using a connection to storm sewers, tail extensions, splash blocks, or dry wells.
2. Placement of gutters with downspouts.
   - Use gutters with downspouts on all buildings with eaves of less than 15.24cm of horizontal projection except for gable ends and roofs above other roofs.

#### *30.2.2.2 Prevent rodents from using downspouts and pipes to climb up exterior walls*

1. Flap valves or mesh on downspouts.
   - In areas of high rodent pressure, use flap valves to prevent rodents from entering downspouts. Mesh is also an option, but periodic cleaning will be necessary.
2. Cones and discs.

- In areas of high rodent pressure, use cones or discs (typically metal) to prevent rodents from traveling up downspouts and pipes. Cones should be mounted with the wide end of the cone facing down and should be 30.48cm in diameter and 30.48cm long. Discs should be 18 inches in diameter.

3. Vertical pipes.
    - Prevent mice and Norway rats from climbing on exterior vertical pipes by applying a 45.72cm band of glossy paint around the pipe.
4. Strainer leaf guards.
    - Use expanded strainer leaf guards (made for keeping leaves out of downspouts) to keep rodents from entering open pipes.

#### *30.2.2.3 Design building perimeter to be unattractive to pests*

1. Gravel strip around perimeter of foundation.
    - To discourage rodent burrowing, install a gravel strip of 0.5cm diameter or larger, laid in a band at least 60cm wide and 15cm deep.
2. Plant-free strips around structures.
    - Maintain plants, grass, and mulch several inches away from the foundation of buildings to minimizing nesting sites for ants.
3. Exterior landscaping.
    - Design exterior landscaping so it does not cause moisture build-up around the foundation. Consider use of drip irrigation. Maintain clearances between vegetation and exterior walls.

#### *30.2.2.4 Design accessory structures, fences, posts, planter boxes, and stairs to minimize termite problems*

1. Contact between accessory structures and the main building.
    - Construct decks, fences, patios, planters, or other wooden structural components that directly abut the sidewall of the foundation or structure to provide: (a) an 45.72cm clearance beneath the component, or (b) a 15.24cm clearance between the top of the component and the exterior wall covering, or (c) have components that are easily removable by screws or hinges to allow access for inspection of the foundation sidewall.
2. Termite-resistant fence and post materials.
    - Use termite-resistant fence and post materials, including naturally durable wood, concrete and steel.
3. Wood steps above grade
    - Wood steps should rest on a concrete base at least 15.24cm above grade to minimize access by wood-destroying pests, particularly in areas with high termite pressure.

#### *30.2.2.5 Prevent animal access under sheds, decks, and porches*

1. Use of metal mesh.
    - Install quality 0.635cm or 1.27cm galvanized hardware cloth from the bottom of the shed/porch/decks without perimeter foundations to 7.62-10.16cm below the ground and then out in a perpendicular fashion at least 30.48cm from the vertical line. To improve appearance of hardware cloth used under sheds, decks, and porches, cover with lattice after installation.

#### *30.2.2.6 Design and construct exterior building surfaces to minimize pest access to interior*

1. Holes or joints in exterior or other cavity walls.
    - Seal all holes or joints in exterior or other cavity walls that are larger than 6.35mm diameter to prevent access by mice. Where larger holes or joints are necessary they should be screened with 6.35mm mesh or otherwise shielded from pest intrusion. Seal smaller holes to eliminate access from smaller pests. Use caulk (non-elastomeric, does not return to original shape when stretched or compressed) for openings of 6.35mm diameter or less. Use an elastomeric sealant to close larger openings. Use a liquid sealer to close pores and hairline cracks.
2. Concrete masonry unit walls.
    - “Cap” concrete masonry unit walls by filling the top row of blocks with cement to eliminate rodent access to the interior of the wall.
3. Sealing along foundation for standard stucco weep-screed construction.
    - For standard stucco weep-screed construction, seal along foundation with 15.24cm minimum rubberized asphaltic, self-adhesive membrane extending down over foundation 2.54-5.08cm. At point above screed section, also seal back of flashing to foundation with generous bead of foundation mastic. Use vinyl weep screed in corrosive environments.
4. Appropriate flashing for stucco walls with offset weep-screed.
    - For offset weep-screed installation use weep-screed flashing with offset in the flashing equal to actual framing offset. Install per standard weep-screed construction procedures except use 8-inch minimum self-adhesive membrane extending to bottom of weep-screed. Use small bead of caulking between base of framing and flashing.
5. Sealing for stucco walls with offset framing and

standard weep screed.

- For offset framing where standard weep screed was used, install closed-cell-foam backing rod between foundation and flashing. Apply suitable, vertical application and resilient caulking between foundation and flashing. Alternatively fill gap between foundation and flashing with self-adhering, expanding foam. Upon cure, trim flush with base of flashing.

#### *30.2.2.7 Design building exterior to minimize attractiveness for roosting birds*

1. Design exterior structures to minimize bird perching, roosting, or nesting.
   - Design exterior structures like decorative screens, moldings and lattices, siding, awnings, window sills, signs, fire sprinkler pipes, and column capitals so that they do not provide opportunities for bird perching, roosting, or nesting especially near building entrances. Use smooth materials and avoid horizontal surfaces. Where necessary, retrofit existing structures with exclusion devices (looped wires, sheet metal spikes, springs, nets, etc.), although these devices are not foolproof and require maintenance. Openings in buildings, exposed rafters on overhanging dock roofs, or any likely perches in semi-enclosed areas can be screened with rust-proof, 1.905cm wire or plastic mesh, or 1.27cm mesh to also exclude rodents. Plastic netting is less durable and must be replaced more often.
2. Avoid semi-enclosed spaces or alcoves.
   - Semi-enclosed alcoves or courtyards, especially with open roofs, provide ideal roosting and nesting opportunities for pigeons and other birds. If these structures must be included in the building design, include bird barriers and minimize horizontal surfaces.

### 30.2.3 Building exterior: lighting

#### *30.2.3.1 Choose exterior light fixtures to discourage bird roosting and nesting*

1. Bird-resistant light fixtures.
   - Choose light fixtures with sloping surfaces rather than horizontal surfaces to deter bird roosting and nesting.
2. Bird deterrents on light fixtures.
   - Install bird spikes, "porcupine wire," netting, or similar devices to discourage birds from nesting on light fixtures.
3. Bird exclusion devices.
   - Use bird exclusion devices, including wires, springs, nets, and electrical strips, to prevent birds from reaching light fixtures.

#### *30.2.3.2 Design and install exterior light fixtures to minimize attraction of flying insects*

1. Motion detectors on exterior lights.
   - Motion detectors allow lights to be on for shorter amounts of time and can reduce accumulation of insects around lights.
2. Timers on exterior lights.
   - Use timers to restrict light operation to high traffic times as appropriate. This may reduce the volume of insects attracted to the lights.
3. Reflected light rather than direct light.
   - Use reflected light rather than direct light to illuminate doorways, as appropriate and allowed by local codes. Insects are more attracted to point sources of light and are therefore less likely to enter doorways.
4. Direct exterior lighting only for essential areas.
   - Minimize direct lighting to high priority areas that maximize resident safety, especially near structures. All such lighting should meet local code requirements. This will minimize insect attraction to point source lights.
5. Yellow or red exterior lights.
   - Use yellow or red lights ("bug" bulbs or sodium vapor lights, for example) in exterior areas where insect attraction to lights is an issue. Both intensity and color are important in insect attraction.

### 30.2.4 Roofs

#### *30.2.4.3 Construct roofs to reduce pest access into the building structure*

1. Bird stops on tile roofs.
   - Fit eave roof tiles with commercially available bird stops, which also exclude bats and flying insects.
2. Screens for attic vents and chimneys.
   - Attic and chimney screens can prevent problems with bats, squirrels, and birds. In areas of where drywood termites are known to be a problem, consider replacing screens on attic vents (typically 6.35mm) with window screening. This may not be appropriate in damp climates, because the smaller mesh screening can impede air flow. Building codes generally allow attic vent screening as long as the mesh size is greater than 1.5875mm.

### 30.2.5 Interior walls

#### *30.2.5.1 Construct interior walls to minimize harborage and pathways for insect and*

are safe for children and the elderly. Follow manufacturer's safety instructions for closure mechanisms.

6. Screen doors.
    - Use screen doors with durable frames to prevent warping and ensure a good seal from the outdoors.
7. Weather-stripping of exterior doors.
    - Use weather-stripping of all exterior doors to better seal against pest entry.

## 30.2.8 Windows

#### *30.2.8.1 Design and construct windows to minimize pest attraction and access to interior*

1. Window ledges.
    - Slope smooth-surfaced window ledges and projections at 45 degrees to minimize bird perching and roosting.
2. Screens.
    - International Property Maintenance Code requires screens on windows in habitable rooms as well as rooms used for food storage and preparation unless air curtains or fans are employed.
3. Weather-stripping.
    - Use weather-stripping for all operable windows.

## 30.2.9 Bedrooms

#### *30.2.9.1 Minimize bed bug harborage*

1. Moldings and joints.
    - Moldings and joints around the room perimeter (floor, doors, cabinets, and windows) should be caulked with silicone sealant to eliminate hiding spots for bed bugs.
2. Hard flooring materials.
    - Use wood, tile, linoleum, or similar flooring materials instead of carpets or rugs.
3. Built-in furniture.
    - Built-in furniture provides harborage for bedbugs that is difficult to inspect. If built-in furniture is used, provide access for inspection.
4. Furniture that minimizes attractiveness to bedbugs.
    - Use leather, metal, plastic or laminate furniture rather than upholstered, wicker, or wood furniture. Metal and laminate furniture is harder for bedbugs to climb than wood furniture. If upholstered furniture is used, it should have metal legs and the fabric should be at least a few inches from the floor and from any other pieces of furniture. If possible, use furniture that is easily washable and light colored. Beds should not have headboards and mattresses should be encased in commercially available, insect-proof coverings.

#### *30.2.9.2 Seal openings that allow bedbug movement between rooms or units*

1. Openings in floors, walls, and ceilings.
    - Openings around pipes or other structures that come through walls, floors and ceilings should be sealed. caulk, foam, seal, paint, or otherwise fill any cracks and holes larger than the thickness of a credit card.

## 30.2.10 Bathrooms

#### *30.2.10.1 Prevent moisture accumulation in bathrooms*

1. Floor, wall, and ceiling penetrations.
    - All penetrations of floors, walls, and ceilings should be sealed with metal escutcheon plates if feasible, or with polyurethane foam, silicone sealant, or other flexible sealant. Penetrations include electrical wires, supply and drain pipes, heating and ventilation systems, and recessed lights. Larger gaps may require the addition of copper or stainless steel wool to the foam, in order to effectively bar access to rodents.
2. One-piece countertops.
    - Countertops should be one piece if possible, that is, with an attached backsplash. If this is not feasible, use an elastomeric sealant to seal along edges of countertops and backsplashes where they meet walls.
3. One-piece tub or shower enclosures.
    - Use one-piece tub or shower enclosures where they are appropriate with the bathroom design, to minimize potential infiltration of moisture.
4. Water controls
    - In large shower enclosures, offset water controls so that they are close to the door. This makes them easier to use,and lessens the likelihood of water escaping the shower.
5. Shower shelves and soap holders.
    - Slope horizontal surfaces of soap holders, shampoo cubbies, and shower seats so water drains into the shower or tub. This reduces moisture buildup.
6. Toilet tanks.
    - Use insulated toilet tanks to minimize toilet sweating and moisture buildup.
7. Slope ventilation ducts.
    - Ensure horizontal ventilation ducts are sloped so that condensation water doesn't accumulate in the ducts.

***rodent pests***

1. Baseboard installation.
    - Use straight base rather than cove base. Cove bases are typically installed with adhesives that may be food for cockroaches, and the gap behind the cove provides potential harborage for a variety of pests, including bed bugs. Alternately, use cove bases that have no gap, and install them to be more easily removable (using screws or nails) to make inspection and treatment easier.
2. Gaps between wall and flooring.
    - In an interior wall made of wood and drywall, the bottom plate is not usually completely tight against the floor due to uneven floors and the natural bends in wood. Similarly, the drywall panels that are hung on the wall framing often have a gap along the bottom edge. Gaps should be minimized as much as possible during construction.

## 30.2.6 Floors

#### *30.2.6.1 Floors should be durable, non-absorbent, without crevices, and capable of being effectively cleaned*

1. Concrete.
    - Concrete floors should be durable, steel-float finished and sealed to prevent dirt accumulation in crevices and provide a non-slip surface.
2. Carpet.
    A. Avoid installing carpet in areas prone to moisture: bathrooms, laundry rooms, kitchens, entryways and damp basements. Moisture promotes fungal growth and accompanying insect infestations.

#### *30.2.6.2 Floors should be durable, non-absorbent, without crevices, and capable of being effectively cleaned*

1. Moisture resistant materials in commercial kitchens.
    - In commercial food preparation areas, use quarry tile, poured seamless epoxy floor, approved commercial grade vinyl, or similar materials to avoid moisture accumulation and harborage of insect pests.

#### *30.2.6.3 Design floor drains for complete drainage and easy cleaning*

1. Floor slope.
    - Where floor drains are installed, slope surrounding floors 0.635cm per 0.3048m to the drain.
2. Drain covers and baskets.
    - Cover floor drains with mesh screen covers or sunken drain baskets. Baskets or covers should be removable for cleaning. Codes usually require removable strainers.
3. Floor drain access.
    - Floor drains should be easily accessible to enable cleaning and inspection. Floor drains should not be located under fixed kitchen equipment.

## 30.2.7 Doors

#### *30.2.7.1 Reduce pest access through doors.*

1. Solid-core doors.
    - Use solid-core doors where possible. Solid-core doors are more durable and do not have hidden recessed areas or cavities that could harbor pests.
2. Doors with metal kick plates.
    - In areas of high rodent pressure, fit external doors with 26-gauge sheet metal kick plates 30.48cm tall and mounted no more than 0.635cm from the bottom of the door. Metal plates should not interfere with the swinging of the door.
3. Thresholds of exterior doors.
    - Doors should fit tightly; the distance between the bottom of the door and the threshold should not exceed 0.635cm. Use tight-fitting door sweeps if gaps are larger than 0.635cm. If appropriate, use automatic door sweeps, which drop to seal against the floor when the door is closed. If automatic sweeps are not possible, bristle sweeps are preferable to rubber or plastic. If rodent pressure is high, protect rubber and plastic sweeps with metal kick plates installed on the outside of the door.
4. Air curtains.
    - In commercial buildings, specify air curtains (air doors) where doors are frequently open. Use models that start automatically when the door is opened to conserve energy. Properly installed and sized air curtains are typically about 80% effective in preventing insect entrance. Users have reported over 99% reduction in fly numbers.
5. Self-closing doors.
    - All doors leading to the outside should be equipped with self-closing devices and supplementary screen doors. For large overhead doors, such as warehouses or processing facilities, consider electrically operated screen doors or a permanent frame with screening. As appropriate, make sure the closure mechanisms

8. Bathroom fans with a humidistat.
    - Install bathroom fans with a humidistat to more effectively avoid moisture buildup. Humidistats automatically turn on fans when humidity reaches a certain level.

## 30.2.11 Kitchens: general

#### *30.2.11.1 Design kitchens for easy cleanability and pest inspections*

1. Joints between toe-kicks and floor.
    - Use curved joints between floor and the vertical toe-kick under cabinets rather than right angle joints. "Roll" the edge of the floor up to the toe-kick with a smooth curve. Ensure that edges are properly sealed to avoid creating harborages for pests.
2. Joints between sinks and countertops.
    - Avoid joints that are difficult to clean between sinks and countertops. Use undermount or integral sinks.
3. Kitchen cabinets with smooth, flat doors.
    - Specify cabinets with flat rather than raised panel doors. Raised panels or elaborate moldings create more opportunities for dirt accumulation. Enamel, gloss paint, or other smooth finishes are preferable to make cleaning easier.

#### *30.2.11.2 Eliminate moisture buildup in kitchens.*

1. One-piece countertops.
    - Use one piece countertops with attached backsplash when possible. If one-piece countertops are not feasible, use an elastomeric sealant to seal along edges of countertops and backsplashes where they meet walls.

#### *30.2.11.3 Eliminate potential pest harborage*

1. Cabinets contacting floor and walls.
    - Using an elastomeric sealant, seal joints where cabinets contact the floor and walls. The wall behind the cabinet should be free of holes or voids. The goal is to prevent access to hidden spaces favored by cockroaches. This is especially critical in institutional kitchens.

## 30.2.12 Kitchens: institutional

#### *30.2.12.1 Design kitchens for easy cleanability and pest inspections*

1. Food storage areas.
    - Food storage should be elevated off the floor and away from walls to facilitate inspection and cleaning.
2. Coved junctions.
    - Wall-wall and wall-floor junctions should be coved to facilitate easier cleaning and prevent the accumulation of debris. Wall-ceiling junctions should be coved or sealed. Rubber or flexible plastic baseboard coving should be avoided, since it is very difficult to remove and inspect. Avoid cove base that is installed with adhesive. Choose coving that does not include an air gap under the curve, which could provide harborage for cockroaches.
3. Lighting in storage areas.
    - Storage areas should have adequate lighting to allow efficient cleaning and easy pest inspection.
4. Access to suspended ceilings.
    - Provide access to voids above suspended ceilings for inspections and cleaning. In large buildings, provide walkways for this purpose.
5. Cabinets with legs.
    - Specify cabinets with legs to facilitate cleaning underneath. Legs should either be bolted to the floor with gaskets or sealant to eliminate gaps, or should be on wheels to enable easy moving.
6. Wheeled appliances.
    - Specify the use of wheeled stoves, mixers, refrigerators, and other appliances to encourage regular cleaning. Wheel fenders should include adequate clearance for cleaning around the wheels.
7. Drains.
    - Locate drains so that they are accessible for cleaning.
8. Flush thresholds in doorways.
    - When possible use flush thresholds in doorways. Thresholds collect dirt and food debris that can attract fruit flies or roaches.
9. Food preparation areas.
    - When possible, locate food preparation areas on islands rather than against walls. Cleanup is generally easier around islands.
10. Stainless steel backsplashes.
    - Install stainless steel backsplashes behind sinks and work surfaces for easier cleaning and avoid moisture buildup. Use sealant around edges.

#### *30.2.12.2 Eliminate moisture buildup in kitchens*

1. Ventilation in moist areas.
    - Provide extra ventilation for dishwasher, cooking line, and in the mop room. This can be accomplished through modifications of venting or through installation of small fans. Reduction of moisture buildup will inhibit fruit flies and other pests.

#### *30.2.12.3 Minimize pest entrance into kitchen*

1. Separation of refuse disposal, recycling areas, and food delivery entrances.
    - Refuse disposal, recycling areas, and food delivery entrances should ideally be located away from frequently used entries. Refuse disposal and recycling areas attract flies and other pests, even when bins are well sealed and frequently cleaned. If the disposal area is adjacent to frequently used entries, such as those used for food deliveries, it is easier for the flies to enter the kitchen.
2. Self-closing doors for food storage rooms.
    - Use self-closing doors for food storage rooms to shut out rodents and some insect pests. Doors should be adequately sealed around the edges, with door sweeps or bottoms and no gaps over 0.635cm.
3. Wiring and pipe penetrations.
    - Seal all penetrations through walls and floors, including wiring and pipe penetrations through wall framing at top and bottom plates. Use either an elastomeric sealant or fire block, depending on the size of the gap, its location, and local building codes. This is especially important in institutional kitchens where there is no tolerance for pest infestations. For larger gaps, including copper or stainless steel wool with foam may be necessary to exclude rodents.

#### *30.2.12.4 Eliminate potential pest harborage*

1. Wall hangings and signs.
    - Any wall storage, ornamentation, signage, bulletin boards, etc. should be sealed using elastomeric sealant or hung at least 0.635cm from the wall to discourage pest harborage.
2. Storage rooms without void spaces.
    - If rodent pressure is high, design food storage rooms without double walls, false ceilings, enclosed staircases, boxed plumbing, and voids under cabinets. This permits easy inspection and removes harborage.
3. Ceramic outside corner tiles.
    - Avoid use of ceramic outside corner tiles. Ceramic tiles located in heavily used areas are highly prone to breakage. Broken tiles provide access to voids that can harbor pest insects. Durable outside corners, such as metal or plastic, are preferred alternatives.

### 30.2.13 Utilities, HVACs, chutes

#### *30.2.13.1 Design and construct utility penetrations, such as water pipes, electrical wires and conduit, cold air return ducts on forced air furnaces, and exhaust vents, to minimize pest intrusions*

1. Rodent-resistant materials to seal around utility penetrations.
    - Use escutcheons, cement mortar, or copper mesh or hardware cloth embedded in patching plaster to seal any openings around utility penetrations.
2. Use sealant on small gaps around penetrations.
    - Where rodent pressure is not high, or with gaps < 6.35mm, use silicone sealant to seal around utility penetrations to deter insect movement.
3. Air intakes and vents.
    - Outside air intakes or vents for wall-mounted heaters, air conditioners, and exhaust fans should be screened to exclude insects a variety of pests. Use 10-mesh screen or smaller and design/install the screen so that it can be easily removed for cleaning.
4. Outlets and switches.
    - Use foam gaskets behind electrical cover plates to seal off access to pests, particularly in pest sensitive areas such as institutional kitchens.
5. Cleaning around utility penetrations.
    - There should be adequate space and access for cleaning around utility penetrations.
6. Dryer exhaust vents.
    - Terminal ends for clothing dryer vents are available that exhaust the air vertically rather than horizontally and may be more effective in excluding rodents than the usual flapper-type vent ends.

#### *30.2.13.2 Design trash and laundry shafts to exclude pests and minimize pest harborage.*

1. Chute doors.
    - Trash and laundry chutes should have tight-fitting doors. Avoid any gaps between door and surrounding wall.
2. Chutes circular in cross section.
    - Use metal garbage and laundry chutes with a circular cross section to avoid accumulation of debris in hard-to-clean corners.
3. Trash chute size.
    - Hopper doors into vertical trash chutes should be large enough to fit a full trash bag, to avoid the accumulation of debris from torn bags and keep chutes cleaner.

### 30.2.14 Refuse and recycling

#### *30.2.14.1 Exclude rodents from refuse and recycling areas*

1. Prevent access to refuse and recycling areas.

- Design refuse and recycling areas with concrete pads that extend past the boundaries of the enclosure so that rodents cannot burrow into the enclosed area.

2. Rodent-resistant enclosures.
    - Enclose refuse and recycling areas with metal, concrete, or similar materials to prevent vertebrates from gnawing or climbing the enclosure. Enclosures should be solid and extend all the way to the ground. Do not plant ivy around enclosures.
3. Pest-resistant containers.
4. Use refuse containers that are heavy duty, rust resistant, rat and damage resistant, and equipped with tight-fitting lids. Racks or stands prevent corrosion or rusting of containers, reduce rat shelter under containers, and minimize the chance of containers being overturned.

#### *30.2.14.2 Design refuse and recycling areas for easy cleaning*

1. Floors areas.
    - Use concrete floors in refuse and recycling areas
2. Drainage.
    - Slope floor of recycling and refuse area to a drain connected to the sanitary sewer.
3. Hose bib.
    - Provide a hose bib near the enclosure for periodic cleaning.

#### *30.2.14.3 Durable pest-resistant construction materials*

1. Termite resistant building materials
    - Termite-resistant materials include brick, concrete, stone, naturally resistant wood, metal, and rigid plastics. Naturally resistant woods commonly used in North America include: western red cedar, redwood, incense cedar, Port Orford cedar, black locust, northern white cedar, and Alaska cedar are known to dissuade termite infestations. Using these durable woods makes infestation less likely but does not guarantee that infestations will not occur. It is also important to note that only the heartwood from these species is resistant. While they do not constitute a food source for wood-destroying insects, brick, concrete block, and plastic may still provide harborage for the pests. Foam insulation mounted on the outside of foundations, for example, provides near-ideal temperature and humidity conditions for termite tunnels. Regular termite inspections are important even when using resistant materials.
2. Rodent resistant building materials.
    - Rodent teeth are well adapted to gnawing through all but the hardest materials. Rats have been known to gnaw through lead. Rodent-resistant materials include concrete with a minimum thickness of 5.1cm if reinforced, or 9.5 cm if not reinforced; galvanized sheet metal if 24 gauge or heavier for wall or pipe barriers, 22-gauge or heavier for kick plates or door edging, or 14-gauge if perforated or expanded sheet metal grills; brick if 9.5 cm thick with joints filled with mortar; hardware cloth (wire mesh) if woven, 19- gauge, 1.3cm x 1.3cm mesh to exclude rats or 24-gauge, 0.6cm x 0.6cm mesh to exclude mice; aluminum if 22-gauge for frames and flashing or 18-gauge for kick plates and guards; plaster; or corrugated metal.

### 30.2.15 General area

#### *30.2.15.1 Design for easy inspection*

1. Minimize inaccessible spaces.
    - Example of inaccessible spaces include: false ceilings, false bottoms under cabinets, pegboard storage systems, air plenums, gaps behind or within machinery, spaces behind coved baseboards, or enclosed spaces under bathtubs.
2. Access to enclosed spaces.
    - Where hard-to-access spaces are necessary, provide enough access to allow inspections of the space. Examples include: 1) Provide hatches or walkways for inspection of voids above suspended ceilings, 2) leave 15.24cm clearance between wood structures and soil (preferably 18 inches in areas with high termite pressure), and 3) make sure expansion joints or utility breaks in foundation are accessible to inspection. Note that access to attics, crawl spaces, and other underfloor spaces is required by code.

# 31 Modularity design optimization

*A.k.a., Modularity engineering.*

Modular architectural structures are built in large three-dimensional sections, which are typically 95% complete when they leave the structural production center. The modules are then transported to the site and placed (often by crane) onto a permanent foundation where final assembly is complete.

## 31.1 Modularity analysis

A modularity analysis involves:

1. Structural analysis
2. Connectivity analysis
3. Fixtures analysis
4. Fitting analysis
5. Internal area module analysis

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**Table 12.** *Table showing BIM related level of development (LOD) stages in relation to model content.*

| Model Content | LOD 100 | LOD 200 | LOD 300 | LOD 400 | LOD 500 |
|---|---|---|---|---|---|
| 3D Model-based Coordination | Site level coordination | Major large object coordination | General object-level coordination | Design certainty coordination | N/A |
| 4D Scheduling | Total project construction duration. Phasing of major elements | Time-scaled, ordered appearance of major activities | Time-scaled, ordered appearance of detailed assemblies | Fabrication and assembly detail including construction means and methods (cranes, man-lifts, shoring, etc.) | N/A |
| Cost Estimation | Conceptual cost allowance Example $/sf of floor area, $/hospital bed, $/parking stall, etc. assumptions on future content | Estimated cost based on measurement of the generic element (i.e. generic interior wall) | Estimated cost based on measurement of specific assembly (i.e. specific wall type) | Committed purchase price of specific assembly at buyout | Record cost |
| Program Compliance | Compliance Gross departmental areas | Specific room requirements | FF & ampE, casework, utility connections | Specific manufacturer selections | Purchase documentation |
| Sustainable Materials | LEED strategies | Approximate quantities of materials by LEED categories | Precise quantities of materials with percentages of recycled and/or locally purchased materials | Precise simulation based on the specific manufacturer and detailed system components | Commissioning and recording of measured performance |
| Analysis/ Simulation | Strategy and performance criteria based on volumes and areas | Conceptual design based on geometry and assumed system types | Approximate simulation based on specific building assemblies and engineered systems | Precise simulation based on the specific manufacturer and detailed system components | |

**Table 13.** *Simplified materials construction technology table (materials technology construction matrix).*

| | Materials | Calculations | Outcomes |
|---|---|---|---|
| Technologies | | | |
| Calculations | | | |
| Outcomes | | | |

**Table 14.** *Design build matrix.*

| Build | Design | | | | |
|---|---|---|---|---|---|
| | Schematic | Design Development | Contract Documents | Bid / Negotiations | Construction Observation |
| Site | | | | | |
| Foundation | | | | | |
| Framing | | | | | |
| Roofing | | | | | |
| Exterior Finish | | | | | |
| Plumbing | | | | | |
| HVAC | | | | | |
| Electrical | | | | | |
| Insulation | | | | | |
| Walls | | | | | |
| Interior Finish | | | | | |
| Landscape | | | | | |

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**Table 15.** *Table shows maximum gap sizes for excluding various pests. (Geiger, 15, 2012)*

| Animal Type | Common Name | Scientific Name | Maximum opening size / mesh size | Reference |
|---|---|---|---|---|
| Insects / arthropods | Biting midges | Ceratopogonidae | 0.605 mm ~30 mesh | AFPMB, 2009 |
| | Cheese skipper | Piophila casei | 0.595 mm ~32 mesh | Ebeling, 1975* |
| | Cockroaches | Blatella germanica | 1.66 mm ~12 mesh | Koehler, 1994** |
| | Cotton aphid | Aphis gossypii | 0.341 mm ~50 mesh | Bethke & Paine, 1991* |
| | Fruit flies | Drosophilida spp. | 2.12 mm ~10 mesh | NPS, 2006 |
| | Honeybees | Apis spp | 3.00 mm ~7 mesh | NPS, 2006 |
| | House flies | Musca domestica | 2.03 mm ~10 mesh | Block, 1946 |
| | Mosquito | Aedes egyptii | 1.03 mm ~18 mesh | Wesley & Morrill, 1956; Block, 1946 |
| | Mosquito | Anopheles quadrimaculatus, Culex quinquefasciatus | 1.38 mm ~14 mesh | Block, 1946 |
| | Redlegged ham beetle | Necrobia rufipes | 0.595 mm ~32 mesh | Ebeling, 1975* |
| | Sand flies | Phlebotominae spp. (Psychodidae) | 0.605 mm ~30 mesh | AFPMB, 2009 |
| | Termites (Eastern subterranean) | Reticulitermes flavipes | 0.610 mm ~30 mesh | Tucker, 2008* |
| | Termites (Formosan | Coptotermes formosanus | 0.660 mm ~28 mesh | Grace et al, 1996* |
| | Thrips | Frankiniella occidentalis | 0.192 mm ~80 mesh | Bethke & Paine, 1991* |
| | Yellowjackets | Vespidae spp. | 3.00 mm ~7 mesh | NPS, 2006 |
| | Scorpions | Scorpionida spp | 1.6 mm | Timm & Marsh, 1997 |
| Birds | Pigeons | Columba livia | 50.8 mm (2 in) | Timm & Marsh, 1997 |
| | Sparrows, Starlings | Passer spp., Sturnus vulgaris | 19.1 mm (0.75 in) | Timm & Marsh, 1997 |
| Mammals | Bats | Chiroptera spp | 6 mm/0.25 in | Greenhall & Frantz, 1994 |
| | Mice | Mus musculus | 6 mm/0.25 in | Greenhall & Frantz, 1994 |
| | Rats | Rattus norvegicus, R. rattus | 9.5mm/3/8 in gaps under doors; 18 gauge 13 mm/0.5 in mesh | Corrigan, 1997 |
| | * Studies marked with an asterisk identified nominal gap sizes; these were matched with the closest Tyler mesh size. All other studies referred specifically to minimum mesh sizes; these were matched with approximate gaps sizes. Mesh opening sizes are nominal, i.e., not diagonal. | | | |
| | **Study pertained to preferred harborage for nymphs, not minimum opening for access, which is likely smaller. | | | |

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**Table 16.** *List of common building materials.*

| | | |
|---|---|---|
| Adhesives | Coal ash | Gypsum. |
| Adobe. | Concrete | Hempcrete |
| Acrylic. | Concrete fibre | High alumina cement |
| Aggregate | Copper. | Icynene spray foam insulation |
| Alkali-activated binder | Daub | Laminated veneer lumber LVL |
| Aluminium. | ETFE | Lead in construction |
| Architectural fabrics | Fibre cement | Limecrete |
| Asphalt | Glass for buildings | Masonry |
| Bulk filling materials | Glass reinforced concrete | Mastic sealant |
| Carbon fibre | Glass reinforced plastic GRP | Metal |
| Cast iron | Glulam | Mortar |
| Cavity wall insulation | Graphene in civil engineering | Mycelium |
| Cement | Gravel | Nylon |
| Ceramics | Gravel v hardcore v aggregates. | Oil - a global perspective |
| Chert | Grouting in civil engineering. | Paint |
| Clay | | |

**Table 17.** *Comparison of BIM work stages.*

| PAS 1192<br>Process map | APM<br>(listed in CIC BIM protocol) | RIBA 2013 | CIC BIM protocol (attributed to PAS 1192) |
|---|---|---|---|
| 1 Brief | 0 Strategy | 0 Strategic definition | 1 Brief |
| | 1 Brief | 1 Preparation and brief | |
| 2 Concept | 2 Concept | 2 Concept design | 2 Concept |
| 3 Definition | 3 Definition | 3 Developed design | 2 Development design |
| 4 Design | 4 Design (production information) | 4 Technical design (Procurement is flexible and does not have a numbered stage) | 4 Production |
| 5 Build & Commission | 5 Build & Commission | 5 Construction (including mobilization) | 5 Installation |
| 6 Handover & Closeout | 6 Handover & Closeout | 6 Handover & Closeout | 6 As constructed |
| 7 Operation<br>In use (no number) | 7 Operation and end of life | 7 In use | 7 In use |

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**Table 18.** *Method of calculating coincident peak demand.*

| Description | Total connected load, kw | Demand factor, % | Maximum demand, % | Load factor, % | Coincidence factor, % | Coincidence peak, kw |
|---|---|---|---|---|---|---|
| Fire station | 14.6 | 30 | 4.4 | 15 | 521 | 2.3 |
| X technology | # | # | # | # | # | # |
| Y technology | # | # | # | # | # | # |
| Z technology | # | # | # | # | # | # |
| | | | | | | |
| | | | | | Total | |
| | | | | | System losses | |
| | | | | | Grand total | |

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**Table 19.** *UniFormat for universal preliminary planning. This list of plannable elements contains numbers and titles associated with phases and/or deliverables. This list may be compared against other "Title and Numbering" standards, including but not limited to: CSI MasterFormat, etc. (Guthrie, 2010)*

| Number | Title |
|---|---|
| **1** | **ELEMENT: PROJECT COORDINATION (CSI, PROJECT DESCRIPTION)** |
| 10 | **Project description** |
| 1010 | Project summary |
| 1020 | Project program |
| 1030 | Existing conditions |
| 1040 | Owner's work |
| 1050 | Funding |
| 20 | **Proposal, bidding, and contracting** |
| 2010 | Delivery method |
| 2020 | Qualification requirements |
| 2030 | Proposal requirements |
| 2040 | Bid requirements |
| 2050 | Contracting requirements |
| 30 | **Cost summary** |
| 3010 | Elemental cost estimate |
| 3020 | Assumptions and qualifications |
| 3030 | Allowances |
| 3040 | Alternatives |
| 3050 | Unit prices |
| **A** | **ELEMENT: SUBSTRUCTURE (CSI - A, SUBSTRUCTURE)** |
| A10 | **Foundations** |
| A1010 | Standard foundations |
| A1020 | Special foundations |
| A1030 | Slab on grade |
| A20 | **Basement construction** |
| A2010 | Basement excavation |
| A2020 | Basement walls |
| **B** | **ELEMENT: SHELL (CSI - B, SHELL)** |
| B10 | **Superstructure** |
| B1010 | Floor construction |
| B1020 | Roof construction |
| B20 | Exterior enclosure |
| B2010 | Exterior walls |
| B2030 | Exterior windows |
| B30 | **Roofing** |
| B3010 | Roof coverings |
| B3020 | Roof openings |
| **C** | **ELEMENT: INTERIOR SURFACES (CSI - C, INTERIORS)** |
| C10 | **Interior construction** |
| C1010 | 11 Partitions and partitioned modules |
| C1020 | 12 Interior doors |
| C1030 | 13 Fittings |
| C20 | **Stairs** |
| C2010 | Stair construction |
| C2020 | Stair finishes |
| C30 | **Interior finishes** |
| C3010 | Wall finishes |
| C3020 | Floor finishes |
| C3030 | Ceiling finishes |
| **D** | **ELEMENT: UTILITY SERVICES (CSI - D, SERVICES)** |
| D10 | **Conveying** |
| D1010 | Elevators and lifts |
| D1020 | Escalators and moving walks |
| D1090 | Other conveying systems |
| D20 | Plumbing |
| D2010 | Plumbing fixtures |
| D2020 | Domestic water distribution |
| D2030 | Sanitary waste |
| D2040 | Rain water drainage |
| D2090 | Other plumbing systems |
| D30 | **Heating, ventilation, and air conditioning (HVAC)** |
| D3010 | Energy supply |
| D3020 | Heat generation |
| D3030 | Refrigeration |
| D3040 | HVAC distribution |
| D3050 | Terminal and packaged units |
| D3060 | HVAC Instrumentation and controls |
| D3070 | Testing, adjusting, and balancing |
| D3090 | Other special HVAC system and equipment |
| D40 | **Fire protection** |
| D4010 | Sprinklers |
| D4020 | Standpipes |
| D4030 | Fire protection specialists |
| D4090 | Other fire protection systems |
| D50 | **Electrical** |

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| | |
|---|---|
| D5010 | Electrical service and distribution |
| D5020 | Lighting and branch wiring |
| D5030 | Communications and security |
| D5090 | Other electrical systems |
| D60 | **Basic materials and methods** |
| E | **ELEMENT: EQUIPMENT AND FURNISHINGS (CSI - E, EQUIPMENT AND FURNISHINGS)** |
| **E10** | **Equipment** |
| E1010 | Commercial equipment |
| E1020 | Institutional equipment |
| E1030 | Vehicular equipment |
| E1090 | Other equipment |
| **E20** | **Furnishings** |
| E2010 | Fixed furnishings |
| E2020 | Movable furnishings |
| F | **ELEMENT: SPECIAL CONSTRUCTION AND DEMOLITION (CSI - F, SPECIAL CONSTRUCTION AND DEMOLITION)** |
| **F10** | **Special construction** |
| F1010 | Special structures |
| F1020 | Integrated construction |
| F1030 | Special construction systems |
| F1040 | Special facilities |
| F1050 | Special controls and instrumentation |
| **F20** | **Selective demolition** |
| F2010 | Building elements demolition |
| F2020 | Hazardous components abatement |
| G | **ELEMENT: BUILDING SITEWORK (CSI - G, BUILDING SITEWORK)** |
| G10 | **Site preparation** |
| G1010 | Site clearing |
| G1020 | Site demolition and relocation |
| G1030 | Site earthwork |
| G1040 | Hazardous waste removal |
| G20 | **Site improvements** |
| G2010 | Roadways |
| G2020 | Parking lots/garages |
| G2030 | Pedestrian paving |
| G2040 | Site development |
| G2050 | Landscaping |
| G30 | **Site civil/mechanical utilities** |
| G3010 | Water supply |
| G3020 | Sanitary sewer |
| G3030 | Storm sewer |
| G3040 | Heating distribution |
| G3050 | Cooling distribution |
| G3060 | Fuel distribution |

| | |
|---|---|
| G3090 | Other site mechanical utilities |
| G40 | **Site electrical utilities** |
| G4010 | Electrical distribution |
| G4020 | Site lighting |
| G4030 | Site communications and security |
| G4090 | Other site electrical utilities |
| G90 | **Other site construction** |
| G9010 | Service tunnels |
| G9090 | Other site systems |
| **Z** | **ELEMENT: GENERAL (CSI - Z, GENERAL)** |
| Z10 | **General requirements** |
| Z1010 | Administration |
| Z1020 | Quality requirements |
| Z1030 | Temporary facilities |
| Z104 | Project closeout |
| Z1050 | Permits, insurance, and bonds |
| Z1060 | Fees |
| Z20 | **Contingencies** |
| Z2010 | Design contingency |
| Z2020 | Escalation contingency |
| Z2030 | Construction contingency |

# **Life Support:** Water Service System

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## Abstract

Water is called the "universal solvent" because it is capable of dissolving more substances than any other liquid. This is important to every living thing on earth. Water is a core component of the planet's ecospheric cycle. Hydrology is the study of water in its totality, including is cycles and qualities. Water is an essential requirement of all life. Water is a uniquely accountable physical resource (Read: object). Different needs, and sub-services therein, have different requirements of and for water. Water is a material with many different sub-compositions, some of which are usable for specific functions, and others of which are not. Water serves many functions in a materialized societal system. The the processing and distribution of water can be integrated into a city platform.

## Graphical Abstract

Image Not Yet Associated

# 1 Hydrology and the earth's hydrological/water cycle

**ASSOCIATION:** *This section, "Water Service System" is linked to a related section of The Material System: HabitatSystem Standard entitled "Life Support: Architecture Service System: Architectural Water Service System".*

Hydrology is the scientific study of the movement, distribution, and quality of water on Earth and other planets, including the hydrologic cycle, water resources and environmental watershed sustainability. Hydrology is subdivided into surface water hydrology, groundwater hydrology (hydrogeology), and marine hydrology. Domains of hydrology include hydrometeorology, surface hydrology, hydrogeology, drainage basin management and water quality, where water plays the central role. In terms of environmental measurements, hydrology refers to the physical movement of a body of water, including changes in water level, flow, and other dynamic processes. Hydrological modeling refers to modeling of the hydrologic cycle (i.e., water cycle). The water cycle, also known as the hydrologic cycle or the H2O cycle, describes the continuous movement of water on, above and below the surface of the Earth. The hydrologic cycle is the term used to describe the natural circulation of "raw" water in, on, and above the earth. Water occurs in many forms as it moves through this cycle. The Earth's water cycle is sub-composed of a set of identifiable processes/steps listed in table ...

Water is placed in the air by evaporation from water and land surfaces and by transpiration from plants. It then condenses to produce cloud formations and returns to earth as rain, snow, sleet, or hail. Some of this evaporates, while some flows as runoff into lakes and streams. The remainder goes into the soil and then into underlying rock formations by seepage or infiltration. The water which has seeped through the earth will finally find its way to the surface through springs. It can also flow through porous media until intercepted by streams, lakes, or oceans. The cycle does not always progress through a regular sequence; steps may be omitted or repeated at any point. For example, precipitation in hot climate may be almost wholly evaporated and returned to the atmosphere.

**NOTE:** *With the appropriate technology, water may be collected at any point in the Earth's water/hydrological cycle.*

The mass of water on Earth remains fairly constant over time but the partitioning of the water into the major reservoirs of ice, fresh water, saline water and atmospheric water is variable depending on a wide range of climatic variables. The water moves from one reservoir to another, such as from river to ocean, or from the ocean to the atmosphere, by the physical processes of evaporation, condensation, precipitation, infiltration, runoff, and subsurface flow. In doing so, the water goes through different phases: liquid, solid (ice), and gas (vapor). The water cycle involves the exchange of energy, which leads to temperature changes. For instance, when water evaporates, it takes up energy from its surroundings and cools the environment. When it condenses, it releases energy and warms the environment. These heat exchanges influence climate.

On earth, water moves continuously through the water cycle which comprises:

- Evaporation and transpiration.
- Condensation.
- Precipitation.
- Run-off.

## *1.1 Primary components of the water service system*

The water system is a system of engineered hydrologic and hydraulic components that provide a water supply, modified where necessary, to meet service requirements.

A water supply system involves everything from the collection of source water through to the point of use, as well as all transformation, recycling, and transportation therein.

A water supply system typically includes:

1. An **ecosystem** that re-cycles water and fulfills the H20 needs of organisms living in a habitat. The ecosystem of a water body is known as an 'aquatic ecosystem'.
2. A **drainage basin** (**catchment basin)** is an extant or area of land where surface water from rain, melting snow, or ice converges to a single point at a lower elevation, usually the exist of the basin where water joins another water body, such as a river, lake, reservoir, estuary, wetland, sea, or ocean. Other terms that are used to describe drainage basins are catchment, catchment area, drainage area, river basin and water basin. The drainage basin includes both the streams and rivers that convey the water as well as the land surfaces from which water drains into those channels, and is separated from adjacent basins by a drainage divide. The drainage basin acts like a funnel, collecting all the water within the area covered by the basin and channelling it into a waterway. Each drainage basin is separated topographically from adjacent basins by a geographical barrier such as a ridge, hill or mountain, which is known as a water divide. In nature, drainage basins are dynamic because the water and sediment-producing areas expand and contract depending

upon the catchment characteristics, the antecedent conditions prior to any water even, and the character of the water input. In the technical sense, a **watershed** refers to a divide that separates one drainage area from another drainage area. However, in some areas, the term is often used to mean the drainage basin or catchment area itself.

3. A **raw water collection point** (above or below ground) where the water accumulates, such as a lake, a river, or groundwater from an underground aquifer. Water in this form is considered "raw", as opposed to water which has been treated before consumption, such as "drinking water" or water which has been used in an materialization process, such as "waste water". Raw water may be transferred using uncovered ground-level aqueducts, covered tunnels or underground water pipes.
4. **Water processing and purification** technologies.
5. **Water storage** locations such as reservoirs, water tanks, or water towers. Smaller water systems may store the water in cisterns or pressure vessels. Tall buildings may also need to store water locally in pressure vessels in order for the water to reach the upper floors.
6. Additional **water pressurizing components** [beyond that of gravity due to elevation differentials] such as pumping stations, which may need to be situated at the outlet of underground or above ground reservoirs or cisterns (if gravity flow is impractical).
7. A **pipe network for distribution/transportation** of water to points of storage, transformation, or usage. Water is transferred using water pipes (usually underground).
8. **Input and output connections** the distribution/ transportation network, including drains and faucets.

## 1.2 Raw water sources and catchment

The collection of water from a raw water source is referred to as **raw water collection/catchment**. The **Earth's water cycle** provides sources of water. Those sources of water are:

1. **Ground sources:** include groundwater, springs, hyporheic zones and aquifers. **Ground water** is water that moves in some manner through the "ground" (i.e., water that has "gone underground"). **Spring water** is water that has moved through the ground and reappeared on the surface of the land. If you travelled underground you would eventually get deep enough to find that all the rock around you is soaked with water. You'd have entered the "saturated zone". The height of water in the saturated zone is called the **water table**. In dry places, the water table is very deep, but in moist places, the water table is very shallow. When the water table is higher than the actual surface of the ground, there are streams, rivers, and lakes on the land (i.e., surface water). Ground water is partially "filtered" through the ground, and partially flows through rivers that disappear beneath the earth. Rain that soaks into the ground, rivers that disappear beneath the earth, melting snow are but a few of the sources that recharge the supply of underground water. Because of the many sources of recharge, ground water may contain any or all of the contaminants found in surface water as well as the dissolved minerals it picks up during its long stay underground. Collection technologies: welling technologies and distribution technologies (e.g., applied hydraulics and pumps).
2. **Surface water:** include rivers, streams, glaciers, including some a superficial cavity of some kind, like a dug well. As water travels over the surface of the land, it dissolves naturally occurring minerals and can pick up substances resulting from the presence of animals or from human activity. Surface water is exposed to many different "contaminants", such as foliage, wastes, -icides, algae, and many other organic and inorganic materials. Collection technologies: land restructuring technologies; catchment technologies; evaporation technologies; distribution technologies
3. **Precipitation:** includes rain, hail, snow, fog, etc. Precipitation is any form of liquid or solid water particles that fall from the atmosphere and reach the surface of the Earth. Precipitation comes in many forms, but it all comes from the same general process. Collection technologies: rain water catchment technologies (e.g., rain barrels) and distribution technologies. Any surface with significant displacement is probably a good water catchment platform. Roofs and trees, for example, work for water catchment. Water rains down on the roof and it is channelled into a gutter that feeds into the water system.
4. **Biological sources:** such as plants. Some plants directly produce a drinking "water" liquid. One of the most well known of these plants is the coconut palm tree. However, drinking water can be collected from the transpiration of water. Most plants constantly transpire water vapor. The transpiration process leads to the release of water vapor from plants and soil into the air. The intent of this technique is to collect and condense

plant-respirated water vapor. This is often done by placing a container over the plant and securing the opening. Collection technologies: desalination technology; evaporation technology; distillation technology; osmotic technology.
- **Ocean water (salinated seawater):** - About 97 percent of the Earth's water can be found in the unified form of an ocean. The ocean covers about 71 percent of the Earth and is blue, while land makes up the other 29 percent and varies in colour. The large presence of an ocean gives the Earth the appearance of a blue marble. Collection technologies: desalination technology; evaporation technology; distillation technology; osmotic technology. Ocean breezes contain elements which are highly corrosive to various substances.

5. **Atmospheric sources:** Water is constantly evaporating into the air. Air can carry water, it is called 'humidity'. All breathable air has some degree of water vapor (moisture) present.
   A. **Relative humidity (RH)** is the amount of water vapor in the air. Water vapor is the gaseous state of water and is invisible to the human eye. Humidity indicates the likelihood of precipitation, dew, or fog. While humidity itself is a climate variable, it also interacts strongly with other climate variables. Humidity depends on water vaporization and condensation, which, in turn, mainly depends on temperature. Humidity is affected by winds and by rainfall. The most humid regions of the earth are generally located closer to the equator, near coastal regions. Relative humidity is not a good measure for how humid it feels outside. Humid air is less dense than dry air. Dewpoint is a more accurate measure of how humid it feels.
   B. **Dewpoint** is a measure of atmospheric moisture. The higher the dewpoint, the more moisture in the air. It is the temperature measure to which air must be cooled to reach saturation (assuming air pressure and moisture content are constant). A higher dew point indicates more moisture present in the air. It is sometimes referred to as dew point temperature, and sometimes written as one word (dewpoint). Frost point is the dew point when temperatures are below freezing.

## 1.3 *Functional usages of water*

The parameters for water quality are determined by the intended use. Work in the area of water quality tends to be focused on water that is treated for human consumption, industrial use, or in the environment.

1. Drinking water (a.k.a., potable water/"spring water") - this is water that is safe for humans to drink and to use in nutrition preparation (i.e., food preparation).
2. Ecological cultivation and aquaculture - water for consumption, or a life-media, by other organisms in the ecology.
3. Good and service production (including medicine, cleaning, and other productive uses)
4. Washing & cleaning.
5. Recreating in (i.e., swimming ponds and pools).
6. As a "waste" recycling medium.
7. Hydronic radiant heat to flooring.
8. Power/Energy production - water turbine and electrolysis (water splitting) to produce hydrogen.
9. Power/Energy emergency control - fire suppressant.

**NOTE:** *Electrolysis is the process of passing electricity through water and splitting the water into its component parts.*

### 1.3.1 Hydraulic water distribution, water movement & distribution

Water is moved around a water system through either pumping or gravity-flow through elevation differentials. Therein, elevation can be used to run distribution sub-systems through gravity pressure.

1. Positive pressure generated by gravity through a water tower. Great big tanks of water up on stilts. Pumps run all day to push water up into them, and when you open the faucet water flows downhill through the pipes and out of the tap. A tall tank is necessary to provide pressure, but it doesn't have to be big to provide quantity, as the water may be pumped up just before use.
2. Gravity flow and pump flow. A water service system could use one or the other, but generally they are used together.
3. There are other ways of providing pressure than gravity flow. A pump can provide positive pressure. Or a pump filling an internal airspace at the top of a tank could provide positive pressure. Pumps are located in "pump stations".
4. Reservoirs or when the water source is at a higher elevation create an environment where water flows downhill by gravity, through processing, into the mains distribution, with no pumps required. In some higher elevation geographic locations the water must be pumped up to the higher elevation to maintain enough pressure.
5. If there is too much pressure due to elevation, then sometimes the water processing system downstream has to decrease pressure rather than

increasing it.

6. Pumps and water towers work hand-in-hand. Without water towers, the pumps would have to operate continuously, even during low-demand periods. With water towers, the pumps pump water up into the towers, which then maintain pressure. As water is consumed, the level in the water tower drops until it reaches a certain point, which actuates a level switch to start up the pumps again. You can't have water towers without pumps. You can have pumps without water towers, but would always need to keep the pumps running (which is not generally practical).
7. Today speed drives control the speed of the pumps. As demand goes up the pumps speed up. Depending on the city the system pressure can run from 50 to 120 PSI.
8. Sometime buildings in a water distribution system have water regulators in them to protect the pipes of the building from the city's higher pressure.
9. However, it's pretty easy to provide the same constant, even, reliable pressure if you let gravity do it, or enclose the water in a tank which also contains a compressed gas like air -- a substance which is highly compressible.
10. You pump water into a tank, even in spurts, or compress air into a tank at irregular intervals, and the resulting gravity or air pressure evens out the flow to a workable level (e.g., positive-displacement pump).
11. When you have a centralized network around a series of main pumps, then the pressure will likely taper off as you approached the periphery of the network. Hence, elevated storage tanks and re-pump stations are necessary at strategic locations.
12. A clear well (a.k.a., clearwell) is an output/finished water storage area.

## 1.4 Water storage points

Water can be stored in the following ways:

- Underground reservoirs; lakes; ponds; streams
- Water channels, wells, and pools
- Water containers including barrels, tanks, and other vessels
- Water pipes
- Water bottles

## 1.5 Water distribution access points

Water access points are the locations where water is accessible to systems, to the community, and to individuals.

Common water distribution access points include, but are not limited:

1. Buildings where water is used.
2. Portable stores of water (i.e., bottled water).
3. Swimming points.
4. Places where people move a lot for hydration and recreation (e.g., bodies of water and water fountains).
5. Ecosystem water distribution points (i.e., sprinklers).
6. Fire suppressant system distribution points.

## 1.6 Human-use water outlets (taps & faucets)

Human use water switches are designed to be as precise, simple, and helpful as possible. Faucets have three primary functional designs:

1. No handle design (i.e., touch interface or other).
2. Single handle design allow the user to turn on and off the tap with one hand. Users of single handle designs are less likely to leave the water on than users of a two handle design. Also, with a single handle design the user can set the temperature of the water more easily than with two handles.

## 1.7 Water as a solvent

Water is one of the most important elements humankind needs to survive. It is a universal solvent for living things, which can dissolve many substances, both solid and gaseous, that come into contact with it. We use water everywhere, constantly.

The temperature of water affects how quickly substances dissolve in it and, in some cases, the quantity that can be dissolved: for example, warm water holds less dissolved oxygen than colder water, but it holds more of most solids. Temperature also has a major effect on living things within the water. Compared to air or soil, bodies of water change temperature slowly, so aquatic life is generally not exposed to sudden fluctuations of temperature.

## 2 Water quality

Water quality testing is an important part of environmental monitoring. When water quality is poor, it affects not only aquatic life but the surrounding ecosystem as well. By measuring the characteristics of water bodies we can determine its ability to sustain life and meet our productive and ecological needs.

"Pure" water is essentially non-existent in the natural environment. Natural water, whether in the atmosphere, on the ground surface, or under the ground, always contains dissolved minerals and gases as a result of its interaction with the atmosphere, minerals in rocks, organic matter, and living organisms. Water is dangerously good at dissolving things. Since water is a polar molecule, its positive end is attracted to negatively charged ions or the negative sides of other polar molecules, and its negative side is attracted to positively charged ions or the positive sides of other polar molecules.

Impurities in raw water are either **suspended** or **dissolved**. Suspended impurities include diseases organisms, silt, bacteria, and algae. Some disease organisms must be removed or destroyed before the water is safe to consume. Dissolved impurities include salts, (calcium, magnesium, and sodium), iron, manganese, and gases (oxygen, carbon dioxide, hydrogen sulfide, and nitrogen). These impurities must be reduced to levels acceptable for human consumption.

As water goes through the hydrologic cycle, it gathers many impurities. Dust, smoke, and gases fill the air and can contaminate rain, snow, hail, and sleet. As runoff, water picks up silt, chemicals, and disease organisms. Water is a carrier of many organisms which cause disease. As it enters the earth through infiltration, some of the suspended impurities may be filtered out. However, other minerals and chemicals are dissolved and carried along. As ground water, in underground reservoirs, it may contain disease organisms as well as harmful chemicals. In addition to the impurities in water resulting from infiltration, many are contributed by an industrialized society. Garbage, sewage, industrial waste, pesticides, and nuclear, biological, and chemical (NBC) agents are all possible contaminants of raw water.

> **DESIGN REQUIREMENT:** *Drinking water must be free of anything that would degrade the human restoration and performance cycle. Additionally, it should not damage the materials used in its transportation and storage.*

In community, we scientifically monitor all water sources for quality (i.e., composition and condition). Generally, ground water (subsurface) and spring water has less chemical and biological contaminants than surface water, provided reasonable care is exercised in the selection of the well site or spring. Harmful microorganisms are usually reduced to tolerable levels by passage through the soil; however, the water should still be tested. Water collected from its raw source does not always require purification/modification.

Water quality is a measure of the condition of water relative to the requirements of one or more biotic species and or to any human need or purpose. It is most frequently used by reference to a set of standards. The parameters for water quality are determined by the intended use.

Environmental indicators and parameters for water quality typically fall under six categories:

1. **Physical properties/indicators**
    - Temperature, specific conductance (EC), electrical conductance, conductivity, total dissolved solids (TDS) + hardness, total suspended solids (TSS), turbidity (a.k.a., transparency), odour, colour, taste, volume and depth
- **Chemical composition/indicators**
    - Potential hydrogen (pH), biochemical oxygen demand (BOD), chemical oxygen demand (COD), dissolved oxygen (DO) + oxidation-reduction potential (ORP), total hardness (TH), metals and metalloids, hormone analogues, pharmaceuticals, metabolites, surfactants, and all other chemical compounds organic/in-organic/natural/man-made which may be found in the water
2. **Biological composition/indicators** (i.e., ecological assemblage - the collection of organisms in the aquatic ecology)
    - Algae, phytoplankton, vegetation, fish, reptiles, insects, and all other aquatic life
3. **Microbiological composition/Indicators**
    - Bacteria, protozoa, viruses
4. **Radiological composition/indicators**
    - Radon, nuclear waste, nuclear medicines, and all other radioactive elements
5. **Quantum electrodynamic coherency**
    - Structure + temperature of water molecules
6. **Movement of water**
    - The properties of water vary naturally depending on the surrounding environment; hence, data collected about water quality must be interpreted in the context of the water body's particular environment and position in the catchment.
    - **Flow** is the volume of fluid (in this case, water) that passes through a passage of any given section in a unit of time. Flow, for the purposes of measurement, is the **velocity** of water multiplied by the cross-sectional area of the stream. Flow is modified by conditions along and around a waterway. The amount of any particular substance carried in the water is known as the **load**.

**Biological assessment (bioassessment)** is an evaluation of the condition of a water body based on the organisms living within it. It reveals cumulative effects, as opposed to chemical observation, which is representative only at the actual time of sampling. Biological systems reflect overall ecological integrity and integrate the effects of different stressors. Thus, their observation provides a broad measure of aggregate impact and fluctuating environmental conditions. The primary reason for bioassessment and monitoring is that degradation of water body habitats affects the biota using those habitats; therefore, the living organisms themselves provide the most direct means of assessing real environmental impacts.

## 2.1 Water standards

There are a variety of national and international standards related to water quality (Safe Plumbing, 2021):

1. **NSF/ANSI Standard 60** - A standard related to chemicals used to treat drinking water. Developed by NSF and conforming to the ANSI voluntary standard, the standard was accepted by the NSF board in 1988 to evaluate products, such as softeners and oxidizers, to assure that usage amounts safeguard the public health and safety.
2. **NSF/ANSI Standard 61** - A standard related to products that come in contact with drinking water. Developed by NSF and conforming to the ANSI voluntary standard, the standard was accepted by the NSF board in 1988 to confirm that such products will not contribute excessive levels of contaminants into drinking water. Most U.S. states and many Canadian provinces require products used in municipal water distribution systems and building plumbing systems to comply with Standard 61.
3. **USA, California, Proposition 65** - Also known colloquially as Prop 65, California's Safe Drinking Water and Toxic Enforcement Act of 1986 requires companies to post notice of chemicals in products that can be released into the environment and have been determined by the state to be a cause of cancer. In early 2008, the list included 775 chemicals. Prop 65 impacts residents in other states when they receive such notices in purchased products, such as bathroom faucets. Companies will often post the notification on all products, rather than incur extra costs to isolate products sold only in California.
4. **USA, Safe Drinking Water Act (SDWA)** - The Safe Drinking Water Act (SDWA) is a federal law originally passed by Congress in 1974 to protect public health by regulating the nation's public drinking water supply. Amendments were passed in 1986 and in 1996. The SDWA requires many actions to protect drinking water and its sources: rivers, lakes, reservoirs, springs, and ground water wells. SDWA authorizes the United States Environmental Protection Agency to set national health-based standards for drinking water to protect against both naturally occurring and man-made contaminants. Enforcement is accomplished through the National Primary Drinking Water Regulations.

## 2.2 Definition of indicators

**Physical indicators** include:

1. **Temperature** - the degree or intensity of heat present in a substance or object, especially as expressed according to a comparative scale and shown by a thermometer or perceived by touch. Temperature is a physical property of water that quantitatively expresses hot and cold. The temperature of a water body directly affects many physical, biological and chemical characteristics. Temperature is measured in Celsius.
   - Water changes phase at specific temperatures (accounting for pressure).
   - The temperature of a body of water influences its overall quality and ecology. Warm waters are more susceptible to eutrophication — a build-up of nutrients and possible algal blooms — because photosynthesis and bacterial decomposition both work faster at higher temperatures. Oxygen is less soluble in warmer water and this can affect aquatic life. By contrast, salts are more soluble in warmer water, so temperature can affect the water's salinity. Temperature directly affects the metabolic rate of plants and animals. Aquatic species have evolved to live in water of specific temperatures. If the water becomes colder or warmer, the organisms do not function as effectively, and become more susceptible to toxic wastes, parasites and diseases. With extreme temperature change, many organisms will die. Changes in long-term temperature average may cause differences in the species that are present in the ecosystem.
   - If the water temperature changes by even a few degrees, it could indicate a source of unnatural warming of the water or thermal pollution.
   - Factors that affect water temperature: air temperature; air movement; amount of shade and sunlight; soil erosion increasing turbidity; thermal pollution; water depth and volume; confluence of water movement.
   - Effects of water temperature: suspended and

dissolved solids are changed; solubility of dissolved gas; rate of plant growth; metabolic rate of organisms; resistance of organisms.

2. **Electrical conductivity (EC)** is the property of a substance which enables it to serve as a channel for medium for electricity. It is a measure of water's capability to pass electrical flow. This ability is directly related to the concentration of ions in the water. These conductive ions come from dissolved salts and inorganic materials such as alkalis, chlorides, sulfides and sulphates, and carbonate compounds. Compounds that dissolve into ions are also known as electrolytes. The more ions that are present, the higher the conductivity of water. Likewise, the fewer ions that are in the water, the less conductive it is. Distilled or deionized water can act as an insulator due to its very low (if not negligible) conductivity value. Sea water, on the other hand, has a very high conductivity. Conductivity, in particular specific conductance, is one of the most useful and commonly measured water quality parameters. In addition to being the basis of most salinity and total dissolved solids calculations, conductivity is an early indicator of change in a water system. Salty water conducts electricity more readily than purer water. There are a number of scales used in EC, most commonly micro-Siemens (μS) or milli-Siemens (mS). For example, if a particular application calls for water with "2.0 EC," this is an incorrect determination. Most likely, the application is calling for an EC level of 2.0 mS. 2.0 mS = 2000 μS.
3. **Total Dissolved Solids (TDS)** is a measure of the combined/total amount of mobile charged ions, including minerals, salts or metals dissolved in a given volume of water, expressed in units of mg per unit volume of water (mg/L), also referred to as parts per million (ppm). TDS is a measure of the combined content of all inorganic and organic substances. The TDS of water is composed of mineral salts and small amounts of other inorganic and organic substances contained in a liquid in molecular, ionized or micro-granular (colloidal sol) suspended form. A TDS measure combines the sum of all ion particles that are smaller than 2 microns (0.0002 cm). Generally the operational definition is that the solids must be small enough to survive filtration through a filter with two-micrometer (nominal size, or smaller) pores. There are three primary classifications of water, based on the concentration of total dissolved solids:
   - **Fresh** - TDS less than 1,000 - 1,500 ppm (milligrams-per-liter of dissolved solids).
   - **Brackish** - TDS between 1,500 ppm and 16,00 ppm; Brackish water (less commonly brack water) is salt water and fresh water mixed together.
   - **Salt water** (seawater) - TDS greater than 15,000 ppm.
4. **Hardness** in water is caused by calcium ($Ca^{2+}$) and magnesium ($Mg^{2+}$) - two nontoxic, naturally occurring minerals in water. Water hardness is typically reported in grains per gallon, milligrams per liter (mg/l) or parts per million (ppm). One grain of hardness equals approximately 17.1 ppm (mg/L) in TDS. Excessive hardness makes it difficult for soap to lather, leaves spots on dishware, reduces water flow, and can cause pipe, valve, and drain "scaling".
   - **Soft water** - water with a low mineral content. Water softening is the removal of calcium, magnesium, and certain other metal cations in hard water. The resulting soft water is more compatible with soap and extends the lifetime of plumbing. However, soft water is more acidic and may leach minerals like cadmium from metal pipes.
   - **Hard water** - water with a high mineral content. Note that mineral waters (with appropriate quantities and types of minerals) are often better for drinking that soft water.
5. **Turbidity** is the measure of relative clarity of a liquid. It refers to the opacity or muddiness caused by particles of extraneous matter. Turbidity is measured in nephelometric turbidity units (NTU). The instrument used for measuring it is called nephelometer or turbidimeter, which measures the intensity of light scattered at 90 degrees as a beam of light passes through a water sample. In general, the more material that is suspended in water, the greater is the water's turbidity and the lower its clarity. Turbidity affects how far light can penetrate into the water. It is not related to water colour: tannin-rich waters that flow through peaty areas are highly coloured but are usually clear, with very low turbidity. Measures of turbidity are not measures of the concentration, type or size of particles present, though turbidity is often used as an indicator of the total amount of material suspended in the water (called total suspended solids). Turbidity can indicate the presence of sediment that has run off from construction, agricultural practices, logging or industrial discharges.
   - Suspended particles absorb heat, so water temperature rises faster in turbid water than it does in clear water. Then, since warm water holds less dissolved oxygen than cold water, the concentration of dissolved oxygen decreases.

- If penetration of light into the water is restricted, photosynthesis of green plants in the water is also restricted. This means less food and oxygen is available for aquatic animals. Plants that can either photosynthesise in low light or control their position in the water, such as blue-green algae, have an advantage in highly turbid waters.
- Regular turbidity monitoring may detect changes to erosion patterns in the catchment over time. Event monitoring (before, during and immediately after rain) above and below suspected sources of sediment can indicate the extent of particular runoff problems.

**Chemical indicators** include:

1. **pH (potential hydrogen) -** The measured indicator for acidity or alkalinity is known as the pH value. A pH value of 7 means a substance is neutral, water with a pH lower than 7 is considered acidic and with a pH greater than 7 water is considered alkaline. The normal range for pH in surface water systems is 6.5 to 8.5. Potential hydrogen is measured with a pH meter.
2. **Dissolved oxygen (DO)** refers to the level of free, non-compound oxygen present in water or other liquids. It is an important parameter in assessing water quality because of its influence on the organisms living within a body of water. In limnology (the study of lakes), dissolved oxygen is an essential factor second only to water itself. A dissolved oxygen level that is too high or too low can harm aquatic life and affect water quality. Dissolved oxygen is a measure of the quantity of oxygen present in water (it has nothing to do with the oxygen atoms within the water molecules).
   - Oxygen is essential for almost all forms of life. Aquatic animals, plants and most bacteria need it for respiration (getting energy from food), as well as for some chemical reactions. The concentration of dissolved oxygen is an important indicator of the health of the aquatic ecosystem. Persistently low dissolved oxygen will harm most aquatic life because there will not be enough for them to use.
   - In some circumstances, water can contain too much oxygen and is said to be supersaturated with oxygen. This can be dangerous for fish. Supersaturated conditions occur in highly turbulent waters in turbines and at spillways, because of aeration, and also on sunny days in waters experiencing algal blooms or with many aquatic plants, because of photosynthesis. In this supersaturated environment, the oxygen concentration in fishes' blood rises. When the fish swim out into water that has less dissolved oxygen, bubbles of oxygen quickly form in their blood, harming the circulation.
   - The air is one source of dissolved oxygen, and aquatic plants, including algae, are another. The speed at which oxygen from the air enters and mixes through a water body depends on the amount of agitation at the water surface, the depth of the water body and the rate at which it mixes itself. As water temperature rises, oxygen diffuses out of the water into the atmosphere.
   - Dissolved oxygen concentrations change with the seasons, as well as daily, as the temperature of the water changes. At very high altitudes, the low atmospheric pressure means dissolved oxygen concentrations are lower
   - Deep muddy lowland rivers, which contain more organic matter than upland streams, are likely to have lower dissolved oxygen concentrations than upland streams because bacteria are using the oxygen to break down the organic matter. Likewise, dissolved oxygen is usually lower than normal after storms have washed organic materials into any water body. Aquatic plants photosynthesise during daylight and increase dissolved oxygen concentrations around them.
3. **Oxidation-reduction potential (ORP)** is a measurement of water's ability to oxidize contaminants. The higher the ORP, the greater the number of oxidizing agents. Checking ORP is a simple method to monitor the effectiveness of a sanitizer or the quantity of anti-oxidants in a liquid. The ORP level of water can also be viewed as the level of bacterial activity of the water because a direct link occurs between ORP level and the count of certain bacterial species in water. ORP sensors work by measuring the dissolved oxygen. An ORP meter measures very small voltages generated with a probe placed in water. The electrode is made of platinum or gold, which reversibly looses its electrons to the oxidizer. A voltage is generated which is compared to a silver (reference) electrode in a silver salt solution, similar to a pH probe. The more oxidizer available, the greater the voltage difference between the solutions. ORP cannot be used as a direct indicator of dissolved ozone residual, except in very clean water applications. If there is ozone in the water, then ORP is a convenient measure of ozone's ability to perform a chemical task.

## 2.3 Water quality standards

Drinking water standard:

- Drinking-water should be supplied under continuous positive pressure in a plumbing system free of any defects that could lead to contamination of any product.
- Drinking-water is unmodified.
- Water that has elements or compounds with additive pharmacological effects (e.g., sodium fluoride/fluoridation) is not pure drinking water.

Radiological standards for water include:

- Radiological water quality standards are based on the fact that radiation has an adverse physical effect on human physiology. Any treated water that contains nuclear contamination should be avoided. When ingested, radioactive isotopes interfere with the reproduction of human cells. They can cause nausea, vomiting, and hair loss and weaken the body's defenses to infections.

# 3 Water processing

> **NOTE:** *Nature makes water "pure" by heating it up, causing evaporation, then eventually condensing into clouds, and finally, falling back to the earth as rain (or snow). However, when water passes through the atmosphere it will pickup pollutants present therein.*

The objective of water processing is to produce water that meets the specified requirements of a specific purpose. Water may be processed so that it is fit for human consumption (as "drinking water"). Water processing may also be designed for a variety of other purposes, including fulfilling the requirements of medical, chemical, and other applications. The most well-known water process is that of water filtration. However, water processing may also include the restructuring of water and the addition of elements to the water, as well as modification of the water's properties, including pH and temperature.

In industry, the processes that make water more acceptable for an end-use, which may be drinking, industry, or medicine are called "water treatment". The term "water treatment" generally refers to potable water production from raw water, whereas "wastewater treatment" refers to the treatment of polluted water, where the pollution could be from human waste, industry, agricultural waste or other sources of pollution.

Many people assume that the water flushed down their drains is of little consequence to the environment, with any contaminants of concern being removed by wastewater treatment plants. In reality, however, most wastewater treatment plants are not equipped to remove various medications and other chemicals that may end up being flushed or poured down your drain. They end up being continuously recycled through a populations water supply and accumulate over time.

There are many different "grades" of water. The common classifications for water are:

1. **Drinking water (drinking-water)** is water that is suitable for drinking. Drinking water is both potable and palatable. Drinking water is the minimum quality of water that should be used for the preparation of productive substances. Once produced, drinking water has to be protected from microorganisms and contaminants that can enter the water through the pipelines that transport it to households. This happens by means of disinfection with various disinfection agents.
   A. **Potable water** (meaning drinkable or fit to drink) is water that is free from disease-producing organisms, poisonous and toxic substances, chemical or biological agents, and radioactive elements, which make it unfit for human consumption or other uses. This is water

that is satisfactory for drinking, culinary and domestic purposes.

B. **Palatable water** is water that is pleasing in appearance and taste. It is significantly free from colour, turbidity, taste, and odor. It should also be cool and aerated. Water may be palatable and at the same time not be potable. However, visual inspection cannot determine if water is of appropriate quality to drink.

2. **Filtered water** is water that has been processed at a basic level to remove chemicals, biologicals, suspended solids, and gases.
3. **Purified water** is water that has been processed to meet the requirements for ionic and organic chemical purity, and is protected from microbial contamination. In other words, purified water is generally free of dissolved minerals. While not all filtered water is purified water, all purified water has been filtered. The minimum quality of source or "feed water" for the production of purified water is drinking water. "Purified" water, being essentially free of minerals, is an active absorber (i.e., it is "aggressive"), in that it tends to dissolve substances with which it is in contact. Notably, when it comes into contact with air, carbon dioxide from the air is rapidly absorbed, making the water acidic and even more "aggressive". Many metals are dissolved by purified water.
4. **Black water (blackwater)** is water that contains animal, human, or food waste. Black water is also referred to as sewage, wastewater and sewer water. Blackwater generally travels from where it is produced as sewage to either an on-site septic system or a water processing system prior to its release into an ecosystem. In general, blackwater can be sent to a biodigester, then go through two filters, then go through a patch of plant filters (e.g., banana plants), before returning back to the clean water table.
5. **Grey water (greywater)** is used water from bathroom sinks, showers, tubs, and washing machines. It is not water that has come into contact with faeces, either from the toilet or from washing diapers. Grey water may contain traces of dirt, food, grease, hair, and biodegradable cleaning products. If grey water does not include pharmaceuticals, corrosive chemicals, or industrial soaps, then it can be used to irrigate a garden.
6. **Waste water (wastewater)** is any water that has been adversely affected in quality by anthropogenic influence.
7. **Recycled/reclaimed water** is water that has been processed and captured for reuse.
8. **Green water (natural, hydrological cycle water)** is water already in the natural hydrological cycle. Green water is water in the environment, as rain, water in ponds, in grass. Essentially water rained onto the ground, as well as the moisture in the ground. For instance, it rains, grass grow, cows eat grass, cows urinate, it rains, and moisture in soil refill aquifers. Water in the natural ecological cycle. Green water cannot be counted as a loss, because it remains in the ecological cycle. Of note, cattle livestock on pasture land use mostly green water (i.e., they use mostly water already in the local environment). Properly grazed grazing animals will increase the carbon in the soil as well as the soil capacity for holding water. They can facilitate the greenwater cycyle in producing more abundant soil.
9. **Blue water** is water in lakes, rivers, oceans, and aquifers. To see blue water, look down on a map and see a blue color. Blue and green water are synonmous in some cases.

Water types can also be classified in the following way:

1. **White water (clean water, drinking water)** - Clean white water is safe to drink.
2. **Waste water** - Once you use your white water, it is considered wastewater and is not fit for human consumption or washing or bathing because it contains bacteria, pathogens and chemicals, like soaps and detergents. There are two types of wastewater, including blackwater and greywater.

A. **Blackwater (black water)** - Blackwater in a sanitation context denotes wastewater from toilets, which likely contains pathogens. Blackwater can contain feces, urine, water and toilet paper from flush toilets. Blackwater has come in contact with organic matter, like food particles, and human and/or pet waste. This water is considered dangerous because it can contain harmful pathogens, like bacteria and viruses. Heavily contaminated water can also come from natural floods where heavy rain causes rivers and streams to overflow. During this scenario, river water can mix with sewer water, creating blackwater. This water can cause illnesses.

B. **Greywater (grey water)** - Greywater is the classification for water that has been used for washing. This water can contain soap and other dirt and debris, and it occurs after you do a load of dishes, wash your clothes, mop your floors or wash your hands and body. This water has not come in contact with organic matter or human or pet excrement. While this water shouldn't be used for cooking or drinking, some people choose to recycle it to water their lawns and flower beds. However, it is important to understand that greywater can turn into blackwater in as little as 48 hours. Blackwater is distinguished from greywater, which comes from sinks, baths, washing machines, and other kitchen appliances apart from toilets. Greywater results from washing food, clothing, dishes, as well as from showering or bathing. Gray water, on the other hand, has not come into contact with solid human waste. This greatly decreases the risk of disease and increases the speed at which it can be broken down and safely reabsorbed into an active garden or lawn. The line between white and gray, however, comes down to a number of possible additions made in the acts of washing, bathing, cooking and cleaning. Unlike white water, gray water may contain soap particles, fat and oil from cooking, hair, and even flakes of human skin. The exact contents of gray water depend heavily on the household producing it, so if you want to start reusing your gray water, you have to start regulating exactly what you send down the drain. If the household chemicals in gray water are kept to a minimum, most plants will be able to handle it. You can keep chemical contamination to a minimum by using environmentally friendly, biodegradable soaps and detergents whenever possible. In commercial and residential buildings that are seeking to be more environmentally friendly, the greywater is funneled through a separate drainage system so that it can be reused. It this automated systems, the slightly contaminated wastewater can be stored in a tank and sent back to be used in toilets and for irrigation systems in order to reduce overall water usage.

1. Note: In some jurisdictions, using water from toilets, kitchen sinks, dishwashers, photo lab sinks and garage floor drains is illegal.

C. **Rainwater** - Rainwater is obviously rain that has fallen out of the sky. In a conventional building, this water is discharged to a surface water sewer, combined sewer, or a soakaway; if it is stored for use back in the building it is still rainwater, until it is used. Once it is used it becomes either foul water (if used to flush WCs or urinals) or waste water if used for washing clothes. If wastewater from a bath, basin or shower is collected for re-use it becomes greywater. If greywater is used to flush WCs it becomes foul water. If it is used in washing machines it becomes waste water (but would not circulate through the greywater recycling system again as waste water from washing machines has too many detergents in it to be considered as suitable for greywater recycling).

D. Brackish water - water occurring in a natural environment that has more salinity than freshwater, but not as much as seawater.

3. **Sewage treatment water**
   A. Direct re-use - The planned and deliberate use of treated sewage. The sewage effluent is cleaned to potable water standard and injected directly into the mains supplying a town or city. However, most direct re-use systems clean the sewage effluent so that it is considered fit for purpose for irrigation, WC flushing and urinal flushing, and supply a secondary network of distribution pipework for this water as well as a mains supply network.
   B. Indirect re-use - Water that is taken from a river, lake or aquifer that has received sewage or sewage effluent. With planned indirect water re-use the sewage effluent is discharged immediately upstream of the water treatment plant or used to recharge aquifers. Indirect re-use of sewage effluent is beginning to be used far more around the world as water demand increases and the water suppliers need a guaranteed supply.

Water system processing service points include:

1. Source-point
2. Continuous storage
3. End-point
4. Mobile/portable

## *3.1 Water usage cycling*

The flow and usage of water can be controlled, and in some cases, reused and/or recycled. The habitat service water cycle (a.k.a., municipal water cycle, urban water cycle) involves the controlled usage, processing, and re-use of water in order to conserve it as a resource.

### 3.1.1 Greywater recycling

An efficient way to maximize greywater disposal is through the use of a greywater recycling system. A greywater system filters the water using a highly effective multi-stage filtration system to remove lint, hair and impurities. Instead of traveling through your septic system, the filtered greywater is diverted to flower beds and gardens, creating an efficient irrigation system. These systems generally consist of a unit that is installed outside your home and is connected to your household appliances as well as your home's irrigation system. Each time you shower or use your appliances, the unit collects and filters the water, removing impurities without the use of chemicals. The filtered water is then delivered via your irrigation system to wherever you need it, including flowerbeds, gardens and landscaping areas. Instead of inefficient greywater disposal, you benefit from recycling what would otherwise be nothing more than wastewater.

#### *3.1.1.1 Greywater disposal and recycling considerations*

If the soil is overly permeable or not permeable enough, or there is not enough area to effectively process the greywater, recycling may not be practical. If the system is in a cold climate, recycling for irrigation may only be possible during the warmer months. Some jurisdictions have certain restrictions against the use of greywater systems.

## *3.1 Water Purification processes*

Typical water purification processes require:

1. **Aeration** is the process of increasing the oxygen saturation of the water. Dissolved oxygen (DO) is a major contributor to water quality and a factor in the pH of water. Not only do fish and other aquatic animals need it, but oxygen breathing aerobic bacteria decompose organic matter. When oxygen concentrations become low, anoxic conditions may develop which can decrease the ability of the water body to support life. Water aeration is often required in water bodies that suffer from anoxic conditions, usually caused by adjacent human activities such as sewage discharges, agricultural run-off, or over-baiting a fishing lake. Aeration is one method of for reducing algae growth in a water body. Any procedure by which oxygen is added to water can be considered a type of water aeration. This being the only criterion, there are a variety of ways to aerate water. These fall into two broad areas – surface aeration and subsurface aeration. There are a number of techniques and technologies available for both approaches. Natural aeration is a type of both sub-surface and surface aeration. It can occur through sub-surface aquatic plants. Through the natural process of photosynthesis, water plants release oxygen into the water providing it with the oxygen necessary for fish to live and aerobic bacteria to break down excess nutrients. Oxygen can be driven into the water when the wind disturbs the surface of the water body and natural aeration can occur through a movement of water caused by an incoming stream, waterfall, or even a strong flood. In large water bodies, autumn turn-over can introduce oxygen rich water into the oxygen poor hypolimnion.
    - A solar aeration unit (i.e., solar aerator) is a pump powered by solar energy that aerates a water body. Fountains are a form of aeration.
2. **pH adjustment** is typically done with chemicals, such as caustic soda, lime, soda ash, or sodium bicarbonate. One natural way to raise the pH of the ground water is through aeration. Aeration will strip off dissolved carbon dioxide and raise the pH of the water. If there is radon present in the water, it will also be stripped.
3. **Ion exchange (IE or ix)** is a chemical water processing method involving reversible chemical reactions for removing dissolved ions from solution and replacing them with other similarly charged ions. In other words, undesirable contaminants are removed from water by exchange with another non-objectionable, or less objectionable substance. Both the contaminant and the exchanged substance must be dissolved and have the same type (+,-) of electrical charge. **Deionized water** (DI water, DIW or de-ionized water), often confused with demineralized water / DM water, is water that has had almost all of its mineral ions removed, such as cations like sodium, calcium, iron, and copper, and anions such as chloride and sulfate. Because most non-particulate water impurities are dissolved salts, **deionization** produces a high purity water that is generally similar to distilled water, and this process is quick and without scale buildup. However, deionization does not significantly remove uncharged organic molecules, viruses or bacteria, except by incidental trapping in the resin. Deionization can be done continuously and inexpensively using **electrodeionization**. Three types of deionization exist: co-current, counter-current, and mixed bed. **Water softening** is the removal of calcium, magnesium, and certain other metal cations in hard water. The resulting soft water is more compatible with soap and extends the lifetime of plumbing. Water softening is usually achieved using lime softening or ion-exchange resins. As water flow through the water softener, it will pass through a resin, bed of small plastic beads or chemical matrix (called Zeolite) that will exchange the calcium and magnesium ions with sodium ions (salt). Therefore, the TDS level will remain virtually constant (there may be minor differences).
4. **Dilution** is a natural process that occurs in nature when "pollution" occurs. Nature provides its flowing waters with the ability to restore themselves through their own self-purification processes. It was only when humans gathered in great numbers to form cities and created novel chemicals that the stream systems were not always able to recover

from having received great quantities of waste. Note, the self-purification discussed here relates to the purification of organic matter only.

### 3.1.1 Emergency water purification

Each individual should select the clearest, cleanest water with the least odor and then process the water using individual water purification procedures from their knowledge skill-set. Productive technologies for emergency water purification include: bottled water; iodine tablets, chlorine ampules, boiling, earth-based filtration, hand operated water purifiers; spring water; and passive water generation techniques.

## *3.2 Water processing technologies*

Disinfection and sterilization are both decontamination processes:

1. To **disinfect** means to eliminate most harmful microorganisms (not including their spores) from surfaces or objects, and to inactivate viruses.
2. To **sterilize** means to kill all organism, whether harmful or not, and their spores present. In other words, sterilization is distinct from disinfection, sanitization, and pasteurization in that sterilization kills, deactivates, or eliminates all forms of life and other biological agents.

### 3.2.1 Physical water processes

> **Clarification:** *A physical process is defined as a passive process that requires no energy. Alternatively, a physiologic process is defined as a living process, and it requires energy. For example, when writing with a pen, penetration of the ink into the surface/substance is a physical process, and the process of oxidation is a chemical reaction of the ink with the oxygen. Consider the settling and filtration of water for purposes of solids separation.*

Physical water processes include:

1. **Distillation -** Distillation is a process of separating the component substances from a liquid mixture by selective **evaporation** and **condensation**. It is a change of state, or a way of separating mixtures. It is the process in which water is evaporated (by an evaporator) and the vapor condensed (by a condenser). It is important to understand that evaporation is not the same as condensation although evaporation in an enclosed environment can subsequently lead to the condition of condensation as evaporated moisture is "condensed" out of the air and is reverted to a liquid stage. Distillation may result in essentially complete separation (nearly pure components), or it may be a partial separation that increases the concentration of selected components of the mixture. In either case the process exploits differences in the volatility of a mixture's components. Distillation is a physical separation process and not a chemical reaction. The process of distillation essentially purifies water by heating it until only the water molecules evaporate and condense in another part of the filter, leaving impurities behind in the original water source. Water and dissolved salts can be separated by distillation. Scientists consider distilled water an unnaturally pure form of drinking water and as a result, substances are routinely added to remineralize it. Minerals are considered a nutritionally necessary (i.e., "healthy") part of drinking water. Distilled water has an exceptionally low TDS, and it is often remineralized before being used as drinking water. Vapor compression distillation (technology: Slingshot water purifier). Solar distillation
2. **Alcoholic Distillation** produces a usable/drinkable concentrate of ethyl alcohol through distillation of a mixture produced from alcoholic fermentation. Distillation comes after the brewing/fermenting of a material (mixed with water) into an alcoholic solution. The product of alcoholic distillation is a water alcohol solution with disinfection, and other, properties. The distillation process purifies the solution, and removes diluting components like water, for the purpose of increasing its proportion of alcohol content (commonly expressed as alcohol by volume, ABV).
   A. **Ethyl alcohol (ethanol)**, the alcohol in alcoholic beverages, is a bacterial metabolite produced by the fermentation of sugar molecules found in various natural substances. It is a by-product of bacterial metabolism and is toxic to bacteria, as well as other organismal programs. Hence, alcohol disinfects, but also makes the result of distillation a poor hydration source. The higher the percentage of alcohol, the greater disinfection effect. Ethanol is also known as pure alcohol, grain alcohol and drinking alcohol. Ethyl alcohol is used in some cosmetics to enhance the absorption of other ingredients, which means that anything mixed with it is likely to move through the skin and into the bloodstream more easily. Ethanol is an "alcohol solvent". Alcohol is highly flammable. Ethyl alcohol has significant and noticeable consciousness altering properties when consumed.
   B. Any alcohol when consumed in enough of a

quantity can be toxic (i.e., a toxicant); however, ethanol is a “natural” by-product of bacterial fermentation and is something our body is evolved to understand. Hence, ethanol is not is not in the same toxicant category as “unnatural toxic alcohols”. “**Toxic alcohols**” are molecules which are not understood and responded to well by our human metabolism -- they cause our human physiology to systemically malfunction in various ways. They have similar harmful effects on most other organisms. This difference in relationship between categories relates to the way humans and other organisms respond when exposed to the substance [in the context of an emergently evolving biology]. To be more clear, medical practitioners refer to these alcohols as “toxic alcohols” due to their effect on human biophysiology. “Toxic alcohols” include, but are not limited to: methanol; ethylene glycol; propylene glycol; and isopropanol (isopropyl alcohol) -- these are all “alcohol solvents” like ethanol, and hence, skin contact will lead to some absorption. In the market-State, “toxic alcohols” are more readily available than ethanol, and are usually cheaper.

C. **Denatured alcohol (SD, methylated spirits)** is ethanol that has additives to make it poisonous, extremely bad tasting, foul smelling or nauseating, to discourage recreational consumption. In some cases it is also dyed. The ethanol is made undrinkable. This alcohol is bad for your skin since it is drying and irritating, even though it has antibacterial, antiseptic, and astringent properties. In the market, denatured alcohol is used as a solvent and as fuel for alcohol burners and camping stoves. Because of the diversity of industrial uses for denatured alcohol, hundreds of additives and denaturing methods have been used. The main additive has traditionally been 10% methanol, giving rise to the term “methylated spirits”. Other typical additives include isopropyl alcohol, acetone, methyl ethyl ketone, methyl isobutyl ketone, and denatonium. Methanol, also called methyl alcohol, is found in windshield wiper fluid, de-icing products, paint removers, photocopying fluid, shellacs, and embalming fluid. In humans, methanol is metabolized first to formaldehyde and then to formic acid or formate salts, which is poisonous to the central nervous system, and in sufficient concentration may cause blindness, coma, and death.

D. **Isopropyl alcohol (a.k.a., rubbing alcohol, isopropanol, Iso, IPA)** is used similarly to ethanol, except it is more toxic than ethanol, but less drying to skin. It is a petrochemical product, and numerous tests have shown it to be a strong neurotoxin (significantly stronger than ethyl alcohol). Isopropyl, like ethanol, is absorbed through the skin -- skin contact with isopropyl alcohol should be avoided. Isopropyl alcohol is a popular alternative to ethyl alcohol in commerce because it cannot be safely consumed by humans. Isopropyl alcohol cannot be used to purify water for human consumption. Isopropyl alcohol is a strong solvent and dissolves a wide range of non-polar compounds. It has the similar disinfectant properties to ethanol. It evaporates into the air quickly, and is relatively non-toxic in comparison to other petrochemical and synthesized solvents. After evaporation, isopropyl alcohol exists in the atmosphere in the gas phase. The dominant atmospheric loss process for isopropyl alcohol in the troposphere is by reaction with the hydroxyl radical. Based on this reaction, the atmospheric half-life and lifetime of isopropyl alcohol is estimated to be 1.9 days and 2.7 days, respectively (Atkinson, 1994). The major reaction product from this reaction is acetone (Atkinson, 1995). Disinfecting solutions generally consist of 60–70% solution of isopropyl alcohol in water. Water is required to open up membrane pores of bacteria, which acts as a gateway inside for isopropyl.

3. **Atmospheric water generation (AWG)** is a process that extracts water from surrounding, ambient air (i.e., from the water vapor in the air), and often, filters it to remove particulates and bacteria. The resulting water is clean and free of chemicals and other hazards. There is vapor/humidity in the air due to the evaporation of water from land. All air on Earth contains at least a little water. Hence, water generators, also known as “water makers”, harvest the moisture suspended in humid air. They use one of three basic methods: water vapor in the air is condensed by cooling the air below its dew point (i.e., **condensation**); exposing the air to desiccants (i.e., **desiccation**); or pressurizing the air (i.e., **pressurization**). The most common method uses technology similar to the refrigerant-based air conditioner to condense the air into a liquid flow, filter it, and then store it in a carafe or other holding tank. The technical approach uses a water extraction method that relies on chemistry. It uses a cocktail of chemical salts to pull water out of the air. Salt is a natural desiccant, which means that it draws and holds moisture. In desiccant based

water generators, humid air passes over a salt mixture. The wet salt is then heated to the boiling point. The steam is condensed and routed to filters for processing. To save on energy, a vacuum is employed to lower the boiling point of water. One big advantage to desiccant-based atmospheric water generation is that it's more energy efficient than the other practical options currently available. Typically, the reclaimed water is filtered a number of times to take out airborne particles and bacteria as part of the process. If the water sits in the reservoir for longer than a day or so, it's filtered again to keep it purified. Unlike a dehumidifier, an AWG is designed to render the water potable. If the atmosphere is contaminated, then the water produced purely from the AWG technology will be partially contaminated also. Atmospheric water generators don't work everywhere. To work effectively, a few conditions must be met: The temperature of the ambient air has to be at least a few degrees above freezing. The humidity should be above a certain concentration, too. The figure varies depending on the manufacturer and method of extraction, but 32 to 40 percent humidity is in the ball park. High altitude can also interfere with the process. Also, because an AWG condenses water from the air it acts as a dehumidifier, and it can be combined with air-conditioning technology.

4. **Passive water generation (air well or dew harvester)** have been used for millennia. An air well or aerial well is a structure or device that collects water by promoting the **condensation** of moisture from air (Read: it uses condensation to collect moisture). Designs for air wells are many and varied, but the simplest designs are completely passive, require no external energy source and have few, if any, moving parts. Three principal designs are used for air wells, designated as high mass, radiative, and active. It appears that air wells designed to promote condensation were used by the ancient Greeks to provide water to large populations.
5. **Sedimentation** is the tendency for particles in suspension to settle out of the fluid in which they are entrained and come to rest against a barrier. This is due to their motion through the fluid in response to the forces acting on them: these forces can be due to gravity (a physical process), centrifugal acceleration (a physical process), or electromagnetism (an electromagnetic process). Controlled sedimentation (in a sedimentation basin) is when water is left undisturbed to allow heavy particles to sink out, and greases and oils to rise to the surface. The material on the top and bottom of the tanks is skimmed away. In geology, sedimentation is often used as the opposite of erosion (i.e., the terminal end of sediment transport).
6. **Filtration** is commonly the mechanical or physical operation which is used for the separation of solids from fluids (liquids or gases) by interposing a medium through which only the fluid can pass. The fluid that passes through is called the filtrate. Oversize solids in the fluid are retained, but the separation is not complete; solids will be contaminated with some fluid and filtrate will contain fine particles (depending on the pore size and filter thickness). Filter media can be cleaned by rinsing with solvents or detergents, or may be cleaned by backwashing. Self-cleaning screen filters utilize point-of-suction backwashing to clean the screen without interrupting system flow. Passing water through a bed of sand and gravel is a common last step in water purification. As water filters through the sand, the remaining particles of suspended matter are trapped in the sand bed. In the filtration process, water flows on top of the sand bed and travels through the bed until it is collected at the bottom in underdrains. Filtered water flows from the underdrains into clear wells or filtered water reservoirs.
7. **Earth filtration** are made of various mineral media, including various types of clays, diatomaceous earth, glass (silica) and other fine particles. The media are blended, shaped by manual or mechanical methods, dried and then fired at various temperatures to achieve different pore sizes and filtration properties. Some are unfired to maintain an open pore structure for filtration. Most ceramic filters are easy to use and are a potentially sustainable technology. The availability of suitable raw materials and the appropriate technology to blend these raw materials, shape the filter units and then perhaps fire them in a kiln are the main technical and accessibility barriers. The need for inspection and other quality control measures, as well as appropriate testing for proper pore size are also important requirements for their production. Some units are brittle and fragile and therefore, can break during use. Broken filters, even if only slightly cracked, are unsuitable for removal of particles and microbial contaminants from water. Well constructed earth filters have been extensively tested for efficacy in reducing various waterborne microbial contaminants. Some of these are rated to remove at least 99.9999% of bacteria, such as Klebsiella terrigena, 99.99% of viruses, such as polioviruses and rotaviruses, and 99.9% of Giardia

cysts and Cryptosporidium oocysts.

8. **Ground rock filtration** is the natural filtering of particles in water by porous rocks as it moves through the ground and reappears in the form of **spring water** or **well water**. Spring water is collected immediately at the source before other particles can dissolve into it.
9. **Carbon filtration** is a method of filtering that uses a bed of activated carbon to remove contaminants and impurities, using chemical absorption. Each particle/granule of carbon provides a large surface area/pore structure, allowing contaminants the maximum possible exposure to the active sites within the filter media. One pound (450 g) of activated carbon contains a surface area of approximately 100 acres (40 Hectares). **Activated carbon** is carbon that has been processed to increase its adsorption properties. Absorption is a process whereby [pollutant] molecules in the fluid become trapped inside the pore structure of the carbon substrate. Carbon filtering is commonly used for water and air filtration. Active charcoal carbon filters are most effective at removing chlorine, sediment, volatile organic compounds (VOCs), taste and odor from water. They are not effective at removing minerals, salts, and dissolved inorganic compounds. Typical particle sizes that can be removed by carbon filters range from 0.5 to 50 micrometres. The particle size will be used as part of the filter description. The efficacy of a carbon filter is also based upon the flow rate regulation. When the water is allowed to flow through the filter at a slower rate, the contaminants are exposed to the filter media for a longer amount of time.
10. **Membrane filtration** (ultra/micro/nanofiltration) is a water separation process. Water processing membranes are thin sheets of material that are able to separate water from other elements based on properties such as size or charge. Water passes through a membrane; but depending on their size, larger particles, microorganisms, and other elements are separated out. Some of these systems are pressure driven and depend on water pressure to separate the particles based on size. Reverse osmosis and nanofiltration are two membrane technologies. Membranes are often made of plastic or ceramic, with tiny openings called pores through which the water is filtered. The smaller the pore, the greater quantity of pollutants rejected and the more energy needed to force the water through the membrane. Membrane filtration produces clean water ("permeate") and a "waste" stream (concentrate/retentate) is discharged that contains all of the material that has been filtered out. The higher the TDS of water, the more difficult it becomes to maintain a membrane filter. Membrane filter types include:
    A. **Hyper filtration (HF)** can separate larger ions and molecules from smaller ones. (0.0001 micron pore size)
    B. **Ultra filtration (UF)** using hollow fibres can filter the smallest bacteria. (0.01 to 0.1 micron)
    C. **Nano filtration (NF)** use membranes to filter viral organisms. (0.001 to 0.01 micron)
11. **Reverse osmosis (RO) membrane filtration** is a physical membrane process for separation of dissolved substances into two streams, permeate (purified) and concentrate (unpurified). Essentially, reverse osmosis (RO) is a physical process for the de-concentration of substances dissolved in liquids. The process occurs by drawing water through a fine membrane under pressure. While the process is comparatively slow, this type of purification system can rid water of almost any contaminant, including radioactive particulates. The filtered water is stored in a closed tank to prevent contamination. The RO process strips the water down to mostly H20 molecules, and hence, minerals are routinely re-added to improve the quality of the water (if it is to be used for drinking water). The pore size of reverse osmosis membranes is so small that mostly water passes through. The filtration generally begins with the water flowing first through an activated charcoal pre-filter where it is cleansed of large molecular materials. Next the water flows through the main RO filter (i.e., screen/diaphragm). The tiny water molecules easily pass through the half permeable ("semi-permeable") diaphragm, which functions like a screen with an extremely small mesh size (2-3 angstroms). Nearly, but not all, pollutants are substantially larger in their molecule size than the H2O (water) molecule; thus, the pollutants get caught in the reverse osmosis diaphragm. These filtered pollutants are then rinsed off by the next flow of water, and washed down the concentrate drain. In this way the diaphragm is constantly cleaned and prevented from accumulating pollutants. Reverse osmosis systems produce larger quantities of wastewater (or "concentrate") than most other systems. They can become clogged with clay or organic materials if particle-rich source water is not filtered first. Maintenance is generally not difficult, but it can be expensive since the main action required is to replace the membrane as necessary. Maintenance problems tend to involve leaking and fouling of membranes.
12. **Membrane bioreactors (MBR)** use a

water purification process that integrates a perm-selective or semi-permeable filtration membrane with a biological process contained within a bioreactor. The anaerobic membrane bioreactor (AnMBR), which is a combination of the anaerobic biological wastewater treatment process and membrane filtration, represents a recent development in the high-rate anaerobic bioreactors.

### 3.2.2 Biological water processes

Biological water processes include:

1. **Bacterial processes** are introduced, and they begin consuming the small particles of organic matter that remain in the water. To facilitate this, oxygen is pumped into the water to allow the bacteria to feed continuously, as low oxygen levels cause feeding rates to slow.
2. **Myco-filtration** as **mycological processes** is a biological approach to water purification that uses the web-like tissue of mushroom-forming fungi (i.e., mycelium) to capture and degrade environmental pollutants. Mycofiltration is a sustainable approach to storm water processing.
3. **Slow sand filters** are large open sand beds without any backwashing mechanism. They are excellent at removing coliform bacteria and protozoans such as Giardia and Cryptosporidium. A slow sand filter not only physically filters the water, but also provides biological treatment from an organic mat which naturally forms on the filter surface. A slow sand filter can reduce microbial contaminants without the high cost of coagulation or pre-processing chemicals needed for common high-rate filters. Slow sand filtration percolates source water slowly through a bed of porous sand, with the influent water introduced over the surface of the filter, and then drained from the bottom. Properly constructed, the filter consists of a tank, a bed of fine sand, a layer of gravel to support the sand, a system of underdrains to collect the filtered water, and a flow regulator to control the filtration rate. No chemicals are added to aid the filtration process. The slow sand filter reduces suspended organic and inorganic matter, and may remove some pathogenic organisms. A granular activated carbon (GAC) sandwich filter is a modified slow sand filter that removes organic material. The removal action includes a biological process in addition to physical and chemical ones. Slow sand filters are less effective at removing microorganisms from cold water because as temperatures decrease, the biological activity within the filter bed declines. Since the purification mechanism in a slow sand filter is essentially a biological process, its efficiency depends upon a balanced biological community in the schmutzdecke. A sticky mat of biological matter, called a "schmutzdecke," forms on the sand surface, where particles are trapped and organic matter is biologically degraded. Slow sand filters rely on this cake filtration at the surface of the filter for particulate straining. As the surface cake develops during the filtration cycle, the cake assumes the dominant role in filtration rather than the granular media. A slow sand filter must be cleaned when the fine sand becomes clogged, which is measured by the head loss. The length of time between cleanings can range from several weeks to a year, depending on the raw water quality. The operator cleans the filter by scraping off the top layer of the filter bed. A ripening period of one to two days is required for scraped sand to produce a functioning biological filter. The filtered water quality is poor during this time and should not be used. Slow sand filter monitoring and operation is not complicated. Daily tasks include reading and recording head loss, raw and filtered water turbidity, flow rates, and disinfectant residual. If necessary, the operator should adjust the flow to bring water production in line with demand.

### 3.2.3 Chemical water processes

A chemical reaction is a process that leads to the transformation of one set of chemical substances to another.

Chemical water processes include:

1. **Coagulation** and **Flocculation** - Particles suspended in water naturally repel other particles. They cannot join to form larger particles that would settle more quickly. Coagulation occurs when a coagulant is added to water to "destabilize" colloidal suspensions. A coagulant, such as alum, is added to the source water to overcome the repulsion between the particles. Flocculation involves gently mixing the water so that the particles can combine and form larger particles. Flocculation, in the field of chemistry, is a process wherein colloids come out of suspension in the form of floc or flake; either spontaneously or due to the addition of a clarifying agent. The action differs from precipitation in that, prior to flocculation, colloids are merely suspended in a liquid and not actually dissolved in a solution. In the flocculated

system, there is no formation of a cake, since all the flocs are in the suspension. These processes are essential pre-processing for many water purification systems. In conventional coagulation-flocculation-sedimentation, a coagulant is added to the source water to create an attraction among the suspended particles. The mixture is slowly stirred to induce particles to clump together into "flocs." The water is then moved into a quiet sedimentation basin to settle out the solids. Dissolved air flotation systems also add a coagulant and flocculate the suspended particles; but instead of using sedimentation, pressurized air bubbles force them to the water surface where they can be skimmed off. A flocculation-chlorination system has been developed as a point-of-use technology. It uses small packets of chemicals and simple equipment like buckets and a cloth filter to purify the water. Finally, lime softening is a technology typically used to "soften" water—that is, to remove calcium and magnesium mineral salts. In this case, the material that is settled out is not suspended sediment but dissolved salts.

2. **Ozone ($O_3$)**, or trioxygen, is an inorganic molecule with the chemical formula $O_3$. It is an unstable form of pure oxygen ($0_2$); it is a gas. Ozone the tri-atomic form of oxygen: instead of the normal arrangement of 2 atoms of oxygen ($O_2$), ozone is comprised of 3 atoms of oxygen ($O_3$). Ozone is nothing other than ionized oxygen. Ozone, however, doesn't want to stay in that tri-atomic state very long and unless held in check or bound by other molecular couplings, ozone will usually break down from $O_3$ to $O_2 + O_1$ within 20 minutes (at approximately atmospheric pressure). $O_1$ is called a singlet oxygen atom and it is highly reactive - it is a powerful oxidant with bactericidal properties very similar to chlorine. Because ozone is highly reactive, it readily oxidizes (i.e., breaks down) organic matter. When ozone encounters another compound, one oxygen atom will break away, attach itself to the compound, and oxidize ("clean" or "purify") it. Ozone quickly reverts back into oxygen, leaving nothing behind other than oxygen. In concentration, it will reduce or prevent the growth of micro-organisms including bacteria, viruses, cysts, spores, mold and mildew. Ozone is also effective in eliminating or controlling color, taste, and odor problems. It oxidizes iron and manganese into solid particles that can be filtered out. Ozone is produced in nature when the ultraviolet rays of the sun strike oxygen molecules. When this occurs stratospheric layer of the atmosphere, it creases what we know as the "ozone layer". Nature also produces ozone near the earth's surface. Ozone is created when lightening, air, and precipitation combine. The sweet, fresh smell after a thunderstorm is the smell of ozone gas. Its efficacy is not dependent upon pH as is that of chlorine. There are 3 common methods of producing ozone: hot spark as corona discharge (CD), ultraviolet light, and cold plasma. A typical ozone system consists of an ozone generator mounted on the wall of a storage tank. The system uses a pump to circulate the ozone through the water. And, a filter is generally placed inside an storage tank to catch particles. Rising bubbles of ozone and air cause water to be drawn through the filter and it cleans the water without a water pump. The ozonation process is currently the most effective, sustainable, and safest non-chemical method of eliminating bacteria from water. Due to the highly reactive nature of ozone, it can corrode some materials. Hence, all surfaces coming in contact with ozone should be made of ozone-resistant materials, such as stainless steel. Ozone is an irritant (i.e., caustic) to lung and nasal tissue at concentration, and hence, generators may leak and could create an ozone hazard. However, ozone dissolved in water will not irritate skin, nose, or ears, nor will it dry out or leave a chemical film on skin. Ozone does not affect the pH balance of water like traditional chemical treatment methods. Ozone is a powerful sanitizer and oxidizer and reverts back into oxygen, leaving no harmful by-products whatsoever. Ozone can be used to purify a water body, including water in containers, storage tanks, spas, bathtubs, fountains, and wading pools. An ozonation system will sanitize the tank as well as the air above the water line. Most ozone systems require a storage tank for the treated water. With ozone treatment, disinfection occurs primarily at the point of contact between the ozone and the water. The disinfection process does not occur beyond the treatment unit. This contrasts with chlorination treatment where the residual chlorine remains in the water and continues the disinfection process for some time. Because ozone is so unstable, it does not produce a reliable residual. Ozone has an active residual time measured in minutes, whereas the active residual time for chlorine is measured in hours. Here, temperature is an important variable. The colder the water the more ozone will be dissolved in water and the longer the residual. Room temperature water looses its concentration of ozone within several minutes. Ozone is continuously moving out of solution and will dissipate completely from very cold water (context dependent) within

about 20 minutes. In general, the lower the water temperature, the more ozone is dissolved in the water. Ozone has been found to be effective over a wide range of pH, but a pH slightly above 7 increases treatment efficiency. The ozone demand is related to the level of contamination in the water. When substances in the untreated water react with ozone, part of the ozone is used up, which may leave less ozone available to treat the targeted contaminants. Ozonation units are installed as a point-of-entry treatment system. At the point where the ozone mixes with the water, turbulence and bubbles are created (through aerated diffusion of the ozone); these ensure that the ozone contacts as much of the raw water as possible, and is dissolved into the water to some degree. The greater the water flow rate, aeration (e.g., “diffuser stone”), and pressure differential/turbulence, the more effective the “treatment”. The effectiveness of ozonation depends significantly on the contact time, temperature, and solubility. In general, ozone requires a shorter contact time than chlorine. Ozone treatment can produce harmful by-products in water. For example, if bromide is present in the raw water, ozone reacts with it to form bromate, shown to cause cancer in rats. The less humidity an ozone generator has to work with, the better the results. The perfect environment for ozone production is close to 15-38°c with no humidity. Ozone can still be made in an environment with high humidity (50-80%), but with an air drier, the ozone generator will double or even triple the amounts of ozone produced, cleaning your water in less time.  An air drier will also lengthen the life of the ozone machine by allowing it to run more efficiently.  After a period of time, an ozone machine (without an air dryer) converts moisture to an acidic yellow coloured paste. This paste build-up will ruin the ozone generator causing poor ozone performance. Most ozone systems do not require extensive maintenance. Some systems use an air-drying material, which needs to be replaced periodically. It is also necessary to periodically clean the water storage tank and check pumps, fans and valves for damage and wear. If UV radiation generates the ozone, the lamp must be replaced periodically. Any pre-treatment or post-treatment devices may require additional maintenance. Additional uses for ozone: Ozonated water can be used to sanitize surfaces when submerged in a sufficient concentration for a sufficient amount of time. In other words, it can be used to disinfect toothbrushes and dentures. It can be used as a gargling solution. I can be used as type of “air purifier”.

### 3.2.4 Electromagnetic processes

Electromagnetic water processes include:

1. **Ultraviolet (UV) radiation/energy** is found in the electromagnetic spectrum between visible light and x-rays and can best be described as invisible radiation with disinfection as a property. The ultraviolet bandwidth occupies wavelengths roughly between 200 and 400 nanometers. Purification via exposure to ultraviolet radiation (UV germicidal irradiation) is unique from other types of sterilization modalities due to the fact that it does not necessarily cause death of the target organism. In those pathogens it does not directly kill, the UV radiation effectively alters the organism’s genetic structure. UV energy penetrates the outer cell membrane, passes through the cell body and disrupts its DNA preventing reproduction. By causing damage to the target bacteria’s Deoxyribonucleic Acid (DNA), the bacteria is sterilized at the genetic level. Thus, the organism is no longer able to reproduce and cause disease. The degree of inactivation by ultraviolet radiation is directly related to the UV dose applied to the water. The dosage, a product of UV light intensity and exposure time, is measured in microwatt second per square centimeter ($\mu ws/cm^2$). UV treatment does not alter water chemically; nothing is being added except energy. UV units only kill bacteria at one point in a watering system and do not provide any residual germicidal effect downstream. The sterilized microorganisms are not removed from the water -- bacteria cells are converted into pyrogens. The killed microorganisms and any other contaminants in the water are a food source for any bacteria that do survive downstream of the UV unit. Due to these limitations, the piping in a watering system treated by UV disinfection will need to be periodically sanitized with a chemical disinfectant. UV disinfection does not remove dissolved organics, inorganics or particles in the water. Although 100% destruction of microorganisms cannot be guaranteed, it is possible to achieve 99.9% reduction in certain applications and with proper maintenance. In order for a UV unit to successfully disinfect water, the following additional variables must be considered: Firstly, the composition of water can reduce the transmission of UV light through the water, which reduces the UV dose that reaches the bacteria. UV disinfection is most effective for treating high-clarity purified reverse osmosis or distilled water.

Secondly, all UV units have a maximum flowrate capacity and some have a minimum flowrate as well. Finally, UV radiation generates ozone that can damage surrounding materials.

2. **Boiling** is the oldest water disinfection technique. Boiling is the rapid vaporization of a liquid, which occurs when a liquid is heated to its boiling point, the temperature at which the vapor pressure of the liquid is equal to the pressure exerted on the liquid by the surrounding environmental pressure. effective despite contaminants or particles present in it, and is a single step process which eliminates most microbes responsible for causing intestine related diseases. In places having a proper water purification system, it is recommended only as an emergency treatment method or for obtaining potable water in the wilderness or in rural areas, as it cannot remove chemical toxins or impurities.
3. **Steam and pressure sterilization** through the use of an autoclave. An autoclave is a pressure chamber used to sterilize materials by subjecting them to high pressure saturated steam for a duration of time.

## 3.2.5 Electrochemical water processes

Electrochemical approaches to water tend to emphasize the recovery of metals and chemicals, and the destruction of organic contaminants.

Electrochemical water processes include:

1. **Desalination** is the process of removing dissolved salts and minerals from seawater or brackish water. It is also called desalination or desalting. Desalination is an advanced technical process involving many different technologies, including distillation, reverse osmosis, electrochemical mediation, and membrane filtration. Desalination produces drinking water and concentrate (the water that contains the salts that were removed in the desalination process, which used to be called brine). Salt water is desalinated to produce fresh water suitable for human and ecological usage. The minerals in the concentrate can be separated to produce, at the very least, a large amount of salt and a complex mineral solution for the biological nutrition needs of various organisms, notably, vegetation In other words, ocean water can be desalinated to produce a complex mineral solution (i.e., nutrient source) for plants and other organisms.
2. **Electrodialysis** is a water processing system that uses electrical potential to remove charged impurities from water. It is widely used for the processing of brackish water and for the desalination of seawater. Unlike other membrane processes, the source water never passes through the membranes during electrodialysis. The migration of ions across the membrane under the influence of a potential gradient is the basis of electrodialysis. Early processes used a three-compartment cell and the membranes were non-selective. Today, an array of membranes are used with alternating cation-selectivity and anion-selectivity.
3. **Disinfection** is the chemical or biological destruction of pathogenic microorganisms such as viruses, protozoa, and bacteria, or at least the deactivation of those microorganisms. Several chemicals are used in water disinfection and electro-chemistry is involved in the production of those chemicals. Common disinfection chemicals include: halogens; chlorine (Cl); chloramine ($NH_2Cl$); chlorine dioxide (ClO2); bromine (Br); hypochlorite (ClO-); ozone ($O^3$); hydrogen peroxide (H202); and iodine (I). The importance of these chemicals is based predominantly on their oxidizing power. They provide a flexible, controllable bioaction that can be maintained throughout a water distribution system. However, these chemicals have varying residual disinfection properties.
   A. **Ozone (O3)** is a strong oxidizing substance with bactericidal properties very similar to chlorine. It is claimed that ozone destroys bacteria more rapidly than chlorine and its efficacy is not dependent upon pH as is that of chlorine. The ozonation process is currently the most effective, sustainable, and safest non-chemical method of eliminating bacteria from water. Note, the major difference between ozone and UV is that ozone is a very powerful oxidizer and kills all known microorganisms—whereas UV typically just inactivates them. Ozone actually opens up the cell wall of the bacteria, virus, mold, fungus, etc. Then, because ozone oxidizes them (opens up the cell wall), the impurities clump together and are more easily filtered out. Water becomes clear with ozone, and the clearer the water is, the more effective UV is. Only clear water can be effectively treated with UV, cloudiness in the water can absorb the UV light. If you use UV, you should definitely use ozone too. But if you use ozone—you don't necessarily need UV. Ozone does everything UV does and more. But UV does not do everything that ozone does.
   B. **Hydrogen peroxide** is a chemical compound with the formula $H_2O_2$. Hydrogen peroxide

should really be called hydrogen dioxide. In its pure form, it is a colourless liquid, slightly more viscous than water; however, for safety reasons it is normally used as an aqueous solution. When exposed to other compounds hydrogen peroxide dismutates readily. The extra oxygen atom is released leaving $H_20$ (water). In nature oxygen ($0_2$) consists of two atoms--a very stable combination. $H_20_2$ is found naturally in rainwater. There is ozone ($O_3$) in the atmosphere, and when it rains, the unstable ozone gives up atoms of oxygen to falling water to form hydrogen peroxide. It turns out that this is one of the reasons that rainwater causes plants to grow more rapidly. In the human body, the cells responsible for fighting infection and foreign invaders in the body (your white blood cells) make hydrogen peroxide and use it to oxidize pathogens. Hydrogen peroxide is the simplest peroxide (a compound with an oxygen–oxygen single bond) and finds use as a strong oxidizer, bleaching agent and disinfectant. When stored under the proper conditions, it is a very stable compound. Concentrated hydrogen peroxide, or "high-test peroxide", is a reactive oxygen species and has been used as a propellant in rocketry. Pure hydrogen peroxide will explode if heated to boiling. Hence, for general usage, it is usually handled as a dilute solution. 3–6% $H_2O_2$ will not burn skin, but will kill bacteria on a wound. 32-35% (a.k.a., food grade) will burn skin on contact and is generally diluted before use. On human skin, peroxide reacts with melanin to oxidize it and convert it into a compound which is free of colour. Hydrogen peroxide's same oxidizing properties allow it to react with bacteria, viruses, spores, and yeasts, making it a functional disinfectant. It is rarely used in drinking water production as a stand-alone treatment process. Hydrogen peroxide solution may be used to disinfect surfaces. When it comes into contact with bacteria on a wound there is a fizzing and bubbling that happens, which is the result of the $H_20_2$ bonds breaking during the reaction. One of the oxygen molecules is liberated, leaving $H_20$. The free oxygen molecules are what you see bubbling to the surface. It has a variety of medical uses including that of mouthwash (wherein it whitens teeth) and used to treat fungal issues on tissue. Hydrogen peroxide is odorless and colorless, but not tasteless. It can also be used in the ear to treat ear infections. It can be used to disinfect surfaces like toothbrushes and countertops. It can be used as a bleach on skin, grout, hair, and clothes. It can be added to a clothes washing agent to facilitate cleaning and to bleach fabric. It can be used on vegetables and will disinfect/ sanitize utensils. Plant seeds can be soaked in a low-grade hydrogen peroxide solution to simulate rainwater. It can be used in aquatic environments to reduce algae.

C. **Chlorine** (and **chloramine**) is used to kill any harmful bacteria that might be present in a water source, and it is the most widely use disinfecting agent in early 21st century society. The amount of chlorine that is used is based on the amount of water that is treated, the amount of contaminants that must be controlled, and the time it takes for the water to reach its first usage (i.e., residual disinfection).

4. **Bleaching** refers to the usage of a number of chemicals which remove color, whiten or disinfect, often by oxidation. Chlorine is the basis for the most commonly used bleaches. Bleach performs two types of actions: it whitens, and has antimicrobial efficacy. There are two primary classes of bleach: chlorine-based bleach and peroxide-based bleach. Sodium hypochlorite is the most commonly encountered bleaching agent, usually as a dilute (3–6%) solution in water. Chlorine bleach forms dioxin after contact with organic compounds. Dioxins are a group of chemically-related compounds that are persistent environmental pollutants (POPs). Dioxins are highly toxic and can cause reproductive and developmental problems, damage the immune system, interfere with hormones and also cause cancer.

### 3.2.6 Ecological processes

Consider the role of water in the structure and function of ecological processes.

1. **Waste Stabilization Ponds (WSP) and Constructed Wetlands (CW) (**or **CWWSP)** are a form of wastewater and stormwater processing, which involve the construction of low energy-consuming ecosystems that use natural processes to transform, decompose, and recycle materials. A CWWSP forms a controlled ecological network of ponds (Read: a pond system) for the transformation, decomposition, and recycling of materials from used water and storm water. Together, the different ecological compositions of the ponds in the network, and the flow of water therein, form a unified ecological transformation

system for processing water with a portion of the material effects of our living into sustainable building blocks (i.e., nutrients) for further life. Therein, interconnected pond water levels dictated by ground water levels. The pond system attract wildlife. It is essentially a system designed to mimic (as in, biomimicry) the way nature transforms water.

2. **Waste Stabilization Ponds (WSP)** are large, shallow basins in which raw sewage is processed (i.e., "treated") entirely by natural processes, primarily involving algae and bacteria.
    A. **Anaerobic ponds** - Anaerobic ponds are commonly 2 – 5m deep and receive wastewater with high organic loads (i.e., usually greater than 100 g biochemical oxygen demand (BOD)/m3 .day, equivalent to more than 3000 kg/ha.day for a depth of 3m). They normally do not contain dissolved oxygen or algae. In anaerobic ponds, BOD removal is achieved by sedimentation of solids, and subsequent anaerobic digestion in the resulting sludge.
    B. **Faculative ponds** - (1-2m deep) are of two types: Primary facultative ponds that receive raw wastewater, and secondary facultative ponds that receive particle-free wastewater (usually from anaerobic ponds, septic tanks, primary facultative ponds, and shallow sewerage systems). The process of oxidation of organic matter by aerobic bacteria is usually dominant in primary facultative ponds or secondary facultative ponds.
    C. **Maturation ponds** are usually 1-1.5m deep, receive the effluent from the facultative ponds. Their primary function is to remove excreted pathogens. Although maturation ponds achieve only a small degree of BOD removal, their contribution to nutrient removal also can be significant. Maturation ponds usually show less vertical biological and physicochemical stratification, and are well-oxygenated throughout the day. The algal population in maturation ponds is much more diverse than that of the facultative ponds, with non-motile genera tending to
3. **Constructed wetlands (CW)** are planned systems designed and constructed to employ wetland vegetation to assist in processing wastewater in a more controlled environment than occurs in natural wetlands, but mirroring the way the natural wetlands function. Herein, aquatic plants as a bio-filter/bio-transformer. Essentially, a constructed wetland is a designed complex of saturated substrate, emergent and submerged vegetation, animal life, and water that simulate wetlands for human uses and fulfillment. In early 21st century society, constructed wetlands are an "eco-friendly" alternative for secondary and tertiary municipal and industrial wastewater treatment. The pollutants removed by CW's include organic materials, suspended solids, nutrients, pathogens, heavy metals and other toxic or hazardous pollutants. In municipal applications, they can follow traditional sewage treatment processes. Different types of constructed wetlands can effectively treat primary, secondary or tertiary treated sewage. However wetlands should not be used to treat raw sewage and, in industrial situations, the wastes may need to be pre-treated so that the biological elements of the wetlands can function effectively with the effluent. CW's are practical alternatives to conventional treatment of domestic sewage, industrial and agricultural wastes, storm water runoff, and acid mining drainage.
    - Constructed wetlands for wastewater treatment can be categorized as either **Free Water Surface (FWS)** or **Subsurface Flow (SSF)** systems. In FWS systems, the flow of water is above the ground, and plants are rooted in the sediment layer at the base of water column. In SSF systems, water flows though a porous media such as gravels or aggregates, in which the plants are rooted.
4. **Riverbank filtration (bank filtration)** - The improvement of water quality through natural filtration by soil and microbial processes caused by the percolation of water through natural or engineered media. Bank filtration involves installing a well near the surface water source to allow pulling water through the ground to effect some natural filtration. This concept requires granular soils adjacent to or under the surface water source. Where these conditions exist, there can be significant benefits with employing bank filtration.
5. **Reed beds** are natural habitats found in floodplains, waterlogged depressions and estuaries. Reed beds are part of a succession from young reed colonising open water or wet ground through a gradation of increasingly dry ground. As reed beds age, they build up a considerable litter layer which eventually rises above the water level, and ultimately provides opportunities for scrub or woodland invasion. Artificial reed beds are used as a method of removing pollutants from grey water, which will concentrate many of the undesirable elements of water into the stems of the plants given sufficient time. The Common Reed (Phragmites Australis) has the ability to transfer

oxygen from its leaves, down through its stem, porous speta and rhizomes, and out via its root system into the rhizosphere (root system.) As a result of this action, a very high population of micro-organisms occurs in the rhizosphere, with zones of aerobic, anoxic, and anaerobic conditions. Therefore with the wastewater moving very slowly and carefully through the mass of reed roots, this liquid can be successfully treated, in a manner somewhat similar to the conventional biological filter bed systems of sewage treatment plants.

#### *3.2.6.1 Additional pond functions in a pond system*

There are many practical uses for a pond. Below are some of the other ponds in a pond system.

> **NOTE:** *Ponds cannot be discharged for aesthetic reasons.*

1. **Evaporation ponds** evaporate water from a surface area by sunlight and exposure to the ambient temperatures. Evaporation ponds have several uses. They can be used to evaporate stormwater. They are also used to dispose of brine from desalination plants. Mines use ponds to separate ore from water. Evaporation ponds at contaminated sites remove the water from hazardous waste, which greatly reduces its weight and volume and allows the waste to be more easily transported, treated and stored. They can be used to produce salt and mineral solutions from sea water (i.e., salt evaporation ponds). However, any contaminants in the seawater will end up resulting solution. The evaporation of water leaves most, but not all, salts and impurities behind. In the agricultural industry, evaporation ponds are used to prevent pesticides, fertilizers and salts from agricultural wastewater from contaminating the water bodies they would flow into.
2. **Irrigation ponds** store and supply water for later usage in irrigation. Ponds can also be used to regulate stream flow. Overhead sprinkler often lead to a lot of water evaporation prior to reaching the soil.
3. **[Storm] Drainage ponds** and **retention basins** for detention/retention/evaporation of storm and flood water. Storm drainage ponds are part of the overall surface water management system on a site and are used for flood control. The purpose is to store water during peak storm events to slow the discharge offsite and contribute to the flood control of a local storm area. There are two basic types of storage: an above ground pond or underground structures of vaults or high-volume pipes. Ponds generally have an"outflow structure" composed of an inlet and a metered outflow structure. Surface ponds are usually planted with vegetation that serves as a pollutant filter of water before being discharged downstream.
4. **Swimming ponds** are used for human bathing and swimming.

#### *3.2.6.2 Natural swimming ponds/pools*

A natural swimming pool or natural swimming pond (NSP) is a system consisting of a constructed body of water, where the water is contained by an isolating membrane or membranes, in which no chemicals or devices that disinfect or sterilize water are used, and all clarifying and purifying of the water is achieved through biological filters and plants rooted hydroponically in the system.

It is called a “natural swimming pool” because the filtration systems used have biological equivalents in the natural world. In fact if there is not an example of the type of filtration being used in the natural world then it is not seen by the IOB (International Organization for natural Bathing waters) to be naturally filtered. Natural aquarium and koi ponds also exist, but use algae scrubbers for their filtration. Systems that use UV, ozone and copper/silver ion disinfection techniques are examples of additive methods.

The NSP is divided into two areas, the swimming zone and the regeneration zone, which are physically separated. The regeneration zone and swimming zone must be equal in area for sufficient purification. The swimming portion of the pool can look like a conventional swimming pool or a natural pond. The regeneration zone and swimming zone must be equal in area for sufficient purification. The swimming portion of the pool can look like a conventional swimming pool or a natural pond. The regeneration zone can be placed adjacent to the swimming area or in a remote location depending on the space available. In up-to-date natural swimming pools there is no minimum depth for the swimming zone and the regeneration zone can now be reduced greatly and in some cases is non existent.

NSPs rely on a combination of hydraulic design techniques in conjunction with a fine filter. They require a specialized skimmer or overflow channel. Downstream, a bioreactive biological filter removes and retains additional particulate matter down to a particle size of 100 micrometres. Pumps different from those found in conventional pools hydraulically optimize water flow rates and volumes, thereby accelerating the cleaning process even further. This mechanically enhanced natural filtration produces clear, clean water. In fact, when NSPs are installed in Europe, pool owners and builders will ceremoniously wrap up an installation with a ceremonial drink of water collected directly from the pool. A biofermenta system is the latest form of filtration for NSPs reducing the need for large plantation areas and filtration beds.

In an NSP, swimming pool water flows via gravity from the swimming pool into distribution shafts. The water then passes through a biological fine filter/bioreactor before it is pumped into the regeneration zone. Plants in the regeneration zone are planted in the substrate, and these plants compete for nutrients that would feed algae. The water is cleaned biologically by the metabolic processes found in the substrate in which the plants are rooted. Thus, microorganisms and the water plants ensure effective, continuous cleaning. No processes beyond these, such as UV sterilization, are necessary unless something is added into the system that causes an imbalance.

Because of their reliance on natural environmental factors, each NSP system is built with consideration to the region and climate where it is installed. Construction elements such as the biological filter and the combination of contaminant ridding plants vary with each pool. These ponds may also be connected to a larger pond water filtration, purification, and recycling system.

Of note, natural swimming ponds can be heated to 27°c, and under certain circumstances, higher than that. These ponds do require some additional pipework and a heating system. Once people become acclimated to swimming in a pond, temperature is often not found to be the issue they thought it was beforehand. Particularly for natural designs, water in the shallow areas heats up quickly in the sun and can raise the natural temperature of the whole pond to 75 degrees during the summer in some climates. Heat pumps and solar panel warming systems can easily be incorporated into NSP construction.

Perhaps more importantly, natural water "feels" much more comfortable on the skin. It has a different composition of suspended and dissolved solids, and so, what might feel cold in chlorinated water, 71 degrees for example, actually feels comfortable in natural water.

Typically, a chemically treated pool can discharge up to 3 times its volume of water into the sewer per year. As there is no use of chemicals in the water of NSPs and their water is maintained as "living" (i.e. the NSP is not drained and refilled), there is no need for this waste of water being discharged into the sewer. Also, there is considerably reduced energy consumption for the mechanical operation of many NSP systems.

Each NSP is unique, and so each has a different "break-in" period during which the system finds balance. While NSPs can be used for swimming immediately, it takes approximately two to three years until a stable biological equilibrium is reached. Once an NSP has reached equilibrium, it requires considerably less regular maintenance than a conventional swimming pool. Seasonal care and maintenance is still required over the course of the year, though even this differs from care of a conventional swimming pool. For example, ducks and other water fowl in migration have been known to visit NSPs during the winter months. Additionally, amphibious and aquatic creatures like frogs, salamanders, and snails often make their homes in the regeneration zones of NSPs.

#### *3.2.6.3 Additional benefits of ponds*

Besides water transformation ponds provide a number of other benefits.

> **NOTE:** *Ponds do not function well on sandy or other highly porous soils*

1. Ponds are often used for frost protection, particularly on wine grapes. The use of water for this purpose typically ranges from 0.4-1.6 inches of water in a year.
2. Ponds can be managed to provide wildlife habitat.
3. Ponds constructed primarily for fish production, typically at least a half-acre in size and a minimum depth of 8 feet, can yield 100-300 pounds of fish per year for each acre of water surface.
4. Ponds can assist in flood control by capturing and slowing the flow of water through a watershed.
5. Ponds help recharge groundwater. Whether filled with water diverted from a stream or with tailwater from irrigation, clay-lined ponds seep water into the ground at highly variable rates (depending on size and construction), but typical seepage loss from a well-sealed pond is estimated at one foot of water per year.
6. Storing water captured from rainfall or from tailwater in on-farm ponds can also reduce energy use by displacing pumped groundwater.
7. Ponds can serve as water sources for fire protection if they are sited in proximity to structures.
8. Ponds can be used to settle and filter runoff, capturing soil that can be returned to use and filtering pollutants and particulates that would otherwise negatively impact the broader ecosystem.
9. A pond network creates a more localized and distributed water supply, which can offset water transported from distant reservoirs, reducing the energy needed for water conveyance.
10. Ponds can be used in the intentional and directed flooding application known as rapid flood flow irrigation. Rapid flood flow irrigation involves the application of a large amount of water to the land, which soaks in, and does not have significant evaporation.

# 4 Water temperature modification

Water resists temperature change, both for heating and cooling. Water can absorb or release large amounts of heat energy with little change in actual temperature. At sea level, pure water boils at 100oC and freezes at oC. The boiling temperature of water decreases at higher elevations (lower atmospheric pressure). For this reason, an egg will take longer to boil at higher altitudes. The high boiling point of water (similar sized molecules are normally gases at room temperature) is also due to its ability to form hydrogen bonds.

## *4.1 Water heating*

Water heating is a thermodynamic process that uses an energy source to heat water above its initial temperature. Heated water is used for cooking, cleaning, bathing, space heating. In materialization and other services, hot water and water heated to steam have many uses. Water heating systems are categorized by their energy source and whether the system is tank-type or tankless.

- **Tank-based water heating system** - either the storage tank is directly heated, or panels that cycle water through the storage tank are heated with an energy source such as solar, geothermal, or wood.
- **Instantaneous water heating systems** - provide hot water on-demand at their point-of-use (POU). These systems may use a water storage tank, but the water in the tank is not hot; it becomes hot at its point of use.

## *4.2 Water cooling*

*A.k.a., Water chilling.*

Herein, refrigeration technology is applied to water in order to reduce its temperature.

# 5 Cleaning with water

Regular cleaning of material surfaces reduces the build-up of environmental materials and decomposition factors, while also reducing the amount of organic (and inorganic) matter that contributes to the proliferation of bacteria and viruses, and may inhibit the intended functioning of the surface. The purpose of cleaning is to remove the build-up of materials and to prevent future accumulation. Cleaning is essential for food production and preservation, as well as for the care of textiles. Cleaning must be considered in the context of an ecology, in particular, a bacterial ecology.

1. Physical / mechanical pressure cleaning - a process that utilizes mechanical energy (e.g., washing machine, pressure washing, scrubbing).
2. Ultrasonic cleaning - a process that utilizes sound energy to create cavitation of microscopic bubbles on the surface of an object.
3. Chemical cleaning - a process that utilizes a chemical agent (i.e., soaps/detergents).

The performance of a "cleaner" can be measured via the following indicators:

1. If a product leaves any residue from the detergent solution, then it is not clean.
2. If a product adds to the weight of the material, then it is not clean.
3. If the cleaning damages the surface unnecessarily, then it is a poor quality cleaner.

## *5.1 Mechanical pressure washing*

Pressure washing uses a high-pressure mechanical sprayer used to remove material from surfaces and objects such as buildings, vehicles, and concrete with water [under pressure]. They are used primarily as exterior cleaning tools. The volume of a pressure washer is expressed in litres per minute, and may be variable or static. The basic pressure washer consists of a motor (either electric, internal combustion, pneumatic or hydraulic) that drives a high-pressure water pump, a high-pressure hose and a trigger gun-style switch. Just as a garden hose nozzle is used to increase the velocity of water, a pressure washer creates high pressure and velocity.

Some washers, with an appropriate nozzle, allow detergent to be introduced into the water stream, assisting in the cleaning process. Different pressure washers can use water at differing temperatures. And, there are different types of nozzles for different applications.

Washers are dangerous tools and should be operated with due regard to safety instructions. The water pressure near the nozzle is powerful enough to strip flesh from bone. Particles in the water supply are ejected from the nozzle at great velocities. The cleaning process can propel objects dislodged from the surface being cleaned, also at great velocities. Pressure washers have a tendency to break up tarmac if aimed directly at it, due to high-pressure water entering cracks and voids in the surface. Washers can damage surfaces: water can be forced deep into bare wood and masonry, leading to an extended drying period. Such surfaces can appear dry after a short period, but still contain significant amounts of moisture that can hinder painting or sealing efforts.

## 5.2 Cleaning instruments

Methods of cleaning instruments with water include, but are not limited to:

1. **Dish/instrument washing (sanitizing) machines:** These machines rely on the following parameters to clean the objects:
   A. Pressure.
   B. Time.
   C. Temperature.
   D. Surface tension modification (often, via a washing agent or soap).
2. A **sponge** is a tool or cleaning aid consisting of porous material. Sponges are usually used for cleaning impervious surfaces. They are especially good at absorbing water and water-based solutions. Natural sponges are generally known as a "loofah". A natural loofah is a plant seed pod in the cucumber or gourd family that grows on a vine. The pod is rough textured when dry, and softens when combined with water.

## 5.3 Cleaning with water 'washing agents'

The two primary types of washing agents are soaps and detergents. The distinction between them is relatively small. One hundred years ago there was no such thing as a "detergent". Today, a "detergent" is anything that grabs onto dirt, soil, grease, oil, odor, bacteria, etc. and holds it well enough to loosen its grip on clothing, skin, hair, wall paint, etc. and pull it into the wash water. If the detergent hooks-up too well it may join the dirt on the fabric or surface and become part of the problem (soap and detergent scum). The cleaning agent must remain well attached to the water so that as the water rinses away, the detergent goes with it still holding fast to the dirts and soils it has released from the material being cleaned. Effectively, the cleaning agent allows insoluble particles to become soluble in water, so they can be washed away. This is how cleaning works whether it is called "soap" or "detergent". The category difference relates to how the cleaner (i.e., cleaning/washing agent) is created (i.e., materialized). A detergent or soap molecule is different on one end from the other. One end is attracted to "dirt" and the other is attracted to water.

Every washing agent contains chemicals to separate added material (a.k.a., "soil") from a surface (e.g., fabric) and carry it away with the water. These are called **surfactants (Read: surface active agents/ substances)** and they do whatever "cleaning" occurs. A properly designed and selected washing agent (i.e., surfactant) should remove matter efficiently from a surface and wash away completely without residue. In order to achieve this, a synergistic blend of two or three compatible surfactants is generally required.

Whereas soap is a metal salts of long chain higher fatty acids, detergents are sodium salts of long chain hydrocarbons like alkyl sulphates or alkyl benzene sulphonates. Soaps are prepared from vegetable oils and animal fats. Detergents are prepared from hydrocarbons of petroleum or coal and are "soapless". Soaps cannot be used effectively in hard water as they produce "soap scum" (i.e., insoluble precipitates of Ca2+, Mg2+, Fe2+ etc.). Detergents are generally not made insoluble by mineralized (so-called hard) water. The polar sulfonate (of detergents) is less likely than the polar carboxyl (of soap) to bind to calcium and other ions found in hard water. Some detergents also have secondary usages as acid solutions and foaming agents. Soap cannot be used as any form of acid solution, but it is sometimes used as a [component of a] lubricant (e.g., textile spinning). Whereas soaps are biodegradable, not all detergents are biodegradable.

- An example of a soap is sodium palmitate: $CH_3(CH_2)_{14}\text{-}COO^- Na^+$
- An example of a detergent is sodium lauryl sulfate: $CH_3(CH_2)_{12}\text{-}OS(O)_2\text{-}O^- Na^+$

Water, although a good general solvent, is also a substance with a very high surface tension. Because of this, water molecules generally prefer to stay together, rather than to migrate to other surfaces. **Surfactants** work by reducing the surface tension of water, allowing the water molecules to better wet the surface and thus increase water's ability to dissolve dirty, oily stains. Soap technology is essential for the removal of oil molecules from a surface. Oil molecules are non-polar, which means that they are not charged, and therefore, are not attracted to polar substances such as water (lipophilic). Because of this, oil tends to stick with its own molecules or other non-polar substances. Water is a polar substance which is made up of one positive and one negative charge. With this, water dissolves salt easily because salt is made up of charged ions in which the positive charge will be attracted to the negative ions in water (hydrophilic). When an appropriate surfactant is applied to oil, the lipophilic parts of surfactant will attach itself to the non-polar molecules of the oil. When water is applied onto this surface with a sponge, the hydrophilic component will be attracted to the water molecules and is lifted from the surface, together with the oil. Also, oil and grease will stick onto plates and cutlery during cleaning, and no amount of water can completely remove it without significant temperature and pressure, unless a surfactant is present.

> **NOTE:** *The presence of surfactants affects the natural micro-organism ecology.*

A surfactant (once dissociated in water) consists of a non-polar hydrocarbon tail and a polar head. The non-polar hydrocarbon tail interacts with non-polar substances through dispersion forces, whilst the polar head interacts with polar substances (normally water) which forms dipole-dipole interactions and hydrogen bonds with water. The presence of soap, for example, in a mixture of oil/grease and water will create an emulsion upon agitation. The hydrocarbon tails of soap dissolves in the oil and promotes droplet formation. These droplets repel each other, as they have the same net negative charge. These individual droplets can be dissolved in water as they form ion-dipole interactions.

An **emulsion** is a type of dispersion in which two normally immiscible substances are stabilised by another substance, called an emulsifier. For example, olive oil and water will not dissolve in one another, as their intermolecular forces differ (like dissolves like). While we can agitate to form a suspension, it is temporary and the oil and water will eventually separate into distinct layers.

### 5.3.1 Soap

Soaps are cleaning agents that are usually made by chemically reacting alkali (e.g., sodium hydroxide) with naturally occurring fat or fatty acids in order to facilitate the removal of organic and in-organic matter from the surface of a material. The metal is often an alkali metal such sodium or potassium, or an alkaline earth metal, such as calcium or magnesium. The fatty acid is often of plant or animal origin. Essentially, soap is a result of combining fat (i.e., oil) with an alkaline solution, and the productive chemical reaction is called **saponification**. The reaction produces sodium salts of these fatty acids, which improve the cleaning process by making water better able to lift away fatty material from skin, hair, clothes, and many other surfaces.

Historically, soap was made by boiling animal fat and adding lye to supply charged ends for the oil molecules. Time and temperature cause various combinations to occur and each will interact differently with the soils and especially with the calcium and magnesium in the wash water.

- Soap is most effective when mixed with mechanical pressure.
- Different oils and alkali solutions produce soaps with different properties. Especially coconut oil and palm oil produce excellent lathering properties.
- Temperature is a significant variable when using soap.
- Essential oils are sometimes added to soaps for their aromatic and anti-pathogenic properties.

### 5.3.2 Natural cleaners and soap

Natural ecologies produce a range of "soft" soap materials that are useful for cleaning. Although rare, soap is indeed found in nature. One family of historical soaps was made by infusing, simmering or mashing 'saponin' rich plants in water. If you have seen frothy puddles on the road near chestnut trees you have got the idea. Plants produce saponins as part of their immune system to deter insect attack and to act as natural anti-microbials, protecting their life bearing seeds. Hunter gatherers still exploit the soap-bearing plants for their medicinal properties and for cleaning. Grated or pounded horse chestnuts (aesculus hippocastanum), soaked and boiled bracken root (pteridium aquilinum), fern root (dryopteris filix-mas), snowberries (symphoricarpos albus), and soapwort (saponaria officinalis) will yield a soft water-based soap. Chestnuts are difficult to process, especially when you need to remove the shell first. Fern or bracken roots can not be collected from the wild and snowberries are best left on the plant as vital winter food for birds. Soapwort, our best known soap bearing plant is certainly worthy of its name and the whole of the plant can be used.

The soap nut tree Sapindus Mukorossi (a.k.a., Indian Soapberry) is a very large tree that produces prodigious amounts of a saponifying nut that you can use as a greywater safe laundry detergent, dish and hand soap. Soap nuts are berries that grow on a tree and naturally contain soap. Sapindus Mukorossi requires a fertile soil and a frost free climate. It's a tall tree that can take as long as ten years to begin fruiting. Just 5 berries can do multiple loads of laundry in a conventional washing machine. The natural soap found in these berries is called saponin. Saponin is a natural cleaner that works as a surfactant, breaking the surface tension of the water to penetrate the fibers of your clothing, lifting stains from the fabric, and leaving dirt suspended in the water that is rinsed away.

In an emergency when soap is not available, then there are many natural alternatives including: clean ash; vinegar, salt, mud, and sand/soil. Mud is a lesser known cleaner for hair (i.e., "shampoo") commonly used in the Mashreq and Maghreb regions.

Vinegar is a natural all-purpose acidic cleaner with anti-microbial properties. It is sometimes added to a surfactant solution to increase its effectiveness. Vinegar can be used to "clean" most standard surfaces including ceramic, glass, and fabrics. Vinegar cannot be used on marble or similar surfaces because its acid content will damage (i.e., "eat away") the surface, and quickly lose its shine.

Both baking soda and salt are excellent scouring powders. Baking soda is an excellent stain and odor remover. The solution can be used as a facial scrub. It can also be used as a toothpaste and tooth whitener. Clay can also be added to toothpaste to fa-ciliate whiter teeth due to its abrasiveness.

There are certain leaves that when diluted in hot water, form a weak cleaning solution. Two of the most well-known leaves for this purpose are palm an bay leaves.

### 5.3.3 Hydrophilic-lipophilic balance (HLB)

A system was developed to assist in making systemic decisions about the amount and types of surfactants needed in stable products. **Surfactants** are compounds that lower the surface tension (or interfacial tension) between two liquids or between a liquid and a solid. Surfactants may act as detergents, wetting agents, emulsifiers, foaming agents, and dispersants. The hydrophilic-lipophilic balance of a surfactant is a measure of the degree to which it is hydrophilic or lipophilic, determined by calculating values for the different regions of the molecule. The system is called the HLB system and has an arbitrary scale of 1-18. HLB numbers are experiment ally determined for the different emulsifiers. If an emulsifier has a low HLB number, there are a low number of hydrophilic groups on the molecule and it will have more of a lipophilic character. For instance, substances with low HLB numbers are generally oil soluble. As a result of their oil soluble character, they will cause the oil phase to predominate and form a water-in-oil emulsion. The higher HLB numbers would indicate that the emulsion has a large number of hydrophilic groups on the molecule and therefore should be more hydrophilic in character. Substances with high HLB numbers are water-soluble. And because of their water soluble character, they will cause the water phase to predominate and form an oil-in-water emulsion.

### 5.3.4 Detergent washing agent residue

Most commercial cleaners are filled with additional chemicals. Industry is not overly concerned with sustainable and efficient cleaning, and so, they create a chemical soup of additives. There are thousands of synthetic fragrances and over 200 brighteners which might be called dyes, colorants, color enhancers, color safe bleach, fluorescent whitening agents (FWA), etc. Then, manufactures add oils, silicones, and polymers to attach the fragrances and brighteners to the washing agents. Lubricants are added to make the fabrics less stiff, other lubricants for the washing machine pump, polyvinylpyrrolidone to seal the surfaces and ends of fibers, antiredeposition agents, perhaps sanitizers (anti-microbial agents), enzymes and oxidizers, also softeners, and of coarse inert fillers so you know by the size of the expensive containers that you got your moneys worth.

> **NOTE:** *In commercial products, the highest levels of fragrance are often found in "Baby" detergents. These fragrances can mask natural body odor/pheromones.*

Fabric softeners coat the surface of a fabric with chemical compounds that are electrically charged, causing threads to "stand up" from the surface, and thereby, causing the fabric to feel softer.

Oxidizers (oxidizing agents) and enzymes react with the smooth surface of fibers causing tiny pits and fissures that hold particles of residue. As temperature and humidity change, these imperfections swell and shrink. The eroded surface scatters light causing colours to look bleached and faded and the fibers weaken, loose memory, and eventually break. Elastomers fail significantly more quickly under these conditions than other fibers.

Optical brighteners are added to make the clothes appear cleaner. It would seem that if you can't clean clothes with less than six chemicals, maybe you're not focused on cleaning. Most of the other ingredients in commercial products are there to help the surfactants, or they are present to make you believe your clothes are clean, and hence, must remain in your clothes to be effective (e.g., optical brighteners).

Gutting (The Detergent Conspiracy) clarifies the effects of some modern detergents on clothing:

> *Tests done at the Clemson University School of Textiles and Polymer Science (Nicholson, 1995) showed that washing in regular grocery store detergent actually added a measurable amount of weight (contamination) to the clothes. Washing added 2% of the weight of the cloth in just 10 washings. The residue was equal to the full amount of detergent recommended to wash clothes. Let me be specific about this. When you pour in the detergent before the wash cycle, the scoop of powder or cup of liquid, you use is equal to the amount of chemical you will have in your clothes after 10 washes. It doesn't increase much beyond 10 washes because you reach a point where you are washing out as much as you are washing in.*
>
> *Detergents for colors and blacks have higher levels of polymer, which attaches to the clothing, to hide the scattering of light (i.e., "fading") caused by fiber erosion.*
>
> *The latest news in home laundry detergents is a Proprietary Protective Fiber Complex. This goes beyond polymers to a new silicone complex that not only provides additional lubrication, but also forms little cells of oiliness to keep the silicone complex and other care ingredients from washing away. This technology is especially important for high efficiency (HE) washing machines.*

> *The new machines not only save water and power, but rinse clothes more completely. Better rinsing is good for you but makes it difficult for the detergent makers to leave enough residue to assure you that your clothes are clean. Detergent makers had initially been forced to add more of the "care" chemicals, but this new technology allows them to overcome the great rinsing performance of your new HE machine and attach exactly the right amount of residue to your clothes.*

Of course, residue is not without consequence. It impacts the functioning of a material. It can degrade wicking, breathability, rapid drying, and water repellency in just a few washings. Detergent residue may not only slow drying, but will rehydrate itself when dry by drawing moisture from the air or from its user. Extra moisture reduces the efficiency of insulation. Insulation is also less able to loft up when coated with sticky residue, this further decreases effectiveness. Fabrics feel stiffer when coated with sticky chemicals because fibers cannot slip against each to allow a soft hand. Detergent manufacturers try to overcome some of this friction with silicone but deliberately leave some stiffness to ensure an opportunity to sell fabric softener. It is only a small exaggeration to say that washing clothes in regular detergents destroys them as fast as not washing them at all.

What are the effects of detergent residue on humans? An increasing slice of the population is experiencing episodes of eczema, psoriasis, and other reactive skin irritations loosely referred to as contact dermatitis. Humans will inevitably get the residue on their hands and likely end up consuming some of it. The human organ known as the skin may absorb some of it.

### 5.3.5 Overuse of soap

Cleanliness has come to mean an effort to remove germs and other hazardous materials. Today we now know that bacterial populations play an important role in the sustainment of a healthy ecological system, and in humans, a healthy immune system. Although cleanliness as the removal of dead cells, decomposition matter, contaminants, and excessive build-up of microorganisms and viruses has an important role in healthy functioning, excessive cleaning is often unnecessary and can damage surfaces.

It is the body oils forming a thin film on the surface of the skin that give human skin its smoothness. When the oils are washed off the body (i.e., stripped off of the skin) it tends to reduce the smoothness and "glow" of the skin. Now when you lather your body with soap during your bath, the lipophilic part attaches itself to your body oils and the hydrophilic part attaches itself to water. When you wash off the soap with water, your body oils are wrenched off from the skin and are washed of with the water. Your skin is deprived of its natural moisture but it gives you a feeling that you are cleaned/scrubbed. This feeling basically comes from the skin reporting the lack of an essential ingredient which we mistakenly feel to be fresh. You feel that you are cleaned off of all the "dirt" and that you are fresh. What really happened is that your body moisture is washed off and you need to replenish the body moisture. The soap industry realized what their soaps are doing to people and started adding moisturiser to the soap itself so that what is washed off by the soap part is replenished by the moisturiser. Excessive washing to remove oil from the skin also prevents vitamin D both from being formed on the skin and absorbed via the oils through the skin [via exposure to sunlight]. It is also relevant to note that soap is not essential for the removal of many pathogens from the hands.

# 6 Drainage

Sustainable urban drainage systems (SUDS) can provide an alternative to, or addition to, traditional drainage systems. They mimic 'natural' drainage by adopting techniques to deal with surface water runoff locally, through collection, storage, and cleaning before allowing it to be released slowly back into the environment. SUDS techniques seek to capture, use, delay or absorb rainwater, rather than reject it as a nuisance or problem.

SUDS techniques might include, but are not limited to:

1. Filter strips and drains.
2. Swales.
3. Permeable surfaces.
4. Basins and ponds.
5. Underground storage.
6. Wetlands.
7. Green roofs.
8. Rainwater harvesting.

# 7 Water transportation

Water is transported around a habitat through a water transportation system (a.k.a., plumbing or hydraulics network/system) involving a network of pipes and pumps.

## *7.1 Pumps*

*A.k.a., Water pumps.*

A pump is a device that moves fluids (liquids or gases). It is a device that moves fluid through a piping system by mechanical action. As such, it is a pressure (hydraulic) driven machine that converts mechanical energy to hydraulic energy. Pumps operate by a rotary and reciprocating mechanism, and they consume energy to move fluid. Water pumps move water (Read: transfer water) from one place to another. A water pump is an electromechanical device that pulls water from a water source (e.g., well, river, etc.) and pumps it into a water pipe system and/or fills a water tank. Water pumps supply the pressure needed to pressurize a plumbing system or fill a water tank with water from an outside source of water.

Pumps can have several functions, including but not limited to (Variable speed, 2021):

1. **Pressure pump** - provides water and creates water pressure for plumbing.
2. **Hot water recirculating pumps** - provide hot water for hot water outlets.
3. **Booster pump** - boosts water pressure in high-rise buildings.
4. **Pool pump** - provides water and circulation of water in pool and other aquatic areas.
5. **Hydronics pump (HVAC pump)** - provides for the circulation of HVAC fluid(s).
6. **Fire pump** - provides water (and water pressure) fire protection.
7. **Manufacturing water pump** - provides water (and water pressure) for manufacturing processes.

There are several additional types of pumps for most architectural structures:

1. **Sump pumps** - remove water that collects in basins from around a structure’s foundation. Many are submersible sump pumps. They have a manual or semi-automatic motor housed in a water-tight compartment. This allows the pump to be fully immersed in liquid.
2. **Trash pumps** - designed for de-watering applications. These pumps help remove water that contains things like vegetation and sludge.
3. **Transfer pumps** - are utility pumps that move

water from one location to another through hoses. They can handle everything from light aquarium applications to heavy de-watering.
4. **Boosting pumps** - add water pressure for washing services or lawn sprinkling. They can also increase pressure where low or inadequate water pressure is an issue. These pumps include water garden pumps.
5. **Lawn sprinkler pumps** - used to draw water from various sources to a garden sprinkler systems.
6. **Pond pumps** and **water garden pumps** - power water flow and circulation for decorative water features.
7. **Sewage effluent pumps** - pump liquids and semi-solids. They are usually located in a basement or a below-grade area. They are powerful enough to pump from a sewage basin up to the main sewer line for removal.
8. **Condensate pumps (evaporative cooler pumps)** - automatically remove condensation in high moisture areas. For example, they can remove collected condensation from furnaces or air conditioning units.
9. **Pool pumps** - for circulating water within a pool and may also be used for removing water from a pool.

In general, pumps are normally powered by either:

1. An electric motor.
2. A combustion engine.

Pumping systems can experience noise and vibration issues due to poor design, poor installation, and inadequate maintenance. Periodic inspections are recommended to make sure all system components are working correctly. Some common causes of vibration are:

1. Inadequate equipment supports and/or vibration dampeners.
2. Unbalance.
3. Misalignment.

Controlling vibration is very important. Vibration can speed up the mechanical wear of system components, decreasing life-span and increasing maintenance.

### 7.1.1 Types of pumps

At a high-level, pumps can be classified into three major groups according to the method they use to move/transport the fluid:

1. Direct lift.
2. Displacement.
3. Gravity pumps.

In general, there are two categories of pump as classified by mechanism of operation (i.e., two functional types). The following list includes many sub-types of these two categories, but not all:

1. **Dynamic pumps (a.k.a., rotodynamic, non-positive displacement)** - the voltage of fluid pumped depends on the viscosity of flow.
    A. **Centrifugal pumps** - are a rotodynamic pump that uses a pivoting impeller to expand the weight and flow rate of a liquid. Centrifugal pumps have most applications in moving fluid through pipes. They have a rotating impeller with curved blades, which increase the pressure of water by accelerating it towards the edges. Centrifugal pumps have a direct relationship between flow rate and pressure, and flow decreases when they work against a higher system pressure. Centrifugal pumps can be further classified into three subtypes based on their flow direction:
        1. **Axial flow pumps** - move water along the same direction of the impeller shaft.
        2. **Radial flow pumps** - move water at a 90° angle with respect to the shaft.
        3. **Mixed flow pumps** - intermediate, producing flow at an angle less than 90°.
    B. **Vertical centrifugal pumps**
    C. **Horizontal centrifugal pumps**
    D. **Submersible pumps (a.k.a., cavitation pump)** - a device which has a hermetically fixed engine close-coupled to the pump body. The advantage this pump has over other pump is that elevation does not affect the flow of fluid.
    E. **Fire hydrant pumps (a.k.a., hydrant boosters, fire pumps, & fire water pumps)**
2. **Positive displacement pumps** - move fluid in "pockets" at regular intervals. These pumps transport fluid by constraining a fixed volume and displacing that trapped volume in a discharge pipe. Positive displacement pumps can sustain a constant flow under variable pressure, due to how the pumping process is carried out. Based on their construction, positive displacement pumps can be described as either:
    A. **Reciprocating-type positive displacement pumps** - use a cavity that expands and contracts to move water, controlling the flow direction with check valves.
        1. **Plunger pump** - pushes the fluid through valves that are opened, closed by suction on way back.
        2. **Diaphragm pump (a.k.a., AOD pumps, air operated diaphragms, pneumatic pumps, and AODD pumps)** - a plunger pressurizes

hydraulic oil which is used to flex the diaphragm in the pumping chamber(cylinder). Diaphragm pumps are used to pump toxic and hazardous fluids.

3. **Piston displacement pump** - are frequently used in water irrigation, scenarios requiring high, reliable pressure and delivery systems for transferring chocolate, pastry, paint, etc.

B. **Rotary-type positive displacement pumps** - trap water in cavities around a rotor, and displace it towards the outlet. In other words, these pumps transport fluid by means of a rotating mechanism that creates a space (vacuum) that captures and draw fluid into the pump.

1. **Gear pumps** - a simple rotary pump which operates by pushing transported fluid between two gears.
2. **Rotary vane pumps** - a round and hollow rotor encased in a comparably formed lodging. As the rotor circles, the vanes trap liquid between the rotor and the packaging, drawing the liquid through the pump.
3. **Peristaltic pumps (a.k.a., tube pumps) -** a kind of positive displacement pumps and the applications of these pumps mainly involve in processing of chemical, food, and water treatment industries. It makes a stable flow for measuring and blending and also capable of pumping a variety of liquids like toothpaste and all kinds of chemicals.
4. **Screw pumps** - state of the internals of this pump is generally two screws turning against each other to pump the fluid.
5. **Lobe pumps**

C. **Linear-type positive displacement**

1. **Rope pumps**
2. **Chain pumps**

### 7.1.2 Pump specifications

Pumps will need to sized for the specific requirements of the water source and water needs. Pump ratings are in terms of gallons per minute (GPM, imperial) and liters per minute (LPM, metric) as well as gallons per hour (GPH) and liters per hour (LPH). An average dwelling with three or four bedrooms needs 30 to 45LPM (8 to 12 GPM). When figuring out how much water a system needs, add 3.7LPM (1GPM) for each water fixture, such as dishwashers, clothes washers, refrigerators, faucets and showers.

It is important to state here that pumps that must transport water over longer distances will require more horsepower. Additionally, an oversized unit will lead to reduced performance and energy inefficiencies. If you need to replace your pump, pick one with identical horsepower. However, note that you may need extra horsepower if you plan to add new family members or appliances.

### 7.1.3 Pump efficiency

Pump efficiency is defined as the proportion of the power bestowed on the liquid by the direct in connection to the power provided to drive the pump. For a centrifugal pump, efficiency increases with flow rate increase up to midpoint and it then starts to decline as flow rate increase further. Generally, pump efficiency decrease overtime due to wear and tear.

### 7.1.4 Hydrualic horsepower of a pump

The hydraulic horsepower of pump is determined by discharge and suction pressure. It is given by

- Power output from pump = (P2–P1) * Q
- P2: Pump discharge pressure in N/m2
- P1: Pump suction pressure in N/m2
- Q: Flow delivered by pump in m3/s

### 7.1.5 Pumping power

The power imparted into a fluid increases the energy of the fluid per unit volume. Thus, the power relationship is between the conversion of the mechanical energy of the pump mechanism and the fluid elements within the pump. In general, this is controlled by a series of simultaneous differential equations, known as the "Navier–Stokes" equations. However a more simple equation relating only the different energies in the fluid, known as "Bernoulli's" equation can be used. Hence the power, P, required by the pump (Pump, 2021):

- P = (ΔpQ) / η
- Where,
  - P = power
  - Δp is the change in total pressure between the inlet and outlet (in Pa).
  - Q is the volume flow-rate of the fluid is given in $m^3$/s.
  - η is the pump efficiency. This may be given by the manufacturer's information, such as in the form of a pump curve, and is typically derived from either fluid dynamics simulation (i.e. solutions to the Navier–Stokes for the particular pump geometry), or by testing.

The total pressure may have gravitational, static pressure, and kinetic energy components (i.e., energy is distributed between change in the fluid's gravitational potential energy as going up or down hill, change in velocity, or change in static pressure). The efficiency of the pump depends upon the pump's configuration and operating conditions (such as rotational speed, fluid density and viscosity etc.).

- $\Delta P = ((v^2_2 - v^2_1) / 2) + \Delta zg + (\Delta P_{static} / p)$

For a typical "pumping" configuration, the work is imparted on the fluid, and is thus positive. For the fluid imparting the work on the pump (i.e. a turbine), the work is negative. Power required to drive the pump is determined by dividing the output power by the pump efficiency. Furthermore, this definition encompasses pumps with no moving parts, such as a siphon.

## 7.1.6 Pump data specification

A data specification table for a pump includes, but may not be limited to, the following data categories:

| Data Category | Specifics |
|---|---|
| Pump type | - |
| Housing material | - |
| Impeller material | - |
| Pump dimensions (W, H, & D) | - |
| Weight (kg or lbs) | - |
| Number of impellers | - |
| Pump switch type | - |
| Discharge flow rate | - |
| Number of electrical wires | - |
| Amperage (Amps) | - |
| Voltage | - |
| Power type required (AC or DC) | - |
| Discharge flow per m (or ft) at x PSI (GPH, LPH, GPM, LPM) | - |
| Maximum pressure (psi) | - |
| Head pressure (m or ft) | - |
| Volumetric flow rate | - |
| Outlet pressure (m or ft *of head*) | - |
| Inlet suction (m or ft *of head*) | - |
| Maximum horesepower (hp) | - |
| Vertical lift (m or ft) | - |
| Minimum working temperature | - - |
| Maximum working temperature | |
| Outlet connection | - |
| Warranty (market only) | - |
| Certifications and listing | - |

Specific terminology related to pump specificationing includes, but may not be limited to:

1. **Best efficiency point (BEP)** - the point where the power coming out of the pump is the closest to the power coming into the pump. In other words the BEP is the point at which the head (pressure) and flow converge to produce the greatest amount of output for the least amount of energy.
2. **Brake horsepower (BHP)** - the actual amount of horsepower being consumed by the pump as measured on a pony brake or dynamometer.
3. **Cavitation** - a process in which cavities or bubbles form in the fluid low-pressure area and collapse in a higher pressure area of the pump - causing noise, damage to the pump, and loss of efficiency because it distorts the flow pattern. Occurs in centrifugal pumps when NPSHa < NPSHr.
4. **Head** - a measure of pressure, expressed in meters or feet of head for centrifugal pumps. Water is used as the default where 10 meters (33.9 ft.) of water equals one atmosphere (14.7 psi. or 1 bar).In other words, head refers to the resistance to flow, such as how many bends in the pipe the water must go through, the size of the pipes, and the distance the water needs to travel. Moreover, this is measured by meters (or feet) of resistance (or, meters or feet of head).
5. **Efficiency** - a ratio of total power output to the total power input, expressed as a percent.
6. **Flooded suction** - a type of system in which the liquid flows to the pump inlet from an elevated source by means of gravity. This is generally recommended for centrifugal pumps.
7. **Flow (flow rate)** - a measure of the liquid volume capacity of a pump. Given in gallons per hour (GPH), gallons per minute (GPM), liters per minute (L/min), or milliliters per minute (mL/min).
8. **Friction head** - the pressure expressed in pounds per square inch or feet of liquid needed to overcome the resistance to the flow in the pipe and fittings.
9. **Net positive suction head available (NPSHa)** - the NPSHa available to prevent cavitation of the pump. To calculate the NPSHa, you take the [Static Suction Head] plus [Suction Vessel Surface Pressure Head] minus [vapor pressure of your product] minus [friction losses in the suction piping, valves and fittings].
10. **Net positive suction head required (NPSHr)** - the NPSHr to stop a pump from cavitating. The NPSHr is generally supplied to you by the pump manufacturer.
11. **Pipe friction loss** - the positive head loss from the friction resistance between the pipe walls and the moving liquid.
12. **Pressure** - the force exerted on the walls of a pipe by a liquid. Normally measured in pounds per square inch (psi).
13. **Pressure drop** - refers to the loss of pressure between two points in a pipeline system. Generally occurs because of pipe friction loss of differences in elevation between the two points.
14. **Pump impeller** - the moving element in a

centrifugal pump that drives the fluid.

15. **Pump performance curve** - a diagram provided by the pump manufacturer to explain the relationship between the head and the flow rate of a pump using various size impellers. The curve also includes efficiency, NPSH required, and horse power consumption as a function of flow.
16. **Specific gravity (liquid)** - the ratio of the weight of a given volume of liquid to pure water. Pumping heavy liquids (specific gravity greater than 1.0) will require more horsepower.
17. **Suction head** - a condition that occurs when the liquid source is above the centerline of the pump.
18. **Suction lift** - a condition that occurs when the liquid source is below the centerline of the pump.
19. **Specific speed** - a formula that describes the shape of a pump impeller. The higher the specific speed the less NSPH required.
20. **Total head / total dynamic head** - the amount of head produced by the pump. Calculated by summing the static head, friction head, pressure head, and velocity head.
21. **Viscosity** - a measure of a liquid's resistance to flow. Essentially it’s a how thick the liquid is. The viscosity determines the type of pump used, the speed it can run at, and with gear pumps, the internal clearances required.

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# TABLES

**Table 20.** Life Support > Water*: Drainage basin components.*

| Drainage basin components | |
|---|---|
| **Drainage basin component** | **Provisional definition** |
| River channel | Linear feature along which surface water may flow, usually clearly differentiated from the adjacent flood plain or valley floor. |
| River reach | A homogeneous section of a river channel along which the controlling factors do not change significantly. |
| Channel pattern | Or channel planform, is the plan of the river channel from the air; may be either single threat or mult-ithread, varying according to discharge. |
| Floodplain | Valley floor area adjacent to the river channel. |
| Drainage network | Network of stream and river channels within a specific basin; may be perennial, intermittent or ephemeral/ |
| Drainage basin or catchment | Delimited by a topographic divide or watershed as the land area which collects all the surface runoff flowing in a network of channels to exit at a particular point on a river. |

**Table 21.** Life Support > Water*: The earth's water/hydrological cycle processes.*

| The earth's water cycle processes | |
|---|---|
| **Process** | **Definition** |
| Precipitation | Condensed water vapor that falls to the Earth's surface . Most precipitation occurs as rain, but also includes snow, hail, fog drip, graupel, and sleet. |
| Canopy interception | The precipitation that is intercepted by plant foliage, eventually evaporates back to the atmosphere rather than falling to the ground. |
| Snowmelt | The runoff produced by melting snow. |
| Runoff | The variety of ways by which water moves across the land. This includes both surface runoff and channel runoff. As it flows, the water may seep into the ground, evaporate into the air, become stored in lakes or reservoirs, or be extracted for agricultural or other human uses. |
| Infiltration | The flow of water from the ground surface into the ground. Once infiltrated, the water becomes soil moisture or groundwater. A recent global study using water stable isotopes, however, shows that not all soil moisture is equally available for groundwater recharge or for plant transpiration. |
| Subsurface flow | The flow of water underground, in the vadose zone and aquifers. Subsurface water may return to the surface (e.g. as a spring or by being pumped) or eventually seep into the oceans. Water returns to the land surface at lower elevation than where it infiltrated, under the force of gravity or gravity induced pressures. Groundwater tends to move slowly, and is replenished slowly, so it can remain in aquifers for thousands of years. |
| Evaporation | The transformation of water from liquid to gas phases as it moves from the ground or bodies of water into the overlying atmosphere. The source of energy for evaporation is primarily solar radiation. Evaporation often implicitly includes transpiration from plants, though together they are specifically referred to as evapotranspiration. |
| Sublimation | The state change directly from solid water (snow or ice) to water vapor. |
| Deposition | This refers to changing of water vapor directly to ice. |
| Advection | The movement of water — in solid, liquid, or vapor states — through the atmosphere. Without advection, water that evaporated over the oceans could not precipitate over land. |
| Condensation | The transformation of water vapor to liquid water droplets in the air, creating clouds and fog. |
| Transpiration | The release of water vapor from plants and soil into the air. Water vapor is a gas that cannot be seen. |
| Percolation | Water flows vertically through the soil and rocks under the influence of gravity. |
| Plate tectonics | Water enters the mantle via subduction of oceanic crust. |

# **Life Support:** Power Service System

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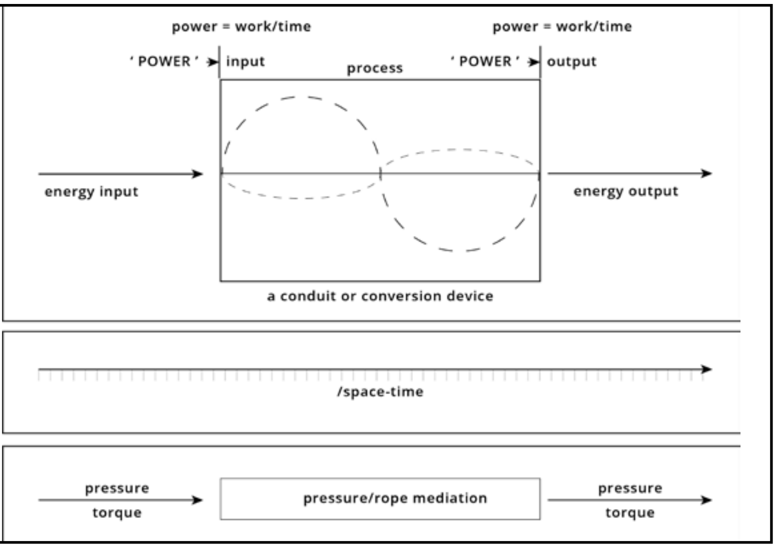
## Abstract

A power service provides power. In physics, 'energy' and 'power' are extremely complex and convoluted concepts, which are themselves not fully understood. Hence, the practical view/perspective on 'energy' and 'power' taken by the Power Service System may be referred to as the substance-like view (or depository view) of energy and power. This view states that 'objects' move and 'energy' is a "substance-like" quantity that some objects/systems "have" and other objects/systems "need" in the "form of" a substance called 'power' in order to carry out functions. It is important to recognize that this is not how 'energy' and 'power' are defined in physics, but for practical application in a material system, this definition is appropriate at the service level. All power, currently, is motion power generation; the trading of one motion for another (i.e., all power generation, currently, relies on motion generation of a new system from a prior source of motion. The primary catalyst in the universe for energy production is hydrogen; the primary source in the universe for energy production is solar bodies. Power is always distributed through objects, because it is always objects that can only be in motion. Power can be distributed through tangible objects as conduits or guides of that power. Certain technologies require guided power; other technologies can use wireless power that moves electromagnetic objects in relation to one another. Many technologies require power to operate. The human life requirement of controlling body temperature can be extended through clothing (structure), but even more greatly extended through the powering of structures in such a way that the effects is an intentional change of temperature (e.g., a useful thermal output). Power's ability to change temperature (mass vibration) can be used to cook, provide warmth, process information, and display calculations. Energy can be stored, and the usage requirements for power can be calculated. Power generation and distribution technologies can be compared.

## Graphical Abstract

**Figure 14.** *A power system transfers prior motion to another location and/or for another function through some other object that acts as a conduit or conversion device. Through this method, electricity, and other sources of power, can be produced.*



# 1 Energy (Introduction)

*It is important to realize that in physics today, we have no knowledge of what energy is.*
*- Richard Feynman, Nobel Prize 1965, Physics Lectures 4-1*

Although it is recognize that 'energy' is not a physical substance, from the perspective of the Habitat Service System, the substance metaphor shall be used. Herein, five principles guide the conceptualization and application of 'energy':

1. Energy can be viewed as *a substance-like, measurable quantity* [relative to all existence] that can be (1) stored in, (2) carried by, or (3) used over a specific time period by, an existent system.
2. Energy can be *transferred and flow* from one system (or carrier) to another, and by doing so, *effect change*. Energy provides the ability to run pre-set processes in systems (i.e., to "do things"). Energy is the instantiating capacity to produce effect\change.
3. Energy *maintains its identity* after being transferred.
4. The total quantity of energy is *conserved*.
5. The term 'energy' can be qualified by the name given to the system that is storing, carrying, or using the energy (e.g., kinetic energy, potential energy, internal energy, electrical energy, mechanical energy, etc.). Energy can exist in numerous carriers ("forms").

Energy is the capacity or ability to produce an effect (i.e., a change). The presence of a quantity of "energy" makes change possible. In physics, **energy** is a measurable property of existence (systems and objects) that can be transferred within and between existence, and converted/transformed into different forms by existence, but cannot be created or destroyed. In terms of a system, energy is the fundamental ability\capacity that allows for the existence\occurrence of the system, and any process, operation, and/or function performed by the system. It is an axiomatic property (and input) for the occurrence of any effect\change (and hence, all existence). In other words, energy is the capacity to produce change and sustain existence.

Energy is present if relationships between objects and fields change (in some way) from moment to moment, in time/memory. In physics, a 'field' is a physical quantity that has a value for each point in space and time. Moving things and doing actions in the physical environment requires energy.

**CLARIFICATION:** *A 'property' is any characteristic of a system. In physical systems, properties are considered to be either intensive or extensive. 'Intensive properties' are those that are independent of the mass of a system (e.g., temperature, pressure, density). 'Extensive properties' are those values that depend on the size or extent of a system. Therein, 'specific properties' are 'extensive properties' per unit mass.*

Hence, there exists for every system a property called 'energy'. As a property, energy is something that existence (e.g., matter) has, not something it is made of. In other words, energy is something possessed by a system or object, a property [of an something's existence relative to all existence] — a property of systems and objects that characterizes their existence, as well as their behavior and their relationships (interactions) to one another.

# 2 Power (Introduction)

Although it is recognized that power is the rate of transfer of energy, from the perspective of the Habitat Service System, the substance metaphor shall continue to be used. Herein, six principles guide the conceptualization and application of 'power'.

1. Power can be *generated* by the conversion of a source of energy.
2. Power can be *transmitted* and *distributed* from one system to another given a conducive pathway.
3. Power can be *modulated* given a control system that adjusts the quantity of energy and/or time-transfer rate the energy.
4. Power can be *applied* to (or *utilized* by) a conducive system to cause processes therein to operate.
5. The total quantity of power is *not conserved*.
6. The term 'power' can be qualified by the name of the system that is generating power, distributing power, or having power applied to it (e.g., electrical power, fluid power, hydroelectric power, wind power, etc.).

**NOTE:** *In the market, the electric power industry does not generate energy. They use the energy available in our common environment to produce and sell a product/service, that of, power as the controlled flow of electric charge (i.e., electricity or electric [potential] pressure). Through the movement of electric charge energy is transferred through useful circuitry that works/functions to provide us with additional (higher order[ed]) services.*

## 2.1 Energy and living systems

**INSIGHT:** *The more energy and power a system has [accessible], the more it can do. With more energy and more power there is more capacity/ability to do [new] things.*

"Energy" is necessary for existence; for the existence of movement, heat, electricity, and life. All organisms need energy to live. In other words, living organisms require available energy to stay alive (survive) and to thrive. Energy is connected to all organismal activities -- whenever organisms think or move, they "use" the energy available to their bodies. In a very real sense, energy makes the climate liveable for a human beings.

**NOTE:** *Energy is a need (a critical requirement\ input) for the sustainment of an existent system.*

Organisms gathering together in the form of a 'city' have a need for energy [to maintain themselves and their material service systems]. Note that the processes of Earth's climate and ecosystem are driven by the energy that Earth receives from the sun, and the geothermal energy contained within the earth. The Sun is the main source of energy for the Earth, and in particular, for changes on the earth's surface. The sun is the major source of energy for phenomena on the earth's surface, including the growth of organisms, wind, ocean currents, and the water cycle. The Earth continuously receives an uninterrupted flow of energy from the Sun. For Earth's ecosystems, the major source of energy is [in the form of] sunlight. Note here that geothermal and nuclear energy do not derive from the subsequent transformations of solar energy, but are instead related to the Earth's formation.

**HISTORICAL NOTE:** *The first technological source of energy used by humans was fire, which hominids began using/controlling [at least] several hundred thousand years ago. Whereupon, they began using it to process/transform biomass, and then later, metals.*

Without energy there is no ability to maintain structure against the entropic movement of the universe -- without energy there is no ability to do anything [constructive]. Life is universally understood to require a source of energy and mechanisms [of action] (i.e., forces) with which to transform it. Energy in many of its forms may be used in natural processes, or to provide a service to society, such as heating, refrigeration, light, or performing mechanical work. Energy, in many of its forms, may be used in our bodies' own natural processes to keep our organisms functioning optimally, and we also use it to provide technological service to ourselves and our ecology through 'energy transformation', examples of which include heating, refrigeration, lighting, performing mechanical work to operate machines, and information processing. We can transform energy, and our transformations may have more or less potential [to facilitate the expression of our highest potential]. Human technology is based largely on the knowledge of methods to manipulate these "energy" forms to produce a desired function/outcome.

**NOTE:** *Technology channels energy into work or heat (i.e., service) for the function of human fulfillment, but it does not replace it.*

The Habitat Service System's Energy Sub-system takes energy [expressed as charge and/or motion] and redirects it (via transfer or transformation) into the iterative re-construction of our material environment for service continuity and higher functioning. In other words, the Habitat Service System redirects environmental energy into material constructions that facilitate our survival and the expanded emergence of our highest potential selves.

**NOTE:** *In physics, 'charge', also known as electric charge, electrical charge, or electrostatic charge (dielectric), and symbolized 'q', is a characteristic of a unit of matter that expresses the extent to which it has "more (-ion) or fewer (+ion) electrons* *than protons".*

At a biological level, energy transformation toward higher functioning occurs through a system known as 'mitochondria'. Biologically speaking, our organisms strip electric charge off food in a similar, though significantly more complex, manner to the functioning of turbines in a hydroelectric dam through which water flows. When water goes through the turbines electric charges are moved (by the technological system), and fed into an electric energy grid through electrical transmission. In fact, our mitochondria are a miniature example of this electric charge transport chain seen in hydroelectric or nuclear generating power systems. Living organisms take high energy [macro]nutrients as proteins, lipids, and carbohydrate (as well as solar energy) and process them through an energy transducer (i.e., "powerhouse") know as mitochondria to produce a set of "high" energy intermediaries (e.g., atp, nadph) that are then directed and delivered to regions of the cell(s) that maintain living function(e.g., muscles to contract or neurons to fire or digestive juices to be released or cells to replicate). This process is technically known as 'mitochondrial bioenergetics'. At a practical level, diet and lifestyle play an important role in sustaining the ability of mitochondria to transform energy for continued functioning of the body (and optimal health)

**NOTE:** *A socio-economic system that increases available energy with equal access is 'egalitarian', and creates an environment where individuals have more freedom.*

## 2.2 The energy system architecture

**CLARIFICATION:** *Energy transfer is required for the creation and operation of all existent systems.*

The Energy-Power System accounts for energy and directs power throughout the Habitat Service System. As a service system itself, the Energy-Power System harvests, stores, and transfers energy in order to generate and transmit power throughout the Habitat Service System in order to run all technical processes. 'Energy' and its transfer rate as 'power' are necessary for all technical change: the control of material resources, the [re] ordering of material existence, and the processing of all information. Without a source of 'energy', an its transfer rate as 'power', there is no ability to effect change in the world. Thus, the Energy-Power System inputs energy carrying resources (i.e., stores of energy) and outputs generated power, which is transmitted throughout the Habitat Service System.

**NOTE:** *Every system in our physical environment needs energy to support its initial setup and sustained existence.*

The Habitat Service System Energy-Power Sub-system consists of:

1. Sources of energy.
2. An energy transfer (carrier conversion) system to generate power.
3. A heat rejection/thermal management system.
4. A power management and distribution system that includes controls for generation, transmission, and modulation of power.

The choice of a particular power system, and its particular architecture, will be determined by application requirements.

**CONSIDER THE FOLLOWING QUESTIONS:**
*<u>As a substance-like entity possessed by a system:</u>*
*Where is the energy stored?*
*Where did it come from?*
*Where did it go?*
*What does it do?*
*<u>As the need of a system:</u>*
*Into what system is the power generated?*
*Through what medium is the power transmitted?*
*Does the power meet required modulation parameters?*
*What is the power use of the system?*

All organisms require a transfer of energy to live, and all real world systems require a transfer of energy to setup and operate. In other words, living organisms and their service systems require available energy to stay alive (survive) and to thrive. Energy is connected to all activities and changes in the real world -- whenever something occurs, energy is present (or transferred).

**NOTE:** *Energy is a useful accounting tool that allows for calculating power sources and requirements, and determining whether change is "energetically" possible.*

Organisms gathering together in the form of a 'city' have a need for [the transfer of] energy to maintain themselves and their material service systems. Note that the processes of Earth's climate and ecosystem are driven by the [transfer of] energy that Earth receives from the sun, and the geothermal [transfer of] energy contained within the earth. The sun is the major source of energy for phenomena on the earth's surface, including the growth of organisms, wind, ocean currents, and the water cycle. The Earth continuously receives an uninterrupted flow of energy from the Sun. Note here that energy from geothermal and nuclear sources do not derive from the subsequent transfer of solar energy, but are instead related to the Earth's formation.

**HISTORICAL NOTE:** *The first technological source of energy "used" by humans was fire, which hominids began "using" and "controlling" [at least] several hundred thousand years ago. Whereupon, they began "using" it to process/ transform biomass, and then later, metals.*

Without energy there is no ability to maintain structure against the entropic movement of the universe

-- without energy there is no ability to do anything [constructive]. Life is universally understood to require a source of energy and mechanisms [of action] with which to transfer (i.e., "transform") it. Energy in many of its carrying forms may be "used" in natural processes, or to provide a service to society, such as heating (temperature regulation), refrigeration, illumination, mechanization, and computation. Additionally, energy may be "used" by our bodies' own natural processes to keep our organisms functioning [optimally]. We can transfer energy, and our transfers of energy into and through material systems may provide us more or less potential to facilitate the expression of our highest potential.

> *"There is no energy in matter other than that received from the environment." – Nikola Tesla*

Human technology is based largely on the knowledge of methods of transferring energy into the generation of power for a desired service function and outcome/output.

> **INSIGHT:** *Energy-power technologies may be designed to channel energy into service (e.g., working and heating) for the function of human fulfillment, but it does not replace human fulfillment.*

The Habitat Service System's Energy-Power Sub-system takes energy and redirects it via technology into the operation and iterative re-construction of the Community's material environment for service continuity and higher functioning. In other words, the Habitat Service System redirects environmental energy into material constructions that facilitate our survival and the expanded emergence of our highest potential selves.

> **INSIGHT:** *Energy is [that which is required for] the temporal [re-]ordering of existence. A constant energy source and transfer as power is needed for maintaining the ordered state of living processes. An energy source is required fro controlling the ordered state of living systems.*

At a biological level, energy transfer toward higher functioning occurs through a system known as 'mitochondria'. Biologically speaking, organisms strip electric charge off food in a similar, though significantly more complex, manner to the functioning of turbines in a hydroelectric dam through which water flows. When water goes through the turbine-generator, electric charges are moved, and transferred into an electrical energy grid through electrical transmission. In fact, mitochondria are a miniature example of this electric charge transport chain seen in hydroelectric and nuclear generating power systems. Living organisms take high energy [macro]nutrients as proteins, lipids, and carbohydrate (as well as solar carrying energy), and process them through an energy "transducer" (i.e., a "powerhouse") know as mitochondria to produce a set of "high energy" intermediaries (e.g., atp, nadph) that are then directed and delivered to regions of the cell(s) that maintain living function (e.g., muscles to contract or neurons to fire or digestive juices to be released or cells to replicate). This process is technically known as 'mitochondrial bioenergetics'. At a practical level, diet and lifestyle play an important role in sustaining the ability of mitochondria to transfer energy for continued functioning of the body (and optimal health).

> **NOTE:** *A socio-economic system that increases available energy with equal access is 'egalitarian', and creates an environment where individuals have more freedom.*

## *2.3 Energy/power grid-network*

> **INSIGHT:** *Possibly, energy is matter in motion relative to the rest of the matter in the universe.*

Within the infrastructure of the habitat service system, energy is transferred and power may be supplied via any of the following possible energy/power networks (grids):

1. Electrical power network (grid)
2. Mechanical power network (grid)
3. Pneumatic power network (grid)
4. Hydraulic power network (grid)
5. Gas transfer network (grid)

## *2.4 Energy-based services*

> *"There is no energy in matter other than that received from the environment."*
> *– Nikola Tesla*

The Energy-Power System provides two main categories of service (two categories of output): heating services and non-heating services.

### 2.4.1 Heating services

Heating services are the services whose primary function is to deliver heat. Examples are space heating, water heating, and oven heating. These heating services have two important characteristics:

- An inherent inertia hence an inherent buffer storage capacity.
- The capability of being powered with a combination of heat and electricity, combination often very flexible.

The operation of heating services usually requires the simultaneous operation of less intensive, accessory non-heating services such as the operation of a pump or a control system.

### 2.4.2 Non-heating services

Non-heating services are all the other services that do not involve energy transfer via heat. It must be noted that the operation of these services may dissipate heat as a by-product, but it is not their prime function and more importantly it is not the amount of heat that will determine the level of operation of the service. These non-heating services have:

- No inherent inertia, hence no inherent buffer storage capacity.
- To be powered exclusively by electricity or [other] pressurized substances.

## 3 Energy carriers

> *Energy is a substance-like/information-like quantity that can flow or be transferred.*

Per the substance-like perception of energy, energy is contained in and/or possess by what are called 'energy [re]sources' and 'energy carriers'. By definition, an energy source/carrier is a substance or a phenomenon that contains energy. In physics, energy always transfers (i.e., flows) simultaneously with at least one substance-like, physical quantity. Here, it is most appropriate to visualize energy as something that can flow from one place to another only when "carried" by another substance-like quantity through which change can be perceived. The thing for which change can be perceived and "carries" the energy is called an "energy carrier". Hence, the term "energy carrier" is able to provide clear language of how energy flows. The substance-like physical quantity which flows while energy is flowing, "carries" the energy, and may be referred to as an "energy carrier".

> **NOTE:** *Transfer does not mean the same thing as transformation or conversion. The terms transformation and conversion mean that the thing itself changes form. Energy does not change form; it changes carrier or system.*

"Energy" is transferred between or within carriers. When energy is transferred, some change is occurring to the carrier(s), but no-thing (no transformation) is happening to the energy. And, the carrier(s) are not necessarily transformed or converted when the energy is transferred. The energy itself is not trans-formed or converted, because it doesn't have form; it is an abstraction (in physics) and remains energy regardless of the carrier or the value of 'energy' given to that carrier.

> **CLARIFICATION:** *Energy cannot be transformed, it can only be transferred within and between carriers, until it is finally transferred through a service, whereupon it may be recoverable or irrecoverable.*

In this visualization, energy is not ever transformed (or converted) from one form into another, but rather, it transfers its carrier. The energy is transferred and the carrier(s) is changed (its motion and/or composition), possibly transformed/converted.

> **CLARIFICATION:** *When people speak about "energy conversion", they mean converting one form of energy into another form. However, energy does not have different forms. There is just energy. Hence, "energy conversion" is a misconception.*

It is customary to say that energy exists in different forms, which are transformed or converted into one another during physical processes. However, using the term "energy form" for the respective categories is unsatisfactory because it easily leads to the misinterpretation that there are different kinds of energy. In other words, the notion that the energy is transformed leads to the incorrect idea that there are different forms of energy, which there are not. It is imprecise to speak about the forms of something that itself does not change, but rather, which only changes carriers. Energy maintains its identity regardless of transfer or material transformation. There is only one energy. In this sense, 'energy carriers' exist, whereas 'energy' is the result of a mathematical expression depicting the motion, action, or change of existence (of energy carriers).

> **NOTE:** *The utilization and generation of power (as the rate at which energy is transferred) always means the transfer of energy within and/or between carriers.*

Of course, there are limits as to how literally the expression "energy carrier" should be understood. The word "carry" implies only a temporal relationship between the flow of energy and the "flow" of an energy carrier. It is not meant to imply that energy and its carrier necessarily occupy the same position in space or even "flow" with the same velocity.

Further, an energy carrier can be "loaded" with more or less energy (as in, 'energy density') in the same sense that a carrier of material objects can be loaded with more or less of the objects.

The picture of "energy carriers" and "energy load factors" is especially useful to describe devices which are traditionally called "energy transformers" or "converters." Traditionally speaking, energy flows into an energy "transformer" in one form and out in another. Unfortunately, such language suggests that one physical quantity of energy is transformed into another within such a device. Instead, energy simply changes its carrier within the device. In other words, the energy is transferred from one carrier to another within the device. Accordingly, the term 'energy transceiver' is more appropriate to the actual function of such a device. A transceiver is a device composed of both a receiver and transmitter, and designed to transmit and receive energy (or data, or a signal).

> **NOTE:** *The common term for anything that is said to convert one form of energy into another (i.e., transfer energy between carriers) is a transducer. In common parlance, a "transducer" is anything that converts one form of energy into another. But, remember that energy cannot ever be converted or transformed, it can only be transferred between carriers. A* **transducer** *is a technological device that transfers ("transforms") energy from one form to another (from trans- "across" + dùcere "to lead"). The process of transferring energy between carriers (i.e., converting one form of energy to another) is known as* **transduction***. Of note, transducers are used in electronic communications systems to convert signals of various physical forms to electronic signals, and vice versa. Examples of transducers include a battery (energy carried by chemical composition which may be transferred to an electrically conductive circuit); a hydro-electric dam (energy carried by falling water transferred to an electrically conductive circuit).*

It is easy to visually represent the energy transfer from one device or region of space to another through an energy flow diagram (or energy transfer diagram).

> **INSIGHT:** *Talking about energy transfer stresses the importance of thinking about energy as staying the same kind of thing, but going from place to place.*

Energy carriers can be acquired, transported, and used. In this sense, energy is like information. We say that it can be stored in books, on computer hard drives, external drives, and disks. Information can be transferred from place to place via cables or by wireless transmission techniques. Information can be read and applied. But, there is nothing substantial about the information itself; it cannot be touched and its mass cannot be measured; it is substance-like. Even though information is moved from place to place and stored in different ways, and received by different people who apply it, nothing about the information itself has changed.

Hence, from the information metaphor (or analogy), three principles are present:

1. Energy can be viewed as a substance-like quantity that can be stored in an existent system.
2. Energy can "flow" or be "transferred" from one system to another and so cause changes.
3. Energy maintains its identity after being transferred. Energy is always energy.

## 3.1 *The energy carrier function pyramid*

Given the availability of technology, certain carriers of energy are more or less functional than other carriers. The presence and control of carriers higher up the pyramid allows for a more flexible and thought responsive environment than those lower on the pyramid. Electricity (electrical energy/power), for instance, is highly functional, because it can be converted to mechanical or thermal energy, and also used in electronics for a variety of functions, including but not limited to communication, computing, and lighting. Carriers higher up the pyramid are more functional than those lower on the pyramid.

When attempting to "convert" a quantity of energy to a form that is higher on the energy usefulness pyramid, invariably a large amount will be degraded. When thermal energy is converted to mechanical or electrical energy, part of the thermal energy has to be expelled into the environment. This energy is considered "degraded". Degraded energy still exists but essentially can no longer be converted into mechanical or electrical energy. In other words, degraded energy can no longer do work.

## 3.2 Energy carrying sources

> **NOTE:** *An energy carrying [re]source is something that can [be used to] produce heat, sustain organisms, move objects, or produce electricity.*

Generating and utilising power means transferring energy from one carrier/source to another. The transfer of energy, as well as generation and utilization of power, necessitates the acquisition and control of sources of energy (i.e., prime moving energy carriers). An **energy carrier** is a substance or sometimes a phenomenon that contains a quantity energy that can be transferred, and in doing so, produce work or heat, or to operate chemical or physical processes. An energy carrier does not produce energy; it simply contains energy imbued by another system. Energy carriers are the source of power for the Habitat Service System's energy-requiring systems. An originating source carrier of energy, prior to any processing by the Habitat Service System, is known as a 'primary energy source/carrier' (a.k.a., prime mover). This source/carrier may be used directly, or the energy therein may be transferred to a secondary (or tertiary) energy carrier prior to being transferred as power through useful service. Secondary and tertiary carriers occupy an intermediate step in the energy-supply chain between primary sources/carriers and end-use applications.

The term '**final energy carrier**' (a.k.a., "useful energy carrier") refers to the energy carrier that delivers the energy through intended end-service (i.e., end use). A 'final energy carrier' may be a primary, secondary, or tertiary energy carrier depending upon the number of intermediary transfers.

The concept of primary and secondary energy is used especially in energy statistics in the course of compilation of energy balances  To avoid double counting, it is important to be able to separate new energy entering the system (primary) and the energy that is transformed within the system (secondary).

> **CLARIFICATION:** *'Fuels' are sometimes specifically and solely referred to as 'energy carriers'.*

There are two general types of energy source/carrier:

1. **Primary energy** is the state/source/carrier in which energy occurs in nature.
2. **Secondary energy** is produced by technically converting energy between carriers (forms). For instance, it can derive from primary energy through a single conversion step (solar radiation to electricity in a PV-panel) or through multiple steps from other forms of secondary energy (hydrogen from electrical energy through electrolysis). This conversion comes always with energy losses.

### 3.2.1 Energy carrier/resource development

> **NOTE:** *Humans can make devices that interact with the source of energy of all existence, and by so doing, increase their potential for creation and fulfillment.*

**Energy development** (a.k.a., energy resource development) is a field of scientific discovery and engineering focused on making available sufficient primary and secondary energy sources to meet power requirements.

## 3.3 Primary energy sources/carriers

> **NOTE:** *Energy in the universe transfers naturally over time in the presence of a triggering mechanism.*

A **primary source of energy (primary energy carrier)** is an energy carrying [re]source found in nature as an object or phenomena that has not been subject to any technical conversion or transfer process (by humans). It is a carrier in its "raw" form, and received as input into the Energy-Power System. The term 'primary energy' only designates those sources/carriers that involve extraction or capture, with or without separation from contiguous material, cleaning or grading, before the energy embodied in that source can be converted into heat or power.

In some cases, the primary energy carrier is the same as the final energy carrier (e.g., wood gathered for combustion and cooking purposes, animate power for pulling, or wind for sailing). Hence, primary carriers of energy can be used directly, such as burning wood sticks biomass for heat and light, or converted into a secondary energy carrying resource for storage/transport and/or higher functioning, such as wood pellets for a wood pellet stove.

The primary energy sources/carriers known to humankind are:

1. Biomass - organism composition (chemical motion)
2. Animate - organism motion (biochemical motion)
3. Solar - light/electromagnetic motion
4. Water (hydro) - type of planetary motion
5. Wind - type of planetary motion
6. Geothermal - type of planetary motion (heat; electromagnetic motion)
7. Mineral fuels (e.g., uranium) - mineral composition (atomic motion)
8. Fossil fuels (hydrocarbons) - fossilized organisms as composition (chemical motion)
9. Gravity - considered a type planetary motion (possibly, electric or electromagnetic motion)

It is observed that these primary energy carrying sources are not the ultimate source of origin of the energy. For instance, animate comes from biomass, whereas biomass ultimately comes from the sun. Apart from geothermal and mineral fuels (a.k.a., "nuclear"), all "primary energy carrying sources" ultimately get their energy from the sun.

> **NOTE:** *The systems that transfer and/or convert this primary source energy are sometimes called 'primary energy conversion/transfer systems'.*

### 3.3.1 Fuels and flows

Besides gravity, there are two types of primary energy carrier: fuels and flows. Fuels like coal, natural gas, and uranium are dense carriers of energy, that are transformed/converted (i.e., "consumed") when used. Flows are natural [motion] processes that carry energy associated with their movement. Using a flow means harnessing the motion of that flow in order to transfer its carried energy.

Fuels are dispatchable, which means the energy is available for transfer whenever it is needed. A flowing carrier differs from a fuel, because energy transfer from a flowing carrier is only available when the carrier is flowing. For instance, the energy carried by solar radiation is only available when there is sunlight, and the energy carried by wind is only available when the atmosphere is flowing (i.e., when it is windy).

### 3.3.2 Renewability

*A.k.a., Continuity.*

Primary energy carrying sources may be classified according to their **renewability** (as in, re-new-able versus non-re-new-able). However, this terminology is rather ambiguous, as the meaning of the word "renewable" often depends on the context of its use. In general, a renewable energy carrier (i.e., "renewable energy") refers to "inexhaustible natural resources", and is contrasted with in-earth exhaustible natural resources (fossil fuels). Hence, energy carrying resources are considered 'renewable' if they are naturally replenished (in a relatively short time-frame).

Presently, there are seven known renewable energy carrying sources:

1. Biomass - fuel
2. Animate - flow
3. Solar (strictly intermittent) - flow
4. Hydro - flow
5. Wind (strictly intermittent) - flow
6. Geothermal - flow
7. Gravity - unknown

Hydrocarbons are primarily contained in coal, oil and natural gas (Read: in-earth hydrocarbons). Some plants also contain hydrocarbons, but these would be classified as biomass sources. Of note, some in-earth forms of hydrocarbon are actually "renewable" in terms of being naturally replenished, but they take a long time (in concern to a human lifespan) to renew. Additionally, it is possible to imagine that a species could draw, harvest, or transfer so much motion from its planet[ary motion cycles] through large scale geothermal or atmospheric wind collection that the draw on those sources could be unsustainable and disrupt the natural motions of the planet. One could also use biomass at such a rate that it too becomes unsustainable.

> **DEFINITION:** *A variable renewable energy (VRE) carrier is a renewable resource that is non-dispatchable due to its fluctuating nature, like wind and solar, as opposed to a controllable renewable sources such as hydroelectricity, or biomass, or a relatively constant source such as geothermal or run-of-the-river hydroelectricity.*

## *3.4 Secondary energy sources/carriers*

A **secondary source of energy (secondary energy carrier)** is derived from the transfer of energy from a primary energy carrier, whereupon the carrier itself may or may not have been transformed/converted in the process. Secondary energy should be used to designate all sources of energy that results from transformation of primary sources. Secondary sources of energy are sometimes confusingly referred to as just "energy carriers", wherein primary sources are referred to as "energy sources", because secondary carriers, unlike primary sources that are not also 'final energy carriers', are generally capable of being stored in a usable "form" and transported in a controlled manner from one place to another.

> **CLARIFICATION:** *Primary carriers transfer energy directly from the environment, while secondary carriers acquire energy transferred from the primary environmental carriers.*

There are four types of secondary energy carrier:

1. Mechanical [solid] carrier - mechanical energy/power
2. Pressurized [fluid] carrier - fluid energy/power (including elevation relocated water or other liquid)
3. Chemical [bond] carrier - chemical energy/power
4. Electrical [charge] carrier - electrical energy/power or electricity
5. Electromagnetic [field] carrier - electromagnetic energy/power
6. Thermal carrier - thermal energy/power or internal energy

> **NOTE:** *The systems that transfer and/or convert this secondary source energy are sometimes*

*called 'secondary energy conversion/transfer systems'.*

For example, petrol fuel (secondary, chemical carrier) is made from the processing of crude oil (primary). Electricity (secondary) may be obtained from the harvesting of planetary motion (hydro-electric and wind-electric). Note that a battery is an example of a secondary energy source, a type of 'fuel' that stores electric charge potential as "chemical energy". Electricity is a secondary energy resource, and it can be generated/made by a number of different primary sources. What we commonly know as "the flow of electric charge/power" (i.e., "electricity") is [to us] a secondary "energy" source. The controlled flow of electric charge (i.e., "electricity") is a product of the transfer of energy from primary sources of energy such as wind, coal, natural gas, or solar [into the controlled flow of electric charge].

**NOTE:** *The electrical carrier takes the form of an electrical cable network or electrical grid reticulating electricity around the generation point. The thermal carrier may take the form of a pipe network reticulating heating "hot" water (HHW) around the system. Heat is then delivered to the services through heat exchangers. Operation of an HHW network requires a minimum of electricity for the circulating pumps and controls.*

The presence of thermal carriers is not strictly necessary in a habitat service system since all heating services could be powered exclusively by electricity (heat on-demand), but the presence of a thermal carrier is generally well justified by the facts that: 1) a large amount of waste heat can be recovered on the electricity generation process; and 2) heat-only can be produced much more efficiently than electricity-only.

The concept of 'renewability' does not apply to secondary energy sources/carriers. For instance, the energy sources we use to produce (make/generate) the controlled flow of electric charge may be characterized as renewable or non-renewable, but electric charge (and its flow) cannot be classified as either renewable nor non-renewable.

## *3.5 Power systems*

**NOTE:** *Conceptually, there is no such thing as an "energy system", because energy is just a quantity. Power involves the transfer of energy per time, and hence, involves a set of relationships that form a system.*

All technological systems require the transfer of energy for their construction and operation. In order to transfer energy effectively, the flow of its carriers must be controlled. The rate at which energy is transferred is called power. Whereas an 'energy system' may be said to account for the presence of and necessity for energy, a 'power system' may be said to control the rate and quality of energy transfer, by controlling its generation, transmission, distribution, and modulation.

Power systems may be categorized according to the type of carrier experiencing the transfer of energy. Note that the suffixes of the types of power system mentioned below, end in either "ic" or "ical" or "al", which are used to form adjectives from nouns (gerunds) with the meaning "of or pertaining to" or "a type of". The suffix "ic" also means "application of", as in electron*ic* (the application of electrons) or atom*ic* (the application of the atom).

Energy can be transferred, and hence, work can be done in the following physical [power] systems:

1. **Kinetic/mechanical power system (mechanical power system)** - a solid is the carrier using linear or rotational motion.
2. **Fluidic/fluidal power system** - a fluid is the carrier.
3. **Atomic/chemical power system** - the structural composition of atoms and molecules (i.e., mass, number of particles, and bonding), is the carrier.
4. **Thermic/thermal power system** - atomic and molecular oscillation in all degrees of freedom is the carrier.
5. **Electric/electrical power system** - electrically conductive circuit within which free charged particles are the carrier.
6. **Magnetic power system** - magnetism is the carrier.
7. **Electromagnetic power system** - an electromagnetic radiating "wave" (the vacuum or ether) is the carrier.

**NOTE:** *Technically, mechanical power can be subdivided into solid mechanical, fluid, and inertia.*

These power systems may be connected to form a network of transceiving (transmitting and receiving, conversion) power systems.

**NOTE:** *As a physical concept, 'power' requires both a change in the universe and a specified time over which the change occurs.*

When building a system to transfer energy for the production of power, three main questions must be considered:

1. What is the original carrier of the energy?
2. What energy transfer process will be used?
3. How will the carrier be changed and/or moved from one place to another?
4. How will the energy eventually be transferred through useful service?
5. Other factors that must be considered include where the energy carrier is located, the amount of

power that must be produced, and the length of time it must be controlled.

Like all technology systems, power systems have inputs, processes, outputs, and feedback. All power systems require the same five resources as inputs:

1. Information
2. Materials
3. Tools and machines
4. Energy
5. Time
6. ~~Capital~~ // no market in community

The operation of a power system requires:

1. Power generation units
2. System controls
3. System stability

## *3.6 Energy transfer/power conversion systems*

**NOTE:** *Power engineering deals with the generation, transmission, and distribution of power as well as the design of a range of related devices.*

Power conversion refers to the time interval transfer of energy between different carriers/sources of energy (Note: In practice, "power conversion" is sometimes referred to as "energy conversion"). A power conversion system (a.k.a., "energy transfer system", "energy transformer", "energy transducer", "energy transceiver", "energy converter") accepts input energy as power from one carrier (i.e., one power/energy system) and delivers output energy as power to another carrier (i.e., in another energy system).

**REMEMBER:** *In the substance-like metaphor, energy does not ever transform, though it can be transferred and stored. And, power (as the rate of transfer) does not convert, though it can be generated, distributed, and utilized.*

The 'utilization' and 'generation' of power always means transferring energy from one carrier to/through another. Whereas the 'generation' of power relates to a source of energy, the 'utilisation' of power serves an end-use of energy. In between, the energy can flow through a number of energy transfer/power conversion steps. The words "generation" and "utilisation" are a little confusing because, in fact, no energy can be created or destroyed, but power can be supplied and cancelled.

The generation, transmission, and utilization of power requires the input, transfer, and output of energy:

1. <u>When generating power</u>, energy is made available (input) from a source, and transferred into/through a technical system to produce power (energy transferring at a specific rate).
2. <u>When transmitting power</u>, energy is carried by the transmitting system at a specific rate.
3. <u>When utilising power</u>, energy is made unavailable (output), possibly irretrievably so, to power a process or service.

Power conversion devices are not 100% efficient. Some input energy is "lost" in the transfer process.

Energy transfer/power conversion devices (technologies and systems) are generally named for their input energy carrying system:

1. Mechanical power conversion transfers energy carried by a mechanical system to:
   - Mechanical > fluidal (e.g, power steering pump)
   - Mechanical > electrical (e.g., alternator)
   - Mechanical > fluidal (e.g., fan, propeller)
   - Mechanical > thermal (e.g., thermal welding)
2. Fluidal power conversion transfers energy carried by a fluidal system to:
   - Fluidal > mechanical as linear/rotational motion (e.g., turbine)
3. Electrical power conversion transfers energy carried by an electric system to:
   - Electrical > mechanical (e.g., electric motor, actuator)
   - Electrical > thermal (e.g., heater, light bulb)
   - Electrical > electromagnetic (e.g., antenna transmitter)
   - Electrical > magnetic (e.g., electromagnetic induction, electrical transformer)
4. Magnetic power conversion transfers energy carried by a magnetic system to:
   - Magnetic > electrical (e.g., electrical generator)
   - Magnetic > mechanical (e.g., magnets)
- Electromagnetic power conversion transfers energy carried by a electromagnetic system to:
   - Electromagnetic > electrical (e.g., antenna receiver, solar panel)
   - Electromagnetic > mechanical (e.g., electromagnet)
5. Thermal power conversion transfers energy carried by a thermal system to:
   - Thermal > fluidal (e.g., steam plant boilers generate electricity)
   - Thermal > mechanical (e.g., combustion engine)
   - Thermal > electric (e.g., thermopile, thermoelectric generator)
6. Chemical power conversion transfers energy carried by a chemical system to:
   - Chemical > mechanical (e.g., chemical motor, internal combustion engine)

- Chemical > electrical (e.g., chemical battery)
- Chemical > electromagnetic (e.g., combustion fire)

Power can be converted from one system to another form in three primary ways:

1. Through the action of forces.
   A. **Electric and magnetic [force] fields** - Charged "particles", upon which electrical fields exert forces, possess potential energy in the presence of an electric field in a way similar to that of an object in a gravitational field. These force fields can accelerate particles, converting a particle's potential energy into kinetic energy. Likewise, charged particles can interact via the electric and magnetic fields they create, transferring energy between them, and in the case of an electrical current in a conductor, cause molecules to vibrate (i.e. converting electrical potential energy into heat).
   B. **Frictional forces** - The macroscopic (large-scale) energy of an object, that is, the potential and kinetic energy associated with the position, orientation, or motion of the entire object, not counting the thermal or heat energy of the system, can be converted into thermal energy (heat), whenever the object slides against another object. The sliding causes the molecules on the surfaces of contact to interact via electromagnetic fields with one another and start vibrating.
   C. **Gravitational force** - when gravity accelerates a falling object it converts its potential energy to kinetic energy. Likewise, when an object is lifted, the object stores the energy exerted by the lifter as a potential energy in the earth-object system.
2. When atoms absorb or emit electromagnetic radiation. When light falls on an object, an incident photon may either pass through the object, be reflected by the object, or be absorbed by the atoms making up the object. If most of the photons pass through, the object is said to be transparent. Depending on the smoothness of the surface on the scale of the photon's wavelength, the reflection may be either diffuse (rough surface) or coherent (smooth surface). If the photon is absorbed, the photon's energy may also be split up and converted in the following ways:
   A. **Photothermal effect:** the energy absorbed may simply produce thermal energy, or heat in the object. In this case the photon's energy is converted into vibrations of the molecules called phonons, which is actually heat energy.
   B. **Photoelectric effect:** the energy absorbed may be converted into the kinetic energy of conduction electrons, and hence electrical energy.
   C. **Photochemical effect:** the energy may bring about chemical changes which effectively store the energy.
3. When nuclear reactions occur, that is, when there are rearrangements of the subatomic particles that make up the nuclei of atoms. There are two basic types: **Fission** - when nuclei combine, and **Fusion** - when nuclei split apart.

## *3.7 Transfer efficiency*

**INSIGHT:** *In community, all energy transfer loses are heat and/or technical losses; there are no administrative loses. In the market, many energy transfer losses are administrative losses.*

Efficiency' is the ability to achieve a desired result with as little "loss" of energy and effort as possible. In concern to energy and power, it is the ability to avoid "wasting" materials, energy, efforts, and time in producing a desired result. It is a dimensionless performance measure of a process or technology. The term 'efficiency' makes sense only in reference to the wanted effect. Energy transfer efficiency is not defined uniquely, but instead depends on (is relative to) the usefulness of the output. An incandescent light bulb, for example, might have 2% efficiency at emitting light, yet still be 98% efficient at heating a room. (in practice it is nearly 100% efficient at heating a room because the light energy will also be converted to heat eventually, apart from the small fraction that leaves through any windows).

**NOTE:** *Energy may be transferred within or between carriers at various efficiencies, depending upon technical ability.*

Transfer efficiency refers to the ratio between the useful output of a system, and the input, and it can be calculated in terms of energy and power. Efficiency is directly calculated through the output-input ratio, where the output is the desired service, and the input is the quantity input into the system. In concern to energy, the efficiency of an energy transfer is the percentage or fraction, of the energy input that is transferred to useful output. This figure is multiplied by 100% to give you the result in percentage.

**NOTE:** *The system boundary must be carefully specified when measuring efficiency.*

Generally, energy transfer efficiency is a dimensionless number between 0 and 1.0, or 0% to 100% (when the ratio is multiplied by 100). Transfer efficiency is usually expressed by the Greek letter $\eta$ = (output energy / input energy) x 100%.

1. In concern to energy, the efficiency of a system transfer process is defined as the "quantity of

energy" output from the transfer (the output) divided by the "quantity of energy" put in for transfer (the input), and then, multiplied by 100%.
   - Energy efficiency % = (useful energy output / useful energy input) x 100%
   - Efficiency = useful energy out / total energy in
2. In concern to power, the efficiency of a system transfer process is defined as "useful power output" divided by the "total power consumed", and then, multiplied by 100%.
   - Power efficiency % = (useful power output / useful power input) x 100%
   - Efficiency = useful power out / total power in
3. In concern to work, efficiency is the ratio of useful work out from the total amount of work done, as a percentage.
   - Efficiency % = (useful work out (J) / Total work done (J)) x 100

If the efficiency of an energy transfer amounts to 60%, this means that out of 100 energy units included in a process (total energy in), 60 were transferred through to desired change (useful energy out), whereas the other 40 were transferred through undesired change (wasted energy out). That energy or power which has gone into the process, but has not come out of the process as useful is generally considered "wasted" or a loss (i.e., cannot be used).

> **NOTE:** *Energy is always transferred from one input carrier to many output carriers (the application + "losses") with perfect efficiency (law of conservation). An energy transfer technology with an efficiency over 100% may be called an 'overunity machine' or 'zero-point machine', and there are no known schematics for such a machine, which breaks the laws of thermodynamics.*

Electrical power transfer has three types of energy loss:

1. The Joule effect, where energy is lost as heat in the conductor (a copper wire, for example).
2. Magnetic losses, where energy dissipates into a magnetic field.
3. The dielectric effect, where energy is absorbed in the insulating material.

# 4 Power system types

There are seven general power system types:

1. Mechanical (kinetic) power systems
2. Fluidic/fluidal power system
3. Atomic/chemical power system
4. Thermic/thermal power system
5. Electric/electrical power system
6. Magnetic power system
7. Electromagnetic power system

## *4.1 Mechanical (kinetic) power systems*

Mechanical power is the time rate of motion, and when motion is applied to a task, then it is the time rate of work [done to accomplish the task].

## *4.2 Mechanics*

**Mechanics** is (physics) an area of science that studies and attempts to predict the behavior of physical bodies when subject to forces and displacements, and the subsequent effects of the bodies on their environment. In other words, it is concerned with the action of forces that displace (i.e., move) material objects with mass. It is the study of interactions between bodies and forces that produce motion. Mechanics describes the motion of bodies, and the causes that effect them. This includes the special case where the "motion" is no motion (i.e. bodies that are stationary).

> **NOTE:** *In physics, a physical body or physical object (sometimes simply called a body or object; also: concrete object) is an identifiable collection of matter, which may be more or less constrained by an identifiable boundary, to move together by translation or rotation, in 3-dimensional space. In classical mechanics a physical body is collection of matter having properties including: mass, velocity, momentum, and energy. The matter exists in a volume of three-dimensional space. This space is its extension. In continuum mechanics an object may be described as a collection of sub objects, down to an infinitesimal division, which interact with each other by forces which may be described internally by pressure and mechanical stress.*

Mechanics is based on the three "Newtonian laws of motion":

1. **First law** - In an inertial reference frame, an object either remains at rest or continues to move at a constant velocity, unless acted upon by a net force.
2. **Second law** - In an inertial reference frame, the sum of the forces F on an object is equal to the mass m of that object multiplied by the

acceleration a of the object: F = ma.
3. **Third law** - When one body exerts a force on a second body, the second body simultaneously exerts a force equal in magnitude and opposite in direction on the first body.

There are two branches of mechanics, each with multiple sub-branches:

- **Classical mechanics** - study of motion above atomic scale.
- **Quantum mechanics** - study of motion below atomic scale.

These branch distinctions, however, are not fundamental in nature. They are distinctions made by humans, which are useful for comprehending and for engineering when nature (i.e., physics) is not fully understood. Hence, any attempt to define the difference is to some extent arbitrary, and will not last as the subject is unified through greater understanding.

## 4.2.1 Energy in mechanics

In concern to mechanics, there are four elements that compose the characterization of energy:

1. **Cause** - that which allows for (gives rise to) a force.
2. **Force** - any interaction that, when unopposed, will change the motion of an object.
3. **Displacement (effect)** - a motion of any distance.
4. **Work** - the act of using a force to cause displacement. Hence, there are three key elements to the concept of 'work' - force, displacement, and cause.

Energy is what allows the exertion of a force. With "zero" energy, no force can be exerted, and no action can be taken. By exerting a force over a distance energy is transferred ("transformed"). Work is technically defined as what is done when a force moves its point of application. Work implies movement of a body by the application of a force. Work may be perceptible or imperceptible to human senses. Energy, can therefore be termed as that which can bring about a change and is the cause of all dynamic manifestations.

## 4.2.2 Classical mechanics

"Classical" mechanics is a branch of physics concerned with the set of physical laws describing the motion of matter (in macroscopic and microscopic form, but not atomic) under the influence of forces. Within classical mechanics are fields of study that describe the behavior of solids, liquids and gases and other specific sub-topics.

Classical mechanics consists of the work mostly done in the areas of chemistry and physics prior to the 20th century. This includes the organization of the periodic table, thermodynamics, the wave theory of light, and Newtonian mechanics.

There are three perspectives (branches) deriving axiomatic formulations for classical mechanics separated into two forms of mechanics, the original Newtonian Mechanics and the reformulated Analytical Mechanics:

**Newtonian mechanics** (original) is classical mechanics based on the Newtonian understanding of motion as understood through the equation (Newtonian second law of motion):

- Force (f) = mass (m) · acceleration (a)
- This formulation of classical mechanics is also widely known as Newtonian mechanics.

**Analytical mechanics** (reformulation of Newtonian mechanics with an emphasis on system energy, rather than on forces):

1. Classical mechanics based on the formulation of Lagrangian mechanics.
2. Classical mechanics based on the formulation of Hamiltonian mechanics. In Hamiltonian mechanics, a classical physical system is described by a set of canonical coordinates r = (q,p), where each component of the coordinate $q_i,p_i$ is indexed to the frame of reference of the system. A particle on a line whose position (q) and momentum (p) are functions of time (t). If the energy (H) is a function of position and momentum, then the time evolution of the system is:
   - $dp/dt = -(\partial H/\partial q)$ and $dq/dt = +(\partial H/\partial p)$
   - where, H = H(q,p,t) is the Hamiltonian, which often corresponds to the total energy of the system.

**NOTE:** *In physics, a force is any interaction that, when unopposed, will change the motion of an object. In other words, a force can cause an object with mass to change its velocity (which includes to begin moving from a state of rest), i.e., to accelerate. Force can also be described by intuitive concepts such as a push or a pull. A force has both magnitude and direction, making it a vector quantity. It is measured in the SI unit of newtons and represented by the symbol F.*

The following branches of Classical Newtonian Mechanics are useful to have in awareness, simply because they are used so frequently in academic and industrial physics and engineering:

1. **Statics** is (mechanics) the study of forces in equilibrium without consideration of changes over time (stationary objects).
   - The study of equilibrium and its relation to forces.
2. **Kinematics** is (mechanics) the study of (relative) motion, including displacement, velocity, and acceleration, without any consideration of why

those quantities have the values they do. Herein, the description of the motion itself (expressed by mechanics) is called kinematics. In other words, kinematics is the branch of classical mechanics that studies and describes the motion of physically joined points/parts (multi-link systems) such as an engine, a robotic arm or the skeleton of the human body. These descriptions setup the relevant degrees of freedom, represented as variables in a relevant mathematical form. Kinematics is concerned with the effects of motion on objects without reference to its causes. Kinematics pertains to motions determined by conservation laws: kinematics tells you that momentum and energy have to balance.
   - The study of the implications of observed motions without regard for circumstances causing them.
3. **Kineto-statics** is (mechanics) is concerned with the study of forces in equilibrium, with the addition of motion related forces (like inertia forces via D'Alembert's principle) one instant at the time. Results from one time frame do not affect the results on the next time frame.
4. **Dynamics** is (mechanics) concerned with the effects of forces and torques on the motion of objects. Dynamics means a study of the rules governing the interactions of particles, which allow for a determination of why the quantities have the values they do. The description of the causes of motion expressed by mechanics, and how these causes effect motion is called 'dynamics'. These causes are often divided into forces and torques. Dynamics provides full consideration of time varying phenomena in the interaction between motions, forces and material properties. Typically there is a time-integration process where results from one time-frame effect the results on the next time-frame. Dynamics depends on interactions, and not just on conserved quantities, which is what kinematics depends on.
   - The study of motion and its relation to forces.
   - In engineering, **dynamics** is sometimes referred to as the combination of kinematics and kinetics of proper motion. And, statics is the kinematics and kinetics of static equilibrium.

The difference between kinematics and dynamics may be understood in terms of programming a computer to simulate the physical system. 'Kinematics' is the data structure required to simulate the general situation, involving what variables with what range of values. 'Dynamics' is the actual algorithm that simulates the motion. The difference is the consideration of forces. 'Kinematics' concerns the range of movement or change a system can undergo, or the state space in which it acts. 'Dynamics' concerns the movement it undergoes according to the laws of motion. This means that conservation of energy and other quantities is dynamical, because it only holds when the equations of motion are in effect.

When mechanics is studied in the context of macroscopic bodies and systems, then following branches are useful to have in awareness, simply because they are used in academic and industrial physics and engineering:

- Continuum mechanics is the study of the physics of continuous materials, and can be subdivided into solid mechanics and fluid mechanics. It is a branch of Classical Newtonian Mechanics that deals with analyses of the kinematics and mechanical behavior of materials modelled as a continuous mass, rather than as discrete particles.
  - **Solid mechanics** is the branch of continuum mechanics that studies the behavior of solid materials, especially their motion and deformation under the action of forces, temperature changes, phase changes, and other external or internal agents. The study of the physics of continuous materials with a defined rest shape.
  - **Fluid mechanics** is the branch of continuum mechanics that studies the behavior of fluids (liquids, gases, and plasmas), and the forces on them. The study of the physics of continuous materials which deform when subjected to a force.
  - **Deformation mechanics** is the branch of continuum mechanics that studies the behavior of a body undergoing transformation from a reference configuration to a current configuration.
  - **Rheology** is the branch of continuum mechanics that concerns the study of materials with both solid and fluid characteristics.

When mechanics is applied to the design and development of technology, then following branches/ disciplines are useful to have in awareness, simply because they are used in academic and industrial physics and engineering:

1. **Applied mechanics** is the practical application of mechanics.
2. **Mechanical engineering** (classical mechanical engineering) is a discipline of engineering that applies the principles of physics and materials science for analysis, design, manufacturing, and maintenance of mechanical systems. It is the branch of engineering that involves the production

and usage of heat and mechanical power for the design, production, and operation of machines and tools.

3. **Biomechanics** is (mechanics) concerned with the study of the movement of living things using the science of mechanics, which provides conceptual and mathematical tools as necessary for understanding how living things move. Biomechanics is the study of the structure and function of biological systems such as humans, animals, plants, organs, fungi, and cells by means of the methods of mechanics.
4. **Mechatronics** is multidisciplinary field of science that includes a combination of mechanical engineering, electronics, electrical engineering, and computer engineering (and possibly other disciplines) in the design and development of technology.

**NOTE:** *In a mechanical-electronic system torque is analogous to current, and speed is analogous to voltage. The product of speed and torque is power (mechanical) and the product of current and voltage is power (electrical).*

## 4.3 Thermodynamics

Simplistically, thermodynamics is a branch of physics that deals with heat and temperature and their relation to energy and work. In other words thermodynamics studies the effects of changes in temperature, pressure, and volume on physical systems on the macroscopic scale, and the transfer of energy as heat. Thermodynamics is the study of the interplay (exchange) between [mechanical] work and heat (as forms of energy). It relates to the exchanges between heat and work. The behavior of these quantities is governed by the four laws of thermodynamics, irrespective of the composition or specific properties of the material or system in question. The laws of thermodynamics are explained in terms of microscopic constituents by ‘statistical mechanics’. The goal of ‘statistical mechanics’ is to extract the macroscopic thermodynamic quantities like pressure, entropy, internal energy, etc. in terms of the microscopic laws governing a particle.

Thermodynamics was established in the 19th century as scientists were first discovering how to build and operate steam engines. Thermodynamics deals only with the large scale response of a system which we can observe and measure in experiments. In more detail, the theory of the relations between various macroscopic observables, such as temperature, volume, pressure, magnetization, and polarization of a system is called ‘thermodynamics’. There are two principal forms of thermodynamics as a study: classical and relativistic.

The starting point for most thermodynamic considerations is the laws of thermodynamics, which postulate that energy can be exchanged between physical systems as ‘heat’ and ‘work’. They also postulate the existence of a quantity named entropy, which can be defined for any system. In thermodynamics, interactions between large ensembles of objects are studied and categorized. Central to this are the concepts of system and surrounding. Therein, a system is composed of particles whose average motions define its properties, which in turn are related to one another.

Classical thermodynamics describes how heat flows in order to maximize total entropy, and is valid only for systems at rest with respect to observer. Relativistic thermodynamics was primarily introduced to account for the effect of relative motion between the observer and the system.

In concern to classical thermodynamics, there are several initial “laws”. The zeroth law of thermodynamics involves some simple definitions of ‘thermodynamic equilibrium’. Thermodynamic equilibrium leads to the large scale definition of ‘temperature’, as opposed to the small scale definition related to the ‘kinetic energy’ of the molecules. The first law of thermodynamics relates the various forms of kinetic and potential energy in a system to the work that a system can perform and to the transfer of heat. This law is sometimes taken as the definition of ‘internal energy’, and introduces an additional state variable, ‘enthalpy’. The first law of thermodynamics allows for many possible states of a system to exist. But, experience indicates that only certain states occur. This leads to the second law of thermodynamics and the definition of another state variable called ‘entropy’. The second law stipulates that the total entropy of a system plus its environment can not  decrease; it can remain constant for a reversible process but must always increase for an irreversible process.

The basic equation in thermodynamics is:

- $dE = dQ - PdY$
- Where, E is internal energy of a subsystem; Q is thermal energy; P is pressure; Y is volume.

The energy change of the selected subsystem is due to the work made by external forces. Therefore, the complete energy change of a subsystem corresponds to dE.

Through equations with the common variable of ‘energy’, it is possible to link classical mechanics with thermodynamics.

**NOTE:** *In thermodynamics, a mechanical equilibrium is defined as a uniform pressure (for a fluid). In classical mechanics, equilibrium is defined by: sum of external forces and external torques equals zero.*

## 4.4 Mechanical systems

A **mechanical system** is defined by its kinematics, which is described by links and coordinates. Links make up the physical composition of a mechanical system. Coordinates are used to express the time-evolution of a continuous state that results in motion. A mechanical system is defined as a collection of bodies (or links and other material components) in which some or all of the bodies can move relative to one another.

A mechanical power system produces, directs, and manages mechanical power to accomplish a task involving forces, energy transfer, and the movement of physical bodies. A mechanical power system uses forces (and energy) and the displacement of physical bodies to do mechanical work and effect change. The bodies may be rigid or non-rigid.

Mechanical work is the amount of energy transferred by a force, and mechanical power is the time derivative of mechanical work. In other words, mechanical power is a measure of the mechanical work done by means of energy transferring through a mechanical system over a certain period of time. Mechanical power is the rate of doing mechanical work; it is how fast mechanical energy is being or can be delivered to/through a mechanical system.

To clarify what is meant by mechanical work, its definition can be re-stated in a number of different ways:

1. Mechanical work is the component of the force that moves the object times the distance the object moves.
2. Mechanical work is defined as the product of the force exerted on a body and the distance it moves in the direction of that force.
3. Mechanical work is the force times the distance on which it acts.
4. Mechanical work is the force times the displacement in the direction of force.
5. Mechanical work is the action of a force moving through a distance.
6. Mechanical work is the product of a force and the displacement caused by the force when both are measured in the same direction.
7. Mechanical work is the scalar product between the applied force and the displacement vector of the motion.
8. If a force is allowed to act through a distance, it is doing mechanical work.
9. Similarly, if torque is allowed to act through a rotational distance, it is doing mechanical work.

In mechanics, the [mechanical] work done on an object is related to the forces acting on it. Mechanical work is a scalar value. A mechanical force has two attributes and two states. The two attributes are:

1. Direction
2. Magnitude

The two states are:

1. The mass of that which is displaced.
2. Its previous state of motion.

Mechanical work is equal to the force acting on an object times the distance the object is displaced (or moved). Note that only motion that is in the same direction as the force "counts". The formula for mechanical work is:

- Work (W) = Force (F) · distance (x)
- $W = \int F \cdot x$
- $W = F \times d \times \cos\Theta$
- Units of work: Joules (do not use N.m)

Differentiating by time gives indicates that instantaneous power is equal to the force times the object's velocity v(t):

- $P(t) = F(f) \cdot v(t)$

Power as a function of time, is the rate at which work is done:

- $P(t) = W / t$

Here, **acceleration** is measured by dividing an object's velocity by a unit time. On Earth, the "gravitational" acceleration constant is 9.8m/s^2, which is the rate at which an object's velocity changes. **Velocity** is equal to the distance that an object travels per unit time in a certain direction. It is a vector quantity, meaning it contains both speed and direction.

- Torque is a vector value.

A mechanical system consists of (at least):

1. A power source and actuators that generate forces and movement.
2. A system of mechanisms that shape the actuator input to achieve a specific application of output forces and movement.
3. A controller with sensors that compares the output to a performance goal and then directs the actuator input.

The 'mechanism' of a mechanical system is assembled from components called machine elements. These elements provide structure for the system and control its movement.

1. Linear kinematics
2. Angular kinematics
3. Linear kinetics
4. Angular kinetics
5. Mechanical equilibrium

**DEFINITION: Mechanical degrees of freedom (DOF)** *are classified as either scleronomic (i.e., time-independent) or rheonomic (i.e., time-dependent). The number of degrees of freedom (DOF) of a mechanical system is defined as the minimum number of generalized coordinates necessary to define the configuration of the system.*

### 4.4.1 Motion

There are four main types of motion:

1. Linear Motion – movement in a straight line
2. Reciprocating Motion – backwards and forwards or up and down movement (e.g., engine pistons and valves)
3. Angular/Rotary Motion – movement around in a circle
4. Oscillating Motion – movement over and back in an arc

There are five main types of force:

1. Tension (tensile force) – is when something is pulled and can result in stretching.
2. Compression (compressive force) – is when something is squeezed and can result in crushing.
3. Shear (shearing force) – is when something is cut or slides and results in sliding or shearing.
4. Torsion (torsion force) - is when something is twisted.
5. Bending (bending force) – is when something is bent and can be permanently deformed.

## *4.5 Mechanical devices*

**CLARIFICATION:** *Commonly, a 'machine' takes in power and converts it to useful output; it is a tool containing one or more parts that transfers energy through mechanical power to perform an intended action/process. There are several types of machines: mechanical machines involving mechanical power, as well as mechanical work; computers and sensors are programmable (usually electronic or mechatronic) machines; and molecular machines (nano-machines) involve molecular components that produce quasi-mechanical movements (output) in response to specific stimuli (input); or some combination thereof.*

A **mechanical device** (or simply, **machine** or **mechanical machine**) is a system that applies mechanical power through the principles of classical mechanics to achieve desired forces and movement (motion). It is an assemblage of parts that transmit forces and motion, and transfer energy, in a predetermined manner. Machines are technological devices used to change the size, direction and speed of forces, and can also change the type of motion produced. Machines control the magnitude and direction of motion. All machines require a power source and transfer [mechanical] energy.

A mechanical device has two functions: transmitting definite relative motion and transmitting force. These functions require strength and rigidity to transmit the forces. Hence, a machine is a combination of rigid or resistant bodies, formed and connected so that they move with definite relative motions and transmit force from the source of power to the resistance to be overcome. In specific, a machine is a collection of resistant bodies arranged to change the magnitude, direction or point of application of a moving force(s) for a specific function (requirement and use). Motion is an essential part of a machine; without it, at least in principle, there is no machine, but only a structure. A **structure** transmits force without motion. A structure is a mechanism in which motion is precluded.

**DEFINITION:** *The* **configuration** *of a mechanical system is defined as the position of each of the bodies within the system at a particular instant. In general, both translation and rotation coordinates are needed to describe the position of a rigid body. Together the translation and rotation coordinates are called generalized coordinates. A configuration is a set containing the positions of all particles of the body.*

Complex machines involve a system of mechanisms that shape the input to achieve a specific application of output forces and movement. The term **mechanism** is applied to the combination of geometrical bodies which constitute a machine or part of a machine. A mechanism may therefore be defined as a combination of rigid or resistant bodies, formed and connected so that they move with definite relative motions with respect to one another. Whereas machines transfer energy to do work, mechanisms modify motion, and may or may not perform the function of transferring energy. In kinematics, a mechanism is a means of transmitting, controlling, or constraining relative movement. Machines may, and usually do, consist of mechanisms, with a source of power added. A mechanism is usually a piece of a larger process or mechanical system considered purely with respect to motion (kinematically). Sometimes an entire machine may be referred to as a mechanism, while still being a part of a larger machine. Examples are the steering mechanism in a car, or the winding mechanism of a wristwatch. Multiple co-joined mechanisms, however, are machines. The term **machinery** generally means machines and mechanisms.

**DEFINITION:** *A 'mechanism' is the fundamental physical or chemical processes involved in or responsible for an action, reaction, or other natural phenomenon.*

Mechanisms can be divided into planar mechanisms and spatial mechanisms, according to the relative motion of the rigid bodies. In a **planar mechanisms**, all of the relative motions of the rigid bodies are in one plane or in parallel planes. If there is any relative motion that is not in the same plane or in parallel planes, the mechanism is called the **spatial mechanism**. In other words, planar mechanisms are essentially two dimensional while spatial mechanisms are three dimensional.

> **NOTE:** *The restriction to resistant bodies sets fluid machines (hydraulic and pneumatic) into their own category of machine, except for a hydraulic press, which depends on statics.* **Statics** *is the branch of mechanics concerned with bodies at rest and forces in equilibrium.*

The mechanical inputs and outputs of a machine may be either forces or torques, and a machine may convert one into the other. A torque causes rotation, while a force causes linear motion. The work done is either torque times angle of rotation, or force times distance. The dimensions of torque are force times distance, and this should be carefully distinguished from work, which has the same dimensions.

A fundamental property of machines is that the input and output work are the same, except for frictional losses that make the output work smaller (the principle of energy conservation).

An "ideal machine" is one in which the parts are considered to be weightless, frictionless, and rigid. Whereas an "ideal machine" is an imagined construction, "real machines" are capable of being constructed. In practicality, there are no "ideal machines", but consideration of an "ideal machine" may aid in thought and analysis about machine design. However, take note that in some machines weight, friction, and/or flexibility/elasticity (lack of rigidity) play an essential role.

> **NOTE:** *A 'perpetual motion machine' is a machine that "works by itself and moves without applied effort from." Magnetism is one potential way of developing a perpetual motion machine. Although, over time, the magnetic force itself would run down, and it would have to be replenished.*

A **simple machine** is a machine from which no part can be removed without destroying it as a machine. A simple machine transforms the magnitudes of the forces and velocities at its point of action, but does not change the mechanical power, product of force, or velocity. **Complex machines** use more than one simple machine to accomplish a function. A complex machine is a system realized by many parts with different functions, linked together to complete a defined task. Complex machine can transform power and/or convert power from one type to another.

There are six simple machines used to control mechanical power (mechanical energy): the lever, the pulley, the wheel and axle, the inclined plane, the screw, and the wedge. Sometimes the wedge and screw are considered special cases of the inclined plane, so there are either four or six simple machines. There are an innumerable multitude of complex machines.

Simple machines can be combined in a limitless variety of ways to produce complex machines. Complex machines are, in general, composed of moving parts. Complex machines range from very basic (i.e., "simple") to highly complex. For instance, pliers, scissors and similar tools are basic-complex machines composed of two levers joined at their common fulcrum with force applied by a mechanical user.

> **NOTE:** *While not machines in themselves, the following elements are important parts of many machines (known as structural components): bearings; springs, lubricants, frames, fasteners, couplings; clutches; cams; springs; gears; and seals. They facilitate the transmission of power within [mechanical] machines.*

Non-basic complex machines may be understood in terms of system dynamics, wherein there are two classes of machine component: transformers and transducers. Transformers and transducers are interfaces that transmit power between subsystems in dynamic system models. They are the dynamic system elements that permit useful systems modelling, since most complex machines are a combination of interacting subsystems. A **transformer** is a machine element that links or interfaces two subsystems of the same type of power (energy). A **transducer** interfaces subsystems of dissimilar power (energy) types. In system dynamics, a transformer and transducer are similar in that they interface the power flow between two subsystems. Transducers differ from transformers, because they interface dissimilar subsystems. Note that the terms transformer and transducer have specific definitions in system dynamics, which differ from, but are based on, their common engineering usage.

> **CLARIFICATION:** *In mechanical engineering, the term 'transducer' most commonly refers to a sensor, such as a load cell, which emits an electrical signal in response to a non-electrical input, such as a force, in the case of a load cell. Sensors typically interface two dissimilar energy systems. In system dynamics terminology, transducers interface subsystems of different types of power (energy). There is a significant difference between a sensor and a system dynamics transducer. Sensors produce signals which are information, not power. An ideal sensor signal is time-varying voltage or current, not power, which is the product of current and voltage. Although the use of term transducer as the classification of machine elements that interface dissimilar types of energetic subsystems is logical, it is also unfortunate because it causes misunderstanding between engineers. It is best to use the term transducer only outside of system dynamics to mean sensor to avoid misunderstanding. It is also important to clarify*

*that in most engineering communication a 'transformer' is an 'electrical transformer'. It is only in a systems dynamics context that the 'transformer' has a broader meaning.*

Examples of transducers include:

1. DC motors interface electrical and rotational mechanical subsystems.
2. Hydraulic pistons interface fluid and translational mechanical subsystems.
3. Racks and pinions interface translational and rotational mechanical subsystems
4. Pumps interface fluid and rotational or translational mechanical subsystems

In the examples above, although the subsystems are linked by a transformer, they are also separated by it. A transformer is an interface between the subsystems that transmits power from one subsystem to another. In a transformer, the power is "transformed" twice during the energy transfer, from its original form to an intermediate form, and then, back to its original form. It is this double "conversion" of power from the power type of the subsystem to a different form and then back again, which separates the two subsystems from each other. The double "conversion" of power also permits a transformer to change the relative magnitudes of the power variables, including the magnitude of the power flow.

A typical electrical transformer consists of two windings: primary and secondary. The primary winding is connected to the power source while the secondary winding is connected to the load. Between the primary and the secondary windings, there is no electrical connection. Instead, electric energy is transferred through inductance within the core that is generally made up of laminated steel. Therefore, transformers operate only on alternating current.

Actual transformers always dissipate some energy as heat due to friction, electrical resistance, or magnetic hysteresis, and retain some amount of energy. In an "ideal" transformer, all of the power which leaves one subsystem is transmitted to the other subsystem without energy storage or loss. Hence, "ideal" transformers neither dissipate nor retain energy. All the energy which flows in must flow out. Real machines with real materials have less than "ideal" links and electrical conductors. Consequently, the energetic model of machine elements that function as transformers may need energy storage and dissipation elements, in addition to the element that represents power (energy) "transformation".

The subsystems linked by transformers are comprised of energetic elements that handle the same type of power. Examples of mechanical transformers include:

- Levers and linkages, which interface translational mechanical subsystems.
- Gear sets, which interface rotational mechanical subsystems.
- Belt drives, which interface rotational mechanical subsystems.
- Double-ended pistons, which interface fluid subsystems.

Additionally, machines equipped with moving parts can be classified three ways by the type of task they perform:

1. Machines that <u>produce mechanical power</u> from other "forms" of energy. A combustion/electric engine is an example of a machine that produces mechanical power. If their purpose is simply to make placements or generate forces/torques, they are called actuators.
2. Machines that <u>absorb mechanical power</u> to accomplish a specific task (machine tools, transportation, agricultural machinery, textile machinery, machine packaging, etc.). For example, a windmill absorbs mechanical power from fluid passing through it, and a generator within the windmill machine converts mechanical power from the windmill to electrical power.
3. Mechanical transmissions: these machines <u>transmit mechanical power</u> by appropriately changing values of torques and speed. Mechanical transmissions are generally made up of mechanisms that have been studied (mainly from the point of kinematic view) to connect motors and users.

For example, an engine/motor is a machine in which the input is not in the form of mechanical power (i.e., it is a transducer), but it converts the power into mechanical power as forces and torques (i.e., produces mechanical power). Here, the input could be electrical (motor), or provided by a heat engine. It could also include machines worked by animate power (considered as part of the machine and not as users of it). A 'prime mover' is sometimes considered an "engine" whose power is derived from some non-mechanical source, such as a heat engine. A prime mover is capable of motion, or being moved, without connection to any other system. Windmills, water wheels and turbines are considered to be prime movers, as clearly are animate (humans and other animals).

**NOTE:** *A* **dynamometer***, or "***dyno***" for short, is a device for measuring force, moment of force (torque), or power. For example, the power produced by an engine, motor or other rotating prime mover can be calculated by simultaneously measuring torque and rotational speed (rpm).*

Every machine has an input and an output, and the output is a modification of the input, not a simple replication of it. A machine is a processor or transformer (transducer or transceiver) in some sense. The motion of the output is fully constrained by the motion of the input, and by its kinematic connection(s). The force at the input is called the effort, and the force at the output, a load.

> **NOTE:** *Weight, as the expression of the force of "gravity" is a way of transmitting force in some machines, but it would not be considered part of a machine itself. Weight is also a common load on a machine which is not located in outer space.*

**Load**, in mechanics, is the external mechanical resistance against which a machine acts. For example, engine load is the power that the outside world takes away from the engine. An engine connected to nothing can have essentially no load, regardless of throttle opening or rotations per minute (RPM). If an engine is connected to a dyno or a machine, then the engine can be loaded. Therein, an engine that produces more power can accommodate more load. If the output power of the engine is less than the external load, the engine will decelerate. If the output power of the engine is greater than the external load, the engine will accelerate. Note here that the term 'load' can be confused between disciplines, because in electricity, a load is a measure of power. But in mechanics, a load is a measure of a force or a torque. In other words, power only describes load in an electrical context. In a mechanical context, it is always a force or a torque. Wherein, load is often be expressed as a curve of force versus speed.

The **mechanical advantage**, which we shall call simply the advantage, is the ratio of the load to the effort. The velocity ratio is the ratio of the movement of the load to the movement of the effort, in linear displacement or rotation. Alternatively, the **velocity ratio (or speed ration)** is the ratio of the movement of the load to the movement of the effort, in linear displacement or rotation.

> **NOTE:** *In an ideal machine the product of the mechanical advantage and the velocity ratio is* **unity**. *There is a trade-off between force and speed. In a real machine the product is less than unity. As a consequence, an ideal machine in equilibrium (when the effort and the load balance) can be moved by the least impetus, as well in one direction as in the other, so the machine is reversible. A real machine, however, requires a certain effort to move it in either direction; it is irreversible, and there is an unavoidable loss of energy whenever it moves.*

## *4.6 Mechanical power generation*

Mechanical power can be generated through the construction of a technological device that transfers/converts/transduces from fluid power (energy), electrical power (energy), thermal power (energy), magnetic power (energy), electromagnetic power (energy), or through simple inertia or gravity.

1. Fluid > linear/rotational mechanical (e.g., turbines, windmills, hydro-dam, hydraulics engine - pressurized fluid)
2. Electrical > mechanical (e.g., rotational electric motors, electrical engine)
3. Thermal > mechanical (e.g., internal combustion engines convert thermal power into rotational mechanical power - thermal engine/heat engine)
4. Chemical > mechanical (e.g., chemical motor)
5. Magnetic > mechanical (e.g., magnet)
6. Electromagnetic > mechanical (e.g., electromagnet)
7. Inertia/gravity > mechanical (e.g., sail, airfoil)

There are devices, which are not always classified as machines, but nevertheless generate mechanical power. These devices depend entirely on inertial forces and are often composed of simple machines. It is because of their reliance entirely on inertial forces that they are sometimes excluded from the definition of a machine. Such devices include but are not limited to: the pendulum; the whole family of fluid turbines; sails; and airfoils.

### 4.6.1 Motors and engines

*Electrical > mechanical*
*Chemical > mechanical*
*Thermal > mechanical*

Motors and engines convert various types of power (chemical, electrical, hydraulic, pneumatic, etc.) into mechanical power; possibly linear, but typically torque on a rotating axis. Although the terms motor and engine are often used interchangeably, they are distinguishable: engines run on thermal combustion; motors run on electricity or chemical power; and turbines run on fluid flow. There are several notable distinctions between motors and engines that may be made here:

1. A 'motor' converts electrical or chemical power into mechanical power, while an engine converts various other (non-electrical and non-chemical) forms of power to mechanical power.
2. An 'engine' is a mechanical device that uses a fuel source to create an output.
3. The word "engine" is generally used to refer to a reciprocating engine (steam or internal combustion), while "motor" is generally used to refer to a rotating device such as an electric motor.
4. An engine is made up of pistons and cylinders, while a motor is made up of rotors and stators.
5. A heat engine uses heating to generate mechanical power.

To add context, it may be useful to look at the etymological origins of the word engine and motor. The word "engine" comes from the Latin word "ingenium". An engine is a device or system (electrical, mechanical, chemical, or even social, human, or political) which effects a result. In classical mechanics, engines are basically the devices which transfer/convert energy to bring about mechanical effects. Originally, "motor" was another word for "mover" (i.e., a thing which moves the rest of the device). "Motor" did not originate from "electric motor". Historically, motors were powered by wound springs. Faraday put the word "electric" in front of "motor" to distinguish it from other motors of that time. The present-day motor, called the electric motor, is a device that transfers electrical energy through to mechanical energy. The electric motor can be broadly categorized into two classes; the AC motor and the DC motor. One could also think of engines and motors in this way: An engine is any useful man-made contrivance that takes in power and possibly raw material, and converts those into a useful mechanical output. A motor is a sub-class of engines, one that produces motive power as its primary output.

**NOTE:** *Electrical motors and combustion engines are best suited for producing angular motion.*

Thermo-mechanical power generation systems (i.e., heat engines) use a source of thermal energy (heat source) to produce mechanical power. Thermal energy sources include: fossil, biomass, and nuclear fuels; fusion; solar; combustion; and geothermal. Power generation systems that require heat as a primary input are subject to the Carnot efficiency limitations. Hence, heat engines distinguish themselves from other types of engines by the fact that their efficiency is fundamentally limited by Carnot's theorem. Although this efficiency limitation can be a drawback, an advantage of heat engines is that most forms of energy can be easily converted to heat by processes like exothermic reactions (such as combustion), absorption of light or energetic particles, friction, dissipation and resistance. Since the heat source that supplies thermal energy to the engine can thus be powered by virtually any kind of energy, heat engines are very versatile and have a wide range of applicability.

A heat engine is a system that transfers heat to mechanical power, which can then be used to do mechanical work. It does this by bringing a 'working substance' from a higher state temperature to a lower state temperature. A heating source generates thermal power that brings the working substance to the high temperature state. The working substance generates work in the "working body" of the engine, while transferring heat to the colder "sink" until it reaches a lower temperature state. During this process some of the thermal energy is converted into work by exploiting the properties of the working substance. The working substance can be any system with a non-zero heat capacity, but it usually is a gas or liquid. During this process, a lot of heat is lost to the surroundings (i.e. it cannot be used).

**NOTE:** *Motors and engines have to be actively held (with feedback controls) or locked in position.*

### 4.6.2 Turbines

*Fluid > mechanical*
*Thermal > mechanical*

A turbine (from the Latin turbo, a vortex, related to the Greek τύρβη, tyrbē, meaning "turbulence"), is a rotary mechanical device (a machine) that transfers energy from the flow of a fluid into mechanical power. A turbine is a spinning wheel that gets its energy from a gas or liquid (i.e., a fluid) moving through or past it. A turbine consists of a shaft connected to a set of blades. As the energy supply source/force moves past, and interacts with the turbine, it produces a torque through the shaft of the turbine. A turbine is a machine (energy transfer/"conversion" device) for generating rotary mechanical power from the energy of a stream of fluid (such as water, steam, or hot gas). Hence, turbines transfer energy from various types of carriers of energy into mechanical power. Essentially, a turbine transfers kinetic energy, and potential energy if the fluid is moving due to a potential difference (e.g., falling water or wind moving from high to low pressure), from the flow of the fluid into mechanical power. This mechanical power can be used for mechanical tasks, or a generator can be added to the system to convert this mechanical power into electrical power (electricity). In the case of electricity generation, turbines provide rotary (angular) mechanical power for the electric generator.

A turbine produces rotational (angular) mechanical power (mechanical energy) that may be used to generate electric power (electric potential current) via electromagnetic induction. Turbines are machines used to harness energy from fluid under pressure, and convert it into mechanical work. A turbine's mechanical power output is significantly dependent on the mechanical design of the device (e.g., blades) and the quantity of the matter (e.g., falling water) that flows through it.

Turbines have blades that spin through contact with a moving fluid material (a.k.a., "working material"). A shaft is connected to the blades that produces a torque. In other words, turbines produce torque through the rotation of a shaft connected to blades that spin due to an outside force. The power in the shaft is sometimes called "shaft power" (mechanical energy). Shaft power can be directly converted into an electrical power through the connection of an electric generator to the shaft.

**NOTE:** *Technically, a turbine is a hydraulic mechanism because it uses the force of a liquid under pressure to work/operate.*

The mechanical power produced by a turbine can be applied directly to do mechanical work (e.g., pumping water), or it can be input into a generator to produce electrical current. Turbines have blades that spin through contact with a moving material (a.k.a., "working material"). A shaft is connected to the blades that produces a torque. In other words, turbines produce torque through the rotation of a shaft connected to blades that spin due to an outside force. The power in the shaft is sometimes called "shaft power" (mechanical energy). Shaft power can be directly converted into an electrical power through the connection of an electric generator to the shaft.

> **NOTE:** *Turbine-generator systems that produce electrical power are generally just called 'turbines'. The terminology here can be confusing, because technically, the turbine itself produces mechanical power, and it must be connected to an electric generator to produce (AC) electric power, but often, the turbine and generator combination are referred to as the turbine, instead of turbine-generator to clarify that the output of the system is electrical power and not mechanical power.*

A turbine is a turbomachine (machines that transfer energy between a rotor and a fluid) with at least one moving part called a rotor assembly, which is a shaft or drum with blades attached. Here, the mechanical work done by the shaft is called 'shaft work'. Moving fluid acts on the blades so that they move and impart rotational power (energy) to the rotor. Early historical examples of turbines include windmills and waterwheels. In an electrical turbine, the rotor is connected to the main shaft of an electrical generator, which spins within the generator to create electricity. When a turbine is connected via a shaft to a generator (which in some cases, can be a motor that is run "backwards"), such an arrangement is called a turbo-generator.

> **NOTE:** *Whereas windmills only do mechanical work, wind turbines generate electricity through mechanical work.*

Here, a 'working fluid' contains potential energy (pressure head) and kinetic energy (velocity head). The fluid may be compressible or incompressible. Several physical principles are employed by turbines to transfer this energy and generate power.

### 4.6.3 Turbine design categories

Turbines transfer the kinetic energy of fluids to kinetic energy of solids through the principle of impulse or reaction, or a mixture of the two. Hence, there are two basic types of turbine, each relying on different mechanical principles to transfer energy in a working fluid into mechanical power. While there are only two basic types of turbines (impulse and reaction), there are many variations. The basic and main difference between impulse and reaction turbine is that there is pressure change in the fluid as it passes through runner of reaction turbine while in impulse turbine there is no pressure change in the runner.

1. **Impulse turbines** - As the name suggests, an impulse turbine operates because of impulses. An impulse is a force for a very short duration. The blades of impulse turbines are impacted by the fluid, causing them to rotate in a certain direction at a considerable speed. The kinetic energy (and potential energy) of the fluid gets transferred into the rotational kinetic energy of the turbine. The resulting impulse spins the turbine and leaves the fluid flow with diminished kinetic energy (due to the transfer of some of the energy into the turbine). Essentially, an impulse turbine is a horizontal or vertical wheel that uses the kinetic energy of a fluid striking its buckets or blades to cause rotation. Newton's second law describes the transfer of energy for impulse turbines. There is no pressure change of the fluid or gas in the turbine blades (the moving blades), as in the case of a steam or gas turbine, all the pressure drop takes place in the stationary blades (the nozzles). Before reaching the turbine, the fluid's pressure head is changed to velocity head by accelerating the fluid with a nozzle. Pelton wheels and de Laval turbines use this process exclusively. Impulse turbines do not require a pressure casement around the rotor since the fluid jet is created by the nozzle prior to reaching the blades on the rotor. After turning the blades or buckets, the fluid flows out.
   - Pelton turbine (hydro turbine) - High pressure heads give rise to very fast water jets impinging in the blades resulting in very high rotational speeds of the turbine. The split bucket pairs divide the water flow ensuring balanced axial forces on the turbine runner. Pelton wheels are ideal for low power installations with outputs of 10kW or less but they have also been used in installations with power outputs of up to 200 MW.
2. **Reaction turbines** - A reaction turbine rotates due to the reaction of the fluid, either leaving or entering the turbine. In reaction turbines, the main working principle is the Newton's Third law of Motion. Reaction turbines develop torque by reacting to the gas or fluid's pressure or mass. The pressure of the gas or fluid changes as it passes through the turbine rotor blades. A pressure casement is needed to contain the working fluid as it acts on the turbine stage(s) or the turbine must be fully immersed in the fluid flow (such as with wind turbines). The casing contains and directs the working fluid and, for water turbines, maintains the suction imparted by the draft tube. Francis turbines and most steam turbines use this concept. For compressible working fluids, multiple turbine

stages are usually used to harness the expanding gas efficiently. Newton's third law describes the transfer of energy for reaction turbines. Essentially, a reaction turbine is a horizontal or vertical wheel that operates with the wheel completely submerged, a feature which reduces turbulence. In theory, the reaction turbine works like a rotating lawn sprinkler where water at a central point is under pressure and escapes from the ends of the blades, causing rotation. Reaction turbines are the type most widely used.

- Francis turbine (hydro turbine) - Water flow enters in a radial direction towards the axis and exits in the direction of the axis. Large scale turbines used in dams are capable of delivering over 500 MW of power from a head of water of around 100 metres.
- Propeller and Kaplan turbines (hydro turbine) - Designed to work fully submerged, it is similar in form to a ship's propeller and is the most suitable design for low head water sources with a high flow rate such as those in slow running rivers. Designs are optimised for a particular flow rate and efficiencies drop of rapidly if the flow rate falls below the design rating. The Kaplan version has variable pitch vanes to enable it to work efficiently over a range of flow rates.

The blades (foils) of a turbine are designed for the given turbine's application and its intended working fluid. The term "foil" is used to describe the shape of the blade's cross-section at a given point, with no distinction for the type of fluid, thus referring to either an airfoil (air is the fluid) or 'hydrofoil' (water is the fluid). Also, blades may be designed for uni-directional or bi-directional functioning.

1. Uni-directional - The blades only work/function [to produce energy] in one direction.
2. Bi-directional - The blades work/function [to produce energy] in both directions.

Generally, turbines depend on the impulse of the working fluid on the turbine blades or the reaction between the working fluid and the turbine's blades to turn the turbine shaft. Several different families of turbines have been developed to optimise performance for particular fluid supply conditions.

### 4.6.4 Power (energy) source for turbines

**NOTE:** *The selection of a turbine for power generation depends largely on site conditions.*

The force to turn a **turbine** could come from a number of fluid sources. Technically, all turbines are driven in some way by the pressure/movement of a fluid; but in specific, turbines can be sub-classified by their [pressure-driven] fluid source:

1. **Fluid turbine** - fluid pressure drives the turbine. Technically, all turbines are fluid turbines, so calling a device a fluid turbine is redundant and unclear.
2. **Air [powered] turbine** - the pressure of moving air/atmosphere drives the turbine. Herein, the turbine's blades/foils are called airfoils.
3. **Wind [powered] turbine** - wind drives the turbine.
4. **Water [powered] turbine** (hydro [powered] turbine) - the pressure of moving water or another liquid drives the turbine. Herein, the turbine's blades/foils are called hydrofoils.
5. **Steam [powered] turbine** - a heat [engine] source boils water (in a boiler) results in steam, which drives the turbine. Steam turbine systems use the dynamic pressure generated by expanding steam to turn the blades of a turbine. Here, steam is produced by heat from a heat source that drives a steam turbine. Steam turbines run on the Rankine Cycle. Steam turbines rotate in the currents caused by the hot water vapour. Simply, a steam turbine system pumps liquid water into a boiler at high pressure, adds heat converting it to a super-critical fluid state and then expands it through a turbine before exhausting it to a condenser which cools it back to liquid water that feeds the pump mentioned above, creating a cycle. Generally, steam powered turbines form part of a closed water cycle in which water condenses and is then heated until it evaporates again. Steam turbines therefore do not come into contact with the fuel source that heats the water to steam. These systems generally work at temperatures between 500 and 650°C. Several steam turbines are often arranged in a row so that – configured for high, medium and low pressure – they are able to optimally convert the respective steam pressure into rotational movement.
   - Sources of heat for the production of steam include, but are not limited to: fuel combustion; solar thermal energy; waste heat; geothermal; and nuclear.
6. **Nuclear [powered] steam turbine** - boiling water (or another working fluid) from a nuclear reaction produces steam that drives the turbine.
7. **Geothermal [powered] steam turbine** - boiling water (or another working fluid) from geothermal heat transfer drives the turbine.
8. **Gas [powered] turbine** - hot gases and their expansion/combustion drives the turbine. Gas turbine systems use the dynamic (compression and then expansion) pressure from flowing gases

(air and combustion products) to directly operate the turbine. Herein, expansion refers to a decrease in pressure, and increase in volume of steam or gas, which converts its pressure energy into kinetic energy (or mechanical work). Gas turbine plants run on the Brayton Cycle. Gas turbines rotate directly in the hot combustion gases. Hence, these turbine system do come into contact with the fuel and/or combustion products of the fuel. These systems reach temperatures up to 1500°C, and the gases are much hotter than those in steam turbines. For this reason the blades are generally cooled with air that flows out of small openings and creates a "protective film" between the exhaust gases and the blades. Without cooling, the blade material would quickly wear out.

9. **Combined cycle turbines** - utilize the hot exhaust gas from the gas turbine.
10. **Combustion [powered] turbine** - the combustion of gas leading to its heated expansion drives the turbine.
11. **Osmotic [powered] turbine** - osmotic pressure drives the turbine.

> **NOTE:** *A* **heat engine** *is a power production system that converts heat (thermal energy) to mechanical power (mechanical energy), which can then be used to do mechanical work (e.g., powering a turbine).*

All thermal sources of mechanical power produce "waste heat" as a by-product of the useful mechanical power produced. The percentage of heat transferred into useful mechanical power (mechanical energy) is know as 'conversion efficiency'. It is not thermodynamically possible for all of the heat (thermal energy) to be transferred into mechanical power, according to the second law of thermodynamics; therefore, there is always heat lost to the environment. If this loss is employed as useful heat, for a separate heating service, the power generating system is referred to as a **cogeneration power plant** or **CHP (combined heat-and-power) plant**. By-product heat can be used for multiple purposes, including: heating the exterior and interior of architecture, and for the desalination of water. Dedicated heat plants called **heat-only boiler stations** do not produce electrical power, but instead generate thermal energy in the form of hot water for use in heating applications. Heat-only boiler stations can generate heat from the same sources that generate electrical power.

### 4.6.5 Biomechanical power generators

In general, animate power is considered a form bio-electric-mechanical power. Animals produce "animate" power through at least bio-electric means, which drive their appendages to produce mechanical power. Animate power may produce a pushing, pulling, or torquing power. This power can then be harnessed to do useful work. For instance, a horse can be used to for its "horsepower" to pull a cart. A human can operate a hand crank. Or, an animal can run in a wheel.

## 4.7 *Mechanical power transmission*

Mechanical Power transmission is the movement of energy from its mechanical place of generation to a location where it is applied to performing useful work. Mechanical power transmission refers to the transmission of motion and power from generation (a driver or source) to use (a load or output). Therein, mechanical power may be transmitted:

1. Within a mechanical device.
2. From a mechanical device to/through its end-point of use (load or output).

Typically, a transmission element will have an input side and an output side, and the motion from input to output is related, assuming no losses, in one of two ways.

1. Geometric constraint: For a transmission element, there will be a relationship between the geometry of the motion at the input to the geometry of the motion at the output.
2. Energy conservation constraint: For an ideal transmission element, the power input to the element will be equal to the power output from the element.

The geometric constraint must hold if the transmission element is operating properly. For example, the speed of the motion at the interface between two meshing gears must be the same or the teeth will be sheared off the gears. The energy conservation constraint holds if the transmission element does not have significant energy dissipation. Typically, this is approximately true for a good transmission element, because it is designed to transmit as much of the input power to the output as possible. Of course, neither constraint is strictly true in reality, but, if deviations are small, these can be incorporated into other ideal elements in the system model.

A linkage can be used to change the direction of a force or to make two or more things move at the same time. A **mechanical linkage (**or **link)** is an assembly of bodies connected to manage forces and movement. A link is a mechanical part that transmits an axial force of compression or tension, and is connected by pins or sliders at its ends. A linkage can be used to change the direction of a force or to make two or more things move at the same time. A link is not a machine by itself (it does not transform its input), but is a typical part of a mechanism, and may transmit forces between simple machines. In general, it involves a rigid body having two or more pairing elements which connect it to other bodies for the purpose of transmitting force or motion.

A slotted link with a sliding block may permit a variable amount of motion to be transmitted. In every machine, at least one link either occupies a fixed position relative to the earth or carries the machine as a whole along with it during motion. In the later case, the link is the frame of the machine, and it is called the fixed link. The movement of a body, or link, is studied using geometry; hence, the link is considered to be rigid. The connections between links, which are called **joints**, and are modelled as providing ideal movement, pure rotation, or sliding. The combination of links and joints without a fixed link is not a mechanism, but a 'kinematic chain'. In other words, a linkage modelled as a network of rigid links and ideal joints is called a 'kinematic chain'.

Linkages may be constructed from open kinematic chains, closed kinematic chains, or a combination of open and closed chains. Each link in a chain is connected by a joint to one or more other links. Thus, a kinematic chain can be modelled as a graph in which the links are paths and the joints are vertices, which is called a **linkage graph**.

Mechanical linkages are usually designed to transform a given input force and movement into a desired output force and movement. The ratio of the output force to the input force is known as the **mechanical advantage** of the linkage, while the ratio of the input speed to the output speed is known as the **speed ratio (velocity ratio)**.

Mechanical power can be transmitted across distances in a variety of ways. Additionally, mechanical power can be transmitted indefinitely, given sufficient power, as well as adequate gear boxes and axles. In general, mechanical power transmission is accomplished in one of five categorical ways, called 'drives':

1. **Belt drives** - Power transmitted through the use of belts under tension between two or more sheaves or pulleys.
2. **Chain drives** - Power transmitted through a chain between two or more sprockets.
3. **Gear drives** - Power transmitted through two or more mating gears. Can be either open (exposed) or enclosed (gears inside a gear box or reducer).
4. **Hydraulic drives** - Power transmitted through fluid pressure.
5. Some combination of the above.

Below are the delineated mechanisms (non-hydraulic) by which mechanical power can be transmitted:

1. **Clutches** - A clutch is a mechanical device that connects the power source to the rest of the machine. A clutch is used in motor vehicles so that the engine can remain running while the car is at rest, start slowly without stalling, and shift gears while moving.
2. **Pulleys and belts** - belts and pulleys control mechanical energy through any of 5 different arrangements: connect and disconnect power like a clutch, change direction, reverse rotation, change speed, and change torque.
3. **Chains and sprockets** - usually used as the drive system to bring power to the driving wheel of the vehicle in bicycles and mopeds.
4. **Shafts and bearings** - used to transfer mechanical energy in many types of machines. Shafts transfer motion (mechanical power) from point to point along their axis of motion.
5. **Gears** transfer power between shafts while keeping fixed ratios between shaft speeds. Gears transfer motion (mechanical power) via their contact point's pitch diameter. In other words, the pitch diameter is the point in which both gears transfer power. The torque from the gears transfer power from one part of a machine to another.
6. **Rails** for conveying suspended objects.

Gears are not just used to transfer power, they also provide an opportunity to adjust the mechanical advantage (the ratio of output force to the input force) of a mechanism.

Below is a delineation of the common types of gears:

1. **Spur gears** transfer motion between two shafts running parallel to each other.
2. **Bevel gears** are conically shaped, and transmit power between shafts that have intersecting axes of motion.
3. **Crown gears** mesh with bevel gears and spur gears so that motion is transferred between shafts with intersecting axes of rotation.
4. **Worm gears** come in pairs (worm gears and worm wheels) combine to transfer power between perpendicular shafts that have axes of rotation offset from each other.
5. **Helical gear**s transmit power between two parallel axes of motion, or between perpendicular non-intersecting axes of motion. Helical gears resemble spur gears, only their teeth are curved in the shape of a helix.
6. **Epicyclic** or **planetary gear** sets consist of one or more planet gears moving along an outer ring gear as a central sun gear drives them. As the planet gears are driven, they typically move a planet carrier plate along with them. The overall mechanical function of a planetary gear set changes depending on the configuration used.
7. **Rack and pinion gear sets** are used to convert rotational motion to linear motion. A rack gear is a gear mounted to a straight rod, such that it moves in a linear fashion when torque is applied to it by a spur gear (known as the pinion gear).

A **transmission** is a machine in a mechanical power transmission system that provides for the controlled application of power. Often the term transmission refers simply to the gearbox that uses gears and gear trains to provide speed and torque conversions from a rotating power source to another device.

> **NOTE:** *An "ideal" transmission element transforms one type of motion/force/moment into another without a loss of power. That is, in an "ideal" transmission element, there is no loss of energy.*

The disadvantages of mechanical power transmission include, but are not limited to:

1. Lubrication problems
2. Limited speed and torque control capabilities
3. Limited transmission distance
4. Uneven force distribution
5. Physical space requirement

## *4.8 Mechanical power production systems*

These are systems that produce mechanical power, either through another mechanical power input (e.g., wind), or through the conversion of power from another carrier (e.g., electrical power).

1. **Magnetic [field] motor systems** - The use of permanent and/or electromagnets to produce mechanical power. There are the three types of permanent magnetic motor system:
    - The imbalanced system (spin alignment system)
    - The induction expulsion system (catch and release)
    - The exchange force pulse system (spin accelerator system)
2. **Electric motor systems** - The use of electrical power and electromagnetic induction to produce mechanical power. A motor is a machine that converts electrical power (electrical energy) into mechanical power (mechanical energy). Electric motors are used to produce linear or rotary force (torque), and should be distinguished from devices such as magnetic solenoids and loudspeakers that convert electricity into motion but do not generate usable mechanical powers, which are respectively referred to as actuators and transducers. In a motor, rotational mechanical power (torque) is transferred through a rotor shaft. Energy loss during motor operation is dissipated as heat, so they sometimes have fans to cool down the motor. There exist both AC and DC electric motors.
    - The electric motor could be called an electromechanical continuous energy conversion device.
3. **Combustion engine systems** - The use of chemical power as combustion to produce mechanical power.
4. **Turbine systems** - The use of the mechanical power of a moving fluid to produce mechanical/fluid power.
5. **Transducers** - The use of electrical power to produce mechanical power (or vice versa) as the vibration of a medium.

# 5 Fluid power systems

**Fluid mechanics** *is a branch of classical mechanics (a branch of physics) that studies the mechanics (and dynamics) of fluids (liquids, gases, and plasmas) and the forces on them (i.e., the behavior of fluids). Fluids at rest are known as hydrostatics, and fluids in motion are known as fluid dynamics. Dynamics divides into two branches depending on the consideration of the viscosity to describe the flow (inviscid flow is where the influence of viscosity is neglected, and viscous flow considers viscosity as a dominant parameter that influences flow.*

**Fluid [mechanical] power** is the use of fluids under pressure to generate, control, and transmit power. Take note that there are two principal types of mechanical system, solid and fluid. A **fluid** (and liquid) is a substance that deforms continuously when a shear stress is applied. Both liquids and gases are fluids. Fluid Power is produced by outside energy sources, such as a motor. The fluids transmit the energy, and are not the source of fluid power. A fluid is a material that can flow, has no definite shape of its own, and conforms to the shape of its container. Fluids spontaneously move from regions of high pressure to regions of low pressure. Fluid power transfers energy through the variables of pressure and flow. Flow is necessary for the development of pressure, which is a function of resistance to fluid flow in the system. Liquids in motion have characteristics different from liquids at rest. Frictional resistances within a fluid (viscosity) and inertia contribute to these differences.

In a fluid power system, the pressure is typically transferred to some type of actuator used to perform work. Actuators can be rotary, linear or a combination of the two. Linear actuators are often referred to as cylinders or rams, while rotary actuators are called motors.

Fluid power is subdivided into hydraulics (using a liquid such as mineral oil or water), and pneumatics (using a gas such as air or other gases). At a very basic level, hydraulics is the liquid version of pneumatics, or said in the opposite way, pneumatics is the gases version of hydraulics.

1. **Hydraulics** is the study of liquids at rest and in motion -- the study of the motion of liquids in relation to disciplines such as fluid mechanics and fluids dynamics. The science and engineering of forces and movement transmitted by means of liquids. The word “hydraulics” originates from the Greek word δραυλικός (hydraulikos), which in turn originates from ὓδωρ (hydor, Greek for water) and ανλός (aulos, meaning pipe).
2. **Pneumatics** is the study of gases and their behavior under pressure. The science and engineering of forces and movement transmitted by means of gases or pressurized air. Pneumatic power is a measure of work produced using pressurized gases/air. The principles of pneumatics are the same as those for hydraulic, but pneumatics transmits power using a gas instead of a liquid.

Fluid systems (hydraulics and pneumatics) are best suited for producing linear motion.

Hydraulics is a topic in applied science and engineering dealing with the mechanical properties of liquids and fluids. Fluid mechanics provides the theoretical foundation for hydraulics, which focuses on the engineering uses of fluid properties. In fluid power systems, hydraulics are used for the generation, control, and transmission of power by the use of pressurized liquids. Hydraulic topics range through some part of science and most of engineering modules, and cover concepts such as pipe flow, dam design, fluidics and fluid control circuitry, pumps, turbines, hydropower, computational fluid dynamics, flow measurement, river channel behavior and erosion.

Hydraulic power is a measure of the work produced by putting liquids under pressure, and their consequential flow. There are three types of energy available in modern hydraulics (of the normal hydrostatic type):

1. **Potential energy & pressure energy** - The static energy of a standing, but pressurized liquid that is ready to do work (e.g., oil in a loaded accumulator).
2. **Kinetic energy** - The energy of the moving liquid, which varies with the velocity (speed) of the liquid.
3. **Heat transfer energy** - Friction or resistance to flow (an energy loss in terms of output). Example: friction between moving oil and the confines of lines or passages produces heat energy.

Hydraulics and hydro-mechanics engineering science of liquid pressure and flow. There are two branches of hydraulics/hydro-mechanics:

1. **Hydrodynamics** - The engineering science of the energy of liquid pressure and flow - dynamic effect through mass times acceleration. Force effect through pressure area.
2. **Hydrostatics** - The engineering science of the energy of liquids at rest - dynamic effect through pressure times area. Force effect through mass acceleration
3. **Free surface hydraulics** is the branch of hydraulics dealing with free surface flow, such as occurring in rivers, canals, lakes,estuaries and seas. Its sub-field open channel flow studies the flow in open channels. It is part of the field of hydrology.

In general, fluid power systems involve a pump driven by a prime mover (such as an electric motor or internal combustion engine) that transfers mechanical power (energy) through to fluid power (energy).

All fluid systems have two things in common. First, each system contains a fluid – either a liquid or a gas – that moves through a system of connecting pipes and devices. Second, a pressure difference in the system creates a net force, which causes fluids to move or perform some special function – like pushing a piston or opening or closing a valve. In this sense, pressure is a prime mover in fluid systems.

> **NOTE:** *Fluid pipe networks and electrical wire networks are analogous. For instance, an adjustable water tap for a home water supply is just like a variable electrical resistor.*

Fluid systems are either of an 'open' or 'closed' type:

1. Open systems move fluids into and out of the system, without retaining or recirculating fluids.
   - Work occurs in a fluid system when a fixed volume of fluid V moves through a pressure difference ($\Delta P$). If the pressure increases, $\Delta P$ is positive and W is negative. A negative value for work means that work is done on the fluid (e.g., a pump for a city's water supply, irrigation system, fire truck water system). If the pressure decreases, $\Delta P$ is negative and W is positive. A positive value for work means the fluid does the work (e.g., a hydroelectric dam). In a hydroelectric dam, water flows from a high-pressure region behind the dam to a low-pressure region, turns a turbine, and does work.
   - The formula is: $W = \Delta P \times V$
2. Closed systems retain and recirculate fluids.
   - Work occurs in a fluid system when fluid pressure p causes a given volume ($\Delta V$) of liquids or gases to move. Here, $\Delta V$ can be positive or negative, but P is always positive. If the fluid volume increases, $\Delta V$ is positive and W is positive. Positive work means the fluid does work, as when a gas expands in a cylinder, lifting a load (other examples include: a hydraulic lift; a hydraulic break system; the body's circulatory blood system). If the fluid volume decreases, $\Delta V$ is negative and W is negative. A negative value for work means that work is done on the fluid (e.g., a weight or force applied to the piston compresses the gas in a cylinder, a scuba tank compressor).
   - The formula is: $W = P \times \Delta V$

Hydraulic and pneumatic power is maintained through a combination of fluid flow and pressure. When discussing fluid power, pressure is the basis for producing any kind of work. Work cannot be achieved without pressure. **Pressure** is defined as the measure of force acting perpendicular to a unit area. Force is anything that tends to produce or modify (push or pull) motion. Pressure is applied in all directions regardless of shape or size. Pressure can act both outward and inward, depending on the circumstances. Additionally, pressure will always act perpendicular to the surface of the body upon which it is acting.

- Force (F) = pressure (P) · area (A)
- Pressure (P) = Force (F) / area (A)
- Fluid pressure (P) = force (F) / unit area (A)
- Fluid flow rate (Q) = volume (V) / unit time (A)
- Fluid power = pressure (P) x flow rate (Q)

The elements of an electrical system are analogous to a fluid system:

- Pressure = voltage
- Volume = capacitance
- Flow rate = current
- Flow restrictions = resistance
- However, air is unlike electricity in that air is compressible. Hence, the elements of a fluid system have more non-linearities than those of electrical systems.

Pressure and flow are essential design considerations for a fluid power system. **Pressure** refers to matter pushing against matter. For instance, an object pushing against another object.

- Absolute (psia) - true matter based pressure.
  - 0 psia - no matter present to press against object(s)
- Gage (psig) - relative to atmosphere.
  - 0 psig - pressure in equilibrium with atmosphere.

**Flow** is a loose term that generally has three distinct meanings:

1. **Volumetric flow** is used to measure volume of fluid passing a point per unit of time. Where the fluid is a compressible gas, then temperature and pressure must be specified or flow normalised to some standard temperature and pressure.
2. **Mass flow** measures the mass of fluid passing the point in unit time.
3. **Velocity of flow** measures linear speed past the point of measurement. Flow velocity is of prime importance in the design of hydraulic and pneumatic systems.

The most important physical properties of fluids are:

1. **Density** - can be considered constant.
2. **Viscosity** - varies greatly with temperature and less greatly with pressure.

## *5.1 Comparison between pneumatic*

*systems and hydraulic systems*

The fluid generally found in pneumatic systems is air; in hydraulic systems it is oil (or water). And, it is primarily the different properties of the fluids involved that characterize the differences between the two systems:

1. Air and gases are compressible, whereas oil is incompressible (except at high pressure).
2. Air lacks lubricating property and always contains water vapor. Oil functions as a hydraulic fluid as well as lubricator.
3. The normal operating pressure of pneumatic systems is very much lower than that of hydraulic systems.
4. Output powers of pneumatic systems are considerably less than those of hydraulic systems.
5. Accuracy of pneumatic actuators is poor at low velocities, whereas accuracy of hydraulic actuators may be made satisfactory at all velocities.
6. In pneumatic systems, external leakage is permissible to a certain extent, but in thermal leakage must be avoided because the effective pressure difference is rather small. In hydraulic systems internal leakage is permissible to a certain extent, but external leakage must be avoided.
7. No return pipes are required in pneumatic systems when air is used, whereas they are always needed in hydraulic systems
8. Normal operating temperature for pneumatic systems is 5° to 60°C. The pneumatic system, however, can be operated in the 0° to 200°C range. Pneumatic systems are insensitive to temperature changes, in contrast to hydraulic systems, in which fluid friction due to viscosity depends greatly on temperature. normal operating temperature for hydraulic systems is 20° to 70°C.
9. Pneumatic systems are fire- and explosion-proof, whereas hydraulic systems are not, unless non-flammable liquid is used.

## *5.2 Hydraulic power generation (sources)*

Most fluid power systems involve a pump driven by a prime mover (such as an electric motor or internal combustion engine) that converts mechanical power into fluid-hydraulic power. Hydraulic power can also be generated through inertia (e.g.,a stream of water or weight of an object).

When a hydraulic pump operates, it performs two functions. First, its mechanical action creates a vacuum at the pump inlet which allows atmospheric pressure to force liquid from the reservoir into the inlet line to the pump. Second, its mechanical action delivers this liquid to the pump outlet and forces it into the hydraulic system.

> **NOTE:** *A pump produces liquid movement or flow: it does not generate pressure. It produces the flow necessary for the development of pressure which is a function of resistance to fluid flow in the system.*

Theoretical hydraulic power is calculated as :

- Hydraulic Power (Watts) = Pressure (Pa) x Flow (m3/s)
- In order to calculate hydraulic power in the units normally use in hydraulics, this formula is modified to:
- Hydraulic Power (kW) = Pressure (Bar) x Flow (l/min) / 600

### 5.2.1 Hydraulic mechanical and electrical power generation

Hydraulic power systems can be designed to produce mechanical power through the application of a hydraulic motor, and electrical power by connecting the hydraulic motor to a generator, thus creating a hydraulic generator. A 'hydraulic generator' converts the hydraulic power of a "working machine" into electrical power. A "working machine" can be equipped with a hydraulic generator, to generate power for itself. A hydraulic generator uses the power of a working machine's hydraulics to turn a generator and produce electrical power.

The hydraulic piston of a working machine can be connected to a set of wheels and gears that transform the translation into rotation, and speed it up. This is called an hydraulic motor. A hydraulic motor is then connected to the generator.

There are some hydroelectric machines that use hydraulics to generate electrical power. For example, the Pelamis wave energy converter used hydraulics to generate electricity from waves.

## *5.3 Hydraulic power transmission and distribution*

Most hydraulic power is transmitted via a cylinder, or via pipe (a.k.a., tube or hose) network. In hydraulic transmission of power, a pump is used to raise the pressure of a liquid (most commonly, oil) and energy in the liquid is transmitted through pipes and hoses to perform useful work. Pipes are suitable for power transmission over intermediate distances; they can be employed over greater distances than mechanical types of power transmission, but not as great as electrical power transmission systems. In order to control the transmission of hydraulic power from the pump to the actuators a range hoses, tubes, and possibly control valves are used. The speed of a motor or cylinder and the torque or force that can be generated is infinitely controllable using directional, flow and pressure control valves.

Hydraulics pumps, motors, and cylinders are “power dense” in that the amount of power they can absorb and transmit provides designers of machines the flexibility to locate the pumps and actuators in the most advantageous position.

Hydraulic systems can be designed to give fast operative power and move heavy loads. They can easily generate linear motion using liner actuators (also called cylinders). Speed control is simple, and precise motion of the actuator is possible.

In general, hydraulic systems use a incompressible fluid, such as oil or water, to transmit forces from one location to another within the fluid.

Hydraulic fluid(s), also called hydraulic liquid(s), are the medium by which power is transferred in hydraulic machinery. Some hydraulic systems work most efficiently if the hydraulic fluid used has zero compressibility.

The disadvantages of hydraulic system include fluid leakage, containments and fire hazards with flammable hydraulic fluids.

One of the key advantages of hydraulic systems is to be able to transmit large amounts of power from a remote power source (electric motor or internal combustion engine) to a compact actuator.

> **NOTE:** *Hydrostatic transmission (hydrostatic drive) - the transmission of mechanical power by pressurizing and releasing fluid through specialized pumps.*

## 5.4 Pneumatic power generation

Most fluid power systems involve a pump or other pressurizing device (e.g., air compressor) driven by a prime mover (such as an electric motor or internal combustion engine) that converts mechanical power into fluid-pneumatic power.

Pneumatic power may also be generated from:

- A trompe is a water-powered gas compressor, commonly used before the advent of the electric-powered compressor. A trompe is somewhat like an airlift pump working in reverse.
- A bleed air systems on an engine.

Pneumatic power system are often capable of, and work through, both pumping and vacuum action.

> **NOTE:** *Air has some basic an important properties. First, it is compressible. Second, if there is higher pressure, then there is higher friction. Third, the ‘Ideal Gas Law’: PV = nRT. Where, pressure is proportional to temperature (T), and pressure is inversely proportional to volume (V).*

## 5.5 Pneumatic power transmission and distribution

Most pneumatic power is transmitted via a cylinder or pipe (a.k.a., tube or hose) network, in the same way that hydraulic power is transmitted. In general, pneumatic systems are used for the transport of objects.

All gases are readily compressible and it is this property which differentiates them most from liquids as a power transmission medium. In pneumatic transmission of energy, a compressor is used as the power source to raise the pressure of the air to the required level quite slowly. They are suitable for power transmission over intermediate distances. Pneumatic systems use simple equipment has small transmission lines, and do not present a fire hazard. The disadvantages of pneumatic system include a high fluid compressibility and a small power to size ratio of components. Pneumatic systems are unsuitable for uniform motion. Operating pressure of pneumatics is around 6 to 8 bar. And hence are capable of generating only medium forces. The switching time of control elements is usually greater than 5 milli seconds and the speed of the control signal is 10 to 50 m/s. Table 1.5 give the comparison of all the systems.

The two primary types of pneumatic power transmission system are: pneumatic conveyors and pneumatic tubes:

1. Pneumatic conveyor - A pneumatic conveyor essentially comprising a tubular channel, the lower part of which defines a rail for guiding and propelling objects to be transported. Generally, the tubular channel is equipped at regular intervals with a means for guiding and supporting pressurised air conduits and electrical wiring, and by covers, which can be click-locked onto the guide and support means and which cover the corresponding edges of the tubular channel.
2. Pneumatic tube system - Pneumatic tube systems (also called PTT, airlift, air transport, Lamson tubes, air tubes, and pneumatic transit systems) has a compressed air pump attached that can either suck air from the tube or blow air into it according to which way down the tube packages need to be sent. This means the compressor may be working like a vacuum cleaner so it sucks air along the tube from the sending station. As the compressor sucks on the tube, it creates a partial vacuum in front of a canister within the tube that sucks it all the way along until it reaches a receiving station, where it can be unloaded. Canisters can be sent in the opposite direction simply by setting the compressor to blow air along the tube in the opposite direction (behind a canister, pushing it along). Just as a vacuum cleaner is limited by the suction power of its electric motor, so pneumatic

transport tubes are limited in what they can carry, how quickly, and how far. Most pneumatic tube systems are very simple networks linking one receiving station with a number of sending stations, or vice-versa. However, much more elaborate, computer-controlled systems are also commonplace, in which many sending stations link to many receiving stations and packages can route and transfer in all manner of complex ways; these are the sorts of systems that hospitals or office buildings use. A large pneumatic system might have up to 500 sending and receiving stations, dozens of transfer units where packages can be routed between senders and receivers in complex ways, and dozens of compressor/blower units to provide the pneumatic power. Pneumatic tube systems are a fast, simple, secure, and reliable way of transporting small objects relatively large distances across a building, or (using underground or overground pipes) between buildings (or within a city) on the same site. They can move things up, down, or sideways and, because they're pneumatic, they provide a soft, air-cushioned ride for fragile items (many systems use air-cushioned brakes or bumpers that bring arriving canisters slowly to a rest at the receiving station).

### *5.6 Pneumatic energy "storage"*

Pneumatic power (energy) may be "stored" in the following ways:

1. Storage Tanks
2. Tubing, Fittings & Valves
3. Compressor

## 6 Electrical power systems

**TERMINOLOGY:**

1. **Electric** is used to describe things pertaining to the set of physical phenomena associated with electric charge (i.e., "electricity").
2. **Electrical** can be used nearly everywhere that electric is used when pertaining to "electricity" and the study or application of electric charge (aside from some set phrases). For instance, generally, people do not say "electric engineer" unless the engineer runs on "electricity"; instead they say "electrical engineer".
3. **Electricity** is the set of physical phenomena associated with the presence and flow of electric charge; it is not a single thing.
4. **Electronics** refers to technology that works by controlling the motion of "electrons" and electric charges in ways that go beyond electrodynamic properties like voltage and current. Electronics is a field of science and branch of engineering. Electronic technologies are powered by electrical charges (and "electrons"), and composed of electrical circuits that involve active electrical components and associated passive interconnection elements. Electronic devices make use of the transistor as a fundamental building block of all modern electronics circuitry. A modern integrated circuit may contain several billion miniaturised transistors in a region only a few centimetres square.

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'Electric power' refers to the "flow rate of electrical energy" or "rate of doing electric work". Remember that power is the flow rate of energy (i.e., rate of energy transfer), or a rate of use of energy (i.e., rate of doing work). Energy is measured in Joules, and when energy flows, the flow is measured in Joules per second (or watts). The word "Watt" is just another way of saying "Joule per Second" -- it is a unit measurement of electrical power. Energy comes in Joules, while power comes in Joules per second (Watts). In other words, the SI unit of electric power is the Watt. The term wattage is used colloquially to mean "electric power in watts".

> **NOTE:** *Electrical energy can be "stored", but electric power is not something that is ever stored. Think in this way: we can store a volume of water, but it's impossible to store any "volumes per second" of water.*

Electrical power is a convenient way to transfer energy, and to manage its transfer through useful service. Unlike hydrocarbon fuels, electrical energy is a low entropy form of energy that can be converted into motion (and many other forms of energy) with high efficiency, as well as provide the ability to store and process information at high efficiency. Through the use of technology, electrical power (energy) can be converted/transformed into light, thermal energy (heat), mechanical energy (macro- and micro-scopic motion), and other carriers of energy. Additionally, the control of electrical power (energy) allows for the creation and reception of electromagnetic radiation (e.g., radio waves) for communication and wireless electric power transmission.

**Electric power** exists where electric current is applied to "energise" electrical technology. All electrical power depends on an energized conductor and a path to ground. It is a path between the two that creates the flow of energy as electricity, through items that use it.

> **CLARIFICATION:** *To '***energize***' means to supply voltage (the force of electrical pressure) through a circuit. To '***de-energize***' means to remove the supply of voltage from some part of the circuit. A circuit can be de-energized through the addition or movement of a voltage isolator, circuit breaker, on/off switch, or the removal of a fuse or transmissive link; whereby, either no electrical current, or no electrical current at the requisite voltage, can flow to or from the transmission system through the de-energized connection point to the load or end-use. Conversely, to energize means to change the state of the circuit through a change in the state of a connection point so as to enable electrical current to flow to or from the transmission system to the load or end-user.*

Electrical power (energy) is "supplied" by the combination of electric current and electric potential delivered by a circuit. At the point that the electric potential energy has been transferred to another carrier of energy, it ceases to be electric potential energy. Thus, all electrical energy is potential energy before it is delivered to the end-use. Once converted from potential energy, electrical energy can always be called another "type" of energy (heat, light, motion, etc.).

Electric current flows from the state of higher potential charge to the state of lower potential charge. This flow is most often called electric power, but it may also be called "electrical energy" flow or "electricity". Therein, electric power is the product of two electric quantities, voltage and current -- there must be both voltage and current for electrical power (energy transfer) to be present:

1. **Current** is the rate at which charge is flowing. Amperage (I) is the rate at which current flows through a conductor. The single unit is the ampere. Note here that current is different than power. Current is the rate at which charge is flowing, and power is the rate at which energy is flowing.
2. **Voltage** is the difference in charge between two points. Voltage (E) is the pressure that pushes current through a conductor. The single unit is the volt.

> **NOTE:** *In Steinmetz' electrical theory, the magnetism (Φ) and dielectricity are the two components of electricity. It is the product of those two quantities. If it is one or the other, then it is not electricity. For instance, a charged capacitor is not electricity.*

> **NOTE:** *Electricity does not flow in conductors. Metals used to be called "non-electrics" because they destroyed the electric field. In metallic electrical conductors (e.g., wires), surface charges accumulate along the wire, which maintain the electric fiend in the direction of the wire. Note that metallic electrical conductors maintain a surface charge distribution since any extra charge on a conductor will reside on the surface. It is the change in, or gradient of, the surface charge distribution on the wire that creates, and determines the direction of, the electric field through a wire or other resistor. In a DC circuit, the surface charge density on the wire near the negative terminal of a battery, for instance, will be more negative than the surface charge density on the wire near the positive terminal. The surface charge density, as you go around the circuit, will change only slightly along a good conducting wire - the gradient is small, and there is only a small electric field. Corners or bends in the wire will also cause surface charge accumulations that make the electrons flow around in the direction of the wire instead of flowing into a dead end. Resistors inserted into the circuit will have a more negative surface charge density on one side of the resistor as compared to the other side of the resistor. This larger gradient in surface charge distribution near the resistor causes the relatively larger electric field in the resistor (as compared to the wire). The direction of the gradients for all the aforementioned surface charge densities determine the direction of the electric fields.*

These two quantities (voltage and current) can vary with respect to time (AC electrical power), or they can be kept at constant levels (DC electrical power). Note that with AC power, both voltage and current are changing in sign (+ / -) each half cycle.

As an expression, electrical power in watts is produced by an electric current (I) consisting of a charge of (Q) coulombs every (t) seconds passing through an electric potential (voltage) difference of (V):

- P = work done per unit time = VQ / t = VI
- V is electric potential or voltage in volts
- Q is electric charge in coulombs
- t is time in seconds
- I is electric current in amperes

Hence, electrical power (P) is delivered by a combination of voltage (V) and current (I):

- power (P) = volts (V) • current (I)

In other words, the electrical power (P) delivered to a component is given by:

- P(t) = I(t) • V(t)
- P(t) is the power, measured in watts
- V(t) is the potential difference (or voltage drop) across the component, measured in volts
- I(t) is the current flowing through it, measured in amperes
- (t) refers to any point in time

There is a difference in how power is determined between direct current (DC) and alternating current (AC) circuits. In a DC system, P = VI, but in an AC system, power is a complex quantity involving the concept of a 'power factor'. There is no 'power factor' in DC circuits because there is no concept of phase angle between current and voltage. The concept of a 'power factor' only arises when voltage and current has a phase difference. It may be said that the power factor in a DC circuit is always 1, because there are no reactive components. The current and voltage are always in phase, which is another way of saying that the phase difference between the current and voltage is zero degrees (0˚), and the cosine (cos) of zero (0) is one (1).

In an AC circuit, the ratio of 'active power' to 'apparent power' is called the **power factor**. In other words, the 'power factor' in an AC circuit is the ratio of the power utilized by load to the 'total power' supplied. In general, the power in a AC circuit (single phase) is the average power (i.e., real power), which is given by:

- $P^{avg}$ = VI cosφ = voltage x current x power factor
- φ is the phase angle between the current and the voltage.
- cos φ is the 'power factor' of the circuit.
- Power factor = Active Power/Total Power

The power factor is one when the voltage and current are in phase. If voltage and current are in phase, then power sine wave(V*I) will always be in one direction when V and I are multiplied at any time-frame, meaning power is utilized through the load. It is zero when the current leads or lags the voltage by 90 degrees. Where the waveforms are purely sinusoidal, the power factor is the cosine of the phase angle (φ) between the current and voltage sinusoid waveforms. Therein, power factors are usually stated as "leading" or "lagging" to show the sign of the phase angle of current with respect to voltage. Voltage is designated as the base to which current angle is compared, meaning that we think of current as either "leading" or "lagging" voltage. This means that power is not being utilized entirely, and that the load tends to act as a source of power. The positive area of power is the power utilized (active power) and the total area is the total power you supply.

The power flow in an AC electrical system has five components (and each is assigned a different unit of expression):

1. **Active power** or **real power** or **true power ($P^{avg}$)**: The average value of power. Power that is actually consumed. Power that does/performs work. In a vector diagram, it is the real axis. Expressed in watts (W).
   - Real power = P = |V| | I | cos φ
2. **Reactive power (Q)**: Also known as "use-less power" or "wattless power" is the powers that continuously bounce back and forth (oscillates) between source and load. This power does not perform work. Expressed in volt-ampere-reactive (VAR). Reactive power represents energy that is first stored in the load, and then released in the form of a magnetic field (in the case of an inductor) or electrostatic field (in the case of a capacitor). In other words, reactive power is power that is stored in components, then released again back to the source through the AC cycle. Capacitors and inductors both do this, just in opposite phase. Reactive power does not do any work, so in a vector diagram it is represented as the imaginary axis of the vector diagram.
   - Reactive power = Q = |V| | I | sin φ
3. **Complex power (S)**: The vector sum (in a vector diagram) of active and reactive power. Expressed in volt-ampere (VA).
4. **Apparent power (|S|)**: The magnitude of complex power S -- the magnitude of the vector sum of active and reactive power. It is the total power in an AC circuit, both dissipated and absorbed/returned. Expressed in volt-ampere (VA). Apparent power is the product of the root-mean-square of voltage and current. The peak voltage times the peak current (or the RMS voltage times the RMS current, depending on if you're looking at peak power or average power). A power supply must be capable of outputting the full apparent power delivered to a circuit, not just the active power.
   - $|S| = \sqrt{(P^2 + Q^2)}$
5. **Phase of voltage relative to current (φ)**: the angle of difference (in degrees) between current and voltage; current lagging voltage (quadrant I vector), current leading voltage (quadrant IV vector). In other words, this is the angle used to describe the phase shift between the voltage and current. The larger the phase angle, the greater the reactive power generated by the system.

The mathematical relationship among these forms of power can be represented by vectors or expressed using complex numbers:

- S = P + jQ (where j is the imaginary unit).

A vector diagram "power triangle" gives a graphical representation of how all these quantities are related.

> **NOTE: Power engineering**, *also called* **power systems engineering**, *is a subfield of energy engineering and electrical engineering that deals with the generation, transmission, distribution and utilization of electric power and the electrical devices connected to such systems including generators, motors and transformers. Making sure that the voltage, frequency (if AC), and amount of power supplied to a load(s) is in alignment with expectations is of principal importance in power system engineering.*

> **CLARIFICATION:** *Electricity flows readily in some materials but not in others. What differentiates materials is primarily the atomic structure of the matter that comprises them. Some conduct electricity readily; they are of course called conductors. Typical good electrical conductors include copper, aluminum, gold and other metals, and water. Materials that do not conduct electricity are called insulators.*

## 6.1 Voltage (a.k.a., electric potential difference or electromotive force, EMF)

Voltage is a force/pressure that makes electricity move through a conductor. It is the potential energy source in an electrical circuit that makes things happen. Voltage is also called electric tension and electromotive force (EMF). Voltage (or electric potential) refers to the pressure that pushes electric charges in a circuit. Voltage is the pressure that drives the current. Technically, the voltage is the difference in electric potential between two points. Therefore, voltage is always measured between two points; for example, between the positive and negative ends of a battery, or between a wire and ground.

The voltage, or potential difference from point a to point b is the amount of energy in joules (as a result of electric field) required to move 1 coulomb of positive charge from point a to point b. A negative voltage between points a and b is one in which 1 coulomb of energy is required to move a negative charge from point a to b. If there is a uniform electric field about a charged object, negatively charged objects will be pulled towards higher voltages, and positively charged objects will be pulled towards lower voltages. The potential difference/Voltage between two points is independent of the path taken to get from point a to b. Thus, the voltage from a to b + the voltage from b to c will always equal the voltage from a to c.

Voltage (V) is a measure of the pressure applied to electric charges to make them move. It is a measure of the strength of the current in a circuit and is measured in volts (V). Voltage is the electric power system's potential energy source. Voltage does nothing by itself, but has the potential to do electrical work (i.e., transfer energy). Voltage is a push or a force. The basic unit (measurement) of electromotive force (EMF) is the volt. Voltage is the amount of potential energy that an electron gains or looses by traveling from one potential to another potential. In this way, voltage is very similar to potential energy in kinetics - if I lift a ball, the ball's properties doesn't change but it gains potential energy. Volts means volume.

> **Transformers** *either they "step up" or "step down" voltage.*

There are two types of voltage, DC voltage and AC voltage. The DC voltage (direct current voltage) always has the same polarity (positive or negative), such as in a battery. The AC voltage (alternating current voltage) alternates between positive and negative. For example, the voltage from the wall socket changes polarity 60 times per second (in America). The DC is typically used for electronics and the AC for motors. Normally, voltage is either constant (i.e., direct) or alternating. If voltage is constant (i.e., direct), then current is continuous/direct. If voltage alternates so does current.

> **ANALOGY:** *In water systems, voltage corresponds to the pressure that pushes water through a pipe. The pressure is present even though no water is flowing.*

Voltage is:

- Voltage is a measure of how much energy is delivered to charge.
- Voltage isn't a property of electrons. However, in electronics, charge is generally carried by electrons.
- Voltage unit is potential energy per change: V = potential energy / charge
- Voltage, or electric potential, is the amount of potential energy (joules) that any "charged body" within an electric field will have, for every 1 coulomb of electric charge in it.
- The potential energy does directly translate into kinetic energy if there is only negligible "friction". For example, in an (evacuated) cathode ray tube. The kinetic energy of an electron is indeed measured in "electron volts", eV, the energy (as charge) an electron gains or loses when charges moving through a potential difference of 1 Volt.
- Voltage is a property of an electric field. Note that a gravitational field behaves like an electric field wherein objects are pulled to together. Drop a stone in a gravitational field and it will accelerate

downwards, taking energy from the field.

- Using the water analogy, if a tank of water were suspended one meter above the ground with a 1-centimeter pipe coming out of the bottom, the water pressure would be similar to the force of a shower. If the same water tank were suspended 10 meters above the ground, the force of the water would be much greater, possibly enough to hurt you. Just as the 10-meter tank applies greater pressure than the 1-meter tank, a 10-volt power supply (such as a battery) would apply greater pressure than a 1-volt power supply. To remain useful, however, the velocity of the water must be excluded from the analogy. The speed of the flowing water (velocity) increases with pressure, while the speed at which an electric charge propagates through any particular medium is constant even if the “pressure” (voltage) is increased. A poorer analogy might be a tube filled with balls. Apply a force to the ball at one end and it will push the ball at the other end out. Apply a continuous voltage to a wire and the electric charges will move in one continuous direction, “forcing out” the charges at the “positive” end (and entering the power source). The amount of force applied corresponds to the voltage applied to the wire.
- For the water pipe analogy, charge (coulombs) is analogous to the volume of water (gallons), current (amps) is analogous to flow rate of water (gallons per minute), and voltage is analogous to the water pressure that is causing the flow.

The volt is defined as the energy transfer per coulomb of charge as charges move between two points in a circuit.

- $V = \Delta W / \Delta Q$
- Energy change per unit charge (so that 1 V = 1 J C-1)

> **NOTE: Phantom Voltage** *or “***induced voltage***” is the result of wire or other metal components appearing to be energized when they in fact are not. When ungrounded wiring (e.g., Knob & Tube) wiring or older ungrounded romex-type wiring is present, and a metallic pathway (wires and conduit) is added to these old circuits, then the metal wires and/or conduit will pick up an induced voltage merely by being in proximity to the hot conductor in the circuit. The ungrounded wire and conduit, and anything attached to it that is conductive and not grounded, will also appear “energized” (i.e., “hot”) when tested with a voltage indicator tool/instrument. Phantom voltage can make the metal sides of ungrounded technological devices like refrigerators, metal light fixtures, metal surface conduits, and metal junction boxes appear energized (when they are not actually energized).*

## 6.2 Electrical current (current)

> **NOTE:** *The electrons that move as an electrically charged current come from the conductors (and other connected sources such as a battery, photovoltaic cell, etc.) Remember that in AC, the electrons don’t actually travel (as in, DC), they oscillate (as in, AC).*

Because there are two types of voltage, there are also two types of current. There is direct current that moves in one direction, and there alternating current that alternates backward and forward (two directions).

Electric current is the rate of flow of [electrical] charge [carriers]. Whenever electric charges moves or flow, that is called an electric current. The words “electric current” are the same as the words “charge flow.” The rate of flow of electric charge is called electric current and is measured in Amperes. Current is the amount of [electric] charge passing through a space per unit time; the rate at which charges flow past a point in space. Current is a physical quantity that can be measured and expressed numerically. If charge is like air, then electric current is like wind. Or, if charge is like water, then electric current is like “volume per second” of water flow. An electric current is the directed movement of electric charge as uni-directional (direct current; DC) or alternating (alternating current; AC). The thing to remember when thinking about energy transfer with AC is that energy still flows from source to sink any time current flows, regardless of the direction of that current. Herein, current density is the electric current per unit area of cross section (amperes per volume).

The term DC is used to refer to power systems that use only one polarity of voltage or current. DC current charge is continuous, while AC current alternates between positive and negative charge. An electric current that flows continuously in a single direction is called a direct current, or DC. The voltage in a direct-current circuit must be constant, or at least relatively constant, to keep the current flowing in a single direction. A sine wave of DC current is a flat line, while AC is an alternating wave of a specific hertz rating. Current in a house circuit (AC) flows in one direction, same as in a battery (DC), hence the polarized plugs and receptacles.

The strength of the current is dependent on the size of the induced charge and the electric resistance the connection. Electromagnetic induction is the generation of voltage across a conductor situated in a changing magnetic field. The difference between the potentials is called the electrical potential difference and is commonly called induced voltage. This generates electric power through the flow of electric charge if both ends of the wire are connected with a conductive wire.

Using the flow of water provides a reasonable analogy for understanding the flow of electric charge. The flow of electric charge in a circuit is similar to water flowing through a hose. If you could look into a hose at a given point, you would see a certain amount of water passing that point each second. The amount of water depends on a number of variables, including how much pressure is being applied (i.e., how hard the water is being pushed). It also depends on the diameter of the hose. Given available water, the harder the pressure and the larger the diameter of the hose, the more water passes each second. The flow of electric charge (measured as electrical current) through a wire depends on the electrical pressure pushing the charges and on the cross-sectional area of the wire.

> **NOTE: Resistance** *is a material's tendency to resist the flow of charge (i.e., the tendency to resist electrical current).*

There are two types of electrical current: alternating current (AC) and direct current (DC). There are two principal types of flowing electric charge (electricity as electric current), and they are used in most cases for very different purposes: direct current (DC) and alternative/alternating current (AC). Often, electrical power is named after the type of current carrying the electrical power, 'DC power' or 'AC power'. Hence, there are two type types of electrical power: alternating current power (AC power) and direct current power (DC power). Either form can be technically converted into the other form.

> **CLARIFICATION:** *You might be wondering why is it called Alternating current when the voltage is the one that switches from positive to negative. It is called alternating current because as we said above, voltage is the pressure that pushes the current thought the circuit, so if the voltage alternates, the current must also alternate in direction as it is being pushed by the voltage in an opposite direction each time.*

## 6.3 Two types of electricity

There are two different ways that electricity (electrical power) is produced, and they are used in most cases for very different purposes. They can also be converted from one form to another. The two types of electricity are: direct current (DC) and alternating current (AC). Remember that to produce electricity (electrical power), both current and voltage must be present; hence, when speaking of the presence of electricity (electrical power) it is most appropriate to write 'direct-current (DC) voltage' and 'alternating-current (AC) voltage', although often, only the acronyms DC and AC may be written (they imply the presence of voltage).

### 6.3.1 Direct-current voltage (a.k.a., DC voltage or DC power)

> **NOTE:** *In a DC system, at the electrical level, it is possible to measure at least: voltage (volts), current (amperes), power (watts), and energy (watt-hours or J/s).*

**Direct current (DC)** is the unidirectional flow of electric charge (electricity flows in one direction). It is the continuous movement of electric charge from an area of negative (-) charge to an area of positive (+) charge -- the difference in charge at two locations connected by a conductor creates an electrical pressure difference (voltage), whereupon charges move from negative to positive until equilibrium is reached. In a direct current system, the voltage does not alternate direction with time. When an electric circuit with DC voltage is complete, the current flows directly, in one direction. It is called direct current as the current is only being pushed in one direction by the voltage. The resultant current creates a unidirectional magnetic field -- a magnetic field with a constant orientation. Hence, a DC current generates a constant magnetic field, and follows the "right hand rule" [wikipedia.org]:

- Induced current 'I' (middle finger)
- Magnetic field 'B' (index finger)
- Motion 'F' (thumb finger)

Direct current is produced by sources such as batteries, power supplies, thermocouples, solar cells, or dynamos (DC generators). Direct current may flow through a conductor such as a wire, but can also flow through semiconductors, insulators, or even through a vacuum, as in electron (dielectric) or ion beams. The electric current flows in a constant direction, distinguishing it from alternating current (AC), which alters its direction of flow at a time interval. Rather than oscillating back and forth as AC does, DC provides a constant uni-directional flow of current.

> **NOTE:** *Direct current was formerly known as galvanic current.*

In a direct current circuit, the power flowing to the load is proportional to the product of the current through the load and the potential drop across the load. Energy flows in one direction from the source to the load. In AC power, the voltage and current both vary approximately sinusoidally.

> **NOTE:** *If the electron flow of a direct current (DC) were converted to a sound, then a DC power signal would sound like a steady tone.*

Almost every electronic device uses DC, and cannot use AC. This is something most people don't realize when they plug some device into a wall outlet. Just because you plug a device into the wall doesn't mean the circuitry inside operates on AC. Very few electronic devices actually can use AC. Almost everything from LED lighting, televisions, stereos, phonographs, tape decks, CD/DVD players, computers, printers, clock radios, battery chargers, along with just about anything that has a micro processor inside or is otherwise computer controlled, all require DC power (if AC power is present, then a connected/internal "power supply" unit must convert AC to DC). If DC were available to begin with there would be no need for AC to DC "power supplies".

> **NOTE:** *The AC to DC power converter for a laptop dissipates (i.e., loses) energy through heat. If the electrical power system was DC, then users could plug in their electronics direct to DC without any need for conversion and any loss of energy to heat. Just like there are standardized plugs for AC, there is likely to be more standardization of DC plugs beyond the relatively low voltage USB DC standard connector.*

A DC voltage source has both negative and positive terminals, and produces a voltage (or potential difference) between those terminals.

Water flow can be used analogistically to describe DC and AC:

1. **Water analogy for DC:** Direct current is like the moving water in a calm river, which has a uniform velocity in and flows only in one direction (from the hills to the sea). DC flows from high potential to low potential, in one direction.
2. **Water analogy for AC:** Alternating current is like the water that is continuously moving forward and backward, such as water waves hitting the beach and receding back. Similarly, AC changes its direction after a particular interval of time.

### 6.3.2 Alternating-current voltage (a.k.a., AC voltage or AC power)

> **NOTE:** *In an AC system, at the electrical level, it is possible to measure at least: voltage (volts as a function of time, V(t), and as waveform amplitude, Vp), current (amperes), [waveform] frequency (hertz), [waveform] phase (degrees), power (watts), and energy (watt-hours or J/s).*

**Alternating current (AC)** is a flow of electric charge that periodically reverses/changes direction - an alternating/changing flow of electric charge (i.e., the current *alternates* its direction over time as it flows; electricity flows in both directions). It is essentially a steady sine wave and the reversal of polarity that, over time, generates an oscillation frequency (i.e., a back and forth movement of electric charge at a "speed" known as a 'frequency', which is measured in the unit, hertz). Alternating currents are accompanied (or caused) by alternating voltages. AC as its definition is alternating current (i.e the amplitude of the current is different for different instants of time). Alternating current is not a single, constant voltage, but rather as a sinusoidal wave that starts at zero, and over time, increases to a maximum value, then decreases to a minimum value, and repeats. AC always implies alternate (and therefore varying). AC switches polarity over time, in a precise sinusoidal-like manner, causing electric charges ("electrons") to pulse back and forth [over a material known as a "conductor"]. Alternating voltage pushes and pulls the charge backwards and forwards in the conductor (e.g., a wire). The two ends of the circuits become both the positive and negative pole at different times. In its pulsating movement, alternating current creates a moving magnetic field inside the conductor.

> **NOTE:** *In an alternating current (AC) system there is no static "plus" (+) or "minus" (-) in the circuit, because each side (terminal) of the circuit is a (+) and (-) at different times.*

The two principal properties of an AC electrical current are: voltage and frequency. These two properties differ between market-State regions. A voltage of (nominally) 230V and a frequency of 50Hz is used in Europe, most of Africa, most of Asia, most of South America and Australia. In North America, the most common combination is 120V and a frequency of 60Hz. Other voltages exist, and some countries may have, for example, 230V and 60Hz.

In AC power system, the (power) "line frequency" or "mains frequency" is the frequency of the oscillations/cycles of alternating current (AC current cycle). Essentially, frequency refers to how often the current changes direction. The two principal frequencies used throughout the world form common (non-specialized) AC power are 50Hz and 60Hz (50-cycle and 60-cycle). For instance, a generator with one pole (one alternating current cycle per revolution) turning at 3600 rpm will rotate 60 times in one second, thus generating 60 alternating current cycles per second or 60 Hz current. It follows that a machine rotating at 1800 rpm will require four poles to produce the same 60Hz current.

Electrical generators (AC) generally seek to produce electric power where the voltage waveform has only one frequency associated with it, the fundamental frequency (e.g., 50Hz or 60Hz). Hence, when an electrical circuit is connected to the coils of an operating generator, there will exist an oscillating electric current "surging" back and forth through each coil at a rate of #Hz times a second (e.g., 50Hz or 60Hz).

> **NOTE:** *The sequence of successive peaks of the currents (i.e., phases) causes a magnetic field to form and move around the stator air gap.*

The appearance of additional frequencies (frequency waveforms) produces harmonics. Harmonics are distortions of the pure sinusoidal waveform. It is the sinusoidal component of a periodic wave or quantity having a frequency that is an integral multiple of the fundamental frequency. Harmonics are a multiple of the fundamental frequency. Some references refer to "clean" or "pure" power as those without any harmonics. Some loads cause the voltage and current waveforms to lose this pure sine wave appearance and become distorted.

Note that in acoustics (as in, music), harmonics are called overtones.

> **NOTE:** *"Mains electricity" (mains AC) is the general-purpose alternating-current (AC) electric power supply fed into commercial buildings and residential homes by the electric power industry in early 21st century society. Mains electricity is also referred to by several names including household power, household electricity, house current, powerline, domestic power, wall power, line power, AC power, city power, street power, and grid power.*

Frequencies can vary from as low as 10Hz (or less) to as high as 400Hz (or more) for specialized AC power systems. Several factors influence the choice of frequency in an AC system, and the design of generators, transformers, transmission lines, and end-load devices depend on the power frequency. The usage of AC technology of a different frequency rating than the one specified by the manufacturer of a device can be dangerous.

> **NOTE:** *AC can be radiated from an antenna, and this capability is responsible for radio communication (e.g., radio, wifi, bluetooth, cellular communication, etc.). In other words, alternating electromotive force ( in the conductor also radiates radio frequencies (as electromagnetic frequency waves, EMF -- not the same as electromotive force EMF) from the conductor. This electromagnetic frequency field (EMF) reverses its polarity when it moves under magnetic poles of opposite polarity.*

The simplest form of AC power consists of a source and a linear load, and both the current and voltage are sinusoidal.

1. If the load is purely resistive, the two quantities reverse their polarity at the same time. At every instant the product of voltage and current is positive or zero, with the result that the direction of energy flow does not reverse. In this case, only active power is transferred.
2. If the loads are purely reactive, then the voltage and current are 90 degrees out of phase. For half of each cycle, the product of voltage and current is positive, but on the other half of the cycle, the product is negative, indicating that on average, exactly as much energy flows toward the load as flows back. There is no net energy flow over one cycle. In this case, only reactive power flows—there is no net transfer of energy to the load.
3. Practical loads have resistance, inductance, and capacitance, so both active and reactive power will flow to real loads. In an AC system, power is measured as the magnitude of the vector sum of active and reactive power. **Apparent power** is the product of the root-mean-square of voltage and current. In alternating current (AC) circuits, energy storage elements such as inductors and capacitors may result in periodic reversals of the direction of energy flow leading to the creation of active power and reactive power
   A. The portion of power that, averaged over a complete cycle of the AC waveform, results in net transfer of energy in one direction is known as **active power** (sometimes also called **real power**).
   B. The portion of power due to stored energy, which returns to the source in each cycle, is known as **reactive power**. Energy stored in capacitive or inductive elements of an AC power network give rise to reactive power flow. Reactive power flow strongly influences the voltage levels across the network. Voltage levels and reactive power flow must be carefully controlled to allow a power system to be operated within acceptable limits.

When there is inductance or capacitance in the circuit, the voltage and current waveforms do not line up perfectly. The power flow has two components - one component flows from source to load and can perform work at the load, the other portion, known as "reactive power" is due to the delay between voltage and current, known as phase angle, and cannot do useful work at the load. It can be thought of as current that is arriving at the wrong time (too late or too early). To distinguish reactive power from active power, it is measured in units of "volt-amperes reactive" or var. These units can simplify to Watts, but are left as VAR to denote that they represent no actual work output.

Alternating current has the compelling advantage over direct current; its voltage can be changed easily and efficiently by a transformer. A transformer is generally composed of a closed iron core surrounded by two windings (first and fourth principles of electrical machinery). The ratio of the voltages in the two windings is the same as the ratio of the number of turns, and the ratio of the currents inversely, so that the power remains the same. The ratio of the voltage fluctuations on each side is the ratio of the number of turns the wire makes around the core (on each side). Since there are no mechanical parts, the efficiency of transformers is very high, and maintenance very low. Alternating current is transformed to higher voltage and smaller current for transmission, and back to lower voltages for use. Transformers with taps can be used to obtain a series of voltages if desired. In fact, an almost continuous voltage variation without loss is possible. It is not easy to change DC voltages. One way to do this was to use a dynamotor, which had a normal field winding, but dual armature windings and two commutators. One winding was supplied at the input voltage and drove the dynamotor by motor action. The other winding supplied the output voltage. This can really be considered a kind of AC transformer. The input commutator creates AC from DC, and the output commutator changes the new AC voltage to DC.

1. Devices that can be designed to work effectively with AC: electric light-bulbs; electric heating elements; small electric motors (food mixers and vacuum cleaners).
2. Devices that preferably or necessarily run on DC: large electric motors; electronics.

**NOTE:** *Earth has a magnetic field, and it is moving in a more or less circular path around the moon, and so, one could theorize that a conductor on the moon may have such a wave induced into it. However, there is not any knowledge, presently, of any organisms in nature that use a reversal of polarity as a force in their sustainment.*

## 6.4 Electrical charge

**NOTE:** *Electricity is commonly defined in practical application (non-theoretical scientific study) as the flow of electric charge (electric current).*

The material things around us are made of 'atoms'. Atoms are the fundamental building blocks of all molecules, and they consist of three types of 'particles': protons, neutrons, and electrons. Of these three subatomic particle types, two (protons and electrons) carry a net electric charge, while neutrons are neutral and have no net charge. Atoms have a "positively" charged nucleus (containing the protons with a "positive" charge and the neutrons with no net charge, hence "positively" charged). The nucleus is surrounded by "negatively" charged electrons.

**NOTE:** *If an atom has an equal number of protons and electrons, its net charge is 0. If it gains an extra electron, it becomes negatively charged and is known as an anion. If it loses an electron, it becomes positively charged and is known as a cation.*

Unlike protons, electrons can move from atom to atom. Hence, electrons are considered mobile charges (i.e., they are the mobile charge carriers in an electric circuit). In physics, 'electrons' are the smallest unit of "negative" electric charge, and protons are the smallest unit of "positive" electric charge. Summarily, there are two types of electric charge: "positive" (proton) and "negative" (electron), with the neutrons having a neutral (0) charge. It is possible to encounter free positive charges (e.g. a free proton or ion) in atomic or nuclear physics, or in chemistry. There are also positively charged electrons (positrons), but they occur under special conditions and do not survive long.

**NOTE:** *If there is a quantity of charge, it cannot be destroyed, it can only be moved from place to place.*

The electric charge (elementary charge) is one of the fundamental quantities/constants of physics, along with mass and time. An elementary charge -- that of a proton or electron -- is approximately equal to $1.6\times10^{-19}$ Coulombs.

The motion of charge carriers is electric 'current'. In other words, when charges move they form a "flow of electric charge", which is called an electric current. In electricity and electronics, the negative charges are the electrons, and the currents almost always refer to the movement of electrons. Note here that the direction of the electric current is always opposite the motion of the electrons, because someone in the past decided that the direction of the current should be in the direction of 'positive' charges, and scientists have not updated their language since.

**NOTE: Electrostatics** *is a branch of physics that deals with the phenomena and properties of stationary or slow-moving electric charges.* **Electrodynamics** *is a branch of physics that deals with the phenomena and properties of moving charges.*

In specific, an **electric charge** is the physical property of matter that causes it to experience a force when placed in an electromagnetic field; this force is known as the 'electric force'. Charges produce electromagnetic fields, which act on other charges. Electrically charged matter is influenced by, and produces, electromagnetic fields (EMF). The interaction between a moving charge and an electromagnetic field is the source of electromagnetic force, which is one of the four fundamental forces.

The concept 'electrical energy' refers to energy carried by [moving] electrical charges. Note here that an electrical charge is not energy; it carries energy. The faster electrical charges are moving, the more electrical energy they carry. Note here that when electrical charges are moving (current), they are considered a form of kinetic energy. Whereas a static charge (unmoving charge) contains potential energy, and when it moves, this energy is said to be "converted" to kinetic energy.

**NOTE:** *Charge carriers are "pushed" around a circuit by an electromotive force (EMF or voltage). Despite its name, EMF is not a force but a voltage, measured in volts. In other words, the pressure that moves charge carriers around an electric circuit, and thus, transfers energy from source to load, is called an electromotive force (EMF), which is not a force, but is in fact voltage. The electromotive force is voltage across a source of electrical energy, and therein, potential difference is voltage across a component that uses electrical energy. EMF is energy supplied per coulomb. In other words, the volt is defined* *as the energy transfer per coulomb of charge as charges move between two points in a circuit: V = ΔW / ΔQ. Charge carriers (electrons being one of such) can be used to transmit an electromotive force (usually called just voltage).*

If a current is present, then there is a net motion of charge carriers, and "electrical" energy is being transferred. However, it is generally not correct to say that an electric current is "a flow of electrons"; instead, it is more correct to say that electric current is a flow of electric charge. Charge can be positive (protons) or negative (electrons), and both types of charged particles can and do flow in electric circuits. In different media, different particles serve to carry charge:

1. In metals - the charge carriers are electrons.
2. In electrolytes (e.g., salt water) - the charge carriers are ions, and atoms or molecules that have gained or lost electrons so they are electrically charged. Atoms that have gained electrons so they are negatively charged are called anions, atoms that have lost electrons so they are positively charged are called cations.
3. In plasma - the electrons and cations (cat-ions) of ionized gas act as charge carriers.
4. In a vacuum [tube] - free electrons can act as charge carriers.
5. In a semiconductor (e.g., transistor) - electrons and traveling vacancies in the valence-band electron population (called "holes") are the charge carriers.
6. In hydrogen fuel cells and water ice - current consists of a flow of protons, which are the charge carriers.

In physics, it is presently understood that the "electrons" do physically move (when a voltage is applied) both in AC and DC, though slowly in DC. In a DC circuit, the electrons move in one direction. In an AC circuit, the electrons don't move continuously forward; instead, they move backwards and forwards (i.e., they oscillate), and may be said to "vibrate". The thing to remember when thinking about energy transfer via electric current, regardless of DC or AC, is that energy flows from source to load any time electric current flows, regardless of the direction of the electric current (or moving "electrons").

**CLARIFICATION:** *There are [at least] two things moving through an electrical power system: "electrical" energy and electric charge carried by a charge carrier (e.g., electron).*

Here, the term "charging" refers to giving an object/ system a[n electric] charge. There are three common methods of "charging":

1. Charging by friction - Rubbing two different materials together, a process known as charging by friction (a.k.a. charging by rubbing), is the simplest way to give something a charge.
2. Charging by induction - It is possible to charge a conductor without touching it. Charging by induction requires a procedure involving [at least] two objects and a ground connection.
3. Charging by conduction - The two objects will come into actual physical contact with each other, and contact transfers the charge (this is why it is sometimes called "charging by contact").

## 6.5 *Electrical power systems*

An electrical power system is a network of electrical components interconnected to supply, transfer and distribute, and use, electrical power.

**NOTE:** *In order to function, an electrical power system must form an electrical circuit.*

In general, when electrical power is supplied and used over a land area larger than a single building, then the power system is known as "the electrical grid", which can be broadly divided into the generators that supply the power, the transmission system that carries the power from the generating source(s) to the load(s), and the distribution system that feeds the power to end-point uses. Hence, a "wide-scale" electrical power system consists of a power station(s) connected to a transmission and distribution system. A localized electrical power system may consist only of an electrical power generator and distribution system. In general, electrical power systems also involve electrical power storage and recovery systems. Herein, the electrical transmission grid is an electrical circuit.

All electrical power systems are composed of the following:

1. **The supplying source:** All power systems have one or more sources of power. For some power systems, the source of power is external to the system, and for others it is part of the system itself. There are two principal types of power supply: alternating current (AC) and direct current (DC).
2. **The electrical circuit with an electrical load:** Power systems transfer energy to loads that perform a function. In general, it is a composition of material converts electrical energy to some other form of useful energy. Most loads expect a certain voltage, and for alternating current devices they necessitate a certain frequency and number of phases. Every load will have a wattage, which specifies the amount of electrical power the load consumes. At any one time, the net amount of power consumed by the loads on a power system must equal the net amount of power produced by

the supplies, less the power lost in transmission.

3. **Conductors:** Conductors carry power from the generator to the load, or from a generator to an induction point, and then, from the opposite side of the induction point to the load. In a grid, conductors may be classified as belonging to the transmission system, which carries large amounts of power at high voltages (typically more than 69 kV) from the generating centres to the load centres, or the distribution system, which feeds smaller amounts of power at lower voltages (typically less than 69 kV) from the load centres to nearby homes and industry. There are also conductors within electronic devices themselves. Note that different materials (and different combinations of materials) carry different conductivity measures. Conductors are typically rated for the maximum current that they can carry at a given temperature rise over ambient conditions. As electrical current flow increases through a conductor it heats up. For 'insulated conductors', the rating is determined by the insulation, and for 'overhead conductors', the rating is determined by the point at which the sag of the conductors would become unacceptable. Electric conductors are substances that possess the quality of electric charge. Within all metals there is a substance which can move.
4. **Power electronics**: Power electronics are semi-conductor based devices that are able to switch quantities of power ranging from a few hundred watts to several hundred megawatts. The classic function of power electronics is rectification, or the conversion of AC-to-DC power, power electronics are therefore found in almost every digital device that is supplied from an AC source either as an adapter that plugs into the wall (see photo in Basics of Electric Power section) or as component internal to the device. High-powered power electronics can also be used to convert AC power to DC power for long distance transmission in a system known as HVDC. HVDC is used because it proves to be more economical than similar high voltage AC systems for very long distances (hundreds to thousands of kilometres).
5. **Earthing system** (**grounding system**) is circuitry which connects parts of the electric circuit with the ground (earth), thus defining the electric potential of the conductors relative to the Earth's conductive surface. The purpose of an earthing system is to provide an alternative path for the fault current to flow so that it will not endanger the user, ensure that all exposed conductive parts do not reach a dangerous potential, maintain the voltage at any part of an electrical system at a known value and prevent over current or excessive voltage on the appliances or equipment. Different earthing systems are capable of carrying different amounts of over current. There are two types of earthing systems:
   A. Unearthed system: IT system
   B. Earthed system: TT system; TN system (TN-S, TN-C, TN-C-S)
6. **Protective devices:** Power systems contain protective devices to prevent injury or damage during failures.
   A. The most common 'protective device' is a fuse. Fuses must be replaced as they cannot be reset once used (i.e., blown). Also, fuses can be inconvenient if the fuse is at a remote site or a spare fuse is not available.
   B. Circuit breakers are devices that can be reset after they have broken current flow.
   C. Protective relays are used in high power applications. They detect a fault and initiate a trip.
   D. Enclosing an arc chamber and flooding it with sulfur hexafluoride (SF6), a non-toxic gas that has sound arc-quenching properties.
   E. Residual current devices (RCDs) - In any properly functioning electrical appliance the current flowing into the appliance on the active line should equal the current flowing out of the appliance on the neutral line. A residual current device works by monitoring the active and neutral lines and tripping the active line if it notices a difference. Residual current devices require a separate neutral line for each phase and to be able to trip within a time frame before harm occurs.
7. **Supervisory Control And Data Acquisition (SCADA)** is used in large electric power systems for tasks such as switching on generators, controlling generator output and switching in or out system elements for maintenance.

In the market, electrical power systems are generally subdivided into residential power systems (small scale) and commercial power systems (large scale):

1. Residential dwellings almost always take supply from the low voltage distribution lines or cables that run past the dwelling. These operate at voltages of between 110 and 260 volts (phase-to-earth) depending upon national standards. Each dwelling has its own circuit breaker.
2. Commercial power systems are uniquely designed for load flow, short-circuit fault levels, and voltage drop for steady-state loads and during starting of large motors. Typically one of the largest appliances

connected to a commercial power system is the HVAC unit.

### 6.5.1 The electric circuit

**NOTE:** *Power in an electric circuit is the rate of flow of energy past a given point of the circuit.*

An electric circuit is a path in which electrons from a voltage or current source flow. The point where those electrons enter an electrical circuit is called the "source" of electrons. The point where the electrons leave an electrical circuit is called the "return" or "earth ground". An electrical circuit is a network consisting of a closed loop, giving a return path for the current. An electrical circuit is a path or line through which an electrical current flows. The path may be closed (joined at both ends), making it a loop. A closed circuit makes electrical current flow possible. It may also be an open circuit where the electron flow is cut short because the path is broken. An open circuit does not allow electrical current to flow. Hence, a working **circuit** is a closed loop -- to be a circuit, all charge must find a path back to its source, regardless of the source (including a battery or a transformer on the pole; this is part of "Kirchhoff's current law").

**NOTE** *that in the case of static electricity, the "Kirchhoff current law" will accept a temporary delay and storage of charge. The most commonly encountered real world example of this is on a cold and dry day: you walk across the carpet and touch a doorknob and experience a spark. As you walked, your socks picked up charge from the carpet; it flowed out onto your body, and when you touched the doorknob that charge began its journey back to the carpet fibers from where it came via material from which the door is composed.*

Electric power is transferred to other carriers of energy when electric charges move through loads in electric circuits. From the standpoint of electric power, the components in an electric circuit can be divided into two categories:

1. **Active devices** or **power sources:** When electric charges move through a potential difference from a higher to a lower voltage, that is when conventional current (positive charge) moves from the positive (+) terminal to the negative (−) terminal, work is done by the charges on the device. The potential energy of the charges due to the voltage between the terminals is converted to kinetic energy in the device. These devices are called passive components or loads; they "consume" electric power from the circuit, converting it to other forms of energy such as mechanical work, heat, light, etc. In alternating current (AC) circuits the direction of the voltage periodically reverses, but the current always flows from the higher potential to the lower potential side
2. **Passive devices** or **loads:** If the charges are moved by an 'exterior force' through the device in the direction from the lower electric potential to the higher, (so positive charge moves from the negative to the positive terminal), work will be done on the charges, and energy is being converted to electric potential energy from some other type of energy (e.g., mechanical energy or chemical energy). Devices in which this occurs are called active devices or **power sources**; such as electric generators and batteries.

Note that some circuitry devices (i.e., devices connected to a circuit) can be either a source or a load, depending on the voltage and current passing through them. For example, a rechargeable battery acts as a source when it provides power to a circuit, but as a load when it is connected to a battery charger and is being recharged.

The three main circuit components are:

1. The resistor
2. The capacitor
3. The inductor

Hence, the types of electrical circuits associated with electrical power production or power conversion systems are:

1. Resistive
2. Capacitive
3. Inductive

Most systems have some combination of each of these three circuit types. These circuit elements are also called loads. A load is a part of a circuit that converts one type of energy into another type. A resistive load converts electrical energy into heat energy.

## *6.6 Electric[al] power generation (electrical power source)*

*- Thermal > electric (e.g., thermopile, thermoelectric generator)*
*- Mechanical > electrical (e.g., alternator)*
*- Fluidal > electrical (e.g., turbine-electric)*
*- Chemical > electrical (e.g., chemical battery)*
*- Magnetic > electrical (e.g., electrical generator)*
*- Electromagnetic > electrical (e.g., antenna receiver, solar panel)*

Electrical power is present when electric charges move (current) through an electric potential difference (voltage). Therein, electrical power is the product of the current and the voltage. Hence, to generate electrical power, a method and/or system must induce voltage across a conductor to produce a current (simplistically, it must produce both voltage (V) and current (I), where Power = VI).

Technically, current is the result of the generation of voltage (electrical potential difference, electromotive force) between two points on a conductive circuit. The product of voltage and current is power, and when power is present, energy is being transferred.

> **DEFINITION:** *A* **power station***, also referred to as a generating station, power plant, powerhouse, or generating plant, is a technical production space (or, location or facility) for the generation of power (generally, electrical power, but if the context is not clear, then it could be any type of power).*

Electric power generation is the process of generating electric power (voltage and current) from other carriers (sources) of energy. Herein, the term 'direct electric power generation' refers to energy transfer methods and technologies that are capable of directly producing electrical power (electricity) from some other type of energy carrying input. There are several fundamental scientific effects that may be applied methodically (procedurally) for producing and/or generating electrical power from other sources/carriers of energy:

1. **Electrostatic effect** (static electricity through friction) - technically, not a form of electric power, but a form of voltage as an imbalance of electric charges within or on the surface of a material. The charge remains until it is forced to move by means of an electric current or electrical discharge. Static electricity is the physical separation and transport of charge (e.g., triboelectric effect, lightning, and friction sparks). The discharge or other movement of static electricity carries electrical power.
    - When an object with a normally neutral charge loses electrons, due to friction, and comes in contact with another object having a normal charge, an electric charge is exerted between the two objects.
2. **Electromagnetic induction effect** (magnetic induction, electromagnetism) - is the production of an voltage (electromotive force) across an electrical conductor due to the conductor's dynamic interaction with a magnetic field. The effect of time-varying magnet fields is to produce a time-varying electromotive force (EMF) that drives/forces charged particles around a circuit. The effect is described exactly by Maxwell's equations. And, electromagnetic induction is based on Faraday's law. Today, electromagnetic induction is the most widely used method for generating electricity. This method generally involves an input of rotational (angular) mechanical energy (e.g., turbine).
    - Induction, as the movement of a conductor in a magnetic field, directly creates an electric potential (a dynamic time-varying electric field) in the conductor, whereupon charges move, and hence, current flows.
    - **Magnetohydrodynamics** (MHD; also magneto fluid dynamics or hydromagnetics) - an electrically conductive fluid passes through a magnetic field, whereupon electrical power may be generated based on Faraday's law of induction. A generator using this mechanism is also known as a magnetohydrodynamics generator.
3. **Electrochemical effect** (electrochemistry) - the direct transfer of chemical energy into electrical energy through chemical reaction (e.g., battery, fuel cell, or nerve impulse). These chemical reactions involve electric charges moving between electrodes and an electrolyte (or ionic species in a solution). Thus, electrochemistry deals with the interaction between electrical energy and chemical change.
    - A chemical reaction in a system directly create an electric potential and current.
    - Combining chemicals with certain metals causes a chemical reaction that transfers electrons.
4. **Photoelectric effect** (**photovoltaic effect**) - a transfer of electromagnetic energy (light) into electrical energy (e.g., photovoltaic solar cells). The photo-electric effect/principle states that a system can only collect/assimilate light when electrons are present. The greater the presence of electrons, the more energy carried by light can be transferred into an electrical circuit.
    - Light (electromagnetic energy) contacting a system directly creates an electric potential and current.
    - Dislodging of electrons from their orbits by light beams creates positively-charged objects.
5. **Thermoelectric effect** (heat) - the direct conversion of temperature differences into electric voltage, and vice versa. A thermoelectric device creates voltage when there is a different temperature on each side (e.g., thermocouples, thermopiles, and thermionic converters). Note, power generation methods that use heat as a primary input are subject to Carnot efficiency limitations. Any thermodynamic driving force (heat) can directly generate electricity.
    - Heat (thermal energy transfer) into a system directly creates electric potential and current.
    - Heating two joined dissimilar materials will cause a transfer of electrons between the materials setting up a current flow.
6. **Thermionic emission effect** (thermal electron emission , Edison effect)- the thermally induced

flow of charge carriers from a surface or over a potential-energy barrier. This occurs because the thermal energy given to the carrier overcomes the work function of the material. A thermionic energy "converter" is a device consisting of two electrodes placed near one another in a vacuum. One electrode is normally called the cathode, or emitter, and the other is called the anode, or plate. At a sufficiently high temperature, a considerable number of electrons are able to "escape" the cathode. The electrons that have escaped from the hot cathode form a cloud of negative charges near it called a space charge. If the plate is maintained positive with respect to the cathode by a battery, the electrons in the cloud are attracted to it. As long as the potential difference between the electrodes is maintained, there will be a steady current flow from the cathode to the plate.
   - Freeing electrons from a hot surface causes electrons to "escape".
7. **Piezoelectric effect** (mechanical pressure) - the electric charge that accumulates in certain solid materials (such as crystals, certain ceramics, and biological matter such as bone, DNA and various proteins) in response to applied mechanical stress. The charge comes from the mechanical strain of electrically anisotropic molecules or crystals.
   - Mechanical stress in a system directly creates electric potential and current.
   - Bending or twisting certain materials will cause electrons to drive out of orbit in the direction of the force. When the force is released, the electrons return to their original orbit.
8. **Nuclear transformation** - charged particles (e.g., betavoltaics or alpha particle emission).
   - The "decay" of nuclear potential energy creates electric potential and current in a system.

Electric power generation considerations:

1. How much electrical power does the generator and or generation station need to supply?
2. Is there a proximity requirement between the generator and load/user?
3. What source of primary energy is available in proximity?
4. What is an acceptable length of time for starting the generator (some generators can take hours to start)?
5. Is the availability of the power source acceptable (some sources create safety issues, such as pollution, and some sources are available only periodically such as sunlight and wind)?
6. How should the generator start (some turbines act like a motor to bring themselves up to speed in which case they need an appropriate starting circuit)?
7. Which of the two types of current-voltage (DC or AC) is required as input?
8. What is the mechanical speed of operation for the turbine, and consequently, what are the number of poles required?

### 6.6.1 Electromagnetic induction

Generally, electromagnetic induction generators require a source of rotational (angular) mechanical power to produce a dynamic interaction between the conductor and the magnetic field. Anything that produces torque at a sufficient number of rotations per minute (e.g., turbines, motors and engines) can be used (as a mechanical power source) to turn the rotor within an electromagnetic induction generator to produces electric power.

Presently, most electrical power on Earth is generated by electromagnetic induction through turbine-generator systems. The turbine produces mechanical shaft power as the power input into an electromagnetic induction generator, which outputs electrical power (AC only, not DC). The turbine turns the rotor of the generator with mechanical torque, and the generator transfers this "mechanical" energy to "electrical" energy.

AC power may be directly generated through rotating electromagnetic equipment. An AC power generator is made up of a stator (which remains still), a rotor (which rotates), and electromagnetic fields that generate electromotive force (i.e., voltage) in conductors. When the rotor turns, the magnetic field begins moving in relation to a conductor. Whereupon, voltage is induced in the conductor (coil), which can be measured between the two ends of the coil. The two ends of the coil are called the generator's terminals. An electrical circuit is hooked up to these terminals, and the ensuing electric power is transmitted to the load on the circuit.

Rotating electromagnetic generators directly produce AC current, which can be modified to produce DC current. There are two types of rotating electromagnetic (AC) generator: synchronous and asynchronous.

### 6.6.2 Dispatchability

Electrical power generating systems may be classified according to their dispatchability (duty). Dispatchable generation refers to sources of electricity that can be dispatched at the request of power grid users (and hence, intersystems team operators). In other words, dispatchability refers to the ability of generating plants to be turned on or off, or can adjust their power output, accordingly to demand, and hence, the output of a control system [as part of the Decision System]. Power stations are either dispatched (scheduled), or non-dispatched (non-scheduled):

1. **Dispatched: Base load power plants (load matching)** run nearly continually to provide that component of system load that doesn't vary during a day or daily cycle (e.g., week). Baseload plants can be highly optimized for low fuel cost, but may not start or stop quickly during changes in system load. Examples of base-load plants would include large coal-fired and nuclear generating stations, or hydro plants with a predictable supply of water.
2. **Dispatched: Peaking power plants (peak matching)** meet the daily peak load, which may only be for one or two hours each day. They operate in tandem with base load power plants as required to ensure production capacity of the system during load peaks. Peaking plants include simple cycle gas turbines and sometimes reciprocating internal combustion engines, which can be started up rapidly when system peaks are predicted. Hydroelectric plants may also be designed for peaking use.
3. **Dispatched: Load following power plants (lead-in times)** follow the variations in the daily and daily cycle (week), at a lower resource usage than peaking plants, and with more flexibility than baseload plants.
4. **Dispatched: Backup for base-load generators** - Nuclear power plants, for example, are equipped with nuclear reactor safety systems that can stop the generation of electricity in less than a second in case of emergency.
5. **Non-dispatchable plants (intermittent renewable energy, frequency regulation)** involve quality and stability changes in the electricity output sent into the system because of a change in the frequency of electricity transmitted; renewable sources such as wind and solar are intermittent and may need flexible power sources to smooth out their changes. While their long-term contribution to system energy supply is predictable, on a short-term (daily or hourly) base it may vary from predictable for some sources (e.g., solar) to unpredictable [given present knowledge] for other sources (e.g., wind). In some cases their generated power can be deferred (e.g., to a battery), and in other cases it must be used as it is generated.

**NOTE:** *The division between dispatchable power plants and renewable power plants is something of a false dichotomy, because if you have sufficient wind or solar generators, then they can be turn on and off (e.g., number of wind turbines operating) and adjusted (e.g., angle of incidence for solar) to control their power output. A solar system obviously cannot be dispatched at night, but that is predictable. Cloud cover is not as yet as predictable. In a planned and integrated power system there are known variables and parameters attached to different power sources: predictability and variability therein, startup and shutdown timing, and output adjustability.*

Electrical grid dispatchable variables include:

1. Electrical system balancing - changes in power demand require changes in supply in order to ensure load following and frequency control
   - Load matching - slow changes in power demand require changes in supply in order to ensure balance.
   - Load following - medium (not slow and not short) changes in power demand require changes in supply in order to ensure balance
   - Peak matching - short/rapid changes in power demand require changes in supply in order to ensure balance.
2. Lead-in times - periods during which an alternative source is employed to supplement the lead time required by primary power sources.
3. Frequency regulation or intermittent power sources - changes in the electric power output sent into the system may change quality and stability of the transmission system itself, because of a change in the frequency of electricity transmitted.
4. Backup for base-load generators - safety systems that can stop the generation of electricity in less than a second in case of emergency.

### 6.6.3 Electromechanical systems (a.k.a., electrical machines)

**NOTE: Electromechanics** *combines electrical and mechanical processes and procedures drawn from electrical engineering and mechanical engineering. Electromechanical machines are also known as electrical machines. Here, the word machine added to electrical implies a mechanical element connected to an electrical element.*

The terms 'electromechanical systems' (a.k.a., electromechanical machines/devices) and 'electrical machines' mean the same thing. These terms refer to a machine (mechanical system) combined with an electrical system (electrical device) to transfer (i.e., "convert") mechanical energy to electrical energy, and vice versa. The electromechanical "conversion" process involves the transfer of energy between electrical and mechanical systems (and vice versa), via motion in combination with electromagnetic phenomena (i.e., the electric and magnetic fields). Electrical machinery are devices that utilize electromagnetic phenomena in the transfer of mechanical power into electrical power, and vice-versa. By the classical definition, an electric machine is synonymous with electric motors and electric generators, all of which are electro-mechanical energy "converters". They convert electricity to mechanical power (i.e., electric motor) or mechanical power to electricity (i.e., electric generator).

> **NOTE:** *The process of electromechanical energy transfer ("conversion") is reversible in nature, apart from the losses taking place in the device.*

Herein, the energy is not created or destroyed, but it is transferred between electrical and mechanical carriers. In practice, there are four basic types of electromechanical system (a.k.a., electrical machines):

1. **Transducers**: These electronic devices transfer (or "convert") energy signals from one carrier (or "form") to another. These devices mostly operate on vibrating motion. Examples are microphones, pickups, and speakers.
2. **Mechanical force producers**: These types of devices produce mechanical force or torque based on translatory motion. These devices handle larger energy signals than transducers. Examples are relays, solenoids (linear actuators), and electromagnets.
3. **Continuous electrical power "converters" (rotating electromagnetic machines)**: There are two types of continuous energy "conversion" devices, both of which operate in rotating mode, and are thus referred to as rotating electromagnetic systems (machines, devices, or equipment):
   - **Generators** transfer mechanical energy to electrical energy.
   - **Motors** transfer electrical energy to mechanical energy.
     - Electric generators and motors operate by virtue of induced electromotive force (emf, voltage). The induction of emf is based on Faraday's law of electromagnetic induction. Every generator and motor is a rotating electromagnetic system and has a stator (which remains stationary) and rotor (which rotates).
     - There are three types rotating electromagnetic/ electromechanical machine:
   - **DC machines** - produce DC current (DC generator) or accept DC current (motor)
   - **Asynchronous AC machines** - produce (generator) or accept (motor) AC current in an asynchronous manner. **Induction machines** denote asynchronous machines of which only one winding is energized.
   - **Synchronous AC machines** - produce (generator) or accept (motor) AC current in a synchronous manner.
4. **Transformers:** These devices do not transfer (i.e., "convert") between mechanical and electrical carriers, but they convert AC current from one voltage level to another voltage level. In order to have a transformer work, there needs to be a changing current, that changes the magnetic flux around the core. The changing magnetic flux, 'cuts' into the other coil and induces a EMF voltage across the two terminals(or more). Depending on the turns ratio, this determines the output voltage compared to the input. Transformers are AC only because a typical transformer consists of two windings: primary and secondary. The primary winding is connected to the power source while the secondary winding is connected to the load. Between the primary and the secondary windings, there is no electrical connection. Instead, electric energy is transferred through inductance within the core that is generally made up of laminated steel. Therefore, transformers operate only on alternating current. Although transformers do not contain any moving parts, they are also included in the family of electric machines because they utilise electromagnetic phenomena. Besides transformers, electromagnetic machines link an electrical energy system to a mechanical energy system. An electrical transformer generally consists of a core made up of laminated steel and two windings. The windings that are connected to the power source are generally called primary windings. The other windings are connected to the load and are generally labeled as the secondary windings. A typical electrical transformer consists of two windings: primary and secondary. The primary winding is connected to the power source while the secondary winding is connected to the load. Between the primary and the secondary windings, there is no electrical connection. Instead, electric energy is transferred through inductance within the core that is generally made up of laminated steel. Therefore, transformers operate only on alternating current only. Electrical transformers are typically very efficient with energy losses representing only 1%–3% of the transformer capacity. The power output from any transformer is always less than an input power. The transformer power losses are typically due to copper losses and core losses. The copper losses, also known as winding losses or $I^2R$ losses, are attributed to the electrical resistance of the transformer windings.
   A. Transformers are electrical components designed to do one of three things:
      1. Decouple one circuit from another,
      2. Increase voltage from one value to a higher

potential, or
3. Decrease voltage to a lower potential.

### 6.6.4 Electrical current for electromechanical systems

An electrical current creates a surrounding magnetic field that is strengthened by passing through an iron core. This principle can be called "electromagnet action."

1. An electrical current causes a magnetic field that surrounds it like a continuous vortexing torus tube. This field, which is not material, is a region of influence on other electrical currents, magnetic fields, and light (EMR). The field is guided and strengthened by passing through iron. When the current reverses in direction, so does the magnetic field. For instance, electrical currents within the earth [in part] cause its magnetic field. The field acts on a compass needle, which is a magnet (magnetized iron). Compass needles are made of iron alloys which can hold their magnetism for a long time. Conversely, the pointers on mechanical watches are not made of iron. In fact they can be made out of almost anything, so long as it is not iron. ( Usually brass, drawn very fine, which can maintain its stiffness while being light enough to be moved easily by the delicate forces employed in watches.) No - one wants their watch to be affected by any magnets bought near the watch, so watches are made from materials that are not attracted to magnets.
2. A force is exerted on an electrical current in a magnetic field perpendicular to the plane of the magnetic field and the electrical current (current is 'x' axis, force is 'y' axis, and magnetic field is 'z' axis). An electrical current in a magnetic field (produced by some other source or electrical current) experiences a force perpendicular to both the direction of the current and the direction of the magnetic field, and reverses if either of these reverse in direction. The force is proportional to the current and to the strength of the magnetic field. This principle can be called "motor action".
3. A voltage (electromotive force) is induced in a conductor moved in a magnetic field. Note that the voltage is opposite to the electrical current causing a force in the direction of motion by principle 2. This principle can be called "generator action".An electrical conductor, such as a copper wire, moving in a magnetic field has an electrical current induced in it. This is expressed by the creation of an electromotive force (EMF, measured in voltage), which causes current to flow just like the voltage of a battery connected to a circuit. The effect is maximum when the wire, the motion, and the magnetic field are all mutually perpendicular. Electromotive force (EMF) is the voltage generated by a source like battery or generator. Voltage can be measured between any two points, but EMF exists only between the two ends of a source. Voltages in a circuit called 'voltage drops' are in the opposite direction of EMF and their sum is equal to EMF according to Kirchhoff's second law.

### 6.6.5 Operating principles of electrical machines

The operation of electrical machines is explained by four general principles:

1. The <u>electromagnetic action</u> principle: An electrical current creates a surrounding magnetic field that is strengthened by passing through an iron core.
2. The <u>motor action</u> principle: An electrical current in a magnetic field (produced by some other source or electrical current) experiences a force perpendicular to both the direction of the current and the direction of the magnetic field, and reverses if either of these reverse in direction. The force is proportional to the current and to the strength of the magnetic field.
3. The <u>generator action</u> principle: A voltage (electromotive force) is induced in a conductor moved in a magnetic field. The induced voltage will cause a electrical current to flow. Note that the voltage is opposite to the electrical current causing a force in the direction of motion by principle 2. Generator action will only produce AC voltage, which must be modified if DC voltage is required.
4. The <u>transformer action</u> principle: A changing magnetic field induces a voltage. Only a change in the magnetic field induces voltage; if the magnetic field remains constant for any length of time, then no voltage will be induced (i.e., voltage = 0).

### 6.6.6 Rotating electromagnetic system elements

Rotating electromagnetic systems have two modes of operation: a motor mode and a generator (AC) mode. Any given rotating electromagnetic machine may be designed to operate as a motor and/or a generator. Some of these machines, without any change in configuration, may operate as a motor and generator (but, not at the exact same time; e.g., induction motor/generator).

> **NOTE:** *Every rotating electromechanical/ electrical machine is capable of working as a generator as well as a motor.*

There are three principal types of rotating electromagnetic system:

1. **DC motors**. - use DC current/power with electromagnetic induction to produce mechanical power.
2. **AC motors** - use AC current/power with electromagnetic induction to produce mechanical power.
3. **AC generators** (which may have their AC output converted to DC, and therein, may be referred to as **DC generators**) - AC generators use mechanical power with electromagnetic induction to produce AC current/power, and DC generators are AC generators with additional equipment to convert the AC current/power into DC current/power.

**NOTE:** *All rotating generators produce AC internally, and must have additional components to convert the AC into DC.*

All rotating electromagnetic systems have two categories of movement (i.e., two mechanical elements to which components are attached): the strator (stationary element) and the rotor (rotating element). They also have two categories of electrical elements: the armature (power producing component) and the field (the magnetic field component). A rotating electrical machine consists of a field and an armature where rotation occurs with respect to each other. The armature is the part of the machine in which the energy “conversion” takes place.

The mechanical elements of rotating electromagnetic systems are:

1. **The stator** - all of the non-rotating electrical parts of a machine (motor or generator). The stator is the outer shell of the motor or generator that remains stationary during operation.
   - Strator electrical element variations include:
   - **Strator armature winding/coil** - generated current to load.
   - **Strator field windings** (forming an electromagnetic electro motor) - AC or DC supplied.
   - **Strator permanent magnets** (strator-PM motor) - magnets mounted to strator.
   - Strator-fed commutator
2. **The rotor** - all of the rotating electrical parts of the machine (motor or generator). The rotor is the central spinning core of the motor or generator.
   - Rotor electrical element variations include:
   - **Rotor armature winding/coil** - generated current to load.
   - **Rotor field windings** (forming an electromagnetic electro motor) - AC or DC supplied.
   - **Rotor winding as cage** (rotor cage) - windings are shorted.
   - **Rotor permanent magnets** (rotor-PM motor) - magnets mounted to rotor.
   - **Rotor-fed commutator**
   - **Slip ring attachment**
3. **The [stator] air gap** - the gap between the stator and the rotor (the air gap separating the inner stator and outer rotor surfaces. A gap must exist for the rotor to rotate.

The electrical elements of rotating electromagnetic systems are:

1. **The armature** - the power-producing component of the machine. It is the main current-carrying winding/coil in which the electromotive force or counter-emf of rotation is induced. The armature has two functions: 1) to carry current crossing the field, thus creating shaft torque in a rotating machine or force in a linear machine; and 2) to generate an electromotive force (EMF).
   - The armature can be on either the rotor or the stator.
   - In other words, the armature winding/coil is that which generates or has an alternating voltage applied to it. The current in the armature winding/coil is known as the armature current. The location of the winding depends upon the type of machine -- it can either be part of the stator (strator coil) or the rotor (rotor coil) as long as voltage is induced. In the armature, an electromotive force is created by the relative motion of the armature and the field. When the machine acts in the motor mode, this EMF opposes the armature current, and the armature converts electrical power to mechanical power in the form of torque (unless the machine is stalled), and transfers it to the load via the shaft. When the machine acts in the generator mode, the armature EMF drives the armature current, and shaft mechanical power is converted to electrical power and transferred to the load.
   - In a generator, the windings from which current is generated are called armature windings. All other windings therein are field windings.
   - The armature always carries current; hence, it is always a conductor or a conductive coil.
2. **The field -** the magnetic field (i.e., magnetic flux) component of the machine. It is the part that generates the direct magnetic field. The field can be on either the rotor or the stator and can be either an electromagnet (field coil) or a permanent magnet. A field coil is an electromagnet used to generate a magnetic field. It consists of a coil of wire (winding) through which a current flows (field

winding or field coil).

- The current in the field does not alternate. The field may either be stationary (magnets attached to the strator), or the field may rotate (magnets attached to the rotor). A rotating magnetic field is one whose north and south poles move inside the stator, just as though a bar magnet, or magnets, were being spun inside the machine.
- The speed at which the magnetic field rotates is called the synchronous speed and is described by the following equation: S = (f x P) / 120 where S = rotational speed in revolutions per minute f = frequency of voltage supplied (Hz) P = number of magnetic poles in the rotating magnetic field.
- The path of the magnetic field is determined by the presence of magnetic "poles", which are located [at equal angles] around the rotor/strator. At each "pole", magnetic field lines pass from stator to rotor or vice versa. The stator (and rotor) are sub-classified by the number of poles they have.

Rotating a conductor through a magnetic field generates an electromotive force (EMF, voltage). The same effect can be accomplished by holding the conductor stationary and rotating the field. Either the conductor or the field must remain stationary, or move at a slower rate. That is to say that relative motion must always exist between the armature and the field in order to generate an EMF in the armature. In either case, "lines of force" are being "cut" by the conductor, generating an EMF in the conductor. If the speed of an armature rotor and strator field were the same (i.e., both rotating at the same speed), there would be no induced EMF, no lines of force would be "cut", and no field built around the conductor; hence, no generator or motor action under those conditions.

> **CLARIFICATION:** *In an electromagnet, magnetism is generated by electrical current. Magnetism is present only while electrical current is flowing. An electromagnet generates heat, but the heat does not significantly affect the magnetism. The more the electrical current and winding turns, the more the magnetism. From a structural and physical standpoint there is no difference between an AC and a DC electro-magnetic coil. They both are made by wrapping of wires around a core. For DC electro-magnets the core is usually made of iron or steel. For AC electro-magnetic coils the "core" could be air. In a permanent magnet, magnetism is retained after a material is magnetized (by an electrical current or by a rapidly moving magnet). Note here that high heating stresses will cause permanent magnets to become [irreversibly] demagnetized.*

The loop ends of the armature can be closed (i.e., "short circuited"), thereby inducing a larger current in the loop, and creating stronger magnetic fields around the conductors.

> **NOTE:** *Coils of wire formed into 'windings' can be classified into two groups: armature windings and field windings. The armature winding is the main current-carrying winding in which the electromotive force (emf, generator) or counter-emf of rotation (motor) is induced. In other words, the armature winding is the winding (conductive coil) to which electrical current is supplied in the case of a motor (to induce rotation), or from which electrical current is extracted/generated in the case of a generator. The current in the armature winding is known as the armature current. The field winding produces the magnetic field in the machine (unless there is a permanent magnet, which produces the field). The current in the field winding is known as the field or exciting current. The location of the winding depends upon the type of machine.*

There are three primary ways of creating a changing/fluctuating (in flux) magnetic field:

1. A constant-magnitude magnetic field pattern is moved repeatedly in space past a stationary conductive path (e.g., a synchronous generator whose magnetized rotor poles move repeatedly past its stator windings/strator coils).
2. A path for an electromagnetic force (EMF) in space (a coil of wire, as in, rotor windings/coils; or other conductive material) is moved repeatedly past a constant magnetic field fixed in space (e.g., AC generator with a commutated armature to produce DC current).
3. A magnetic field that varies in both time (electromagnetic fluctuation) and in space (physical fluctuation) moves past a stationary conductive path (a strator winding/strator coil). Here, currents are induced in the rotor and create a changing magnetic field that sweeps repeatedly past the stationary stator windings. Depends on an external voltage source to produce the electromagnetic fluctuations.

The source of the magnetic field for #1 and #2 can be either one or more permanent magnets or externally supplied currents in coils of wire. Permanent magnet generators exist in contrast to generators with field windings, which have "field circuitry", and require an external power sources to pass electric current through the field windings (to create an magnetic field via electromagnetism).

### 6.6.7 DC voltage [power] Generation

There are a number of ways of producing direct current voltage. A potential difference (voltage) between which direct current flows can be generated in the following ways:

1. **Rectification [of alternating current]** - The task/process of converting (i.e., rectifying) alternating current into DC current is known as rectification. A **rectifier** (literally, "to make straight") is an electrical device that converts alternating current (AC), which by definition periodically reverses direction, to direct current (DC), which flows in only one direction. A rectifier contains electronic elements (usually) or electromechanical elements (historically) that allow current to flow only in one direction - alternating current is supplied and direct current is output.
    - *Rectifier AC -> DC*
    - Take note that all 'generators' produce AC as their first internal output, which may then be rectified by another (external or directly incorporated) device (e.g., commutator) to produce DC. A 'DC generator' is an 'generator' (AC), with a rectifier attached to it (or incorporated into it).
    - **Commutation** - Commutation is a type of rectification used in rotating electromagnetic generators. Commutation uses the positioning of conductive elements (contact bars or metallic brushes) connected to the rotor to convert the armature's AC input to a DC output by changing direction at the same time the incoming armature AC changes direction. A commutation device/mechanism is known as a commutator. The commutator serves to "rectify" the induced AC voltage in the armature. Commutation changes the direction of current so that the system's output always experiences "somewhat continuous" EMF (i.e., does not experience an alternating current voltage). In general, commutation produces a type of pulsating electromotive force (pulsating DC) that can be "smoothed out" by additional electrical techniques to give a sufficient imitation of direct current (essentially, DC). In other words, when the shaft of an AC motor is mechanically coupled to a commutator (creating a DC generator), then DC is output.
2. A **homopolar generator** (a.k.a., **unipolar dynamo** or **Faraday disk**) - a unique type/configuration of rotating electromagnetic generator that produces a direct current without the need for a rectification (e.g., commutator), using a copper disc rotating within a magnetic field. This setup produces a low DC voltage, and high amount of current.
3. **Photovoltaics (PV)** - A photovoltaic cell is simply a semiconductor device made of P-type (positive charge) and N-type (negative charge) materials. The boundary between P and N acts as a diode allowing electric charges to move from N to P, but not from P to N. When light with sufficient energy makes contact with the N-type material, electric charges move toward the P-type material creating a voltage difference which results in current generation. The current generated is direct current.
4. **Osmotic power** - Osmotic power can be used to produce DC through the use of a semi-permeable membrane that separates two fluids with different solutions. Ions travel through the membrane until the ionic concentrations in the two fluids reach equilibrium. When the ions pass through the membrane, charges are transferred to an electrode and produce DC voltage.
5. **Batteries** - a chemical reaction inside of the battery produces DC voltage at its terminals.
6. **Fuel cells** - A fuel cell is a device that converts the chemical energy from a fuel into DC voltage through a chemical reaction of positively charged hydrogen ions with oxygen or another oxidizing agent. Fuel cells are different from batteries in that they require a continuous source of fuel and oxygen (or air) to sustain the chemical reaction, whereas in a battery the chemicals present in the battery react with each other to generate an electromotive force (emf). Fuel cells can produce electricity continuously for as long as these inputs are supplied.
7. **Capacitors** - once charged, capacitors give a regulated DC supply. In an energized circuit, however, capacitors will "block" DC (Note: there are a variety of uses for capacitors in circuits).

**NOTE:** *Motor-generator set (M-G set), which combine a motor's mechanical output connected to the rotor of a generator may be used to create DC voltage and/or modify existing DC voltage. Such devices have the*

- (1) To convert from AC to DC. An AC powered motor connected to a DC generator.
- (2) To modify DC voltage - DC at a fixed voltage to DC at a different voltage.
- (3) To create or balance a 3-wire DC system.

*Also, generally, the term* **dynamo** *(or dynamotor) refers to a DC only motor-generator set (i.e., DC input and DC output).*

### 6.6.8 AC voltage [power] Generation

There are three ways of producing alternating current voltage: (1) conversion of DC current via an inverter (inversion-type); (2) an AC generator (alternator-type or induction-type); and/or (3) a motor-generator set, which is an AC generator with a motor connected to its rotor/ shaft.

1. A **power inverter** (or **inverter**) is a device that converts direct current (DC) into alternating current (AC). The input voltage, output voltage and frequency, and overall power handling depend on the design of the specific device or circuitry. The inverter does not technically "produce" power; the power is provided by the DC source, and flows through to its AC output. One means of changing from direct to alternating current is to use a motor-generator set (M-G set) as an inverter. The converted AC can be output at any required voltage and frequency with the use of appropriate transformers, switching, and control circuits.
    - *Inverter DC -> AC*

2. An **AC generator** (alternator and induction generator) converts mechanical energy into AC electrical energy (as its output) based on the principle of electromagnetic induction. All "generators" produce AC internally. It requires a moving magnetic field and a conductor, which together form an electromotive force (EMF) in the conductor. Take note that a simple generator without a commutator will produce an electric current that alternates in direction as the armature revolves -- with a commutator it will produce DC current. Alternator technology may be classified by method of excitation, number of phases, the type of rotation, and their application.

    AC can be produced using a device called an alternator. This device is a special type of electrical generator designed to produce alternating current. Typically, a rotating magnet, called the rotor turns within a stationary set of conductors wound in coils on an iron core, called the stator. The rotating magnetic field induces an AC voltage in the stator windings. Since the currents in the stator windings vary in step with the position of the rotor, an alternator is a synchronous generator. A loop of wire is spun inside of a magnetic field, which induces a current along the wire. The rotation of the wire can come from any number of means: a wind turbine, a steam turbine, flowing water, and so on. Because the wire spins and enters a different magnetic polarity periodically, the voltage and current alternates on the wire.

    The speed at which the rotor spins in combination with the number of generator poles (i.e., magnetic "poles" in the generator) determines the frequency of the alternating current produced by the generator. All generators on a single synchronous system, for example the national grid, rotate at sub-multiples of the same speed and so generate electric current at the same frequency. If the load on the system increases, the generators will require more torque to spin at that speed and, in a typical power station, more steam must be supplied to the turbines driving them. Thus the steam used and the fuel expended are directly dependent on the quantity of electrical energy supplied. An exception exists for generators incorporating power electronics such as gearless wind turbines or linked to a grid through an asynchronous tie such as a HVDC link — these can operate at frequencies independent of the power system frequency. Depending on how the poles are fed, alternating current generators can produce a variable number of phases of power. A higher number of phases leads to more efficient power system operation but also increases the infrastructure requirements of the system

    AC can come in a number of forms, as long as the voltage and current are alternating. If we hook up an oscilloscope to a circuit with AC and plot its voltage over time, we might see a number of different waveforms. The most common type of AC is the sine wave. The AC in most homes and offices have an oscillating voltage that produces a sine wave. Other common forms of AC include the square wave and the triangle wave. Triangle waves are found in sound synthesis and are useful for testing linear electronics like amplifiers.

3. An **AC motor-generator set** (a.k.a., **M-G set; MG; engine-generator; gen-set; generator**) is a combination motor and generator system for converting electrical current from one form to another (or converting voltage and or frequency of the same current or between two different currents). Such devices may also be used to isolate electrical loads from an electrical power supply line. Herein, an electrically powered motor (either DC or AC powered) is mechanically connected to an AC generator. A motor-generator set involves a motor operating from an available electric power supply to drive a generator, which delivers (outputs) the current and voltage wanted (external power runs motor > motor powers generator > generator outputs desired power). The motor is mechanically coupled to an appropriate generator, creating the desired conversion. In AC applications, an M-G set

has four possible functions:

A. To convert from DC to AC (as an inverter). A DC powered motor connected to an AC generator.
B. To modify frequency - AC at one frequency to AC at another harmonically-related frequency.
C. To modify voltage - AC at a fixed voltage to AC of a variable voltage.
D. To modify phase - AC single-phase to AC three-phase.

The mechanical torque required to power a generator may come from the following sources:

1. Animate power (animal movement generates shaft power; animal-generator)
2. Turbine power (fluid movement, gaseous expansion or combustion spins a propeller-like device and generates shaft power; turbine-generator)
3. Motor power (a motor or engine generates shaft power; motor-generator)

Voltage and frequency regulation in a generator is maintained by controlling:

1. Generator excitation
2. The speed of the prime mover
3. Shaft speed through a gearbox
4. Electronically

Aside from the internal configuration of a generator, the frequency expressed by all generators depends upon the rotational speed of the generator's shaft (rotor) and the load. A faster rotation of the shaft will generate a higher frequency. A higher load will slow the rotor, possibly to the point where it reduces the frequency. At no-load, the mechanical system is rotating at the 'no-load speed', and results in the generation of voltages at 'no load frequency'. When a generator is loaded, power is drawn from the mechanical system and the generator experiences a torque that opposes the direction of motion of the mechanical system. As a result, the mechanical system of the generator tends to slow down.

## 6.6.9 AC voltage generation: phase

**CLARIFICATION:** *Phase, like frequency, is a concept restricted to AC voltage generation (and does not apply to DC voltage generation).*

AC voltage may be sub-classified by phase, wherein there are three principal types of AC voltage: single phase, two phase, and polyphase (e.g., three-phase). Systems with more than two phases are generally termed polyphase. Polyphase systems have three or more energized electrical conductors (three or more phases) carrying alternating currents with a definite time offset between the voltage waves in each conductor. Polyphase systems are particularly useful for transmitting power to electric motors. Once polyphase power is available, it may be converted to any desired number of phases with a suitable arrangement of transformers. Conversion between polyphase systems of different phase numbers is always possible. Polyphase systems are qualitatively different from single phase systems. Note here that the order of voltage waveform sequences in a polyphase system is called *phase rotation* or *phase sequence*.

**NOTE: Phase converters** *convert between different AC phases.*

There are several basic types of AC voltage generation:

- **Single phase AC voltage** are defined by having an AC source with only one voltage waveform. In other words, there may be more than one voltage, but all voltage waveforms are in phase, or in step, with each other. Here, when more than one phase is present, the currents in each conductor reach their peak instantaneous values sequentially, not simultaneously. Note that a single phase supply connected to an alternating current electric motor does not produce a revolving magnetic field; single-phase motors need additional circuits for starting, and such motors are uncommon above 10 kW in rating.
    - Single-ended single-phase system: 1 phase, 2 wire - one of the wires is for the power, and one wire is for neutral.
    - Split-phase (single-phase three-wire): 2 phase, 3 wire - two of the wires are for phases (phase A, phase B), and one wire is for neutral.
- **Two phase AC voltage** by having voltage phases differing by one-quarter of a cycle, 90°. Usually circuits used four wires, two for each phase.
    - 2 phase, 4 wire - two separate pairs of current carrying conductor, and no neutral.
    - 2 phase, 3 wire - two wires carry two separate phases, and the common conductor (wire) carries the vector sum of the phase currents, which requires a larger conductor. No neutral.
    - Note: Two-phase power can be derived from a three-phase source using two transformers in a Scott connection.
- **Three phase AC voltage (polyphase)** are defined by having three or more energized electrical conductors carrying alternating currents with a definite time offset between the voltage waves in each conductor. All 3-phase generators (or motors) use a rotating magnetic field. A polyphase power system uses multiple voltage sources at different phase angles from each other (many "phases" of voltage waveforms at work). A polyphase power system can deliver more power at less voltage with smaller-gage conductors than single- or split-phase systems. The phase-shifted voltage

sources necessary for a polyphase power system are created in alternators with multiple sets of wire windings. These winding sets are spaced around the circumference of the rotor's rotation at the desired angle(s). A major advantage of three phase power transmission (using three conductors, as opposed to a single phase power transmission, which uses two conductors), is that, since the remaining conductors act as the return path for any single conductor, the power transmitted by a balanced three phase system is three times that of a single phase transmission but only one extra conductor is used.

- 3 phase, 4 wire - three wires for the power and one for neutral.
- 3 phase, 4 wire Delta - three for the power and one for neutral.

### 6.6.10 AC voltage generation: synchronous and asynchronous speeds

AC machines (generators and motors) can be divided into two main categories: synchronous speed machines and asynchronous (induction) speed machines. In concern to generators, synchronous speed AC voltage generators are commonly referred as alternators. And, asynchronous speed AC voltage generators are also known as 'induction generators'. Regardless of naming, both synchronous and asynchronous devices (motors and generators) use electromagnetic induction as their primary operational effect.

The 'synchronous speed' is that which causes the generator to produce the grid frequency exactly. If the grid frequency is constant, so is the 'synchronous speed'. Asynchronous means that the machine cannot produce torque (motor) or power (generator) when turning at the synchronous speed. To emphasize, an asynchronous machine cannot operate at the synchronous speed. In an asynchronous machine, when the rotor rotates at synchronous speed, no interaction takes place between magnetic field and the rotor because they are moving together (creating the condition of 'zero slip'), and thus, no torque or power will be induced. This difference between the actual speed of the rotor and the synchronous speed is called the 'slip'.

In an asynchronous machine, when the rotor rotates faster than synchronous speed, it inputs electrical power into the power network as 'positive slip', and when it operates below synchronous speed it acts as a load and pulls power from the power network as 'negative slip'. Conversely, a synchronous generator operates at exactly the same frequency as the [power] network to which it connects.

**EXAMPLE OF SYNCHRONOUS SPEED:** *For a typical four-pole induction machine (two pairs of poles on stator) operating on a 60 Hz electrical grid, the synchronous speed is 1800 rotations per minute (rpm). Hence, the machine must rotate faster than 1800rpm to begin generating electrical power.*

This difference of rotor speed from magnetic field speed in both motoring and generation is referred to as positive and negative slip, respectively.

- Slip = $(f_0 - f_r) / f_0$
- where:
  - $f_0$ = frequency of the electrical grid (synchronous speed in revolutions per minute)
  - $f_r$ = frequency of the rotor (rotor speed)
  - (at start-up slip = 1, at synchronous-speed slip = 0)

### 6.6.11 Synchronous generators (alternators)

*A.k.a., Syn-chronous (same-time) generators of electrical power.*

**Synchronous generators (SG; alternators)** are called "synchronous" because the waveform of the generated voltage is synchronized with the rotation of the generator -- there is no phase shift, the speed of the rotor is called synchronous speed (constant speed) -- the rotor and magnetic field rotate at the same speed. Each peak of the sinusoidal waveform corresponds to a physical position of the rotor. Synchronous motors and generators are nearly identical.

For a synchronous generator, frequency is determined by the rotational speed of the generator's shaft -- faster rotation of the shaft generates a higher frequency. In other words, if the electrical output frequency of the generator is synchronised to its shaft/rotor speed, then it is a synchronous generator system. The synchronous generator's rotational speed is locked to its stator frequency. However, the electrical output frequency is not necessarily synchronised to the grid frequency. External controls may be necessary to achieve the correct grid frequency.

In the majority of designs, the 'rotor' contains the magnet (rotating field), and the 'stator' is the stationary armature (armature windings) that is electrically connected to a load. The magnetic field source (magnetic flux) may be supplied by either permanent magnets (in the rotor) or an excitation current fed into field windings (in the rotor):

1. **Permanent-magnet synchronous generator (PMSG)** has permanent magnets (permanent magnet excitation). Also known as **permanent magnet alternator (PMA)**. PMSG's are simpler and do not consume/require power to generate the field flux.
2. **Wound field synchronous generator (FESG)** has direct current flowing in wound field windings (wound field excitation) to create an electromagnet.

If the field winding is directly connected across the armature output terminals to obtain its power, it is called 'shunt excitation'. If the field current is controlled separately from the armature voltage, it is called 'separately excited'. FESG's allow for greater control, but require power (DC voltage) to generate the field flux (field current). The torque and output power of a wound field generator can be controlled by adjusting the field current (electromagnets) of the generator.

The direct current in the rotor field winding is fed through a slip-ring assembly or provided by a brushless exciter on the same shaft. Thus, electrical power is generated by moving rotor and its attached permanent magnet or electromagnetic within a stationary casing that contains armature windings around the outside, which are electrically connected to a load. When an electromagnet is used, it draws its excitation from a power source external to, or independent of, the load or transmission network it is supplying.

**NOTE:** *Slip rings act as load connectors (i.e., they connect the armature winding(s) to an external load).*

When voltage is applied to the armature windings, then electromagnetic induction causes the rotor (field) magnet to spin/rotate (creating a synchronous motor). Conversely, when the rotor with the permanent magnets are spun through mechanical power applied to rotate the shaft, then electromagnetism induces an a voltage as an alternating current in the armature windings (synchronous generator or alternator).

The expression relating the rotational speed in revolutions per minute, the number of magnetic poles in the machine, and the electrical frequency in hertz can be expressed as:

- rpm = 120 x frequency/poles

**NOTE:** *There are fixed-speed synchronous generators and there are variable-speed synchronous generators.*

### 6.6.12 Induction generators (asynchronous generators)

*A.k.a., Asyn-chronous (alternating-time) generators of electrical power.*

**Induction generators (IG; asynchronous generator, AG)** are essentially the same machine as an asynchronous or induction motor - an induction generator is mechanically and electrically similar to an induction motor. The principle of operation of the induction motor (and hence, generator) is based on generating a rotating, constant magnetic field. This rotating magnetic field interacts with a set of short circuited conductors arranged on the rotor. In other words, an induction generator is a type of electrical (AC voltage) generator that is mechanically and electrically similar to an induction motor. Hence, a regular asynchronous motor can usually be used as an asynchronous/induction generator, without any internal modifications.

Induction generators produce electrical power when their rotor shaft is rotated faster than the synchronous speed (frequency) of the equivalent induction motor. The rotating magnetic field induces currents in a set of copper loops in the rotor, and magnetic forces on these current loops exert a torque on the rotor and cause it to rotate (as a motor). When it is forced (from an outside energy source) to rotate past the synchronous speed, then it becomes a generator. In other words, they produce AC voltage when their rotor runs (moved by an outside mover such as wind) above the synchronous speed of the supplied voltage frequency. This requires an external torque applied to the rotor to turn it faster than the synchronous speed. If the generator's rotational speed is greater than the synchronous speed (the speed at which the magnetic field rotates), power is produced; if the speed drops below the synchronous speed, the generator becomes a load.

Summarily, induction machines have two operational modes:

1. Motor operation - When the current is connected, the machine's strator windings, the rotor will start turning like a motor at a speed which is just slightly below the synchronous speed of the rotating magnetic field from the stator. A phased induction motor works on the principle of electromagnetic induction, where the relative motion between the flux and the rotor, caused by the rotating magnetic field induces a current in the rotor, forcing it to rotate in the same direction. In an induction motor, the rotor rotates because of "slip" (i.e. relative velocity between a rotating magnetic field and the rotor). In order to maintain relative EMF, there must be a "slip" in the induction motor, or else the motor will stop. The rotor of the induction motor does not rotate as fast as the rotating AC [electro] magnetic field. In other words, the rotor goes slower than the rotating magnetic field in order to have relative motion. Within a 3 phase induction motor, motion is achieved by orientating the three electromagnetic coils (magnetizing flux) 120 physical degrees apart in space, and imposing 3 phase voltages on the windings also separated in time by 120 electrical degrees.
2. Generator operation - When the rotor moves faster than the rotating magnetic field from the strator, the strator induces a strong current in the rotor. The faster the rotor rotates (turning force, moment, or torque), the more power will be transferred as

an electromagnetic force to the stator, and in turn converted to electric current (fed into an electrical grid).

**CLARIFICATION:** *The strator contains electromagnets, and the rotor may simply be conductive and/or may contain permanent magnets. When current is supplied to the strator creating electromagnets, then the rotor will spin as a motor; but, when the rotor spins above synchronous speed due to a sufficient supply of outside power, then the strator windings will have current induced in them and produce [asynchronous] current on the circuit.*

Induction generators may be classified according to whether the rotor contains permanent or wound field windings, and whether the rotor's conductor is excited (i.e., energized, electrified):

1. When the rotor contains permanent magnets, then the system is called a permanent-magnet asynchronous generator (PMAG) has permanent magnets (permanent magnet excitation). PMAG's are simpler.
2. When there are no permanent magnets on the rotor, then the system is called a wound field asynchronous generator (FEAG) has direct current flowing in a wound field winding (wound field excitation) to create an electromagnet. FEAG's allow for greater control.
3. The term, 'doubly-fed induction machine' applies to a system where both the stator and rotor winding of a slip-ring machine are supplied with voltage (electrical power).

When the strator field windings are electrically excited, they behave like electromagnets, producing independent (per coil/winding) [electro]magnetic fluxes. The position of the [electro]magnetic fluxes around the strator keeps changing with time in a circular manner. Whereupon, net flux (resultant of all magnetic fluxes in the stator) develops a rotating magnetic field in the stator, which causes relative motion between the net flux (strator) and the rotor (current flows in the rotor winding) -- the rotor moves (i.e., rotates) as the magnetic flux in the strator rotates. The direction of rotation of the rotor is the same as that as the rotating magnetic field of the stator.

Induction generators (and motors) are not self-exciting; they require an external electrical supply to produce a rotating magnetic flux, and thus, induce current in the rotor. The electrical [supply] power required for this is called reactive current/power (i.e., they require reactive power for excitation). The induction generator depends on an external voltage source to produce a magnetic field (electromagnet) in the stator, which is to say that it consumes VARS (volt-ampere, reactive) in order to produce power (watts). In other words, an induction machine requires externally supplied armature current to start, and cannot start on its own as a generator. A source of excitation current (reactive power) is required to maintain the [electro]magnetic field (i.e., magnetizing flux) that induces current in the rotor. The excitation current supply can originate from: 1) the electrical grid; 2) from the generator itself (once it starts producing power); or 3) from a capacitor bank. If an induction generator is meant to supply a standalone load, a capacitor bank needs to be connected to supply reactive power. In other words, asynchronous machines are capable of self-excitation when, in order to supply the magnetizing current, capacitors are connected parallel to the machine terminals. Once the rotor reaches a speed above the armature currents supplied frequency, it will begin producing current.

Induction generators do not need to be synchronized with the grid before being connected. The generator is simply connected at dead standstill and grid power is used to operate the generator as a motor (at first), bringing it up to synchronous speed, whereupon it becomes a generator. Power is transmitted to the grid as long as the system turns faster than synchronous speed. Below synchronous speed, the generator acts as a motor and will consume power.

An asynchronous generator with an electronic controller can be allowed to vary with the speed of the energy source (e.g., wind). The output frequency and volts are regulated by the power system and are independent of input mechanical speed variations.

**NOTE:** *Unlike synchronous generators, induction generators are load-dependent and cannot be used alone for grid frequency control. Wind turbine induction generators cannot support the electrical grid's system voltage during faults, unlike synchronous generators.*

There are two kinds of induction generators used in wind turbines:

1. Cage rotor induction generator/machine (a.k.a., squirrel cage rotor, SCIM) - has rotor windings (a cage winding), which are shorted (connected to themselves) and strator windings, which are connect to the grid or another power source. The rotating magnetic field in the strator induces a very strong current in the rotor bars, which offer very little resistance to the current, since they are short circuited by the end rings. The rotor then develops its own magnetic poles, which in turn become dragged along by the electromagnetic force from the rotating magnetic field from the stator.
2. Wound rotor induction generator/machine (WRIM) - has rotor windings (connected to a load or power converter) and strator windings connected to the grid. Slip rings (and brushes) are used as parts of the rotor current. If the rotor coil windings were short circuited, then this machine would be

similar to the cage induction machine; however, the rotor conductor cross section geometry is still different than that of a cage rotor induction machine. Induction machines with a wound rotor allow access to the rotor winding via slip rings and brushes. In other words, WRIMs require "slip rings" and brushes to supply electrical power (and resistance), whereas other induction machine configurations do not.

**MAINTENANCE:** *Brush wear comes from two basic causes: mechanical friction and electrical wear. Mechanical friction is caused by the rubbing of the brushes on the commutator or slip ring. Electrical wear is caused by the arcing and sparking of the brush as it moves over the commutator. Mechanical friction increases with brush pressure; electrical wear decreases with brush pressure. For any given brush installation, there is an optimum amount of brush pressure. If the pressure is decreased below this amount, the total wear increases because the electrical wear increases. If the pressure is increased above the optimum amount, the total wear again increases because mechanical friction increases.*

If an induction generator is supplying a standalone load, the output frequency will be slightly lower (by 2 or 3%) that calculated from the formula:

- f = N * P / 120.
- where, N is speed of the rotor in rpm and P is number of poles.

## 6.7 Voltage conversion and inversion

The process of changing AC voltage into DC voltage is called conversion (actually, this is an imprecise term because "conversion" also refers to changing one DC voltage to another, and other things as well, but it will do for our purposes). Devices that perform this process are called converters, but are also sometimes called [power] 'adapters', and if being used for charging batteries, they are often just called [power] 'chargers'. Changing DC into AC is the opposite process and is called inversion. A device that does this is, of course, called an 'inverter'.

A transformer is an electromagnetic device that changes (or "transforms") AC current at one voltage (in one circuit) to AC current at another voltage (in another circuit). In the simplest case, most transformers consist of a metal rectangular core, around two sides of which two separate wires are wound each connected to a separate circuit. The rectangular core is generally iron (ferromagnetic), and hence, nearly all the flux from the first circuit will be transferred to the secondary circuit's windings (inducing current in the secondary circuit). That which makes the transformation is the difference in the number of coil/winding turns on both sides.

**NOTE:** *When a transformer is present, then two electrical subsystems are created, because electrical current on one side of a transformer does not flow into the circuit on the other side. There is a physical coupling between the two subsystems, but no direct electrical connection. The transformer becomes an interface between the two subsystems.*

For a transformer to work, the current in one coil has to somehow make current flow in the other coil (and the circuit it's connected to). A DC current in one coil will make a magnetic field on the other coil, but a magnetic field by itself won't drive any electrons around (electromotive force is not produced). A *changing* magnetic field (i.e., time-varying magnetic field), however, does create an electric force, which accelerates the electrons in the other coil into carrying a current. This process is described by Faraday's law of induction. AC current produces a changing field, because the current which makes the field is changing.

Transformers work via induction of electrical forces by changes in magnetic fields. Both AC and DC generate a magnetic field. However, because DC currents produce a constant magnetic field, their passage through a transformer will not generate an electromotive force in the secondary circuit; however, it will still be "consuming" energy. In AC, when the current changes direction, so does the field, which causes an EMF in the secondary circuit and moves charges therein.

A DC to DC (DC/DC) converter can be described as the DC equivalent of an AC transformer. It changes the ratio between the input and output voltages and currents by introducing 'power electronics' that, with the help of passive components, transmit the power through the converter. These solid state devices, which are products of the semiconductor revolution, make it possible to transform DC power to different voltages. The advantages of using DC/DC converters are many: To regulate the output voltage, to build subsystems supplied by the same bus and to reduce transmission losses.

## 6.8 Electric power transmission & distribution (transportation)

**REMEMBER:** *Every transfer between energy carrier ("conversion") represents a loss of energy.*

Electrical power transmission refers to the movement of electrical power from one location to another. Electrical power transmission refers to the bulk movement of electrical energy a significant spatial distance from a generating site, such as a power plant, to a point where it is distributed for end-use/service. Thus, electrical power distribution refers to the distribution of electrical power a relatively short distance (in comparison to transmission) from a source location its end-use/service. Electrical power generated proximate (i.e., near) to end-use does not involve long-distance transfer (transmission), but will still require short-distance transfer (distribution).

Presently, there are two primary forms of electric power transmission & distribution, categorized by their medium of transmission.

1. **Wired** - the transmission (and subsequent distribution) of electricity with the use of wires or other conductive guiding structures that form an electrical power network ("the grid").
2. **Wireless** - the transmission of electricity without wires or other guiding structures.
3. **Storage** - the storage of energy in a carrier, which may be transported, and then easily transferred through to electrical power.

## 6.8.1 Wired electric power transmission and distribution

Electric power transmission is the bulk movement of electrical energy from a generating site, such as a power plant, to a point where it is distributed for end-use/ service. The interconnected [conductive] lines which facilitate this movement are known as a [electrical power] 'transmission network' (long-distance transmission). This is distinct from the local wiring between high-voltage substations and customers, which is typically referred to as [electric power] 'distribution network' (short-distance transmission). The combined transmission and distribution network has several names, including but not limited to: "power grid"; "the grid"; and the "National Grid".

> **CLARIFICATION:** *Electrical power transmission is the transfer of electric energy as electrical power over an interconnected group of conductive lines and associated equipment between points of supply and points at which it is transformed for delivery to end use (or other electric systems). Transmission is considered to end when the energy is transferred for distribution to end use (e.g., at a substation).*

The best way to transmit power (both AC and DC voltage) efficiently is to send it at very high voltage and very low current: high voltage AC (HVAC) or high voltage DC (HVDC). Current is affected by line resistance (impedance), and so, it is necessary to send very little amperage to reduce power loss from heat. Once the voltage is increased to a very high voltage, then there is no inherent advantage to its being AC or DC. The generated electric power is often stepped up (at a step-up transmission station) to a higher voltage, whereupon it connects to an electric power transmission network. On arrival at a step-down substation, the power will be stepped down from a transmission level voltage to a distribution level voltage for distribution to end use -- as it exits the substation, it enters the distribution wiring. Finally, upon arrival at the service location, the power is often stepped down again [in voltage] from the distribution voltage to the required service voltage(s).

> **NOTE:** *All "modern countries" are criss-crossed with high-voltage transmission lines, which transport electrical power from generators at power plants to substations and ultimately consumers. This is partly because most electrical power generation systems are located away from population densities, and also, partly because are so spread out (i.e., 'population sprawl').*

Hence, most wired electric power transmission and distribution systems ("grids") consist of the following components, listed in order from generation to end-use:

1. Power station - power supply (generation).
2. Step-up transmission substation - steps up the voltage for transmission.
3. Transmission network - conductive lines for transmission across a significant spatial distance (long-distance transmission).
4. Step-down transmission substation - steps down the voltage for distribution.
5. Distribution network - conductive wires for distribution to end use/service (short-distance transmission).
6. End-use voltage transformers (AC)/converters (DC) - step down the distribution voltage to the voltage required for individual electrical devices.
7. Load - the end-use/service.

High-voltage transmission lines transport power over long distances much more efficiently than lower-voltage distribution lines for two main reasons. First, high-voltage transmission lines take advantage of the power equation: power is equal to the voltage times current ($P = VI$). Therefore, increasing the voltage allows a decrease in current for the same amount of power. Second, since transport losses are a function of the square of the current flowing in the conductors, increasing the voltage to lower the current significantly reduces transportation losses. Additionally, reducing the current allows for smaller transmission conductor sizes. As the length of any conventional transmission line increases, both the energy transfer capacity of the line and the efficiency of energy transfer decrease. The primary ways in which to overcome energy loss are to increase the transmission line voltage, and/or to increase wire diameter.

> **HISTORICAL NOTE:** *The reason AC is the primary power transmission and end-point access goes back to the late 1800s. Back then there were two competing power grids, one for AC and one for DC. Thomas Edison developed DC power, and Nikola Tesla developed AC. With the technology available at that time, Tesla's AC power could be transported long distances more efficiently and with lower cost. At the time, the invention of the electrical transformer meant that AC electrical power could be stepped up relatively easily to a higher voltage and transmitted more efficiently (at a higher*

*voltage, but lower current). Efficient electrical transmission meant in turn that electricity could be generated at centralised power stations, where it benefited from economies of scale, and then be despatched relatively long distances to where it was needed. Hence, in the market, AC won out and became the only grid available. At the time that the primary power grids linking major cities on this planet were first built, starting around the 1880s, there was no convenient way to change the voltage of DC power, whereas the materialized presence of a "transformer" made AC voltage modification possible. Transformers do not work for DC (there are no DC transformers). Up until 1956, only AC power could be readily changed from one voltage to another (via transformers). the voltage level that came out of the DC generator was essentially all you had to work with and that voltage was usually too low to transmit power very far without substantial losses. Hence, AC is the dominant form of power today for the simple reason that when these grids were first being setup, the technology required to easily and cheaply manipulate DC voltages did not exist. Today, the universal standard power grid on earth is alternating current. With the technology available today, high voltage DC (HVDC) is the optimal way of transmitting large amounts of power great distances.*

In power systems where generation is distant from the load, AC voltage (or DC) can be stepped-up (increased) at the generation or transmission point, and then, step-down (decrease) the voltage near the load. Conversely, generators can be designed produce higher voltages.

AC power has the advantage of being easy to transform between voltages and is able to be generated and utilised by brushless machinery. Stepping DC voltage up and down (for high voltage transmission lines) is a more complex issue than AC voltage stepping (using transformers). However, DC can be more economical to transmit over long distances at very high voltages (via HVDC). In voltage transmission, compared to the charge movement of DC, AC power is inefficient due to the energy radiated (i.e., lost) with the rapid reversals of the currents polarity. We often hear these reversals as the familiar 50 or 60 cycles per second (50 or 60 hertz) hum of the appliance. AC power is also prone to harmonic distortions, which occur when there is a disruption in the ideal AC sinusoidal power wave shape, which also happens to be a wave shape lethal at sufficient voltage if it crosses the human heart.

**NOTE:** *Transmission of any current over long distances requires lethally high voltages.*

Presently, AC suffers from a variety of problems created by line impedance (X of C and X of L), which does not affect DC. AC suffers from losses due to "skin effect", as well as dielectric losses, that typically limit the voltage it can be increased to, which is approximately 765,000Vrms (765kV). Dielectric losses are caused when dipoles in matter align with a changing local electric field. As the polar structures turn to follow the field, the movement causes local heating. AC requires special wire, and wiring techniques, to control these losses. DC, however, can be stepped up to much higher voltages. Presently, transmission voltages as high as 1,600,000VDC, are being used. This means that high voltage DC (HVDC) can be sent more efficiently, at present, than AC. There are other technical reasons why AC suffers certain limitations in certain applications like underground power transmission, or that AC line power must be synchronized with the local AC grid at both ends of the line, whereas DC power can bridge between two different synchronized AC grids that are not synchronized with each other.

**NOTE:** *DC power remains the only practical choice in digital electronic systems. In other words, they require direct current for the circuit to correctly complete. Hence, with an AC distribution grid, a technology is needed to convert the current to DC. This technology is commonly known as a 'power supply', and they may be built into, or an external attachment to, a DC electronic device. Conversely, a technology known as an "inverter" changes a direct current (DC) into an alternating current (AC).*

In general, the distribution lines of an electrical grid are passive systems (i.e., they are not actively managed by operators or computer programs). Also, since they are traditionally unidirectional in power flow (from high voltage to low voltage), they do not require much maintenance.

When a part of the network or grid connects to another part of the network or grid, the area where the two or more grids/networks connect is called a grid 'interconnection'. Grid interconnection variables include but are not limited to:

1. Frequency regulation (AC only)
2. Voltage regulation
3. Disconnection and reconnection protocols
4. Safe intentional islanding operation
5. Control of faults

## 6.8.2 High-voltage AC and DC Grids

High voltage AC (HVAC) and high voltage DC (HVDC) electrical grids have different requirements due inherent differences in the characteristics of their currents.

1. **HVAC Grids:** AC grids must maintain steady frequency and voltage levels to avoid damaging demand-side equipment. Hence, they must actively limit harmonics, which are distortions of the normally smooth sinusoidal variation of an AC grid's voltage. Harmonics contribute to system inefficiency: they decrease the efficiency of motors

by their inability to contribute to motor torque; they result in the heating of motors; they cause unbalanced currents in power systems; and they can damage electronic and computer components.

A. Frequency regulation: When large generators are connected to the grid, they will set the grid's frequency. Therein, small generator do not have to regulate their own frequency.
B. Voltage regulation: Whereas frequency is a variable that is constant across the whole utility electric power system (and thus subject to control throughout the system by a few large generators) voltage varies from node to node throughout the system depending on the distribution of loads, generation, and power factor correcting capacitor banks.

2. **HVDC grids:** DC grids are concerned with maintaining steady voltage, and the notion of frequency and harmonics do not apply. There is no such thing as DC harmonics, as DC is defined as zero frequency (zero sequence harmonic).

### 6.8.3 The wired electrical/power grid

An electrical/power grid is an interconnected network for delivering electricity from its point(s) of generation to its point(s) of usage/demand. The term 'grid' usually refers to a network, and should not be taken to imply a particular physical layout or a scale. The word 'grid' may also be used to refer to an entire continent's electrical network, a regional transmission network, or it may be used to describe a sub-network, such as a local utility's transmission grid or distribution grid. Electricity grid systems connect multiple sources/generators and loads. In electrical grids, a power system network integrates transmission grids, distribution grids, distributed generators and loads that have connection points called buses.

The structure, or "topology", of a grid can vary depending on the requirements of the system, including reliability, and the load and generation parameters. The physical layout is often forced by what land is available and its geology. There are multiple types topologies, including:

1. **Radial network topology** - The simplest topology for a distribution or transmission grid is a radial structure. This is a tree shape where power from a large supply radiates out into progressively lower voltage lines until the destination homes and businesses are reached. Most transmission grids offer the reliability that more complex mesh networks provide. The expense of mesh topologies restrict their application to transmission and medium voltage distribution grids. Redundancy allows line failures to occur and power is simply rerouted while workmen repair the damaged and deactivated line. A substation receives its power from the transmission network, the power is stepped down with a transformer and sent to a bus from which feeders fan out in all directions across the countryside. In an AC system, these feeders carry three-phase power, and tend to follow the major streets near the substation. As the distance from the substation grows, the fanout continues as smaller laterals spread out to cover areas missed by the feeders. This tree-like structure grows outward from the substation, but for reliability reasons, usually contains at least one unused backup connection to a nearby substation. This connection can be enabled in case of an emergency, so that a portion of a substation's service territory can be alternatively fed by another substation. This connection can be enabled in case of an emergency, so that a portion of a substation's service territory can be alternatively fed by another substation.
2. **A mesh network topology** - Resembles a web of interconnections, and is thus, more complex than a radial network. In general mesh topologies are applied to transmission of medium voltage distribution grids. A mesh network allows for redundancy. Redundancy allows line failures to occur and power is simply rerouted while lines are deactivated and repaired.

The most common type of transmission grid on the planet at the present is the wide-area synchronous grid (a.k.a., "interconnection" or "synchronous area") is an electrical grid at a regional scale or greater that operates at a synchronized frequency and is electrically tied together during normal system conditions (as a "synchronized zone" at 50Hz or 60Hz). In a synchronous grid all the generators run not only at the same frequency but also at the same phase, each generator maintained by a local governor that regulates the driving torque by controlling the steam supply to the turbine driving it. Generation and consumption must be balanced across the entire grid, because energy is transferred almost instantaneously as it is produced. Energy is stored in the immediate short term by the rotational kinetic energy of the generators. A large failure in one part of the grid - unless quickly compensated for - can cause current to re-route itself to flow from the remaining generators to consumers over transmission lines of insufficient capacity, causing further failures. One downside to a widely connected grid is thus the possibility of cascading failure and widespread power outage. The benefits of synchronous zones include pooling of generation, pooling of load, resulting in significant equalizing effects (i.e., even out the load, reducing generating capacity); common provisioning of reserves. It is not possible to form a wide area synchronous network between two networks operating on different frequency standards (e.g., 50Hz vs. 60hz).

Wide-area synchronous grids can be tied to each other via high-voltage direct current power transmission lines (DC ties), or with variable frequency transformers (VFTs), which permit a controlled flow of energy while also functionally isolating the independent AC frequencies of each side. High-voltage direct current lines or variable frequency transformers can be used to connect two alternating current interconnection networks which are not synchronized with each other. This provides the benefit of interconnection without the need to synchronize an even wider area. For example, compare the wide area synchronous grid map of Europe (above left) with the map of HVDC lines (below right).

### 6.8.4 The Smart Grid

A 'smart grid' is a type electrical grid that includes variety of operational control and monitoring, and energy "loss", devices. These devices include but are not limited to: "smart" meters, "smart" appliances, renewable energy resources, and energy efficiency resources. Essentially, the "smart grid" is the "grid" enhanced with a variety of control and monitoring devices for improving the efficiency, safety, and reliability of the grid, as well as further increasing the control both industry and the State have over the consumers use of electrical power. With that said, the "smart grid" also gives users more information and tools (when these are made available) to make better choices about their own energy usage.

Here, the term "smart" is used for two purposes. First, it is a marketing term to aid the adoption of these energy control and monitoring devices by consumers and industry -- as in, "it is the smart thing to do pay for these devices, which function [in part] to enhance the monitoring and control of consumers power usage by the power industry". Second, "smart" is similar in meaning to "intelligence", and the term 'intelligence' is applied in engineering to mean that a system is capable of taking decisions or aiding a control system in taking a more informed decision. The addition of these "intelligent" devices to a basic electrical grid adds resiliency to the electric power system by making it better prepared to address emergencies, such as severe storms, earthquakes, large solar flares, and attacks.

## *6.9 Electrical Power Generation: localization*

The localization of electrical power generation can be categorized in three main ways: using network terminology; the presence of a grid connection; and using interconnection-type as a parameter.

There are two network-based categories of generated power localization:

1. **Centralized generation systems** - refers to power which is produced at large generation facilities, and transported though the transmission and distribution grids (far in space) to the end-use.
2. **Distributed generation systems (a.k.a., on-site, decentralized, or localized)** - refers to power that is produced next to (near in space, proximate) its point-of-use. Distributed power generation may also be referred to as on-site generation (OSG), district/decentralized generation, or localized generation. Distributed generators may or may not be connected to a wider transmission and distribution grid. The key criteria in this definition is the proximity to the end-use (and not whether the generators are connected to a wider transmission and distribution grid).

Some generation technologies are more easily distributed than others (e.g., solar panels and wind turbines are relatively easily distributed). Historically, distributed generators were complementary to centralized generation (i.e., they provided solutions to overcome the shortfalls of centralization, such as backup generators for when power was cut to the central generators). Today, however, distributed generators are more widely available because of advances in technology. Conversely, a hydro-electric dam has a definitive position of placement relative to its energy source (the body of water and the dam).

In concern to the presence of a grid connection, a generation system either has a grid connection (is grid connected) or does not have a grid connection (is off grid):

1. **Stand alone (off grid) generation systems** - Systems that are not connected to the grid or do not require the grid. These are the simplest form of electrical power system, with the fewest components. They consist of an electrical source (or several localized and networked sources) and a load(s), which operate independently from the grid. If these system are ever connected to a grid, then their voltage (DC and AC), frequency and waveform (AC) will likely need to be modified to match the grid. Multiple stand alone systems can sometimes be networked.
   - Examples include, backup generators and specific purpose power units. Specific purpose power units are used for applications such as pumping water, electric fences, navigational/safety signaling, and remote monitoring. These systems are generally designed to run on DC rather than AC (and do not require inverters and control systems).
   - Batteries are not required for off grid systems, but their presence has [at least] three benefits:
   - Storing energy for use when energy from the primary source is unavailable.

- As a buffer between an intermittent supply and varying/peak demand (a form of load demand management).
- Creating a clean regulated AC supply from an unregulated source.

2. **Grid connected generation systems (a.k.a., grid-joined and grid-tied)** - Systems that are connected to the gird and output power into the grid. In AC grid connected systems the generator voltage and frequency are locked to the grid system, or the voltage and frequency of the generator are modified to match the grid system (this is sometimes known as 'supply regulation'). Also, the generator's output waveform should be a pure sine wave, without harmonics. Some generators are required to reach a minimum speed before they can be connected, so that their output frequency matches the grid frequency. These are also known as: on-grid, grid-tied, utility-interactive, grid-intertied, and grid-direct.
   - When the grid is shut down (for maintenance or emergency), grid connected systems must also be shut down (or disconnected from the grid). Hence, depending upon design, when the grid fails, these systems cannot operate. This is a safety issue. If the grid is shut down and undergoing maintenance, then a grid connected generation system that hasn't been shut down or isn't disconnected could [accidentally] energize the grid and electrocute someone or damage equipment.

**NOTE: Islanding** *refers to the condition when a portion of the grid becomes temporarily isolated from the main grid but remains energized by its own distributed generation resource(s). Islanding may be unintentional (accidental) or intentional. Unintentional islanding is a potentially hazardous condition, and occurs when a generator fails to properly shut down or disconnect. However, with appropriate safety and control mechanisms, intentional islanding can be used to provide service to mini-grids where the grid is unreliable or parts of the grid have been shut down.*

## *6.10 Electrical system earthing/grounding*

In general, 'earthing' and 'grounding' are different terms for expressing the same concept. The term 'earthing' is more commonly used in some countries and in their accompanying standards, and 'grounding' is more commonly used in other countries and in their own standards. Both terms imply a non-charged state, a common potential, a common point with which the potentials of other points are defined. When this common point is the earth, some standards use the term earth, while other standards use the term ground. When this common point is not the earth, most standards use the word ground, but some still use the word earth.

In electrical circuits, the term 'ground' (or 'earth') can be very confusing, because it has different meanings. The word 'ground' (or 'earth'), without context, could mean any of the following:

1. A 'common' connection, but not connected to Earth.
2. A direct connection to the power supply (usually to the DC negative terminal).
3. A point on a circuit used as a zero-voltage (0V) reference for measuring potential differences (this is the case with most electronics).
4. A connection to the inside of a shielded metal box.
5. A connection to a metal object much larger than the circuit (e.g., car chassis).
6. A connection to a conductive stake driven into the Earth (or a connection to a metal water pipe which extends out of a building into the earth). In an electrical power system, the ground or earth is a conductor that provides a low impedance path to the earth to prevent hazardous voltages from appearing on equipment.

In general, grounding (uncharging) is the process of removing the excess charge on an object by means of the transfer of electric charge (electrons) between it and another object of substantial size. When a charged object is "grounded", the excess charge is balanced by the transfer of electrons between the charged object and a ground. A ground is simply an object that serves as a seemingly infinite reservoir of electrons; the ground is capable of transferring electrons to or receiving electrons from a charged object in order to neutralize the charge on that object. Grounding requires a conducting pathway. "Ground" may be used as a reference point for measurement. The "earth" is the most common ground reference. It is sometimes said that 'earth'/'ground' is a statement of voltage.

**WATER ANALOGY:** *Imagine a lake, either man-made or natural, then the top of the lake is equivalent to ground, a place where the water/charge is all at the same potential and where lots of flow/current can easily go in or out without changing the potential.*

In an electrical circuit, ground or earth is the reference point from which voltages are measured, a common return path for electric current, or a direct physical connection to the Earth. In electrical power distribution systems, a protective ground conductor is an essential part of the safety earthing/ground system. Here, 'earth'/'ground' refers to a body that has such a large charge sink/source capacity that for circuit purposes any current flows do not affect its potential. In electrical systems, the Earth is commonly used as ground because it is very large and conductive (generally); it also then serves as a common reference point. The minerals and moisture in the Earth (in soil) will conduct.

> **HISTORICAL NOTE:** *An essential part of radio is an antenna, and an essential part of early antennas was a connection to the Earth.*

The concept of system grounding is extremely important, as it affects the susceptibility of the system to voltage transients, determines the types of loads the system can accommodate, and helps to determine the system protection requirements.

> **NOTE:** *In a DC circuit, current from a battery leaves the positive terminal and it has to return to the negative terminal before any current can flow. So connecting it to ground has no effect although it also won't do any harm. The circuit will operate just the same if you connect one side of the battery, while the circuit is complete, to ground.*

An **earthing system** (**grounding system**) is circuitry which connects parts of an electric circuit with the ground (earth), but not necessarily the Earth, thus defining the electric potential circuit. If a fault within an electrical device connects a live supply conductor to an exposed conductive surface, anyone touching it while electrically connected to the earth will complete a circuit back to the earthed supply conductor and receive an electric shock.

A **protective earth (PE) connection (a.k.a., equipment grounding conductor)** avoids electrical shocks by keeping the exposed conductive surfaces of a device at earth potential. To avoid possible voltage drop no current is allowed to flow in this conductor under normal circumstances. In the event of a fault, currents will flow that should trip or blow the fuse or circuit breaker protecting the circuit. A high impedance line-to-ground fault insufficient to trip the overcurrent protection may still trip a residual-current device (ground fault circuit interrupter or GFCI) if one is present. This disconnection in the event of a dangerous condition before someone receives a shock, is a fundamental tenet of best practice wiring, and is often referred to as automatic disconnection of supply (ADS). The alternative is 'defence in depth', where multiple independent failures must occur to expose a dangerous condition - reinforced or double insulation come into this latter category.

In contrast to protective earth (PE), a **functional earth connection (functional ground connection)** serves a purpose other than shock protection, and may carry power or signal current as part of normal operation. The most important example of a functional earth is the neutral line in an AC electrical power supply system. It is a current-carrying conductor connected to earth, often, but not always, at only one point to avoid flow of currents through the earth. This connection is sometimes called a "grounded supply conductor" to distinguish it from the "equipment grounding conductor". Common examples of devices that use functional earth/ground connections include surge suppressors, electromagnetic interference filters, certain antennas, and measurement instruments. Great care must be taken when functional earth's from different systems meet to avoid unwanted and possibly dangerous interactions, for example lightning conductors and telecom systems must only be connected in a way that cannot cause the energy of the lightning strike to be redirected into the telecom network.

Earthing/grounding systems can be subdivided at a top-level into low-voltage earthing/grounding systems and high voltage earthing/grounding systems.:

1. In low-voltage distribution networks, which distribute the electric power to the widest class of end users, the main concern for design of earthing systems is safety of consumers who use the electric appliances and their protection against electric shocks. The earthing system, in combination with protective devices such as fuses and residual current devices, must ultimately ensure that a person must not come into touch with a metallic object whose potential relative to the person's potential exceeds a "safe" threshold, typically set at about 50 V.
2. In high-voltage networks (above 1 kV), which are far less accessible to the "general population", the focus of earthing system design is less on safety and more on reliability of supply, reliability of protection, and impact on the equipment in presence of a short circuit. Only the magnitude of phase-to-ground short circuits, which are the most common, is significantly affected with the choice of earthing system, as the current path is mostly closed through the earth. Three-phase HV/MV power transformers, located in distribution substations, are the most common source of supply for distribution networks, and type of grounding of their neutral determines the earthing system.

> **NOTE:** *A connection to the earth/ground is essential to protect a structure from lightning strikes. It directs the lightning through the earthing system and into the ground rod rather than passing through the structure.*

In an electrical current distribution system, there are three possible elements through which current may travel:

1. **The positive wire (DC)** - current enters or current returns (depends on terminology).
2. **The negative wire (DC)** - current enters or current returns (depends on terminology).
3. **The hot wire (AC, positive wire)** is the path for current to flow from source to load.

4. **The neutral wire (AC)** is the return path for the current from the load; it is the return path provided to complete circuit. Neutral carries current equal to that carried by the Hot wire. It is the return path for the Hot. Things in nature like to be "balanced". Without a return path, there's no movement of electrons, and thus, no "electricity". In a single phase branch circuit, the current on the hot wire and neutral should be identical (unless there is ground leakage).
5. **The ground/earthed wire (AC & DC)** is a low impedance pathway between things that might become energized (i.e., has voltage), but are not supposed to be. Under normal conditions, a grounding conductor does not carry current (or voltage). If a fault occurs and if ground is energized/connected, then it completes the circuit back to the source. In other words, ground is there for safety, and it should not carry current, except when something has failed.

**NOTE:** *When a connection has not been made between the neutral point and earth/ground, it is said that the neutral is unearthed/ungrounded.*

### 6.10.1 AC voltage specific issues

An AC voltage system will pass current in the following ways:

1. Balanced: If a three phase load is balanced, and also if the generator system is perfectly balanced then equal current flows through all three wires and no current flows through the neutral line. When the electrical system is "balanced" (a balanced load), the neutral line/wire is 0V (no current flow).
2. Unbalanced: When the system is "unbalanced", then the current through neutral will not be 0. In all the cases (except faults), no current flows through ground wire.
3. Nominal single phase operation (2 wire): In the case of single phase AC (with 2 wires; not SWER), the return path is the neutral wire. Here the question of balanced or unbalanced doesn't arise.
4. Nominal single-wire earth return (SWER; 1 wire): In the case of single-phase earth return, one conducting wire passes from the source to the load, and the grounded/earthed wire is the neutral return path from the load.
5. Except in the case of SWER, only in case of a fault current will flow through the earth wire, otherwise no current flows to "ground".

In electrical AC transmission/distribution systems, neutral sometimes goes "to ground" (to earth), and sometimes does not go "to ground" (to earth). The United States National Electric Code (US NFPA 70) requires that neutral and ground be bonded at the main service entrance for residential electrical service. This bonding is done in this and only this location. Bonding ground and neutral again elsewhere in the system will create parallel ground paths, which is very dangerous.

In AC (more than single phase), ground is connected to neutral for safety. If the bond between ground and neutral is removed, the system will have a "floating neutral", that is, a neutral that has no reference to earth ground. However, in such a configuration, when a ground fault occurs (a specific type of short where the hot wire touches something grounded), it will not trip the breaker. This is a safety hazard, because when a ground fault does occur, no one will know (because breaker isn't tripped). Therein, everything that is grounded may be energized up to system voltage. Hence, ground and neutral are connected at the main service entrance so that when a ground fault occurs, the breaker is tripped, and power is cut to the circuit. It's a safety issue, with a minor secondary issue being improperly grounded equipment can be prone to premature failure.

Some AC grids, like the United States and New Zealand grids, allow electric charges (electricity) to be released back (shunted) into the Earth. AC grids in other countries do not allow this and add an additional wire to the transmission/distribution system as the return path. One name for an electrical transmission/distribution system that continuously releases charge into Earth is called single-wire earth return.

**Single-wire earth return (SWER)** or **single-wire ground** return is a single-wire transmission line which supplies single-phase AC voltage electric power from an electrical power grid -- an electrical transmission/distribution method using only one conductor with the return path through earth. Single-wire earth return systems are significantly different from the three-phase, three-wire and single-phase, two-wire systems. As the name implies, it is a single-wire distribution system in which all equipment is grounded to earth and the load current returns through the earth. Its loads are light and its lines are long, often causing the current to have a leading power factor. Its distinguishing feature is that the earth (or sometimes a body of water) is used as the return path for the current, to avoid the need for a second wire (or neutral wire) to act as a return path. The SWER line is a single conductor that may stretch for tens or even hundreds of kilometres, with a number of distribution transformers along its length. At each transformer, such as a customer's premises, current flows from the line, through the primary coil of a step-down isolation transformer, to earth through an earth stake. From the earth stake, it is claimed by some that "the current eventually finds its way back to the main step-up transformer at the head of the line, completing the circuit". SWER is therefore a practical example of a 'phantom loop'.

There are several issues with single-wire earth return, including but not limited to:

1. The SWER must be designed to prevent dangerous step and touch potentials.
2. Telephone interference, similar to 2 wire single phase lines, worse than three-phase lines.
3. Load balance problems can erode efficiency.
4. Load density limitations.
5. Voltage control can be difficult.
6. Power quality can be compromised.
7. The Earth in a given location is an inadequate composition to conduct electricity.
8. Stray voltage and interference with the Earth's natural electrical currents.

## 6.10.2 Topological layouts for grounding/ earth systems

There are several basic topological layouts for a grounding/earthing system: ungrounded; solidly grounded; impedance/resistance grounded; and reactance grounded.

### *6.10.2.1 Ungrounded*

Electrical power systems that are operated with no intentional connection to earth ground are described as ungrounded. The term "ungrounded system" is actually a misnomer, since every system is grounded through its inherent charging capacitance to ground.

Some systems should not be grounded. A system may be left ungrounded when it is determined that the hazards of grounding outweigh the safety benefits of grounding. One such determined system-type may be an isolated hospital operating room power system, which is a local distribution power system of limited size. Such a system will be left ungrounded, because it is considered unacceptable to have a power outage during a surgical procedure.

Advantages include:

1. Offers a low value of current flow for line-to-line ground fault (5A or less).
2. Presents no flash hazard to personnel for accidental line-to-ground fault.
3. Assures continued operation of processes on the first occurrence of a line-to-ground fault.
4. Low probability of line-to-ground arcing fault escalating to phase-to-phase or 3-phase fault.

Disadvantages include:

1. Difficult to locate line-to-ground fault.
2. Doesn't control transient over voltages.
3. Cost of system maintenance is higher due to labor involved in locating ground faults.
4. A second ground fault on another phase will result in a phase-to-phase short circuit.

### *6.10.2.2 Solidly grounded*

Grounding conductors are connected to earth ground with no intentional added impedance in the circuit. A main secondary circuit breaker is a vital component required in this system, although it has no bearing in other grounding systems. This component is large in size because it has to carry the full load current of the transformer. Back-up generators are frequently used in this type of grounding system in case a fault shuts down a production process. A solidly grounded system has high values of current ranging between 10kA and 20kA.

Advantages include:

1. Good control of transient over-voltage from neutral to ground.
2. Allows user to easily locate faults.
3. Can supply line-neutral loads.

Disadvantages include:

1. Poses severe arc flash hazards.
2. Requires the purchase and installation of an expensive main breaker.
3. Unplanned interruption of production process.
4. Potential for severe equipment damage during a fault.
5. High values of fault current.
6. Likely escalation of single-phase fault to 3-phase fault.
7. Creates problems on the primary system.

### *6.10.2.3 Impedance grounded system*

An impedance/resistance grounded system incorporates the benefits of both the grounded and the ungrounded system. Impedance grounded systems include high resistance ground (HRG) and low resistance ground (LRG) configurations. Low-resistance grounding (impedance-type) is typically used in medium voltage systems, which have only 3-wire loads, such as motors, where limiting damage to the equipment during a ground fault is important enough to include the resistor, but it is acceptable to take the system offline for a ground fault.

1. **High-resistance grounding (impedance-type)** systems are commonly used in plants and mills where continued operation of processes is paramount in the event of a fault. High-resistance grounding is normally accomplished by connecting the high side of a single-phase distribution transformer between the system neutral and ground, and connecting a resistor across the low-voltage secondary to provide the desired lower value of high side ground current. With an

HRG system, service is maintained even during a ground fault condition. If a fault does occur, control systems can locate and correct the fault, or shut down the system in a safe and orderly manner. An HRG system limits ground fault current to between 1A and 10A.

Advantages include:

1. Limits the ground fault current to a low level.
2. Reduces electric shock hazards.
3. Controls transient over voltages.
4. Reduces the mechanical stresses in circuits and equipment.
5. Maintains continuity of service.
6. Reduces the line voltage drop caused by the occurrence and clearing of a ground fault.

Disadvantages include:

1. High frequencies can appear as nuisance alarms.
2. Ground fault may be left on system for an extended period of time.

#### *6.10.2.4 Reactance grounded*

Reactance grounded (reactance-grounded) describes the case in which a reactor is connected between the system neutral and ground. it is commonly used in the neutrals of large AC generators. It provides limiting effect to fault current passage through the circuit and also doesn't consume active power.

### 6.10.3 Fault types

In electrical power systems, a fault or fault current is any abnormal electric current. The design of systems to detect and interrupt power system faults is the main objective of power-system protection. There are four principal categories of fault:

1. A short circuit is a fault in which current bypasses the normal load.
2. An open-circuit fault occurs if a circuit is interrupted by some failure.
3. Phase faults: In three-phase systems, a fault may involve one or more phases and ground, or may occur only between phases. In a "ground fault" or "earth fault", current flows into the earth. In a polyphase system, a fault may affect all phases equally which is a "symmetrical fault".
4. In a "ground fault" or "earth fault", current flows into the earth.

There are several types of faults that an electrical system must be designed to withstand. Electrical equipment is typically sized and noted with a fault current rating based on fault calculations. A designer must account for the worst-case scenario. Among the four principal types of faults are several categories of fault:

1. **Transient fault** - a fault that is no longer present if power is disconnected for a short time and then restored; or an insulation fault which only temporarily affects a device's dielectric properties which are restored after a short time
2. **Persistent fault** - a fault that does not disappear when power is disconnected.
3. **Symmetric fault (balanced fault)** - a fault in an AC phased system that affects each of the [three] phases equally.
4. **Asymmetric fault (unbalanced fault)** - a fault in an AC phased system that does not affect each of the [three] phases equally. Common asymmetric faults include:
   A. Line-to-line (line-line) - a short circuit between lines, caused by ionization of air, or when lines come into physical contact, for example due to a broken insulator.
   B. Line-to-ground - a short circuit between one line and ground.
   C. Double line-to-ground - two lines come into contact with the ground (and each other).
5. **Bolted fault** - a fault with zero impedance, giving the maximum prospective short-circuit current.
6. **Arcing fault** - a fault where the system voltage is high enough that an electric arc may form between power system conductors and ground. Arcing faults are often formed via intermittent failures between phases or phase-to-ground. They're discontinuous currents that alternately strike, extinguish, and strike again.

# 7 Combustion power systems

**CLARIFICATION:** *In practice, combustion and burning refer to the chemical reaction's occurrence in different environments: combustion refers to when the process occurs in an environment with a "fixed" amount of air/oxygen, whereas burning refers to when the process has access to an infinite amount of air/oxygen (i.e., done in the "open"). And, fire is said to exist when the surrounding atmospheric air is the source of the oxidant/oxygen.*

Thermal radiation, process by which energy, in the form of electromagnetic radiation, is emitted by a heated surface in all directions and travels directly to its point of absorption at the speed of light; thermal radiation does not require an intervening medium to carry it.

Chemical kinetics is the quantitative study of chemical systems that are changing with time. (Thermodynamics, another of the major branches of physical chemistry, applies to systems at equilibrium—those that do not change with time.) Chemical kinetics, the branch of physical chemistry that is concerned with understanding the rates of chemical reactions. It is to be contrasted with thermodynamics, which deals with the direction in which a process occurs but in itself tells nothing about its rate. Thermodynamics is time's arrow, while chemical kinetics is time's clock.

**Combustion**, **burning,** and **firing** refer to the same complex sequence of exothermic redox chemical reactions between a fuel and an oxidant accompanied by the production of heat, or both heat and light. In other words, combustion is an oxidative decomposition in which oxygen (the oxidant) oxidizes a fuel. Combustion is the rapid oxidation of a material (the fuel), which releases energy (as, at least, heat). As a chemical reaction, combustion is an irreversible process, and leads to the formation of principal gaseous products (i.e., new chemical species). The interdisciplinary scientific study of combustion combines [at least] heat transfer, thermodynamics, chemical kinetics, and multiphase turbulent fluid flow. Because the reaction is exothermic, the product gases heat up and expand, and in turn can be harnessed to do work. Hence, combustion produces the following sources/carriers of energy:

1. Heat (heat energy transfer; thermal EM radiation/power)
2. Light (electromagnetic radiation; EM power)
3. Turbulent fluid flow (directly, fluid power; indirectly, mechanical power)

All forms of combustion involve the redox chemical reaction of oxidation and reduction, which control the release of heat (light and fluid flow) from the chemical reaction between a fuel and an oxidizer. Therein, combustion is a sequence of elementary radical reactions. For instance, most solid fuels first undergo endothermic pyrolysis (thermochemical decomposition) to produce gaseous fuels whose combustion then supplies the heat required to produce more of them.

Combustion reactions are exothermic (i.e., they give off thermal energy, heat emitting). In a combustion reaction, the fuel (substance undergoing combustion) is oxidized by the oxidant. Usually the oxidizing agent is molecular oxygen ($O_2$), but there are other oxidants (e.g., halogens; hydrogen burns in chlorine). The amount of heat released in a chemical reaction can be calculated through thermodynamics.

**NOTE:** *During chemical reactions, energy is either released to the environment (exothermic reaction) or absorbed from the environment (endothermic reaction). In other words, a chemical reaction that releases energy is termed exothermic, and one that absorbs energy is termed endothermic.*

The products (substances produced by the reaction) of combustion will always have a higher oxidation state than the reactants (substances that start the reaction). In combustion reactions, heat, light, and fluid flow are produced, and work can be done from the transfer of energy. However, for oxidation reactions without combustion, this is not always true.

**NOTE:** *Carbon is the universal element of organic compounds. The molecule of an organic substance must have at least one carbon atom in its molecule. Notice that water does not contain any carbon atom in its molecule, $H_2O$. Hence, water is only an inorganic compound.*

Both organic and inorganic (e.g., gunpowder and magnesium) compounds are capable of combustion, whereupon they become oxidized. All organic matter can be combusted, but only some inorganic matter can be combusted. The burning of a combustible substance can occur in gaseous, liquid, or solid form.

**NOTE:** *Substances that are able to combust [under useful conditions] are called* **flammable**.

When organic molecules combust, the reaction products are [at least] carbon dioxide ($CO_2$) and water ($H_2O$); however, the products will vary depending upon the starting material. In the process of burning, the carbon in these organic fuel substances becomes bonded with oxygen, while some of the oxygen used to "burn" the fuel bonds to the hydrogen atoms from the fuel. Combustion reactions are good examples of **redox reactions** where one molecule gains oxygen (is oxidized) and one molecule gains hydrogen (is reduced).

**NOTE:** *Fires occur naturally, ignited by lightning strikes, significant static electricity, or by volcanic products.*

In order to visualize combustion as a chemical process, imagine separating the carbon and hydrogen atoms of a hydrocarbon molecule (e.g., alkane) and the oxygen atoms of oxygen molecules, and letting the individual atoms attract to form carbon dioxide and water. Separating the atoms (i.e., breaking bonds) involves the input of energy (bond dissociation energy), because the bonding electrons represent a negative charge density, which attracts and holds the positive nuclei of bonded atoms together. As the atoms move in separation, kinetic energy arises (as exothermic energy) from the potential energy of the bonds. When their attracted connection is complete, a new potential energy state/well is formed (e.g., carbon-oxygen as $CO_2$ and hydrogen-oxygen as $H_2O$ bonds).

> **NOTE:** *Electronegativity, symbol χ, is a chemical property that describes the tendency of an atom or a functional group to attract electrons (or electron density) towards itself. An atom's electronegativity is affected by both its atomic number and the distance at which its valence electrons reside from the charged nucleus. The higher the associated electronegativity number, the more an element or compound attracts electrons towards it. The opposite of electronegativity is electropositivity: a measure of an element's ability to donate electrons.*

As a general rule, the greater the electronegativity difference between bonded atoms, the stronger the bonds. Hence, during combustion, relatively weak, low-electronegativity-difference bonds (carbon-carbon, carbon-hydrogen, and oxygen-oxygen) are replaced by stronger, high-electronegativity-difference bonds (carbon-oxygen and hydrogen-oxygen). Oxygen is highly electronegative, and in the presence of sufficient [endothermic] energy input will pull the bonded electrons of other atoms toward itself, separating them and reconnecting in favour of a gain in an electron.

## 7.1 Oxidation reduction reactions (Redox)

In general, combustion is considered a redox reaction. Oxidation reduction reactions (a.k.a., redox reactions) are a basic and common type of chemical reaction found in nature. In a redox reaction, two reactions occur: oxidation and reduction. Take note that an oxidation reaction cannot happen without a corresponding reduction reaction.

Originally oxidation reactions were identified as reactions in which oxygen gas participates, which is why this type of reaction is presently known as oxidation (e.g., $2H_2 + O_2 \rightarrow 2H_2O$). However, as scientific understanding grew, it was discovered that another way to characterize oxidation is through a loss of hydrogen, and not the adding of oxygen (e.g., $CH_4 + 2O_2 \rightarrow CO_2 + 2H_2O$). As scientific understanding grew further, it was discovered that another way to characterize oxidation is through the loss of electrons, where there is no observation of an oxide formation or hydrogen loss (e.g., $Mg + Cl_2 \rightarrow Mg^{2+} + 2Cl^-$). Therefore, today, oxidation means either:

1. Gain of oxygen
2. Loss of hydrogen
3. Loss of electrons

Characterizations 2 and 3 are not combustion reactions. And, and not all observations of characterization 1 are combustion reactions. Therefore, combustion reactions are oxidation reactions, but not all oxidation reactions are combustion reactions. The term oxidation is now something of a misnomer, because it starts with the same prefix as oxygen, suggesting that oxygen is involved in the process, which is not always true and only representative of one characterization of the process.

Today, scientific understanding has determined that a more appropriate definition of oxidation and reduction includes the movement of electrons between the compounds involved. Hence, oxidation-reduction reactions or redox reactions are reactions in which electrons are transferred from one atom or molecule to another. In the most broad definition of redox reactions:

1. Oxidation is the loss of electrons (or an increase in oxidation state by a molecule, atom, or ion).
2. Reduction is the gain of electrons (or a decrease in oxidation state by a molecule, atom, or ion).

In terms of combustion, whenever combustion takes place, oxidation is the end result via redox reaction. For combustion, the usual oxidant is oxygen, but for an oxidation reaction to take place, oxygen is not essential -- all combustion is oxidation, but oxidation includes other reactions.

> **NOTE:** *Rust[ing] is another example of a redox reaction. When something made of iron is exposed to oxygen atoms in the presence of moisture, the iron acquires electrons from the oxygen. The iron and oxygen have opposite charges, which attract, converting the iron into a flaky reddish material called iron oxide (rust).*

## 7.2 Elements of the combustion process

All forms of combustion require at least the following three primary inputs and/or conditions, and if any of these are removed the combustion (fire) will cease to exist:

1. **Fuel (reactant):** The input that burns - a combustible/flammable material. The fuel can be a solid, liquid, or gas that is capable of undergoing combustion. The simplest possible fuel is pure hydrogen gas. During combustion, the fuel donates electrons. The lower a substances electronegativity, the more reactive it will be as a fuel.
2. **Oxidizer (reactant):** The molecule that accepts electrons, which is then reduced. Combustion

requires the fuel to be oxidized, that is, it donates electrons. The oxidizer must be of sufficient quantity to support combustion. Oxygen is a good oxidizer, because it is so electronegative, which means it will relatively easily accept electrons. Only fluorine is more electronegative than oxygen; however, it rarely exists in free elementary form. The predominant oxidizer used in most manufacturing heating processes is atmospheric air.

3. **Heat (i.e., energy input):** Sufficient heat to bring the fuel to its ignition temperature and keep it there. In a combustion reaction, there is energy input and energy output. The input energy (power) starts and/or ignites the reaction, which is true of most chemical reactions. In other words, in order for combustion to occur, there must be sufficient [thermal] energy to bring the fuel (in the presence of an oxidizer) to its ignition temperature, and keep it there. Note that this so-called "activation energy" is usually much less than the energy ultimately released from combustion (as energy output). Metaphorically, ignition/input energy is like rolling a boulder some distance in order to let the natural process of "falling" take over as it rolls it down a hill; as it begins falling down the hill it releases ["gravitational"] potential energy.
4. **Chemical chain reaction (redox)** - In other words, the redox reaction. The heat produced by combustion can make the reaction self-sustaining. Combustion (burning and fires) start when a flammable or a combustible material, in combination with a sufficient quantity of an oxidizer, such as oxygen gas or another oxygen-rich compound (though non-oxygen oxidizers exist), is exposed to a source of heat (or ambient temperature above the flash point for the fuel/oxidizer mix), and is able to sustain a rate of rapid oxidation that produces a chemical chain reaction.

**NOTE:** *Fire (combustion) is normally represented as a triangle of only three inputs: oxygen; heat; and fuel. However, it is more accurate to model fire as a combination of four elements, because fire can be extinguished by removing any one of these four (and not just three) elementary conditional inputs.*

## 7.3 The Combustion continuum (types of combustion)

The terms used to describe combustive decomposition depends on characteristics, such as the speed of the reaction. Combustion can be divided into several types:

#### 7.3.3.1 Unintentional combustion

- **Spontaneous combustion** - Combustion in which substances suddenly burst into flames, without the application of any apparent or intentional cause.

#### 7.3.3.2 A type of combustion, but also, part of the definition of combustion

- **Rapid combustion** - Combustion in which substances burn rapidly to produce heat and light. Combustion, itself, is generally defined as a rapid redox reaction.

#### 7.3.3.3 The continuum from a slower speed of reaction to a faster speed of reaction

1. **Smouldering** - The slow, low-temperature, flameless form of combustion, sustained by the heat evolved when oxygen directly attacks the surface of a condensed-phase fuel. Smouldering is typically an incomplete combustion reaction.
2. **Deflagration (a.k.a., mild burn)** - The opposite of an explosion is termed a mild burn, where the intended products of combustion (such as CO2, H2O, and N2) eventually dominate the composition, as exists in most well-controlled combustion processes (car engine, jet engine, furnace, gas stove top, fireplace, power plant boiler, etc). Deflagration results in subsonic flame velocities. A combustive reaction occurs at less than the speed of sound, it is called deflagration. This term can also be applied to what we mean by the term "burning," in which the flame speed is less than the speed of sound.
3. **Detonation/explosion** - A detonation combustion results in a shock wave of supersonic velocities and can loosely be described as an explosion. Detonation is similar to explosion with the difference lying in the fact that the rapid increase in volume is so high that the production of a supersonic shock wave takes place. The detonation of an explosive (fuel) causes a reaction front that moves faster than the speed of sound (~ 741 mph, or 331 m/s). Take note that there are non-combustive forms of explosion. Technically, it is scientifically incorrect to define an explosion as "a type of combustion". Explosions are defined primarily as a rapid, violent uncontrolled release of energy. Although explosions often involve some kind of temperature difference, they quite commonly occur though means that are totally without combustion - such as mechanical explosions driven by gases. It is sometimes said that combustion means burning, and explosion

means bursting.

#### *7.3.3.4 A combustion-related process, but technically not a type of combustion*

- **Flame/glowing** - Some combustion processes and combusting substances produce a flame. Substances which vaporise while burning give flame and those which do not vaporise while burning do not give flame. Fuels that burn with a flame produce light. Flames and/or glowing represent combustion reactions that are propagating through space at subsonic velocity, and are accompanied by the emission of heat and light (EM radiation). In other words, any chemical process that produces light and heat as either glow or flames is combustion. What we observe as fire is only a small portion of the combustion/burning reaction called the 'flame'. The flame is the result of complex interactions of chemical and physical processes. The flame is the part of the fire made of burning gaseous compounds and fine suspended particles. Evaporation/gasification of the fuels (if these are liquid/solid) and subsequent thermal degradation into smaller molecules and/or reactive radical species forms the gaseous compounds. The composition of the flame can change depending on the nature of the fuel. In their material composition, flames are mostly made up of reaction by-products, such as carbon dioxide (carbon and oxygen), water (hydrogen and oxygen, and oxygen. A flame is a mixture of reacting gases and solids emitting visible, infrared, and sometimes ultraviolet light, the frequency spectrum of which depends on the chemical composition of the burning material and intermediate reaction products. Because flames emit energy in the form of light, the flame is referred to as the visible part of the fire. The color of a flame depends on a variety of conditions; temperature, chemical composition, and the amount of oxygen present can change the color of a flame/fire. Any smoke emitted from the yellow flame is unburnt fuel, also called soot. The more smoke and the more yellow the flame, the more "impure" it is, such that the reactants haven't fully combusted.

## *7.4 The Two reactant forms of combustion*

**NOTE:** *Combustion is used either directly or indirectly to produce virtually every product in common use. Combustion processes produce and refine fuel, generate electricity and other forms of power, prepare foods and other materials, and transport goods.*

The degree of combustion can be measured and analyzed with test equipment. Combustion analyzers may be used to test the efficiency of a burner during the combustion process. In general, there are considered to be two forms of combustion: complete combustion and incomplete combustion:

1. **Complete combustion** - occurs when a sufficient supply of the oxidant is present so that the elements in the fuel react fully - complete burning of the fuel. In complete combustion, the reactant burns to the extent that it produces no (or, a limited number of) by-products. When a fuel undergoes complete combustion, it releases the maximum amount of energy from the fuel being reacted. Complete combustion is usually characterized by a blue flame. In other words, a more complete combustion of gas, for example, has a dim blue color due to the emission of single-wavelength radiation from various electron transitions in the excited molecules formed in the flame. For example, the complete combustion of a ideally pure hydrocarbon with oxygen would produce only carbon dioxide and water (i.e., hydrocarbon + oxygen > carbon dioxide + water).
2. **Incomplete combustion** - occurs when a insufficient supply of the oxidant is present so that the elements in the fuel are not fully reacted - incomplete burning of the fuel. In incomplete combustion, the reactant burns to the extent that it produces by-products. Incomplete combustion is often undesirable because it releases less energy than complete combustion and produces carbon monoxide which is a poisonous gas. Incomplete combustion will produce pure carbon (soot), which is "messy" and will build up on/in equipment. Incomplete combustion is characterized by an orange coloured flame. In incomplete combustion, products of pyrolysis remain unburnt and contaminate the smoke with noxious particulate matter and gases. Partially oxidized compounds may also be present, and are often toxic. When hydrocarbon fuels are used, the products after a complete burning are usually carbon dioxide and water. However, if the burning didn't happen completely, carbon monoxide and other particles can be released into the atmosphere as pollution. In other words, the incomplete combustion of a ideally pure hydrocarbon with oxygen would produce carbon monoxide, carbon and water, as well as carbon dioxide (i.e., hydrocarbon + oxygen > carbon monoxide + carbon + water, and carbon dioxide). The quality of combustion can be improved by selecting a purer fuel and/or improving the designs of combustion devices.

Note that any combustion at high temperatures in atmospheric air, which is 78 percent nitrogen, will also create small amounts of several nitrogen oxides, commonly referred to as $NO_x$, since the combustion of nitrogen is thermodynamically favored at high, but not low temperatures. Since combustion is rarely clean, flue gas cleaning or catalytic converters may be required. Further improvement of combustion outputs is achievable by catalytic after-burning devices (such as catalytic converters) or by the simple partial return of the exhaust gases into the combustion process.

**NOTE:** *When physical elements are burned, the products are primarily the most common oxides. Carbon will yield carbon dioxide, sulfur will yield sulfur dioxide, and iron will yield iron(III) oxide.*

Combustion that produces more relative by-products is dangerous to the health of biological organisms, uses more fuel, and leaves more residue when the chemical reaction is finished. The more efficient and cleaner a combustion, the easier it is to work with and the better it is for practical applications. A more optimal fire is one that uses less fuel and leaves less by-products.

## *7.5 Fuel*

Substances or materials which undergo combustion/ burning/firing are known as fuels. A fuel is any substance (material) capable of undergoing combustion and transferring energy in the form of heat, or heat and light. A fuel is that which is flammable. Combustion, burning, and/or setting fuel aflame will release usable energy. Every phase of matter may be formed into, or otherwise compose, a fuel: solid fuel; liquid fuel; gaseous fuel; plasma fuel. Fuels can be used either by themselves, or they can be mixed with other fuels (into a 'fuel mixture'). Different fuels produce different amounts of heat and light, and different by-products when combusted.

**NOTE:** *Technically, only vapors burn, not liquids or solids. Each type of fuel has a different volatility. Volatility is a measure of how rapidly the liquid turns into vapors. The vapors still must be raised to at least its flash point before ignition can occur.*

Fuels can generally be classified as gaseous, liquid, or solid. In cases where a solid fuel is finely ground, such as pulverized coal, and can be transported in an air stream, its control characteristics approach those of a gaseous fuel. Liquid fuels, as they are atomized and sprayed into a furnace, also have control characteristics similar to those of a gaseous fuel. The control treatment of a solid fuel that is not finely ground is quite different from that of a gaseous or liquid fuel.

**NOTE:** *A chemical analysis of the fuel will assist in determining how much air (oxidizer) must be mixed with it for complete combustion. The relationship between fuel and air is called the 'fuel/air ratio' or 'fuel/air mixture'. In an engine-type combustion system, the mixture is typically adjusted by controlling the amount of fuel or air entering a carburettor. Therein, supplying too much fuel is called a "rich" mixture and causes excess emissions or smoke from the exhaust. Supplying too little fuel is called a "lean" mixture and causes poor heat generation and a rough running engine.*

The choice of fuel has an important influence on a combustion system and its heat transfer ability. In general, solid fuels (e.g., coal and liquid fuels, like oil) produce luminous flames when combusted, which contain soot particles that radiate like blackbodies to the heat load. Gaseous fuels (e.g., natural gas) often produce non-luminous flames, because they burn more cleanly and completely, and are less likely to produce soot particles. A fuel like hydrogen is completely non-luminous, because there is no carbon available to produce soot. (Londerville, 2013)

There are combustion situations where highly radiant flames are required, and therein, a luminous flame is preferred. Alternatively, in cases where only convection heat transfer is applicable, then a non-luminous flame may be preferable in order to minimize the possibility of contaminating the heat load with soot particles from a luminous flame. (Londerville, 2013)

All flammable material has a flash point and an ignition point:

1. The **flash point** of fuel is the lowest temperature at which sufficient vapors are given off for in a momentary flash when an ignition source is applied near the surface. Flash point is the minimum temperature at which liquid will give off vapours that will ignite. The fuel does not have to remain ignited, and may just "flash".
2. The **ignition point/temperature (a.k.a., auto-ignition)** is the temperature at which the ignited material provides enough heat to start combustion (i.e., start burning). Ignition temperature is the minimum temperature that a substance must be raised to before it will ignite. The "ignition temperature" is the temperature that will start a fuel to rapidly ignite with an oxidizer causing combustion to take place. In other words, it is the lowest temperature at which a combustible substance, when heated catches fire and continues to burn.
3. **Fire point** is the lowest temperature at which a fuel will give off vapours sufficient to cause self sustained combustion for 5 seconds or more. Fire point is nothing but the minimum or the lowest temperature at which vaporization occurs, and

these vapors will start to burn (and burn for at least 5 seconds or more), provided an external source of ignition.

**CLARIFICATION - Ignition** *is the process/phenomena of initiating the overall burning/combustion/firing process. Before a substance will burn, it must be heated to its ignition point, or kindling temperature. In other words, sufficient heat must be present to ignite the combustion process. The 'ignition temperature' is the temperature that will start a fuel to rapidly ignite in the presence of an oxidizer (e.g., oxygen) causing combustion to take place. Regardless of the fuel, it must be vaporized in order to burn. Oil, a liquid, and coal, a solid, must be heated to the point where gaseous vapors are rapidly given off. It's these vapors which burn, NOT the solid or liquid. This is what makes it possible, for example, to put out a match in a bucket of light oil that is below its flash point.*

### 7.5.1 Material sources of fuel for combustion

Besides the different phases of matter, there are several different sources of fuel for useful power-oriented combustion purposes. Take not that all of these sources of fuel originate from (or are themselves) biomass, and hence, from solar radiation and photosynthetic production.

1. **Biomass** - Raw biomass from recently living organisms.
2. **Biofuel -** A biofuel is a fuel that is produced through contemporary biological processes, such as agriculture and anaerobic digestion, rather than a fuel produced by geological processes such as those involved in the formation of fossil fuels, such as coal and petroleum, from prehistoric biological matter. A biofuel is a fuel, produced from living organisms.
3. **Fossil fuel** - A fossil fuel is a highly concentrated store of ancient photosynthetic production. Fossil fuel is a general term for buried combustible geologic deposits of organic materials, formed from decayed plants and animals (and their excrement) that have been converted to its three primary forms (as crude and heavy oils, coal, or natural gas) by exposure to heat and pressure in the earth's crust (geological activity) over thousands to millions of years. As organic material (former living organisms) decay within the earth they de-compose into hydrocarbon-type material. And, because of their molecular makeup (i.e., primarily carbon and hydrogen), they readily combine with oxygen under combustion to produce a different compound and release heat. After organisms die, their organic material settles to the surface of the planet, which over time, becomes more deeply buried. This buried organic material eventually forms a layer of partly decomposed spongy-like material called 'peat'. Peat, itself, may be used as a soil nutrient amendment or a fuel. As the peat subsides further and is exposed to greater heat and pressure, it forms into the various types of fossil fuels (i.e., underground hydrocarbon resources). In other words, 'peat' is the material precursor to all fossil fuels.
4. **Refined fossil fuels** - In general, oil-based fossil fuels are refined prior to their final intended usage. Therein, oil is processed and refined into more useful products, such as petroleum, naphtha, gasoline, diesel fuel, asphalt base, heating oil, kerosene, and liquefied petroleum gas.
5. **Hydrocarbon fuel -** All fossil fuels are hydrocarbons, and certain plant species produce hydrocarbons, which may be separated from the remainder of the plant material.

### 7.5.2 Physical phases of fuel for combustion

Fuel can take any of three (more or less) phases of matter.

### 7.5.3 Gaseous fuel

The term 'gaseous fuel' refers to any combustible fuel that exists in the gaseous state under normal temperatures and pressures. Gaseous fuels are typically composed of a wide-range of chemical compounds. Low boiling point hydrocarbons (both paraffins and olefins), hydrogen, carbon monoxide, and inert gases (nitrogen and carbon dioxide) are among the many chemical constituents of common gaseous fuels.

Examples of common gaseous fuels include:

1. **Natural gas (fossil fuel)** is a gaseous fossil fuel that is formed naturally beneath the Earth and is typically found with or near crude oil reservoirs. Natural gas consists of a fluctuating range of low boiling point hydrocarbons. Methane is the primary chemical component, and can be present in amounts ranging from 70% to 99.6% by volume. Ethane can be present in amounts ranging from 2% to 16% by volume. Natural gas consists primarily of methane (CH4). The heat is released as the carbon (C) and hydrogen (H2) combine (react) with oxygen and produce water (H20) and carbon dioxide (CO2).Carbon dioxide, nitrogen, hydrogen, oxygen, propane, butane, and heavier hydrocarbons are also typically present in the fuel analysis.3 The exact analysis usually varies somewhat depending

on the source of the gas and on any heating value adjustments or supplementation."

2. **Liquified petroleum gas (LPG)** is the general term used to describe a hydrocarbon that is stored as a liquid under moderate pressure, but is a gas under normal atmospheric conditions. The primary chemical components of LPG are propane, propylene, normal butane, isobutane, and butylene.
3. **Gaseous biofuel** - Gaseous fuels produced from biomass.

### 7.5.4 Liquid (and oil) fuels

The term 'liquid fuel' refers to any combustible fuel that exists in the liquid state under normal temperatures and pressures. By definition, a liquid fuel is a fuel substance that deforms continuously when shear stress is applied. The most common liquid fuels are hydrocarbon-based, but there are many non-hydrocarbon-based liquid fuels, such as 100% hydrogen-peroxide.

The combustion of a liquid fuel in an oxidizing atmosphere happens in the gas phase. It is the vapor [of the liquid] that burns, not the liquid. The liquid, however, can still combust so rapidly that it explodes. A liquid fuel will normally catch fire only above a certain temperature: its flash point. The flash point of a liquid fuel is the lowest temperature at which it can form an ignitable mix with air. It is the minimum temperature at which there is enough evaporated fuel in the air to start combustion.

In general, liquid fuels are combusted in devices called 'burners', with a pre-combustion atomization phase using an appropriate fuel atomizer. Atomization is the process of breaking up bulk liquid into many small droplets (i.e., "spraying" the liquid). In order to have good combustion, fuel and air must mix well. A bulk liquid fuel has a limited surface area to contact with the air. This is the reason that liquid fuel, requires atomization before burning. Oils, in particular, must be atomized for optimal combustion.

Examples of liquid fuels include:

1. **Crude oil (fossil fuel)** - The primary chemical components of crude oil are carbon, hydrogen, sulfur, oxygen, and nitrogen. The percentages of these elements found in a crude oil are most frequently used to characterize the oil. Crude oils also contain inorganic elements such as vanadium, nickel, and sodium, and usually contain some amount of water and ash (noncombustible material). The main hydrocarbon constituents of crude oils are alkanes (paraffins), cycloalkanes (naphthenes), and aromatics. The end products derived from crude oil number in the thousands.
2. **Fuel oils (a.k.a., marine fuel or furnace oil)** - Fuel oil is a fraction obtained from petroleum distillation, either as a distillate or a residue. It is the most common fuel on the planet today. If the petroleum context of the term is removed, then a 'fuel oil' could otherwise be defined as any liquid fuel that is burned in a furnace or boiler for the generation of heat or used in an engine for the generation of power, except oils having a flash point of approximately 40°C, and oils burned in cotton or wool-wick burners. In the hydrocarbon context, 'fuel oil' is made of long hydrocarbon chains, particularly alkanes, cycloalkanes and aromatics. The term fuel oil is also used in a stricter sense to refer only to the heaviest commercial fuel that can be obtained from crude oil (i.e., heavier than gasoline and naphtha). The two classifications that separate hydrocarbon fuel oils are "distillates" and "residuals," where distillates indicate a distillation overhead product (lighter oils) and residuals indicate a distillation bottom product (heavier oils).
3. **Liquid biofuel** - Liquid fuels produced from biomass.

**NOTE:** *Fossil-based oil and natural gas are found under ground between folds of rock and in areas of rock that are porous and contain the oils within the rock itself. The folds of rock were formed as the earth shifts and moves. It's similar to how a small, throw carpet will bunch up in places on the floor.*

### 7.5.5 Solid fuel

Solid fuels often need to be prepared (e.g., pulverized and grinding) to increase surface area for more efficient combustion. The primary furnace considerations when firing solid fuels revolve around the high levels of ash that are generated. All solid fuels oxidize in a similar manner: the flow of processes are heat-up, devolatilization, volatile oxidation, and finally char burnout. With a solid fuel, the act of combustion consists of three relatively distinct but overlapping phases:

1. <u>Preheating phase</u> - when the unburned fuel is heated up to its flash point and then fire point. Flammable gases start being evolved in a process similar to dry distillation. All solid fuels require initial heat-up as the first step in oxidation to dry the material. Depending on the fuel type, swelling, shrinking, and breakup may occur partially at this stage.
2. <u>Distillation phase or gaseous phase</u> - when the mix of evolved flammable gases with oxygen is ignited. Energy is produced in the form of heat and light. Flames are often visible. Heat transfer from the

combustion to the solid maintains the evolution of flammable vapours.

3. Charcoal phase or solid phase - when the output of flammable gases from the material is too low for persistent presence of flame and the charred fuel does not burn rapidly and just glows and later only smoulders

Examples of solid fuels include:

1. **Biomass** and **solid biofuel** - Raw biomass and solid fuels produced from biomass. Note that raw biomass is technically a fuel source, but it is not a processed or concentrated fuel source.
   - **Pete (turf)** - Peat (turf) is an accumulation of partially decayed vegetation or organic matter (i.e., partially composted organic matter) that is unique to natural areas called peatlands, bogs, or mires. Peat has a high carbon content and can burn under low moisture conditions. Once ignited by the presence of a heat source (e.g., a wildfire penetrating the subsurface), it smolders.
2. **Coal** - A combustible black or brownish-black sedimentary rock usually occurring in rock strata in layers or veins called coal beds or coal seams. The harder forms, such as anthracite coal, can be regarded as metamorphic rock because of later exposure to elevated temperature and pressure. Coal is composed primarily of carbon, along with variable quantities of other elements, chiefly hydrogen, sulfur, oxygen, and nitrogen. A fossil fuel, coal forms when dead plant matter is converted into peat, which in turn is converted into lignite, then sub-bituminous coal, after that bituminous coal, and lastly anthracite. This involves biological and geological processes that take place over time. Coal may be ranked by class from oldest to youngest, geologically. Coal is, relatively speaking, pure carbons. Coal starts initially forming from vegetation and wood under pressure and temperature over a long period of time. During this time period, the initial formation goes from humates to anaerobic and then peat. Final formation to coal then proceeds in order to yield lignite, subbituminous, bituminous and finally anthracotic coal over time. Coal is a hard, black colored rock-like substance. It is made up of carbon, hydrogen, oxygen, nitrogen and varying amounts of sulphur, as well as many other minerals in lesser amounts (including, mercury). There are three main types of coal – anthracite, bituminous and lignite. Anthracite coal is the hardest and has more carbon, which gives it a higher energy content. Lignite is the softest and is low in carbon but high in hydrogen and oxygen content. Bituminous is in between.
3. **Petroleum coke (**abbreviated **pete coke** or **petcoke)** - is a carbonaceous solid delivered from oil refinery coker units or other cracking processes.

## 7.5.6 Combustion power production systems

> **NOTE:** *Combustion is currently the only currently known power source capable of placing objects in earth's orbit, by powering rockets. These rockets are often powered by liquid ~100% hydrogen peroxide ($H_2 0_2$ is a type of rocket fuel). This fuel is atomized before combustion.*

Combustion systems include, but are not limited to the following primary types:

1. **Match system** - One end is of a combustible material (e.g., wood) is coated with another material that can be ignited by frictional heat generated by "striking" the material against a suitable surface.
2. **Wick system** - A wick is usually a braided textile (e.g., hemp or cotton) that holds the flame of a candle or oil lamp for a set period of time depending upon the amount of wick. A candle wick works by capillary action, conveying ("wicking") the fuel to the flame.
3. **Firepit system** - A structure made to contain a fire (outside). In general, firepits are designed for the combustion of biomass in an open space.
4. **Fireplace** or **firebox** - A enclosure/structure made of brick, stone or metal designed to contain a fire. Therein, a chimney or other flue allows exhaust to escape. There are three primary types of fireplaces: biomass combustion; gas combustion; and non-combustion electric fireplaces.
5. **Burner system** - A device/structure responsible for: (1) proper mixing of fuel and air in the correct proportions, for efficient and complete combustion; and (2) determining the shape and direction of the flame. The burner is where combustion takes place; where fuel is combusted with an oxidizer to transfer ("convert") the chemical energy in the fuel into electromagnetic [and thermal] energy. In other words, a burner is the part of the equipment where the fuel is actually burned/combusted; it combusts fuel and generates products of combustion, EM radiation (light), heat, and a change in the surrounding fluid. When the fuel is a liquid or gas, then it flows into the burner and is burnt with the oxidizer (e.g., air), which may be provided by a blower (e.g., air blower). Note that the word 'burner' may also be used in a more general sense to describe the overall apparatus in which the fuel is burned and heat is

produced (a.k.a., a furnace). Hence, it may be said that burners for [utility] boilers are designed to efficiently transfer ("convert") the chemical energy of a fuel into heat within the space provided by the boiler's radiant section, also called the 'furnace' (i.e., a boiler-furnace system). A given combustion system may have a single burner or many burners, depending on the size and type of the application. In concern to a boiler, the 'firing rate' of the burner defines the boiler's output (as steam or other). The burner's design and placement must be engineered to achieve the boiler's essential operation. Burners have a variety of applications, including but not limited to: heating liquid in a boiler; incinerating material in an incinerator; and producing heat for a furnace.

A. **Furnace** or **kiln** - An enclosure/structure in which a fuel (independent of its state of matter) is converted to a high temperature heat.
B. **Incinerator** - An incinerator is a furnace for burning waste. Modern incinerators include pollution mitigation equipment such as flue gas cleaning. There are various types of incinerator plant design: moving grate, fixed grate, rotary-kiln, and fluidised bed.
C. **Boiler** - An enclosed vessel in which water or other fluid is heated (and possibly, circulated) for a separate purpose/function. The fluid does not necessarily boil. The heated or vaporized fluid exits the boiler for use in various processes or heating applications. Hence, there are many sub-types of boiler. A kettle is the most elementary form of a boiler. Common uses for a boiler include, but are not limited to: producing hot water or steam for heating (e.g., water heating, central heating, or cooking); producing steam for use within a manufacturing facility (e.g., atomizing oil for oil-fired burners or for sanitizing equipment); and producing steam to turn a turbine and generate electrical power (i.e., boiler-based power generation). The most common combustible materials (or fuels) used in heating boilers are oil and gas.

**NOTE:** *Sometimes the word 'boiler' is used in a way that it includes the burner (or heater or furnace) component.*

Combustion systems can be chambered or unchambered. A chamber is an enclosed space specifically for combustion:

- **Chambered system** - A combustion chamber is a space where a fuel/air mixture is burned. Combustion chambers are found in all internal combustion engines (ICEs). Internal combustion engines include, but are not limited to: petrol (gasoline) engines; diesel engines; gas turbines and jet engines (therein, called a combustor); rocket engines. The term combustion chamber is also used to refer to an additional space between the firebox and boiler in a steam locomotive. 'Micro combustion chambers' are the devices in which combustion happens at a very small volume, due to which surface to volume ratio increases which plays a vital role in stabilizing the flame.
  - **Combustor (a.k.a., burner)** - A combustor is a component or area of a gas turbine, ramjet, or scramjet engine where combustion takes place. It is also known as a burner, combustion chamber or flame holder.

### 7.5.7 A waste combustion system

*A.k.a., Waste incineration, incineration.*

It is possible to have a factory burn organic trash to produce energy/power. This type of power and trash disposal system is likely to be necessary for every habitat network because of the amount of trash produced under market conditions (and availability of ground disposal sites). The habitat will have a recycling organization for the separation of waste and the proper processing of that material. The processing of some organic-type waste can be combusted to produce electricity (via turbine) and residual metals. These types of combustion system need to have their exhaust gases filtered to be safe for people and the ecology.

### 7.5.8 The ideal combustion system

An "ideal" combustion/fuel burning system would have [at least] the following characteristics:

1. No excess oxygen or unburned combustibles in the end products of combustion.
2. A low rate of auxiliary ignition-energy input to initiate the combustion process.
3. An economic reaction rate between fuel and oxygen compatible with acceptable nitrogen and sulfur oxide formation.
4. An effective method of handling and disposing of the solid impurities introduced with the fuel.
5. Uniform distribution of the product weight and temperature in relation to the parallel circuits of heat absorbing surface.
6. A wide and stable firing range, fast response to changes in firing rate, and high equipment availability with low maintenance.
7. A reaction that produces low emission of harmful particulate output.

### *7.6 Environmental impact*

**NOTE:** *Combustion can be used to destroy (incinerate) waste, both non-hazardous and hazardous.*

Combustion/burning/fire and its by-products can be extremely dangerous to living organisms and ecosystems. All forms of combustion must be carefully monitored and unintentional/undesirable combustive processes must be safely extinguished. In a human habitat, fire control/"fighting" services must exist to extinguish and/or contain uncontrolled fires. Further, fire prevention as a design consideration, is intended to reduce sources and/or the probability of ignition. Fire prevention also includes education to facilitate knowledge of what causes fires, how to avoid fires, and what to do if an uncontrolled fire occurs.

Uncontrolled fires are extremely dangerous to living organisms and other environmental materials. Burning releases carbon monoxide, carbon dioxide, nitrogen oxides, and other pollutants and particulates. If these pollutants are not captured and recycled, burning can create smog. Emission from combustion will enter the atmosphere and spread for hundreds, if not thousands of kilometres. Coal, for example, is often high in mercury. Emissions from coal-fired systems account for 13 to 26 percent of the total (natural plus anthropogenic) airborne emissions of mercury in various locals.

## 8 Hydropower (water power)

**DEFINITION: Hydrokinetic** *technologies and devices produce power by harnessing the kinetic energy of a body of water (i.e., the energy contained in its motion).*

Hydropower or water power (from the Greek: ύδωρ, "water") is power derived from the energy of falling or otherwise fast moving water, which may be harnessed for useful purposes. Hydropower refers to the power that is produced by the pressure of moving water (i.e., force of water moving at a velocity). However, it should be noted here that although moving water has kinetic energy, water itself is a carrier of energy. Note here that hydropower is similar to hydraulic power, except that hydraulic power more generally refers to any intentionally pressurized liquid (there is some overlap between hydro- and hydraulic-power). Hydropower has been used since ancient times to grind flour, irrigate, and perform other tasks (e.g., watermills). Through hydropower technology, the potential and/or kinetic energy of water is transferred (i.e., harnessed) to mechanical power, and then, to useful work or to electrical (or other) energy. When hydropower is used to produce electric power it is known as hydroelectric power (hydroelectricity).

**HISTORICALLY NOTE:** *Hydropower has been used for thousands of years to mill grain. In a 'tide mill', the incoming tidal water is contained in large storage ponds, and as tide goes out (recedes), its movement/pressure turns a waterwheels that uses the mechanical power to mill grain.*

Hydro power/energy is available in many forms: potential energy from high "heads" of water (i.e., water at elevation) retained in dams; kinetic energy from current flow in rivers and tidal barrages; and kinetic energy also from the movement of waves on relatively static water masses. Most ways of harnessing this energy involve directing the water flow through a turbine to generate mechanical power, which may then be used to generate electric power. Those hydropower harnessing systems that do not use a turbine, usually involve using the movement of the water to drive some other form of hydraulic or pneumatic mechanism to perform the same task.

**TERMINOLOGY:** *The difference in height between the water source and the water outflow is known as 'head', and the potential energy of the water is directly proportional to the 'head'.*

Generally speaking, every form of hydropower is originally derived from one or more of the following other sources of energy: solar, geothermal, and/or "gravitational"/planetary. Specifically, when hydropower takes the form of water moving over or through land (i.e., "running" water), then it may be considered a form of solar energy, as the sun drives water evaporation from the ocean, and winds carry the moisture overland. Similarly, when hydropower takes the form of waves, then it may be considered a form of solar energy since the wind is the most significant factor in wave generation, and the wind comes from the interface of solar energy with the Earth. When hydropower takes the form of an ocean current or tide, then it may be considered a form of "gravitational" energy, due to its movement being significantly derived from the pull of the Moon (and Sun) on water. When hydropower comes from thermal differentials in water, then it may be considered a form of solar and/or geothermal energy, since temperature differentials in the Earth, and sunlight, generate the movement of the water.

> **NOTE:** *Planetary energy refers to the interactive force between the earth, moon, and sun, causing a periodical state change in natural water reservoirs called 'tide'.*

## 8.7 Hydro-electric power

Hydro-electric power (hydroelectric or hydroelectricity ) is a form of hydropower. Hydroelectric power is generated by harnessing/controlling the power of moving water (water pressure, mechanical energy) to produce electric power. In most cases, hydroelectric power (hydroelectricity) is generated through the mechanically powered rotation of a turbine connected via shaft [power] to a generator that produces electric power through the electromagnetic induction effect.

> **NOTE:** *Electrolysis and electrodialysis involve the production of electrical power through the use of water, they are not technically hydropower sources, because they do not produce electric current through the direct movement/pressure of water.*

Hydroelectric power may be sub-classified based on the location of the water used and the direct source of the water's movement. There are two top level location-based categories of hydroelectric power:

- Land
- Ocean/marine

In general, ocean energy can be sub-classified into six types of different origin and characteristics:

- Ocean wave (wave)
- Tidal range (tidal)
- Tidal current (current)
- Ocean current (current)
- Ocean thermal energy (thermal)
- Salinity gradient (osmotic)

A [water] 'current' is a relatively large movement of water in one direction. In a current, water is moving forward. Water passing over/through land, and water in the ocean, can have a current. In the ocean, currents can be temporary or long-lasting; they can be near the surface or in the deep ocean. Ocean currents are driven by several factors, including gravitational/planetary motion and thermohaline circulation. Thermohaline circulation generates large ocean currents driven by differences in temperature (thermo) and salinity (haline). A current, in a river or stream, is the flow of water influenced by gravity as the water moves downhill to reduce its potential energy. The current varies spatially as well as temporally within the stream, dependent upon the flow volume of water, stream gradient, and channel geometrics. The term 'current' (as in, 'water current') can be applied in three ways to hydroelectric power:

1. Current as tide (tidal current)
2. Current as stream/river (river/stream current)
3. Controlled current as dam

The form (i.e., "sculpting") of water into waves (located on the surface of a body of water) is commonly caused by wind transferring its energy to the water. Large surface waves, known as 'swells', can travel over long distances. A surface wave's size depends on wind speed, wind duration, and the area over which the wind is blowing (the 'fetch'). Tides may be viewed as waves; the largest waves on the planet, and they cause the sea to rise and fall along the shore around the world. Tides exist due to the gravitational/planetary pull of the moon and the sun, but vary depending on where the moon and sun are in relation to the ocean as the earth rotates on its axis.

### 8.7.1 Hydroelectric power generation

Hydroelectric power generation systems can be classified in the following ways:

1. According to the availability of head (elevation drop of water):
   A. High head power
   B. Medium head power
   C. Low head power
2. According to the nature of load:
   A. Base load generation
   B. Peak load generation
3. According to capacity (quantity of water available):
   A. Large (>100MW); medium (25-100MW); small (1-25MW); mini (100KW-1MW); micro (5-100KW); pico (<5KW)
4. According to hydrological region:
   A. Single
   B. Cascade
5. According to transmission system:
   A. Isolated
   B. Connected to grid
6. As land - according to quantity of water available:
   A. Hydroelectric generation with storage reservoirs

(controlled current as dam)
   B. Run of river generation without pondage (current as river/stream)
   C. Run of river generation with pondage (current as river/stream)
   D. Pump storage
7. As ocean/marine:
   A. Current (current in general)
   B. Tidal (current as tide)
   C. Wave
   D. Thermal
   E. Osmotic

### 8.7.2 Land-based hydroelectric power

There are three basic landed ways in which hydroelectric power may be generated from water. They all involve the use of a turbine-electric system. Land-based hydroelectric power generation systems can be classified according to the characteristics of the watercourse which is being used as a power (energy) source:

1. **Dammed-hydro** (hydroelectric dams; reservoir-type; impoundment power station) - The potential energy of water is collected in a dam. A dam is used to store river water in a reservoir. Water is released from the dam in a controlled manner. Water released from the reservoir flows/falls through a turbine, spinning it, which in turn powers an electric generator to produce electricity. A hydroelectric dam installation uses the potential energy of the water retained in the dam, and its release as kinetic energy, to drive a water turbine, which in turn drives an electric generator. The available energy therefore depends on the 'head' of the water (i.e., elevation) above the turbine and the volume of water flowing through it. Turbines used for this purpose are usually reaction type, whose blades are fully submerged in the water flow. The height of the dam and mass of water behind the dam (as well as the turbine-electric system) determines power output. Herein, available power is expressed as:
   - Potential energy per unit volume = ρgh
   - Where, ρ is he density of the water (103 Kg/m3 ), h is the head of water and g is the gravitational constant (10 m/sec2)
   - Where, Q is the volume of water flowing per second (the flow rate in m3/second) and η is the efficiency of the turbine.
   - The power P from a dam is given by: P = ηρghQ
2. **Run-Of-The-River** (ROR; in-stream; diversion-type; channel-type) - A diversion in a river/stream channels/diverts a portion of a water through a canal or penstock to a turbine. The kinetic energy of the flowing water is used to drive the turbine. It generally does not require the use of a dam. An ROR system may or may not have pondage associated with it. 'Pondage' usually refers to a relatively small water storage area behind the weir of a run-of-the-river hydroelectric power plant. A 'weir' is a barrier across a river designed to alter its flow characteristics. Therein, the 'head' is often zero (or close to zero). The available energy therefore depends on the quantity of water flowing through the turbine and the square of its velocity. Impulse turbines, which are only partially submerged, are more commonly employed in fast flowing run of river installations. In deeper, slower flowing rivers, submerged Kaplan turbines may be used to extract the energy from the water flow. Herein, available power is expressed as:
   - The maximum power output from a turbine used in a run of river application is equal to the kinetic energy (½mv$^2$) of the water impinging on the blades. Taking the efficiency η of the turbine and its installation into account, the maximum output power $P_{max}$ is given by: $P_{max}$ =½ηρQv$^2$
   - Where v is the velocity of the water flow and Q is the volume of water flowing through the turbine per second.
   - Q is given by: Q = A v
   - Where A is the swept area of the turbine blades.
   - Thus, $P_{max}$ =½ηρAv$^3$
   - Note that the power output is proportional to the cube of the velocity of the water.
3. **Pumped storage** - Under this method, electric current is generated through a turbine-generator by intentionally moving water between reservoirs located at different heights. This method is useful for supplying electricity on occasions of high peak demands. When the demand is high, water is released from a higher to a lower reservoir, and run through a turbine-electric system to generate electrical power. During times of low demand, water from lower reservoirs is pumped (using electric power and fluid pressure) up into higher reservoirs. Pumped storage works like a battery, storing potential energy "in" water until it is needed. A pumped storage system can be independent of other land-based hydroelectric production systems, or connected to these systems.

A land-based hydro-electric turbine uses water pressure to turn a generator before the water flows out at very low pressure through a 'tail race'. There is no heat involved. This is not a heat engine. The following turbines are most commonly used in land-based hydroelectric power systems:

1. Francis turbines - suitable for middle-sized available

heads. An inward-flow reaction turbine that combines radial and axial flow concepts.
- Kaplan turbines - suitable for low available heads and larger water flows.

2. Pelton turbines - suitable for high available heads and smaller water flows. A type of impulse turbine

Each type of land-based hydroelectric plant has advantages and disadvantages. It is important to recognize that whenever there is a turbine in a natural water source, then the turbine can/will pose a danger to aquatic organisms.

Land-based hydroelectric systems, dams in particular, have several advantages, including:

1. Technically, “non-pollutive”
2. Climatically renewable
3. Possibility of use as flood control
4. Multiple crop cultivations per year
5. New ecosystem

Land-based hydroelectric systems, dams in particular, have several disadvantages, including:

1. May require the construction of a dam/reservoir, which will modify the local habitat.
2. If a drought occurs, the power station may not have an energy source.
3. Turbines can pose a danger to aquatic lifeforms, and human swimming, and dams pose an obstacle to the movement of aquatic life.
4. Dams have other drawbacks, including:
   A. Loss of nutrient flow down river.
   B. Loss of sediment flow down river.
   C. Sedimentation behind the dam limits lifetime of the dam and increases maintenance requirements.
   D. Flooding of scenic areas and alteration of ecology to create the dam system.
   E. Ecosystem below the dam is usually changed.
   F. Colder, nutrient poor water.
   G. Aesthetics and ecological change as the loss of wild rivers.

### 8.7.3 Ocean/marine-based hydroelectric: Tidal power

Tidal power, also called “tidal energy”, is a form of hydropower that converts the energy obtained from tides into useful forms of power, mainly electric power. Tidal power uses the energy available from the ocean’s tidal motions. Tidal motions represent the cyclical rise and fall of water due to tidal phenomena. Tides are highly predictable, and significantly more predictable than wind power and solar power.

In general, tides cycle every 12.5 hours, so daily peak production times and slack times vary, this causes a mismatch in supply and demand, as industrial demand is high during the day and low at night. Tides vary seasonally and monthly as well. The general ‘tidal range’ around the earth is about 2 feet to about 20 feet, the higher the ‘tide range’, the more useful the energy.

A tidal stream generator, often referred to as a tidal energy converter (TEC), is a general term for a machine that extracts energy from moving masses of water, in particular tides, although the term is often used in reference to machines designed to extract energy from run-of-river and tidal estuarine sites. Certain types of these machines function very much like underwater wind turbines, and are thus often referred to as tidal turbines.

Tidal power can be classified into four generating methods:

1. **Tidal stream generator (TSG)** - use the kinetic energy of moving water to power turbines. Tidal stream generators can be built into the structures of existing bridges, entirely or partially submersed, thus avoiding concerns over impact on the natural landscape. Land constrictions such as straits or inlets can create high velocities at specific sites, which can be captured with the use of turbines. These turbines can be horizontal, vertical, open, or ducted, and are typically placed near the bottom of the water column (entirely submerged) where tidal velocities are greatest.
2. **Tidal barrage** - use the potential energy in the difference in height (or hydraulic head) between high and low tides. When using tidal barrages to generate power, the potential energy from a tide is harvested through strategic placement of specialized dams. When the sea level rises and the tide begins to come in, the temporary increase in tidal power is channelled into a large basin behind the dam, holding a large amount of potential energy. With the receding tide, this energy is then transferred into mechanical power as the water is released through turbines. Barrages are essentially dams across the full width of a tidal estuary.
3. **Dynamic tidal power (DTP)** - uses an interaction between potential and kinetic energies in tidal flows. It involves the construction of sea dams (30–50 km length) from coasts straight out into the sea or ocean, without enclosing an area. Tidal phase differences are introduced across the dam, leading to a significant water-level differential in shallow coastal seas.
4. **Tidal lagoon** - generally, uses constructed circular retaining walls embedded with turbines that can capture the potential energy of tides. The created reservoirs are similar to those of tidal barrages,

except that the location is artificial and does not contain a pre-existing ecosystem. The lagoons can also be in double (or triple) format without pumping or with pumping that will flatten out the power output. The pumping power could be provided by excess to grid demand renewable energy from for example wind turbines or solar photovoltaic arrays. Excess energy rather than being curtailed could be used and stored for a later period of time. Geographically dispersed tidal lagoons with a time delay between peak production would also flatten out peak production providing near base load production.

The European Marine Energy Centre recognizes six principal types of tidal energy converter (TEC). The types/characteristics of tidal turbines are as follows (Note: any given turbine can have more than one of these characteristics):

1. **Axial turbines** - These are close in concept to traditional windmills, but operating under the sea.
   A. **Horizontal axis turbines** - the main rotor shaft (and generally, electrical generator) are pointed into the current flow (generally set horizontally, but not necessarily horizontally).
   B. **Vertical axis turbines** - the main rotor shaft is set transverse to the flow (generally set vertically, but not necessarily vertically). In other words, the axis is positioned perpendicular to current flow.
2. **Crossflow turbines** (Banki-Michell turbine, Ossberger turbine) - These are impulse turbines; water flows through the runner transversely, striking the blades once on entry and meeting them again as it leaves the runner. Unlike most water turbines, which have axial or radial flows, in a crossflow turbine the water passes through the turbine transversely, or across the turbine blades. As with a waterwheel, the water is admitted at the turbine's edge. After passing the runner, it leaves on the opposite side. Going through the runner twice provides additional efficiency. When the water leaves the runner, it also helps clean the runner of small debris and pollution. The cross-flow turbine is a low-speed machine. These turbines can be deployed either vertically or horizontally. Crossflow turbines are often constructed as two turbines of different capacity that share the same shaft. The turbine wheels are the same diameter, but different lengths to handle different volumes at the same pressure.
3. **Flow augmented turbines** - Turbine that use flow augmentation measures (e.g., a duct or shroud) such that the incident power available to the turbine can be increased. The most common example uses a shroud to increase the flow rate through the turbine, which can be either axial or crossflow.
4. **Shrouded tidal turbine** - a turbine enclosed in a venturi shaped shroud or duct (ventiduct), producing a sub atmosphere of low pressure behind the turbine. The venturi shrouded turbine is not subject to the Betz limit and allows the turbine to operate at higher efficiencies than the turbine alone by increasing the volume of the flow over the turbine. The performance of a shrouded turbine varies with the design of the shroud. The available power from a shrouded tidal turbine is expressed as:
   - The maximum power output from a shrouded water turbine used in tidal energy applications is equal to the kinetic energy of the water impinging on the blades, similar to the "run of river" calculation. Taking the efficiency η of the turbine and its installation into account, the maximum output power $P_{max}$ is given by
   - $P_{max} = ½ηρAv3$
   - Where, v is the velocity of the water flow and A is the swept area of the blades.
5. **Oscillating hydrofoils** - Oscillating devices do not have a rotating component, instead they use aerofoil sections that oscillate (pushed sideways) by the flow of water. In other words, oscillating hydrofoils are a form of hydroelectric generation system in that they are not turbines. However, they still use the electromagnetic induction effect to generate electric power. Oscillating stream power extraction was proven with the omni- or bi-directional winged pump windmill.
6. **Venturi devices** - These devices use a shroud or duct in order to generate a pressure differential which is used to run a secondary hydraulic circuit which is used to generate power. These devices make use of the venturi effect.
7. **Archimedes screws** - Water is pumped by turning a screw-shaped surface inside a pipe. A machine historically used for transferring water from a low-lying body of water into irrigation ditches.
8. **Tidal kites** - A tidal kite turbine is an underwater kite system or paravane that converts tidal energy into electricity by moving through the tidal stream. The kite is tethered by a cable to a fixed point. It "flies" through the current carrying a turbine. It moves in a figure-eight loop to increase the speed of the water flowing through the turbine tenfold.

These systems have several possible mounting positions:

1. **Bottom-mounted** - mounted stationary to the sea

floor/bed.

2. **Fully underwater cable tethered** - tethered via cables connected to the sea floor, while the turbine remains fully in the water.
3. **Surface floating cable tethered** - the turbine is connected to a floating platform, which is tethered to the sea floor.
4. **Structure mounted** - mounted onto an architectural structure, such as a bridge.

### 8.7.4 Ocean/marine-based hydroelectric: Wave power

Wave power uses the energy available from the ocean's surface wave motion to generate electrical power. There are several types of devices design to harvest wave power for the generation of electric power:

1. **Oscillating float system** - a float is housed inside an cylinder shaped buoy which is open at the bottom, and moored to the seabed. Inside the cylinder the float moves up and down on the surface of the waves as they pass through the buoy. Various methods have been employed to turn the motion of the float into electrical energy. These include:
   A. Hydraulic systems in which air is compressed in a pneumatic reservoir above the float during its upward movement on the crests of the waves. After the crests have passed, the air expands and forces the float downwards into the following troughs of the waves. A hydraulic system then uses the reciprocating movement of the float to pump water through a water turbine which drives a rotary electrical generator. Instead of generating the electricity on board the buoy, some systems pump the hydraulic fluid ashore to power shore based generators.
   B. Pneumatic systems in which the air displaced in the cylinder is used to power an air turbine which drives the generator.
   C. Linear generators to turn the reciprocating motion of the float directly into electrical power.
2. **Oscillating paddle system** - uses large paddles moored to the ocean floor to mimic the swaying motion of sea plants in the presence of ocean waves. The paddles are fixed to special hinged joints at the base which use the swaying motion of the paddles to pump water through a turbine generator.
3. **Oscillating snake system** - uses a series of floating cylindrical sections linked by hinged joints. The floating snake is tethered to the sea bed and maintains a position head on into the waves. The wave-induced motion at the hinges is used to pump high-pressure oil through hydraulic motors via smoothing accumulators. The hydraulic motors in turn drive electrical generators to produce the electrical power.
4. **Oscillating water column** - waves enter and exit a partially submerged collector from below, causing the water column inside the collector to rise and fall. The changing water level acts like a piston as it drives air that is trapped in the device above the water into a turbine, producing electricity via a coupled generator. Water columns are often formed within large concrete structures built on the shore line, or on rafts. The structure is open at both the top and the bottom. The lower end is submerged in the sea and an air turbine fills the aperture at the top. The rising and falling of the water column inside the structure moves the air column above it driving the air through the turbine generator. The turbine has movable vanes which rotate to maintain unidirectional rotation when the movement of the air column reverses.
5. **Pressure transducer system** - uses a submerged gas-filled tank with rigid sides and base and a flexible, bellows-like, top. The gas in the tank compresses and expands in response to pressure changes from the waves passing overhead causing the top to rise and fall. A lever attached to centre of the top drives pistons, which pump pressurized water ashore for driving hydraulic generators.
6. **Wave capture system** - use a narrowing ramp to funnel waves into an elevated reservoir. Waves entering the funnel over a wide front are concentrated into a narrowing channel which causes the amplitude of the wave to increase. The increased wave height coupled with the momentum of the water is sufficient to raise a quantity of water up a ramp and into a reservoir situated above the sea level. Water form the reservoir can then be released through a hydroelectric turbine located below the reservoir to generate electric power.
7. **Overtopping wave system** - channel waves onto a tapered ramp that causes an increase in their amplitude. The crests of the waves overtop the ramp and spill into a low dam. Water from the low dam then flows through hydroelectric turbines back into the sea beneath the floating structure. A floating reservoir, in effect, is formed as waves break over the walls of the device. The reservoir creates a head of water—a water level higher than that of the surrounding ocean surface—which generates the pressure necessary to turn a hydro turbine as the water flows out the bottom of the

device, back into the sea.

8. **Lever system** - long levers may be mounted on steel piles or on floating platforms. Large floats or buoys are attached to the extremities of the levers which move up and down with the waves. The movement of the lever arms forces fluid into a central hydraulic accumulator and through to a generator turbine. Alternatively high-pressure water can be pumped ashore to power shore based generators.
9. **Point absorber system** - utilizes wave energy from all directions at a single point by using the vertical motion of waves to act as a pump that pressurizes seawater or an internal fluid, which drives a turbine. This type of device has many possible configurations. One configuration, called a hose pump point absorber, consists of a surface-floating buoy anchored to the sea floor, with the turbine device as part of the vertical connection. The wave-induced vertical motion of the buoy causes the connection to expand and contract, producing the necessary pumping action. Through engineering to generate device-wave resonance, energy capture and electricity generation by point absorbers can be maximized.
10. **Attenuator system (heave-surge devices)** - are long, jointed floating structures are aligned parallel to the wave direction and generate electricity by riding the waves. The device, anchored at each end, utilizes passing waves to set each section into rotational motion relative to the next segment. Their relative motion, concentrated at the joints between the segments, is used to pressurize a hydraulic piston that drives fluids through a motor, which turns the coupled generator.

The available power in a wave powered electrical generation system is expressed as:

1. The wave power per unit length of the wave front $P_L$ is given by: $P_L = \rho g a^2 \lambda / 4T$
2. where, ρ is he density of the water (e.g., 103 Kg/m3), a is the wave amplitude (half of the wave height), g is the gravitational constant (10 m/sec$^2$), and λ is the wave length of the oscillation and T the period of the wave.

### 8.7.5 Ocean/marine-based hydroelectric: Osmotic power

Osmotic power (salinity gradient power or "blue energy") is the energy available from the difference in the salt concentration between seawater and river water. There are several methods for generating electric power from the salinity gradient. The key waste product is brackish water. This byproduct is the result of natural forces that are being harnessed: the flow of fresh water into seas that are made up of salt water.

1. **Reversed electrodialysis (RED)** - A process that relies on osmosis with ion specific membranes.
2. **Pressure retarded osmosis (PRO)** - A process that relies on osmosis with ion specific membranes. Seawater is pumped into a pressure chamber where the pressure is lower than the difference between fresh and salt water pressure. Fresh water moves in a semipermeable membrane and increases its volume in the chamber. As the pressure in the chamber is compensated a turbine spins to generate electricity.
3. **The capacitive method** - With this method energy can be extracted out of the mixing of saline water and freshwater by cyclically charging up electrodes in contact with saline water, followed by a discharge in freshwater. Each completed cycle effectively produces energy.
4. **Vapor pressure differences** - Does not rely on membranes, so filtration requirements are not as important as they are in the PRO and RED methods.
   A. Open cycle - Similar to the open cycle in ocean thermal energy conversion (OTEC).
   B. Absorption refrigeration cycle (closed cycle) - For the purpose of dehumidifying air, in a water-spray absorption refrigeration system, water vapor is dissolved into a deliquescent salt water mixture using osmotic power as an intermediary. The primary power source originates from a thermal difference, as part of a thermodynamic heat engine cycle.
5. **Solar pond** - This method does not harness osmotic power, only solar power. Sunlight reaching the bottom of the saltwater pond is absorbed as heat. The effect of natural convection, wherein "heat rises", is blocked using density differences between the three layers that make up the pond, in order to trap heat. The upper convection zone is the uppermost zone, followed by the stable gradient zone, then the bottom thermal zone. The stable gradient zone is the most important. The saltwater in this layer can not rise to the higher zone because the saltwater above has lower salinity and is therefore less-dense and more buoyant; and it can not sink to the lower level because that saltwater is denser. This middle zone, the stable gradient zone, effectively becomes an "insulator" for the bottom layer (although the main purpose is to block natural convection, since water is a poor insulator). This water from the lower layer, the storage zone, is pumped out and the heat is used to produce energy, usually by turbine in an

organic Rankine cycle. A technology called salinity gradient solar pond (SGSP) may be used. In theory a solar pond could be used to generate osmotic power if evaporation from solar heat is used to create a salinity gradient, and the potential energy in this salinity gradient is harnessed directly using one of the first three methods above, such as the capacitive method.

6. **Boron nitride nanotubes** - An impermeable and electrically insulating membrane is pierced by a single boron nitride nanotube with an external diameter of a few dozen nanometers. With this membrane separating a salt water reservoir and a fresh water reservoir, an electric current passes through the membrane using two electrodes immersed in the fluid either side of the nanotube.

### 8.7.6 Ocean/marine-based hydroelectric: Ocean thermal Energy conversion

Ocean thermal energy conversion (OTEC) is a hydrothermal process that can produce electric power by using the temperature difference between cooler deep water and warmer shallow (or surface seawaters) to run a binary cycle electric generating heat engine. In a heat engine, thermal energy does the work. An OTEC system pumps large quantities of deep cold seawater and surface seawater to run a power cycle and produce electricity. The thermal energy of the warmer oceans of the world can be used to generate electricity in much the same way as geothermal heat is used for electrical energy generation. Warmer water is taken from the surface of the ocean to vaporise the fluid in the turbine circuit. Cold water is pumped from the depths of the ocean to condense the working fluid. OTEC is a base load electricity generation system. In the oceans the temperature difference between surface and deep water is greatest in the tropics, although still a modest 20°C to 25°C. It is therefore in the tropics that OTEC offers the greatest possibilities. OTEC energy harvesting is similar to geothermal energy extraction described above except that the temperature gradient has an opposite slope.

Sea water is heated by energy both from the Sun and from the Earth below. The solar energy falling on the water surface is greater than the heat flow emanating from the Earth so that the temperature at the surface is greater than the temperature in the depths of the water.

In a dual cycle “binary plants” the hot water circuit passing through the thermal source is separated from the closed loop working fluid circuit used in the turbine by a heat exchanger. The hot water gives up its heat in the heat exchanger to a working fluid with a low boiling point and high vapour pressure at low temperatures when compared to steam. The working fluid is typically an organic compound (e.g., ammonia, butane, pentane or isopentane) which circulates through the secondary side of the heat exchanger where it vaporises and the vapour is then used to rotate a turbine in a conventional Rankine cycle electricity generating plant. After the vaporised binary liquid has passed through, and given up its energy to, the turbine it is condensed and recycled for re-use through the heat exchanger.

There are a variety of potential working fluids. Ammonia, which has superior transport properties, is easy availability, but it is toxic and flammable. Fluorinated carbons such as CFCs and HCFCs are not toxic or flammable, but they contribute to ozone layer depletion. Hydrocarbons too are good candidates, but they are highly flammable; in addition, this would create competition for use of them directly as fuels. The power plant size is dependent upon the vapor pressure of the working fluid. With increasing vapor pressure, the size of the turbine and heat exchangers decreases while the wall thickness of the pipe and heat exchangers increase to endure high pressure especially on the evaporator side.

Cold seawater is an integral part of each of the three types of OTEC systems: closed-cycle, open-cycle, and hybrid. To operate, the cold seawater must be brought to the surface. The primary approaches are active pumping and desalination. Desalinating seawater near the sea floor lowers its density, which causes it to rise to the surface.

OTEC systems may be either closed-cycle or open-cycle:

1. **Closed-cycle OTEC (Anderson cycle)** - Uses working fluids with a low boiling point that are typically thought of as refrigerants (e.g., ammonia or R-134a) to power a turbine, which powers a generator. Warm surface seawater is pumped through a heat exchanger to vaporize the fluid. The expanding vapor turns the turbo-generator. Cold water, pumped through a second heat exchanger, condenses the vapor into a liquid, which is then recycled through the system. The most commonly used heat cycle for OTEC to date is the Rankine cycle, using a low-pressure turbine.
2. **Open-cycle OTEC (Claude cycle)** - Uses vapour from the seawater itself as the working fluid -- warm surface water at around 27 °C (81 °F) enters an evaporator at pressure slightly below the saturation pressures causing it to vaporize. Warm seawater is first pumped into a low-pressure container, which causes it to boil. In some schemes, the expanding vapour drives a low-pressure turbine attached to an electrical generator. The vapour, which has left its salt and other contaminants in the low-pressure container, is pure fresh water. It is condensed into a liquid by exposure to cold temperatures from deep-ocean water. This method produces desalinized (desalinated) fresh water, suitable for drinking water, irrigation or aquaculture. In other schemes,

the rising vapour is used in a gas lift technique of lifting water to significant heights. Depending on the embodiment, such vapour lift pump techniques generate power from a hydroelectric turbine either before or after the pump is used.

3. **Hybrid OTEC** - A hybrid cycle combines the features of the closed- and open-cycle systems. In a hybrid, warm seawater enters a vacuum chamber and is flash-evaporated, similar to the open-cycle evaporation process. The steam vaporizes the ammonia working fluid of a closed-cycle loop on the other side of an ammonia vaporizer. The vaporized fluid then drives a turbine. The steam condenses within the heat exchanger and provides desalinated water.

**NOTE:** *OTEC and electrolysis technologies can be combined to produce electrical power and hydrogen.*

There are three possible locations for the placement of an OTEC plant:

1. **Land-based** and **near-shore** - Systems constructed on or near land do not require sophisticated mooring, lengthy power cables, or the more extensive maintenance associated with open-ocean environments. They can be installed in sheltered areas so that they are relatively safe from storms and heavy seas. Electricity, desalinated water, and cold, nutrient-rich seawater could be transmitted from near-shore facilities via conduits. In addition, land-based or near-shore sites allow plants to operate with related industries such as mariculture or those that require desalinated water. Land-based or near-shore sites can also support mariculture or chilled water agriculture. Tanks or lagoons built on shore allow workers to monitor and control miniature marine environments.
2. **Shelf-based** - To avoid the turbulent surf zone as well as to move closer to the cold-water resource, OTEC plants can be mounted to the continental shelf at depths up to 100 meters (330 ft). A shelf-mounted plant could be towed to the site and affixed to the sea bottom. The complexities of operating an OTEC plant in deeper water may make them more expensive than land-based approaches. Problems include the stress of open-ocean conditions and more difficult product delivery. Addressing strong ocean currents and large waves adds engineering and construction expense. Platforms require extensive pilings to maintain a stable base. Power delivery can require long underwater cables to reach land.

- **Floating [off shore]** - The difficulty of mooring plants in very deep water complicates power delivery. Cables attached to floating platforms are more susceptible to damage, especially during storms. Cables at depths greater than 1000 meters are difficult to maintain and repair. Riser cables, which connect the sea bed and the plant, need to be constructed to resist entanglement. As with shelf-mounted plants, floating plants need a stable base for continuous operation. Major storms and heavy seas can break the vertically suspended cold-water pipe and interrupt warm water intake as well. To help prevent these problems, pipes can be made of flexible polyethylene attached to the bottom of the platform and gimballed with joints or collars. Pipes may need to be uncoupled from the plant to prevent storm damage. As an alternative to a warm-water pipe, surface water can be drawn directly into the platform; however, it is necessary to prevent the intake flow from being damaged or interrupted during violent motions caused by heavy seas.

Technical difficulties include, but are not limited to:

1. **Dissolved gases** - As cold water rises in the intake pipe, the pressure decreases to the point where gas begins to evolve. If a significant amount of gas comes out of solution, placing a gas trap before the direct contact heat exchangers may be justified.
2. **Microbial fouling** - Because raw seawater must pass through the heat exchanger, care must be taken to maintain good thermal conductivity. Biofouling layers as thin as 25 to 50 micrometres (0.00098 to 0.00197 in) can degrade heat exchanger performance by as much as 50%. (Berger, 1986)
3. **Sealing** - The evaporator, turbine, and condenser operate in partial vacuum ranging from 3% to 1% of atmospheric pressure. The system must be carefully sealed to prevent in-leakage of atmospheric air that can degrade or shut down operation. In closed-cycle OTEC, the specific volume of low-pressure steam is very large compared to that of the pressurized working fluid. Components must have large flow areas to ensure steam velocities do not attain excessively high values.
4. **Parasitic power** consumption by exhaust compressor.

## *8.8 Hydroelectric issues*

There are a variety of technical challenges/issues associated with hydroelectric generation, including but not limited to:

1. Ecological/environmental concerns - Tidal power

systems can have effects on marine life and marine ecology. Turbines can accidentally kill swimming sea life with their rotating blades, although it is possible to create safety mechanisms that turn off the turbine when marine animals approach. Some marine life may no longer utilize the area if threatened with a constant rotating or noise-making object. The Tethys database provides access to scientific literature and general information on the potential environmental effects of tidal energy. These system can interfere with the migrating fish species.

A. Tidal turbines - High speed water increases the risk of organisms being pushed near or through these devices leading to entanglement and blade strikes. There is also a concern about how the creation of EMF and acoustic outputs may affect marine organisms. It should be noted that because these devices are in the water, the acoustic output can be greater than those created with offshore wind energy. Depending on the frequency and amplitude of sound generated by the tidal energy devices, this acoustic output can have varying effects on marine mammals (particularly those who echolocate to communicate and navigate in the marine environment, such as dolphins and whales). Tidal energy removal can also cause environmental concerns such as disrupting sediment processes and degrading far-field water quality.

B. Tidal barrage - Installing a barrage may change the shoreline within the bay or estuary, affecting a large ecosystem that depends on tidal flats. Inhibiting the flow of water in and out of the bay, there may also be less flushing of the bay or estuary, causing additional turbidity (suspended solids) and less saltwater, which may result in the death of fish that act as a vital food source to birds and mammals. Migrating fish may also be unable to access breeding streams, and may attempt to pass through the turbines. There are also acoustic concerns. Shipping accessibility is also a concern.

C. Tidal lagoon - The main concerns are blade strike on fish attempting to enter the lagoon, acoustic output from turbines, and changes in sedimentation processes. However, all these effects are localized and do not affect the entire estuary or bay.

2. Variability of the sea conditions - Sea conditions are highly variable and the system must be able to cope with a wide-range of wave amplitudes and frequencies as well as changes in the directions of currents.
3. Matching the generating equipment to the wave/ current characteristics - Mechanisms are required to convert the power of the irregular oscillating mechanical forces induced by the waves into electrical power (synchronised with the grid). This could involve some power electronics. Hydraulic accumulators can be used in-situ, or on shore, to smooth out the energy delivery to the generator.
4. Housing and mooring the equipment - Substantial housings must be provided to protect the generating equipment from the harsh environment. Holding the installation in place is also particularly difficult in deep water.
5. Corrosion - Materials must either have anti-corrosive properties or be protected from corrosion by salt water and atmospheric salts.
6. Fouling - The biological events that happen when placing any structure in an area of high tidal currents and high biological productivity in the ocean will ensure that the structure becomes an ideal substrate for the growth of marine organisms.
7. Energy transmission - Low loss armoured and insulated cables or high pressure pipes must be developed for delivering the electrical or hydraulic energy back to the shore.
8. Resistance to storm damage - The frequency of occurrence of waves of any particular amplitude follows a Rayleigh distribution similar to that which applies to wind speeds. Though the frequency of serious storms may be rather small, a wave of ten times the average amplitude may be expected once every 50 years. From the power calculation below, the wave power is proportional to the square of the wave amplitude. This means that the installation must be designed to withstand forces one hundred times greater than the normal working level.
9. Ship traffic course correction - Ships must redirect their course to avoid hydropower systems.

# 9 Wind power

Wind (kinetic energy) is the movement of air across the surface of the Earth, affected by areas of higher pressure and of lower pressure. Wind power uses the wind as a primary source of energy. Wind power is the use of the wind to transfer energy and generate useful power. Therein, power generation (energy transfer) from wind ("wind energy") is based on the kinetic energy provided by air currents. It could also be considered mechanical energy, as kinetic and potential energy, because the energy is moving between two potentials (high and low pressure). Effectively, wind power is the harvesting of atmospheric air flow (air current) in order to transfer energy and produce power. In a wind turbine-electric system, for example, the [kinetic] energy of moving air (wind) is transferred into rotational mechanical energy (the wind rotates the blades of a turbine), which in turn produces electricity (the turbine turns a shaft rotating an electrical generator). In other words, the kinetic energy of the wind (air current) turns the blades of a turbine-type wind power generation system, which rotates a rotor that produces rotational mechanical power. In a turbine-electric system, the rotor connects to a shaft that leads to the electric power generator.

**NOTE:** *Wind power, like hydropower, is also a manifestation of solar power.*

There are four primary types of wind power system (a.k.a., wind harvesting systems; wind energy conversion system, WECS) -- note that some of these are also propulsion systems:

1. Wind turbines (aerofoil-powered systems), which include:
   A. Windmills (e.g., gristmills that grind grain into flour and windpumps that move water) - produce mechanical and/or fluid power.
   B. Wind turbine-electric (a.k.a., wind-electric turbines, wind turbines, aerofoil powered generator) - produce electrical power.
2. Airborne wind power, which include:
   A. Kite propulsion - mechanical propulsion power
   B. Airborne wind power (non-propulsion) - kites/ aircraft designed to produce mechanical and/or electrical power.
3. Sails (e.g., sailing boat sails) - mechanical propulsion power.
4. Magnus effect systems - mechanical propulsion power.

**CLARIFICATIONS:** *The term, 'wind turbine', appears to have been adopted from hydroelectric technology (rotary propeller). The technical description of a wind turbine is an aerofoil-powered system/generator. A wind energy conversion system (WECS), or wind energy/power harvester is a machine that, powered by the movement of the wind, generates mechanical power that can be used to directly power machinery (mill, pump, etc.) or to power an electrical generator to produce electricity.*

The capacity of a wind powered device to harvest wind and transfer the energy to another carrier is affected by several parameters, including but not limited to:

1. Variability of wind at the site.
2. Aerodynamic design
3. Weight and positioning of blades (and other structural components)
4. Size of the generator relative to the turbine's swept area.

## 9.1 Wind power formula

The [wind] power generated by wind is:

- $Pwi = pAV^3/2$
  - where, p is air density (kg/m3), A is a projected area (m3), and V is wind speed (m/s).
  - Note: Wind power is abbreviated Pwi

Total wind energy flowing through an imaginary surface with area (A) during the time (t) is expressed as:

- $E = ½mv^2 = ½(Avt\rho)v^2 = ½At\rho v^3$
  - Where, ρ is the density of air; v is the wind speed; Avt is the volume of air passing through A (which is considered perpendicular to the direction of the wind); Avtρ is therefore the mass m passing through "A". Note that ½ ρv2 is the kinetic energy of the moving air per unit volume.
  - Power is energy per unit time, so the wind power incident on A (e.g. equal to the rotor area of a wind turbine) is:
- $P = E/t = ½At\rho v^3$
  - Wind power in an open air stream is thus proportional to the third power of the wind speed; the available power increases eightfold when the wind speed doubles. Wind turbines for grid electricity therefore need to be especially efficient at greater wind speeds.
  - The power in the wind of the area A, perpendicular to the wind direction, is given by the formula:
- $P = ½A\rho v^3$
  - The theoretical power available from wind:
  - The power P available in the wind impinging on a wind driven generator is given by:
- $P = ½CA\rho v^3$
  - Where, C is an efficiency factor known as the Power Coefficient which depends on the machine design, A is the area of the wind front intercepted

by the rotor blades (the swept area), ρ is the density of the air (averaging 1.225 Kg/m3 at sea level) and v is the wind velocity.

- Note that the power is proportional to area swept by the blades, the density of the air and to the cube of the wind speed. Thus doubling the blade length will produce four times the power and doubling the wind speed will produce eight times the power.
- Note also that the effective swept area of the blades is an annular ring, not a circle, because of the dead space around the hub of the blades.

**NOTE:** *According to Betz's law, the maximal achievable extraction of wind power by a wind turbine is 16/27 (59.3%) of the total kinetic energy of the air flowing through the turbine. Hence, the maximum theoretical power output of a wind machine is 0.59 times the kinetic energy of the air passing through the effective disk area of the machine.*

- If the effective area of the disk is A, and the wind velocity v, the maximum theoretical power output P is:
  - $P = E/t = 0.59½A\rho v^3$
    - Where, ρ is air density
    - The fraction of the energy captured by a wind turbine is given by a factor $C_p$, called the power coefficient and is defined as:
- $C_p(\lambda) = 16/27\eta_{turbine}(\lambda)$
  - Where, λ is the tip speed ratio of the blade, i.e. the tip speed divided by the wind speed and ηturbine is the efficiency of the turbine. Betz' law states that less than 16/27 (or 59%) of the kinetic energy in the wind can be converted to mechanical energy using a wind turbine. The power coefficient indicates how efficiently a turbine converts the energy in wind to electricity. Very simply, the electrical power output is divided by the wind energy input to measure how technically efficient a wind turbine is. The power curve divided by the area of the rotor gives the power output per square meter of rotor area.

## *9.1 Wind power system placement*

Possible wind power locations include:

1. **Land/onshore** - refers to the construction of wind power systems on land. Conventional ground-level wind power is limited to the surface wind velocity.
2. **Offshore** - refers to the construction of wind turbines in a large body of water. In general, offshore wind is steadier and stronger than on land, and offshore wind arrays have less visual impact, but construction and maintenance requirements are higher.
3. **Infrastructural** - a wind turbine connected or somehow attached to infrastructure, such as the roof/side of a building or mast of a sailing boat.
4. **Airborne / atmospheric** - refers to the construction of wind turbines that float or are otherwise airbone like a kite or balloon. Airborne wind power can operate at a variety of heights above the earth's surface, and thus, has the potential to harvest higher-altitude winds, which become more consistent, predictable, and of a higher velocity at higher altitudes.

Surface and low-altitude wind power gives variable power which is very consistent from year to year, but which has significant variation over shorter time scales. Wind power can be highly variable at several different timescales: hourly, daily, or seasonally. Solar power tends to be complementary to wind. On a daily to weekly timescales, high pressure areas tend to bring clear skies and low surface winds, whereas low pressure conditions tend to be windier and cloudier. On seasonal timescales, solar energy peaks in summer, whereas in many areas wind energy is lower in summer and higher in winter. Thus, the intermittencies of wind and solar power tend to cancel each other somewhat. Similarly, conventional hydroelectricity complements wind power well. When the wind is blowing strongly, nearby hydroelectric stations can temporarily hold back their water. When the wind drops they can, provided they have the generation capacity, rapidly increase production to compensate.

**NOTE:** *The major drawback of surface and low altitude wind power is the variability of the wind. In some locations, some of the time, wind speed happens to be positively correlated with peak electricity use. In other locations on the planet, it is not positively correlated.*

When in an array, wind turbines must have sufficient space between them. On most horizontal wind turbine farms, a spacing of about 6-10 times the rotor diameter is often upheld. However, for large wind farms distances of about 15 rotor diameters should be more economically optimal, taking into account typical wind turbine and land costs. This conclusion has been reached by research conducted by Meneveau and Meyers (2012) based on computer simulations that take into account the detailed interactions among wind turbines (wakes) as well as with the entire turbulent atmospheric boundary layer. Moreover, recent research by John Dabiri of Caltech suggests that vertical wind turbines may be placed much more closely together so long as an alternating pattern of rotation is created allowing blades of neighbouring turbines to move in the same direction as they approach one another. (Calaf, 2010)

## *9.2 Wind supply characteristics*

The wind has characteristics that should be accounted for in the design of wind powered devices. The wind always has a velocity and a direction, and wind powered devices must account for both (or they may not operate efficiently or safely). Many of the characteristics of wind are relative to the devices intended location of placement.

> **NOTE:** *Wind loads are cyclical because of natural variability in wind speed and wind shear (higher speeds at top of rotation).*

Site-specific wind characteristics relevant to wind powered devices include:

1. Wind specific characteristics:
   A. **Wind speed (wind flow velocity)** - caused by air moving from high pressure to low pressure, usually due to changes in temperature.
      - The Beaufort scale is one measure in common use for wind force and power (from 0 = calm to 12 = hurricane force).

   B. **Mean wind speed (average wind speed)** - the average speed of the wind over a period of time (e.g., annual). A data point, but does not tell how often "high" wind speeds occur.
      - Average wind speeds usually tend to increase with height then level off which is why wind turbines are usually installed as high above ground as possible.
      - Note that published average wind speeds are only reliable for open rural environments. Wind speeds just above roof level in urban environments will be considerably less than the quoted averages because of turbulence and shielding caused by buildings and trees.

   C. **Modal wind speed** - the speed at which the wind most frequently blows. A data point, but does not tell how often "high" wind speeds occur.

   D. **Wind speed distribution:** diurnal, seasonal, annual patterns.

   E. **Turbulence (turbulent flow)** - characterized by "chaotic" changes in pressure and flow. Measured as short-term fluctuations and long-term fluctuations. The wind itself may contain turbulence, and the affect of the rotating blades (and turbine) on the wind will generate their own turbulence.

   F. **Distribution of wind direction** - the frequency at which the wind blows with any particular speed follows a Rayleigh Distribution.

   G. **Wind shear (atmospheric windshear/wind gradient)** - variation in wind speed and/or direction over a relatively short atmospheric distance.

2. Atmospheric characteristics (atmospherics):
   A. **Air density (atmospheric density)** - the mass per unit volume of atmosphere.

   B. **Air pressure (atmospheric/barometric pressure)** - the pressure exerted by the weight of air in the atmosphere of Earth.

   C. **Temperature (atmospheric temperature)** - thermal quality of atmosphere.

   D. **Humidity (atmospheric humidity)** - the amount of water vapor in the air.

   E. **Air viscosity** - a measure of a fluid's resistance to gradual deformation by shear stress or tensile stress.

Wind velocities increase at higher altitudes due to surface aerodynamic drag (by land or water surfaces) and the viscosity of the air. The variation in velocity with altitude, called wind shear, is most dramatic near the Earth's surface. Typically, the variation follows the wind profile power law, which predicts that wind speed rises proportionally to the seventh root of altitude. Hence, doubling the altitude of a turbine, is expected to increase wind speeds by 10% and the expected power by 34%. Wind velocity increases logarithmically with the height above the earth's surface (altitude), reaching maximum velocity at 7 to 12 km above the surface.

The term power density is commonly used to compare geographical and altitudinal wind velocities and air densities. Power density is an expression of the potential power per turbine area that the wind possess in a certain location. This measure is useful because it does not depend on the turbine or power generator, but rather simply on the atmospheric conditions important to power production.

Although varying globally, the mean wind power density at 1km above the earth's surface is four times greater than a conventional wind turbine height (approximately 100 meters). And, at an altitude of 10 km, the power density is more than 40 times greater.

> **NOTE:** *In concern to surface-based wind power systems, in order to avoid buckling, doubling the tower height generally requires doubling the diameter of the tower as well, increasing the amount of material by a factor of at least four.*

At night time, or when the atmosphere becomes stable, wind speed close to the ground usually subsides whereas at turbine hub altitude it does not decrease that much or may even increase. As a result, the wind speed is higher and a turbine will produce more power than expected from the 1/7 power law: doubling the altitude may increase wind speed by 20% to 60%. A stable atmosphere is caused by radiative cooling of the surface and is common in a temperate climate: it usually occurs when there is a (partly) clear sky at night. When the (high altitude) wind is strong (a 10-meter wind speed higher than approximately 6 to 7 m/s) the stable atmosphere is disrupted because of friction turbulence and the atmosphere will turn neutral. A daytime atmosphere is either neutral (no net radiation; usually with strong winds and heavy clouding) or unstable (rising air because of ground heating—by the sun). Here again the 1/7 power law applies or is at least a good approximation of the wind profile.

### 9.2.1 Wind resource assessment

A **wind resource assessment** is the process by which site-specific wind power energy production is assessed. A wind resource assessment includes:

1. Wind resource maps - a map of estimated wind resources (a.k.a., wind atlas).
2. Wind and atmospheric measurements and trends.
3. Calculations:
    A. Correlations between on-site meteorological towers.
    B. Correlations between long-term weather stations and on-site meteorological towers.
    C. Vertical shear to extrapolate measured wind speeds to turbine hub height.
    D. Wind flow modeling to extrapolate wind speeds across a site.
    E. Estimated energy production using a wind turbine manufacturer's power curve.
    F. Application of energy loss factors applied to gross energy production:
        1. Wind turbine wake loss.
        2. Wind turbine availability.
        3. Electrical losses.
        4. Blade degradation from ice/dirt/insects.
        5. High/low temperature shutdown.
        6. High wind speed shutdown.
        7. Curtailments due to grid issues.
        8. Atmospheric simulation modeling.
        9. Wind flow modeling.
        10. Wind farm modeling.
        11. Medium scale wind farm modeling.
        12. Software applications.
        13. Wind data management.
        14. Wind data analysis.

Energy "generation" will cut in (start) when wind reaches a lower limit m/s speed relative to the specific design of the wind powered device. Under that lower limit (relative to the specific design of the wind powered device), energy "generation" is not possible. This is known as a **lower operating limit**. Wind devices also have an upper limit. High wind speeds cause high rotation speeds and high stresses in the wind device, which can result in damage to the installation. To avoid these dangerous conditions, wind turbines are usually designed to cut out (stop) at upper limit wind speeds, either by braking or feathering the rotor blades allowing the wind to spill over the blades. This is known as an **upper operating limit**. Because of the limitations of the wind device and its generating system, and also upper speed limit at which the wind turbine can safely be used, it may capture less than the available wind energy.

For a given wind speed, the wind energy available also depends on the elevation of the wind powered device above sea level. As the density of air decreases with altitude, the wind energy density also decreases -- wind energy is proportional to air density. However, at the same time, the actual wind speeds tend to increase with increases in elevation above ground level. Since the wind energy is proportional to the cube of the wind speed (theoretical wind power), the net effect is that wind energy tends to increase with the height above ground level, even though wind energy density (as air density) decreases.

## *9.3 Wind power types*

Wind power types include, but may not be limited to:

1. Windmill
2. Wind turbine
3. Sail power
4. Airborne power
5. Magnus power

### 9.3.1 Wind power type: Windmill

A windmill is a type of wind turbine whose final output is mechanical power, and doesn't produce electricity. Windmills convert wind power into rotational energy by means of vanes called sails or blades. The mechanical power generated from a windmill may be used for any number of mechanical processes, including but not limited to, historically, milling grain and pumping water. Thus, windmills are often called gristmills (grinds grain into flour) and windpumps (moves water).

Windmills consist of sails (blades), a tower structure that holds the sails, and internal machinery. Gears inside a windmill convey power from the rotary motion of the sails to a mechanical device. A wind turbine (wind-electric) is a windmill-like structure specifically developed to generate electricity. Windmills came first, but are categorically a type of wind turbine.

### 9.3.2 Wind power type: Wind turbine

Wind turbines are used to capture wind power -- wind drives the turbine. Technically a wind turbine is anything that captures wind energy the application of a turbine-like system. Both windmills and wind-electric turbines (a.k.a., turbine) are wind turbines because they both use a turbine to harvest wind power. However, in general, a wind-electric turbine is just called a "wind turbine", which can be confusing. The standard wind-electric turbine of today consists of a turbine, which has three blades that face into the wind such that the tubular steel or concrete tower is behind the turbine (downwind). A wind turbine (wind-electric) installation consists of the necessary systems needed to capture the wind's energy, point the turbine into the wind, convert mechanical rotation into electrical power, and other systems to start, stop, and control the turbine.

An array of wind turbines (turbine + generator) is known as a wind farm. In other words, a wind farm is a group of wind turbines in the same location connected to an electric power transmission network.

Wind turbine power depends on both rotor speed and wind speed (as well as the turbine-electric system itself), and harvested power can be represented on a three-dimensional surface (with output power kW as the y-axis and wind speed m/s as the x-axis). The power that wind produces through a turbine is dependent on the area the turbine's blades cover as they sweep through the air, and also, the wind's velocity as it flows over the blades. To increase the power produced by a wind turbine, either the length of the turbine blades or the wind velocity must increase. Wind power generation is cubically proportional to wind velocity, while only linearly proportional to area. Therefore, doubling the size of a turbine's sweeping area would only double the power generated, but doubling the wind velocity flowing into the turbine will increase the power eight times.

#### *9.3.2.1 Wind Turbine structural classifications*

Wind turbines can rotate about a horizontal or a vertical axis, the former being both older and more common. They can also include blades (transparent or not) or be bladeless.

1. **Horizontal-axis wind turbines (HAWT):** The main rotor shaft and electrical generator at the top of a tower, and must be pointed into the wind. Small turbines are pointed by a simple wind vane, while large turbines generally use a wind sensor coupled with a servo motor. Most have a gearbox (for stepping up the speed), which turns the slow rotation of the blades into a quicker rotation that is more suitable to drive an electrical generator. Turbine towers produce turbulence (mast wake) behind them; hence, the turbine is usually positioned upwind of its supporting tower. Instead of a gearbox some turbine designs use the direct drive of an annular generator. Conventional horizontal axis turbines can be divided into three components:
    A. The rotor component: includes the blades for converting wind energy to low speed rotational energy.
    B. The generator component: includes the electrical generator, the control electronics, and most likely, a gearbox (e.g., planetary gearbox) and adjustable-speed drive or continuously variable transmission for converting the low speed incoming rotation to high speed rotation.
    C. The structural support component: includes the tower and rotor yaw mechanism.
    D. The turbine in a HAWT, also called "low-speed rotor", usually has two to six blades. The most common number of blades is three since they can be positioned symmetrically (120° apart), and maintain the system's lightness in mass, while ensuring the stability of the overall wind power system (WPS).
    E. Wind is a form of "linear" kinetic energy, and hence, horizontal axis turbines with a horizontally positioned shaft, ease the conversion of the wind's linear energy into a rotational one.
2. **Vertical-axis wind turbines (or VAWTs):** The main rotor shaft is arranged vertically. One advantage of this arrangement is that the turbine does not need to be pointed into the wind to be effective, which is an advantage on a site where the wind direction is highly variable. It is also an advantage when the turbine is integrated into a building because it is inherently less steerable. Also, the generator and gearbox can be placed near the ground, using a direct drive from the rotor assembly to the ground-based gearbox, improving accessibility for maintenance. The key disadvantages include: the relatively low rotational speed with a consequential higher torque; the inherently lower power coefficient; the 360-degree rotation of the aerofoil within the wind flow during each cycle leads to higher dynamic loading on the blade(s); the pulsating torque generated by some rotor designs on the drive train; and the difficulty of modelling the wind flow accurately and hence the challenges of analysing and designing the rotor prior to fabricating a prototype. In general, this design involves blades extending upwards that are supported by a rotating framework. Subtypes of the vertical axis design include:
    A. Darreius wind turbine
    B. Giromill
    C. Savonius wind turbine
    D. Twisted savonius
    E. Vortexis
3. Unconventional designs: These designs differ significantly from the most common types in use.
    A. Modified horizontal - for which there are many subtypes. Sub-types include, but are not limited to: twin-bladed rotor; downwind rotor; ducted rotor; co-axial, multi-rotor; counter-rotating horizontal-axis; furling tail and twisting blades; wind-mill style; ducted 2-blade HAWT.
    B. Modified vertical axis - for which there are many subtypes. Sub-types include, but are not limited

to: aerogenerator; savonius; augmented.

C. VAWTs are not self-starting machines and must be started in motoring mode, and then switched to generating mode.
D. Aerial - airborne wind turbines; high-altitude wind power; crosswind kite power.
E. Blade Tip Power System (BTPS)
F. Fuller - The "Fuller" wind turbine is a fully enclosed wind turbine that uses boundary layers instead of blades.
G. H-rotor - one blade is pushed by the wind while the other is being pushed in the opposite direction. Consequently, only one blade is working at a time.
H. INVELOX - not a turbine, rather a wind capturing and delivery system to a turbine.
I. Motion-driven - drive by the motion of objects (e.g., cars) moving past.
J. Piezoelectric - Turbines with diameters on the scale of 10 centimeters work by flexing piezoelectric crystals as they rotate.
K. Ram air turbine (RAT) - a turbine fitted to small aircraft.
L. Saphonian - uses a dish to generate wind pressure and back-and-forth motion that drives a piston.
M. Solar chimney - Wind turbines may also be used in conjunction with a solar collector to extract the energy due to air heated by the Sun and rising through a large vertical Solar updraft tower.
N. Vaneless ion wind generator - produces electrical energy directly by using the wind to pump electric charge from one electrode to another, with no moving parts.
O. Vortex bladeless - The vortex bladeless device deliberately maximizes vortex shedding, converting wind energy to fluttering of a lightweight vertical pole, then captures that energy with a generator at the bottom of the pole.
P. Windbeam - The generator consists of a lightweight beam suspended by durable long-lasting springs within an outer frame. The beam oscillates rapidly when exposed to airflow due to the effects of multiple fluid flow phenomena. A linear alternator assembly converts the oscillating beam motion into usable electrical energy. A lack of bearings and gears eliminates frictional inefficiencies and noise.
Q. Wind belt - A tensioned but flexible belt vibrates by the passing flow of air, due to aeroelastic flutter. A magnet, mounted at one end of the belt translates in and out of coiled windings producing electricity.
R. Wind tower technology - A Wind Tower uses pressure differentials produced by wind flow around a building moving through a ducted turbine to generate electricity. A windcatcher assembly directs the flow into the tower, The tower structure together with the embedded nozzles inside it will accelerate the flow.

Advantage and disadvantage comparison:

1. VAWTs' electrical machines and gearbox can be installed at the bottom of the tower, on the ground, whereas in HAWTs, these components have to be installed at the top of the tower, which requires additional stabilizing structure for the system.
2. Another advantage of the VAWTs is that they do not need the yaw mechanism since the generator does not depend on the wind direction.

#### *9.3.2.2 Wind turbine electric generators*

Turbine generators turn the shaft power of the turbine into electric power. The generator in a wind turbine produces alternating current (AC) electricity, which may be rectified to produce DC. However, wind turbines can connect to both AC and DC grids. When connected to an AC grid, some turbines have an AC>DC>AC converter—which converts the AC to DC, with a rectifier, and then back to AC with an inverter, in order to match the frequency and phase of the grid. However, the most common method in large modern turbines is to use a doubly fed induction generator directly connected to the electricity grid.

Modern turbines use variable speed generators combined with a partial- or full-scale power converter between the turbine generator and the collector system, which generally have more desirable properties for grid interconnection and have low voltage ride through-capabilities.

As an AC generator speeds up and slows down, due to changes in the source of supplied energy (e.g., changes in the wind), the electrical output characteristics of the generator (its frequency and voltage) will change. Hence, either the rotor's power output must be controlled, or the voltage and frequency output of the generator itself must be transformed/controlled.

Different types of wind turbine generators behave differently during transmission grid disturbances, so extensive modelling of the dynamic electromechanical characteristics of a new wind farm is required to ensure predictable stable behaviour during system faults.

In concern to power generation per rotation speed (i.e., speed architecture), wind turbines can operate at either fixed or variable speeds:

1. **Fixed-speed turbine/generator** (FS architecture; FSG) - turbine speed is not adjustable as a function

of wind speed; a fixed-rpm machine. These turbines have synchronous electric generators and operate on the grid's frequency. These machines are not the best solution for the wind turbines, because the wind always changes its speed. For fixed-rpm wind turbines, there is only one wind velocity on the turbine's power curve (power versus wind speed) at which the tip-speed ratio is optimum. Those turbines designed to operate at fixed speed (an FS architecture) generally have a gearbox in between the turbine's rotor and the shaft of the electric generator, and are connected directly to the grid as long as the wind speed is within operation limits. Constant speed using a synchronous generator (out-dated design). In other words, the generator expects a constant shaft speed. Fixed speed induction generators (FSIG) operate within a few percent of constant speed. When connected to an AC grid, fixed speed (FS) turbines use synchronous machines, and operate at an FS that depends on the grid's frequency. Early versions of the wind turbine were fixed speed turbines; that is, the rotor speed was a constant for all wind speeds.

2. **Variable-speed turbine/generator** (VS architecture; adjustable speed generator; ASG) - turbine speed is adjusted as a function of wind speed. These turbines can operate over a wide-range of speeds and usually have asynchronous generators. When the input power changes/ fluctuates (randomly), then the output voltage and frequency is variable. In variable-speed turbines have greater output efficiency over fixed-speed turbines. A wind turbine that can produce power over a continuous range of rotor speeds (varying wind supply) can be controlled to operate constantly at or near its optimum tip-speed ratio. All variable-speed turbines require power electronics to change varying AC power to a constant voltage and frequency. Electrical distribution grids (to which a wind turbine may be connected) must maintain steady frequency and voltage levels to avoid damaging demand-side equipment of other users on the same network. Electrical harmonics are also a critical issue for any variable-speed design. Harmonics distort the normally smooth sinusoidal variation of a grid's voltage.
3. Since the input voltage and input frequency are variable, this variable AC magnitude and frequency must be converted to constant frequency AC.
    A. A variable-speed system may base its variability on generator speed variability and/ or mechanical speed variability. Variable-speed generator methods/architectures are based on allowing the speed of the generator to vary as the supplied [wind] energy varies. Variable-speed mechanical methods are based on the use of continuously variable-speed mechanical or hydraulic drives, which allow the rotor rpm to vary while maintaining a constant generator speed. By using power electronics and controllers, AC can be converted to DC and then back to AC (AC>DC>AC) to produce a reliable and steady frequency, instead of a just outputting varying AC voltages and frequencies ("wild AC"). In other words, the "wild" AC is rectified into a steady direct current, which is then inverted to grid-grade alternating current of constant voltage and frequency. Variable-speed operation was accomplished with a current source-load commutated inverter, also known as a DC current link frequency converter. This provided AC-DC-AC conversion These power control elements can be located within the turbine itself, or located at some distance away from the turbine where its output connects to an electrical circuit/grid.
    B. Synchronous generator with in-line frequency control - the rotor and turbine can be run at a variable speed corresponding to the prevailing wind conditions. This will produce a varying frequency output from the generator synchronised with the drive shaft rotation speed. This output can then be rectified in the generator side of an AC-DC-AC converter and the converted back to AC in an inverter in grid side of the converter which is synchronised with the grid frequency.
    C. Doubly fed induction generator (DFIG) - the DFIG system consists of a 3 phase wound rotor generator with its stator windings fed from the grid and its rotor windings fed via a back to back converter system in a bidirectional feedback loop taking power either from the grid to the generator or from the generator to the grid. The doubly fed induction generator design means that the electronic control circuits and frequency converter do not have to be dimensioned to carry the full generator power.
    D. Variable speed turbines use DC machines, brushless DC (BLDC) machines, and induction machines. DC machines are not commonly used due to the maintenance problems with the brushes.
    E. AC regulation by the control system: The control system regulates the speed of the blades, and hence torque of the shaft, in an effort to match

the electrical networks required parameters. This may be done by changing the pitch of the blade tips.

F. Generator operating principle: The feedback control system monitors the stator output voltage and frequency and provides error signals if these are different from the grid standards. The frequency error is equal to the generator slip frequency and is equivalent to the difference between the synchronous speed and the actual shaft speed of the machine.
G. Grid Side Converter (GSC): Carries current at the grid frequency.
H. Machine Side Converter (MSC): Carries current at slip frequency. It is a DC to AC inverter used to provide variable AC voltage and frequency to the rotor to control torque and speed.

**NOTE:** *The output of a variable-speed turbine with no frequency/voltage output controls is known as "***wild AC***", because it varies with the variability of the "wild" primary energy source.*

A typical fixed speed system employs a rotor with three variable pitch blades (generally), which are controlled automatically to maintain a fixed rotation speed for any wind speed. The rotor drives a synchronous generator through a gear box, and the whole assembly is housed in a nacelle on top of a substantial tower with massive foundations requiring hundreds of cubic metres of reinforced concrete. Fixed speed systems may suffer excessive mechanical stresses, because they are required to maintain a fixed speed regardless of the wind speed. There is no "give" in the mechanism to absorb gusty wind forces, resulting in high torque, high stresses and excessive wear on the gear box, increasing maintenance requirements and reducing service life.

Variable speed wind turbines can capture more of the wind's energy than constant speed machines; they can speed up and slow down per wind conditions, and the electronic control systems will keep the generator's output frequency constant during fluctuating wind conditions. For variable speed wind turbines, one of two types of generators can be used: a DFIG (doubly fed induction generator) or an FRC (fully rated converter). For variable speed wind turbines, one of two types of generators can be used: a DFIG (doubly fed induction generator) or an FRC (fully rated converter).

A DFIG generator draws reactive power from the electrical network; this can increase the vulnerability of a transmission system in the event of a failure. A DFIG configuration will require the generator to be a wound rotor; squirrel cage rotors cannot be used for such a configuration.

Consider a variable speed wind turbine with a permanent magnet synchronous generator. The generator produces AC electricity. The frequency of the AC voltage generated by the wind turbine is a function of the speed of the rotor within the generator:

- N = 120f/P
- where N is the rotor speed, P is the number of poles in the generator, and f is the frequency of the output Voltage. That is, as the wind speed varies, the rotor speed varies, and so the frequency of the Voltage varies. This form of electricity cannot be directly connected to an AC balanced transmission system. Instead, its AC electrical output must be corrected such that its frequency is constant. For this, power converters are employed, which results in the de-coupling of the wind turbine from the transmission system. As more wind turbines are included in a national power system, the "inertia" of the transmission system is decreased. This means that the frequency of the transmission system is more strongly affected by the loss of a single generating unit.

The voltage generated by a variable speed wind turbine is non-grid compliant (AC grid). In order to supply the transmission network with power from these turbines, the signal must be passed through a power converter, which ensures that the frequency of the voltage of the electricity being generated by the wind turbine is the frequency of the transmission system when it is transferred onto the transmission system. Power converters first convert the signal to DC, and then convert the DC signal to an AC signal.

**NOTE:** *All wind turbines that generated electricity were variable speed before 1939. All grid-connected wind turbines, from the first one in 1939 until the development of variable-speed grid-connected wind turbines in the 1970s, were fixed-speed wind turbines. As of 2003, nearly all grid-connected wind turbines operate at exactly constant speed (synchronous generators) or within a few percent of constant speed (induction generators). (Bassyouni, 2013)*

#### *9.3.2.3 Wind turbine aerodynamics*

Wind powered devices are designed [in part] for their aerodynamic characteristics. Aerodynamics the study of the properties of moving air, and the movement of substances and system moving through air -- the interaction between the air and solid bodies moving through it. As the wind blows, an aerodynamic force produces a torque that is transmitted through the drive-train to the generator.

The aerodynamic efficiency of a wind turbine depends on the wind's characteristics and the design of the wind turbine itself:

1. Design of the airfoils (blades) - The aerodynamics of the blades/airfoils (wing-shaped) include: chord

length; blade shape; blade mount position/angle - angle of attack; blade dimensions; and revolutions per minute (rpm). Note that aerodynamic torque [from wind] is "captured" by the blades. The design of the airfoil and its angle of attack are critical to the power-producing capacity of the rotor. Each airfoil/blade has an optimum angle of attack to produce an optimum lift-to-drag ratio (the point at which the airfoil will have its optimum performance).
2. Design of the system's other structural components: rotor hub (if there is one), nacelle, tower structure, and foundation.

In addition to aerodynamic design of the blades, the design of a complete wind power system must also address the design of the hub, controls, generator, supporting structure and foundation. Further design questions arise when integrating wind turbines into electrical power grids.

> **NOTE:** *It is generally understood that noise increases with higher blade tip speeds.*

#### *9.3.2.4 Wind turbine blades/airfoils*

The number of blades in the turbine's rotor, their aerodynamic design, and the rotor's rotational speed must be optimised to extract the maximum amount of power (energy) from the available wind. While using rotors with multiple blades may capture more wind energy, there is a practical limit to the number of blades that can be used, because each blade of a spinning rotor leaves turbulence in its wake and reduces the amount of power the following [rotational] blade can extract from the wind. This same turbulence effect also limits the possible rotor speed, because a high speed rotor does not provide enough time for the air flow to settle after the passage of a blade before the next blade comes along.

There is a lower limit to both the number of blades and the rotor speed for the turbine to function. With too few rotor blades, or a slow turning rotor, most of the wind will pass undisturbed through the gap between the blades reducing the potential for capturing the wind energy. The fewer the number of blades, the faster the wind turbine rotor needs to turn to extract maximum power from the wind.

The ratio between the speed of the blade tips and the speed of the wind is called **tip-speed ratio (TSR)**. In part, tip-speed ratio is a concept used by wind turbine designers to optimise a blade set to the shaft speed required by a particular electricity generator to generate maximum energy output from the available wind. It is also one way of comparing performance between variable- and constant-speed turbine operation.

Tip-speed-ratio is generally plotted on a two dimensional graph with wind speed (m/s) as the x axis, and rotor speed (rpm) as the y axis.

Operating closer to their optimal tip speed ratio during energetic gusts of wind allows wind turbines to improve energy capture from sudden gusts (typical in urban settings).

The tip-speed-ratio for a wind turbine is given by the following formula (λ, lambda = TSR):

- $\lambda = \omega R/v$ (sometimes written as $TSR=\Omega R/V$)
  - Where, ω is the rotor speed (i.e., the angular velocity of the rotor; in radians per second), R is the length of a blade (the distance between the axis of rotation and the tip of the blade), and v is the wind speed.
- For a fixed-speed wind turbine, the value of the tip-speed ratio is only changed by wind speed variations. In reference to a $C_p$-λ graph (the power coefficient versus tip-speed ratio $C_p$ vs λ curve), illustrates the relationship between tip-speed ratio and efficiency, it is evident that only one value of λ yields the highest efficiency. $C_p$ is the power co-efficient. That is, the fixed speed wind turbine is not operating at peak efficiency across a range of wind speeds.

The tangential velocity S of any blade section at a distance r from the centre of rotation (the root of the blade) is given by:

1. $S = r\,\Omega$
2. Where, Ω is the angular velocity of rotation in radians.

Larger rotor blades are useful for maximizing air stream conversion to mechanical energy. Unfortunately, larger blades (in high wind conditions) lead to very high tip speeds. And, higher tip speeds equate to higher (possibly unacceptable) noise levels. Hence, depending upon the surrounding environment smaller blades/ turbines may be necessary to reduce noise levels to a sufficiently safe (and non-polluting/non-disturbing) level.

Additionally, system reliability is affected by blade count and weight through the dynamic loading of the rotor within the drive train and tower systems. While aligning the wind turbine to changes in wind direction (yawing), each blade experiences a cyclic load at its root end depending on blade position. This is true of one, two, three blades or more. When these loads are symmetrical, the turbine with yaw more smoothly during operation. Turbines with one or two blades can use a pivoting teetered hub to also nearly eliminate the cyclic loads into the drive shaft and system during yawing.

> **NOTE:** *High capacity wind turbines, such as those used by the electricity utilities in the electricity grid, typically have blades with a cross section similar to the aerofoils used to provide the lift in aircraft wings.*

In general, ideal materials for blades should meet the following criteria:

1. Low weight or density to reduce gravitational forces.
2. High [tensile] strength to withstand strong loading of wind and gravitational force of the blade itself.
3. High fatigue resistance to withstand cyclic loading.
4. High stiffness to ensure stability of the optimal shape and orientation of the blade and clearance with the tower.
5. High fracture toughness.
6. The ability to withstand environmental impacts such as lightning strikes, humidity, and temperature.

Today, wind turbine blades are mainly made of composite, materials including: polyester resin, vinyl resin, epoxy thermosetting matrix resin, E-glass fibers, S-glass fibers, and carbon fiber reinforced materials. Construction may use manual layup techniques or composite resin injection molding. The majority of current commercialized wind turbine blades are made from fiber-reinforced polymers (FRP's), which are composites consisting of a polymer matrix and fibers. The long fibers provide longitudinal stiffness and strength, and the matrix provides fracture toughness, delamination strength, out-of-plane strength, and stiffness. Material indices based on maximizing power efficiency, and having high fracture toughness, fatigue resistance, and thermal stability, have been shown to be highest for glass and carbon fiber reinforced plastics (GFRP's and CFRPs). (Griffin, 2003)

Use of aluminum and composite materials in their blades has contributed to low rotational inertia, which means that newer wind turbines can accelerate quickly if the winds pick up, keeping the tip speed ratio more nearly constant.

Manufacturing blades in the 40 to 50 metre range involves fibreglass composite fabrication techniques. There are a variety of applied variations on this technique, some including carbon and wood with fibreglass in an epoxy matrix. Other options include pre-impregnated ("prepreg") fibreglass and vacuum-assisted resin transfer molding. Each of these options use a glass-fibre reinforced polymer composite constructed with differing complexity. Perhaps the largest issue with more simplistic, open-mould, wet systems are the emissions associated with the volatile organics released. Pre-impregnated materials and resin infusion techniques avoid the release of volatiles by containing all VOC's. However, these contained processes have their own challenges, namely the production of thick laminates necessary for structural components becomes more difficult. As the preform resin permeability dictates the maximum laminate thickness, bleeding is required to eliminate voids and ensure proper resin distribution.

> **NOTE:** *The transportation of long blades and towers to their final placement may require unconventional transportation methods due to their significant length.*

#### *9.3.2.5 Wind turbine control systems*

The control system of a wind turbine allows for programmed adjustment of the system (mechanically and/or electrically) for maximum, or less than maximum, power output. Wind turbines designed for maximum power output (i.e., maximum power point tracking) attempt to pull the maximum possible electrical power from a given turbine under the current wind conditions. However, wind turbines control systems can also be designed to deliberately pull less electrical power than they possibly could in most circumstances, in order to provide other benefits, which include:

1. Spinning reserves to quickly produce more power when needed—such as when some other generator suddenly drops from the grid—up to the max power supported by the current wind conditions.
2. Variable-speed wind turbines can (very briefly) produce more power than the current wind conditions can support, by storing some wind energy as kinetic energy (accelerating during brief gusts of faster wind) and later converting that kinetic energy to electric energy (decelerating, either when more power is needed elsewhere, or during short lulls in the wind, or both).
3. Damping (electrical) subsynchronous resonances in the grid.
4. Damping (mechanical) resonances in the tower.

In wind turbines with a nacelle, the nacelle houses the gearbox and generator connecting the tower and rotor. Sensors detect the wind speed and direction, and motors turn the nacelle into the wind to maximize output. In conventional wind turbines, the blades spin a shaft that is connected through a gearbox to the generator. When present, a gearbox is inserted between the rotor hub and the generator. The gearbox increases the generator's incoming shaft rotations per minute. The presence of a gearbox may allow a reduction in the generators weight. In gearless wind turbines (also called 'direct drive turbines') the rotor shaft is attached directly to the generator, which spins at the same speed as the blades.

Wind turbines without gearboxes are called direct-drive wind turbines. An advantage of a gearbox is that generators are typically designed to have the rotor rotating at a high speed within the stator. Direct drive wind turbines do not exhibit this feature.

> **NOTE:** *Older style wind turbines rotated at a constant speed, to match power line frequency, which allowed the use of less costly induction*

*generators[citation needed]. Newer wind turbines often turn at whatever speed generates electricity most efficiently. The varying output frequency and voltage can be matched to the fixed values of a power network (the "grid") using multiple technologies (e.g., doubly fed induction generators or full-effect converters) where the variable frequency current produced is converted to DC and then back to AC.*

The speed at which a wind turbine rotates must be controlled for efficient power generation and to keep the turbine components within designed speed and torque limits. The centrifugal force on the spinning blades increases as the square of the rotation speed, which makes this structure sensitive to overspeed. If the rated wind speed is exceeded the power has to be limited via a control system. A control system involves three basic elements: sensors to measure process variables, actuators to manipulate energy capture and component loading, and control algorithms to coordinate the actuators based on information gathered by the sensors.

**NOTE:** *Wind powered devices often include an anemometer for measuring wind speed and direction (a common weather station instrument).*

Methods of control for dumping power include (because of a rapid increase in the velocity of the wind):

1. Change aerodynamic efficiency
   A. Variable pitch, feather or stall
   B. Operate at constant rpm
   C. Spoilers
2. Change intercept area
   A. Yaw rotor out of wind
   B. Change rotor geometry
3. Brake
   A. Mechanical, hydraulic
   B. Air brake
   C. Electrical (resistance, magnetic)

#### *9.3.2.6 Wind turbine pitch control*

Active pitch control, where the blades are twisted from the hub. The pitch angle of turbine blades can be changed to control for speed (blade control):

1. Stalling works by increasing the angle at which the relative wind strikes the blades (angle of attack), and it reduces the induced drag (drag associated with lift). Stalling is simple because it can be made to happen passively (it increases automatically when the winds speed up), but it increases the cross-section of the blade face-on to the wind, and thus the ordinary drag. A fully stalled turbine blade, when stopped, has the flat side of the blade facing directly into the wind.
2. Furling works by decreasing the angle of attack, which reduces the induced drag from the lift of the rotor, as well as the cross-section. One major problem in designing wind turbines is getting the blades to stall or furl quickly enough should a gust of wind cause sudden acceleration. A fully furled turbine blade, when stopped, has the edge of the blade facing into the wind. Since furling requires acting against the torque on the blade, it requires some form of pitch angle control, which is achieved with a slewing drive.
3. Some blades are designed to automatically increase their angle of attack at higher wind speed, as the blades speed up.

Modern large wind turbines are variable-speed machines. When the wind speed is below rated, generator torque is used to control the rotor speed in order to capture as much power as possible. Applied generator torque controls the rotor speed.

**NOTE:** *All turbines are equipped with protective features to avoid damage at high wind speeds, by feathering the blades into the wind which ceases their rotation, supplemented by brakes.*

There are three ways of braking (slowing) the rotation of a turbine: aerodynamic stalling or furling, electrical breaking (electromagnetic breaking), and/or mechanical breaking. In concern to electrical breaking, the braking of a small wind turbine can be done by dumping energy from the generator into a resistor bank, converting the kinetic energy of the turbine rotation into heat. This method is useful if the kinetic load on the generator is suddenly reduced or is too small to keep the turbine speed within its allowed limit. Doing this process cyclically (i.e., cyclically braking) causes the blades to slow down, which increases the stalling effect, reducing the efficiency of the blades. This way, the turbine's rotation can be kept at a safe speed in faster winds while maintaining (nominal) power output. In concern to mechanical breaking, a mechanical drum brake or disk brake is used to stop turbine in emergency situation such as extreme gust events or over speed. This brake is a secondary means to hold the turbine at rest for maintenance, with a rotor lock system as primary means. Such brakes are usually applied only after blade furling and electromagnetic braking have reduced the turbine speed generally 1 or 2 rotor RPM, as the mechanical brakes can create a fire inside the nacelle if used to stop the turbine from full speed. The load on the turbine increases if the brake is applied at rated RPM. Mechanical brakes are driven by hydraulic systems and are connected to main control box.

#### *9.3.2.7 Wind turbine yaw control*

Wind devices that operate with their blades or sales pointing into the wind require a control systems for reorienting their blades/sales into the wind as the wind direction changes (typically, horizontal axis wind turbines). In general, only the yaw axis is used for this type of reorientation (although, the blades themselves may also have secondary re-orientational capabilities). Hence, the 'yaw system' of wind turbines is the component responsible for the orientation of the wind turbine rotor into the wind.

By minimizing the yaw angle (the misalignment between wind and turbine pointing direction), the power output is maximized and non-symmetrical loads minimized. However, since the wind direction varies quickly the turbine will not strictly follow the direction and will have a small yaw angle on average. The power output losses can simply be approximated to fall with $(\cos(\text{yaw angle}))^3$. Particularly at low-to-medium wind speeds, yawing can make a significant reduction in turbine output, with wind direction variations of ±30° being quite common and long response times of the turbines to changes in wind direction. At high wind speeds, the wind direction is less variable.

There are two types of yaw system:

1. Passive yaw (self-orientation)
2. Active yaw (automatic mechanical orientation)

Both passive and active systems require a yaw bearing, which allows for a horizontal rotation of the turbine element itself. In active systems, in order to stabilize the yaw bearing against rotation a means of braking is necessary. Active systems involve yaw drives (consisting of an electric motor and gearbox), and passive systems involve a yaw vane.

Passive yaw systems utilize the wind's force itself in order to adjust the orientation of the wind turbine rotor into the wind. In their simplest form these system comprise a roller bearing connection between the tower and the nacelle and a tail fin (yaw vane) mounted on the nacelle, designed in such a way that it turns the wind turbine rotor into the wind by exerting a "corrective" torque to the nacelle. Therefore, the power of the wind is responsible for the rotor rotation and the nacelle orientation. The tail fin (or yaw vane) is commonly used for small wind turbines since it offers a low cost and reliable solution. It is however unable to cope with the high moments required to yaw the nacelle of a large wind turbine.

Alternatively in case of downwind turbines, the tail fin is not necessary since the rotor itself is able to yaw the nacelle into the wind.

Passive yaw systems have to be designed in a way that the nacelle does not follow the sudden changes in wind direction with too fast a yaw movement, in order to avoid high gyroscopic loads. Additionally the passive yaw systems with low yaw-friction are subjected to strong dynamic loads due to the periodic low amplitude yawing caused by the variation of the inertia moment during the rotor rotation. This effect becomes more severe with the reduction of the number of blades.

Active yaw systems use a torque producing device for rotating the nacelle of the wind turbine against the stationary tower, based on automatic signals from wind direction sensors or manual actuation (control system override). The design of an active yaw system varies depending on the design characteristics of the wind device; however, all active yaw systems include: a rotatable connection between nacelle and tower (yaw bearing); an active variation of the rotor orientation (i.e. yaw drive); a means of restricting the rotation of the nacelle (yaw brake) and a control system which processes the signals from wind direction sensors (e.g. wind vanes) and gives the proper commands to the actuating mechanisms.

Modern large wind turbines are typically actively controlled to face the wind direction measured by a wind vane situated on the back of the nacelle. This process is known as yawing.

#### *9.3.2.8 Wind turbine design limits*

For safety and efficiency reasons wind turbines are subject to operating limits depending on the wind conditions and the system design.

1. **Cut-in Wind Speed:** This is the minimum wind velocity below which no useful power output can be produced from wind turbine, typically between 3 and 4 m/s (10 and 14 km/h, 7 and 9 mph).
2. **Rated Wind Speed** (also associated with the Nameplate Capacity): This is the lowest wind velocity at which the turbine develops its full power. This corresponds to the maximum, safe electrical generating capacity which the associated electrical generator can handle, in other words the generator's rated electrical power output. The rated wind speed is typically about 15 m/s (54 km/h, 34 mph) which is about double the expected average speed of the wind. To keep the turbine operating with wind speeds above the rated wind speed, control systems may be used to vary the pitch of the turbine blades, reducing the rotation speed of the rotor and thus limiting the mechanical power applied to the generator so that the electrical output remains constant. Though the turbine works with winds speeds right up to the cut-out wind speed, its efficiency is automatically reduced at speeds above the rated speed so that it captures less of the available wind energy in order to protect the generator. While it would be possible to use larger generators to extract full power from the wind at speeds over the rated wind speed, this would not normally be economical because of the lower frequency of occurrence of wind speeds above the rated wind speed.
3. **Cut-out Wind Speed:** This is the maximum safe working wind speed and the speed at which the wind turbine is designed to be shut down by

applying brakes to prevent damage to the system. In addition to electrical or mechanical brakes, the turbine may be slowed down by stalling or furling.

A. Stalling: This is a self correcting or passive strategy which can be used with fixed speed wind turbines. As the wind speed increases so does the wind angle of attack until it reaches its stalling angle at which point the "lift" force turning the blade is destroyed. However increasing the angle of attack also increases the effective cross section of the blade face-on to the wind, and thus the direct wind force and the associated stress on the blades. A fully stalled turbine blade, when stopped, has the flat side of the blade facing directly into the wind.

B. **Furling or Feathering:** This is a technique derived from sailing in which the pitch control of the blades is used to decrease the angle of attack which in turn reduces the "lift" on the blades as well as the effective cross section of the aerofoil facing into the wind. A fully furled turbine blade, when stopped, has the edge of the blade facing into the wind reducing the wind force and stresses on the blade.

The cut-out speed is specified to be as high possible consistent with safety requirements and practicality in order to capture as much as possible of the available wind energy over the full spectrum of expected wind speeds (See diagram of Wind Speed Distribution below). A cut-out speed of 25 m/s (90 km/h, 56 mph) is typical for very large turbines.

4. **Survival Wind Speed:** This is the maximum wind speed that a given wind turbine is designed to withstand above which it can not survive. The survival speed of commercial wind turbines is in the range of 50 m/s (180 km/h, 112 mph) to 72 m/s (259 km/h, 161 mph). The most common survival speed is 60 m/s (216 km/h, 134 mph). The safe survival speed depends on local wind conditions is usually regulated by national safety standards.

#### *9.3.2.9 Wind turbine monitoring*

Wind turbines must be monitored for their structural health/safety and performance, which requires data transmission. Structural monitoring is usually done through accelerometers and strain gages attached to the nacelle to monitor the gearbox and other equipment. Digital image correlation and stereophotogrammetry are used to measure dynamics of wind turbine blades. These methods usually measure displacement and strain to identify locations of defects. Dynamic characteristics of non-rotating wind turbines have been measured using digital image correlation and photogrammetry. Three dimensional point tracking has also been used to measure rotating dynamics of wind turbines

Wind turbines require regular maintenance to stay operable (operability - reliable and available). Modern turbines usually have a small onboard crane for hoisting maintenance tools and minor components. However, large heavy components like generator, gearbox, blades and so on are rarely replaced and a heavy lift external crane is needed in those cases. If the turbine has a difficult access road, a containerized crane can be lifted up by the internal crane to provide heavier lifting. Wind turbines can be "repowered", meaning that instead of installing new turbines, an existing turbine is replaced with a larger and more powerful one.

A major cause of wind turbine failure is the accumulation of fatigue damage from turbine rotor fatigue loads (i.e., rapid changes in rotor torque due to wind gusts producing load spikes).

### 9.3.3 Wind power type: Sail power

A sail is means for redirecting the power of the wind to propel a craft on water, ice, or land. Hence, sails provide mechanical propulsion power to a traveling craft/ platform. In doing so, sails behave aerodynamically like wings, generating high and low pressure on either side of the sail, and hence, craft. Therein, the sails mobilize lift aerodynamics (as air passes along the surfaces), and they mobilize drag aerodynamics to the degree that air is directed at the surface. When both lift and drag are present, a sail will function similarly to a wing in a vertical orientation. Lift aerodynamics refers to the air moving faster and having a longer way to travel along the outside curve of the sail, and a slower, shorter travel along the inner curve.

In most cases sails are supported by a mast rigidly attached to the sailing craft, however some craft employ a flexible mount for a mast. Sails also employ spars and battens to determine shape in the axis perpendicular to the mast. As a result, sails come in a variety of shapes that include both triangular and quadrilateral configurations, usually with curved edges that promote curvature of the sail.

Sails propel the craft in one of two ways. When the craft is going in the direction of the wind (i.e., downwind), the sails may be set merely to trap the air as it flows by. Sails acting in this way are aerodynamically stalled. Drag, which is always parallel to the wind, contributes the predominant driving force. The other way sails propel the craft occurs when the craft is traveling across or into the wind. The sails acting as airfoils propel the craft by redirecting the wind coming in from the side towards the rear. By the law of conservation of momentum, the wind moves the sail as the sail redirects downwash air backwards. Air pressure differences across the sail area result in forces on sails including drag and lift. A component of the lift is the main driving force.

### 9.3.4 Wind power type: Airborne wind power

Airborne wind power (i.e., kite power; also known as airborne wind energy, AWE; tethered aircraft wind power) involves the use of kites and wind to generate mechanical and/or electrical power. The kites themselves may or may not be inflatable, and if inflated, they may be inflated with air, or a gas lighter than air. Often the kites are similar to those used in recreational kite surfing and parasailing. They are lightweight structures that can dynamically change with wind direction and altitude.

Airborne wind power systems have several advantages over conventional ground-based wind systems. The first advantage is that airborne wind power density steadily increases with altitude. This is important because not only does it mean that more power can be generated, than would be generated with a conventional ground-level turbine, but that increase in power will not require an increase in size of the airborne structure. Often, geographic locations that are not suitable for conventional wind farms at surface level have ample wind speeds at higher altitudes. Secondly, airborne wind power systems are often less complex and require fewer materials. Most ground-based wind turbines require massive structural foundations in order to support the large blades, while also requiring significant transportation tasks to move the systems into place (i.e.,, each blade must be transported separately, and typically requires unconventional transportation methods due to its size). Further, ground-based wind turbines take-up land area and output polluting acoustics. When airborne, these systems take-up minimal land area, and their acoustic pollution has little affect on the ground. Some airborne are highly portable.

> **NOTE:** *Airborne power generation platforms can double as platforms for instrumentation and/or communication.*

There are two primary types of airborne wind power system:

1. **Kite propulsion systems** - Kites propulsion systems are similar to sails in that they capture the wind with a concave surface, except they are airborne.
2. **Airborne wind power (non-propulsion) systems** (airborne aerofoil-powered system) - kites/aircraft that produce mechanical and/or electrical power.
   A. **Ground-gen** - Systems that generate the electric power on the ground.
   B. **Fly-gen** - Systems that generate the electric power in the airborne/flying part.

Due to their significant elevation above ground level (and ground-based wind power systems) airborne machines come into contact with the more consistent and stronger wind resource at altitude. At 2,000 feet wind speeds above 8 m/s are blowing more than 40 percent of the time at most locations in the northern hemisphere. Furthermore, power densities (kW/m2) are on par with the world's most favorable sites for ground-based wind. Although boundary layer winds provide reasonable power densities, the jet stream winds of the troposphere at ~10km, where average power densities soar beyond 20 kW/m2 and the total available resource is measured in thousands of terawatts (TW), hundreds of times higher than world energy demand.

Every airborne wind power system has three parts:

1. A grounded part
2. An airborne/flying part
3. A connection between the two primary parts - a tethering cable. The tether allows the airborne structure's altitude to be adjusted and periodically brought back to the ground. In addition, depending on the design of the system, the tethering cable can also serve a conduit or conductive wire that connects the system's electrical components to surface electrical components and/or the electrical power grid. In order to counteract the kite moving sporadically, sometimes two tethers are placed on opposite ends of the kite/aircraft, which work to control the kite's position and keep it positioned correctly.

There are three surfaces that the airborne wind power system may be tethered (i.e., connected) to:

1. Land
2. Stationary structure (e.g., building)
3. Moving structure (e.g., boat)

#### *9.3.4.1 Kite propulsion systems*

Kite propulsion systems use wind power (energy) to propel (or aid in propelling) a transportation platform (e.g., ship). These wind power systems use large foil kites, similar to those used in kitesurfing. Kite propulsion systems are similar to sails, except the sail is airborne. These kites are supported and controlled by lines that lead from the kite to the transportation platform.

#### *9.3.4.2 Airborne wind power (non-propulsion) systems*

In ground-gen systems, the electrical power of the system is produced by a generator on the ground. The generator on the ground is powered by the mechanical power generated by the wind moving the airborne aircraft/kite. The aircraft's mechanical motion is transferred by the tether to the ground. Generally, this system consists of a turbine positioned within a kite/aircraft, placed in the atmosphere, with the turbine therein is spinning horizontally (instead of vertically). Although the ground-gen systems can stand alone, it is possible to connect multiple aircraft and tethers to a single ground-based generator to maximize output.

*Company: KiteGen [kitegen.com]*

In fly-gen systems, the electrical generator is located in the airborne/flying part of the system. In fly-gen systems, the tether contains the conductive, insulated cables that run from the generator in the atmosphere to the ground. Unlike ground-gen systems, fly-gen systems do not use the wind to move the aircraft and generate mechanical power that is transferred to the ground. Instead, airfoils (e.g., propellers) are mounted onto the aircraft/kite and generate electrical power by the wind moving past their position. Fly-gen systems can be designed to use their rotors as propellers to thrust the aircraft into the sky, using the generators onboard in "reverse", as engines. Once at the proper altitude, the rotors stop propelling, and allow the aircraft to flow with the wind like a kite, relying on the aircrafts aerodynamics and the wind (i.e., air lift) to keep it afloat. Once at a sufficient altitude, air flow forces the rotors, causing them to spin in the opposite direction, and generate electricity. The electricity is conducted down the tether and into an electrical network. The rotor's controls can be operated from the ground either manually or with an automated system that can adjust the aircraft's flight path according to wind conditions. When it is time to land the aircraft, the rotors can take over as propellers once again and guide the gliding aircraft to the ground with power (i.e., "under control with engine power").

*Companies: Makani [makanipower.com]; Altaeros Energy [altaeros.com]*

#### 9.3.4.3 Issues with airborne wind power

There are limitations and/or other issues and concerns with airbone wind power systems. Firstly, areas where these airborne wind power platforms are flying are considered no-fly zones, in order to avoid accidents (i.e., air traffic must be re-routed around them). Secondly, weather conditions can be an issue. Depending the operational weather parameters for the system, inclement weather may preclude its airborne functioning, and require its retraction from the atmosphere. During lightning, hail storms, or tornado-strength winds, airborne wind systems must be landed. Icing on the wings will also affect the aircraft performance. Further, without proper monitoring and adhering to safe operation parameters, these systems could break free from their tethering cable, causing them to crash land or cause air accidents, and/or additional air traffic re-routing.

### 9.3.5 Wind power type: Magnus power effect

The Magnus effect is the commonly observed effect in which a spinning ball (or cylinder) curves away from its principal flight path. The effect involves a force acting on a spinning body in a moving airstream, which acts perpendicularly to the direction of the airstream. The effect can be used to generate propulsion. A "rotor ship", or Flettner ship, is a type of ship designed to use the Magnus effect for propulsion. Rotor ships typically use rotor sails powered by a motor to take advantage of the effect.

## *9.4 Environmental impact of wind power*

The environmental impact of wind power, when compared to the environmental impact of fossil fuels (and other energy sources), is relatively minor. Environmental issues include, but are not limited to:

1. Ecological disturbances - primarily, bird strikes.
2. Noise emission - Some turbines emit low frequency acoustics, which distress complex organisms. Noise emissions are affected by the systems aerodynamics, the location of the blades upwind or downwind of the tower, and the speed of the rotor. Given that the noise emissions from the blades' trailing edges and tips vary by the 5th power of blade speed, a small increase in tip speed can make a large difference in the noise produced.
3. Fires - are particularly dangerous due to the material composition of the blades, and their rotation.
4. Electromagnetic interference - the design of the rotating element can interfere with radar and other electromagnetic transmitting and receiving systems.

# 10 Solar power

*A.k.a., Sun power, solar electromagnetic power.*

The sun's energy is the primary source of energy for all surface phenomena and life on Earth. Electromagnetic power (energy) from the sun comes to Earth in the form of radiation. The term 'radiation' denotes the fact that the energy travels as rays, that is, in relatively straight lines. In general, the terms 'solar power/energy' and 'solar radiation' refer to energy from a star (i.e., a sun). The Sun radiates electromagnetic power (energy) "equally" in all directions, and the Earth receives part of this energy. However, because the earth revolves around itself (and the sun), any point on the earth will only receive sunlight periodically (cyclically as a day/night cycle); thus, solar power is directly effective during sunlight (daylight) hours only (although residual heating effects exist). Atmospheric conditions also affect the amount and quality of light reaching the Earth's surface at any given sunlight time.

**NOTE:** *Solar power is only available during sufficient sunlight conditions.*

The range of electromagnetic power (energy) emitted by the sun is known as the 'solar spectrum', and lies mainly in three regions: ultraviolet, visible, and infrared (of which there are multiple bands of infrared). Therein, the solar spectrum extends from about 0.29 μm (or 290 nm) in the shorter wavelengths of the ultraviolet region, to over 3.2 μm (3,200 nm) in the far infrared. Small amounts of radio waves are also given off by the sun and other stars.

Electromagnetic energy can be discussed in terms of its 'energy distribution' - the spread of energy over a range of wavelengths. This distribution of energy is also known as the 'spectral distribution'. Therein, the measure of radiation may be quantified in terms of the amount of energy falling per second (measured in Watts) per unit area (in square meters, $m^2$) in each band of 1 μm (1000nm) wavelength.

It is often said that the sun radiates electromagnetic and thermal energy. However, this is not technically correct, because that which is called "thermal radiation" is in fact 'electromagnetic radiation'. Take note here that 'thermal radiation' is 'electromagnetic radiation' generated by the thermal motion of charged particles in matter (i.e., due to the temperature of matter), and when that electromagnetic radiation from those charged particles comes into contact with matter, it will transfer energy (through heating), and raise its internal temperature. Hence, the term 'thermal radiation' describes the source of the radiation and implies that when that radiation contacts matter after its release/generation, that it will likely heat the matter. All matter with a temperature greater than absolute zero emits thermal [electromagnetic] radiation. When the temperature of a body is greater than absolute zero, inter-atomic collisions cause the kinetic energy of the atoms or molecules to change. This results in charge-acceleration and/or dipole oscillation, which produces electromagnetic radiation (i.e., thermal radiation"). The spectrum distribution of EM radiation will reflect the spectrum of accelerations and oscillations that occurred to release that radiation. Herein, the "emissivity" of the surface of a material is its effectiveness in emitting energy as thermal radiation.

Solar [electromagnetic/thermal] radiation heats the earth during the day, while at night the earth re-radiates some energy via heat back into space. In other words, the sun generates solar power (energy), which transfers energy to the earth, heating it and raising its atmospheric and surface temperatures. Whereupon the earth emits electromagnetic/thermal radiation back into space due to its earlier temperature rise and the internal accelerations and oscillations that occurred therefrom.

**NOTE:** *When light falls on a surface, it can either be reflected, transmitted, absorbed, or varying degrees of all three.*

There are four ways in which solar power (as electromagnetic effects and thermal effects) can be utilized as an energy source. Three of the ways produce electric power, and the fourth produces heating ("thermal power"):

1. Photoelectric effect/power - Solar electromagnetic power can be converted into electrical power through the photoelectric effect, of which there are a variety of sub-types of this effect. This is an active form of solar power.
2. Non-photoelectric effect - Solar electromagnetic power can be directly converted into electrical power through processes other than the photoelectric effect. This is an active form of solar power.
3. Solar heating can be indirectly converted into electrical power (indirect solar-thermal electric). This is an active form of solar power.
4. Solar heating can be used for its direct heating effect (e.g., direct heating, drying, distillation). Whereas this is a form of passive solar power, the other three are active forms of solar power.

These effects/technologies can be combined to increase the overall effectiveness and/or efficiency of useful power generation.

These uses of solar power (energy) can be divided into two categories representing two different types of solar power conversion (energy transfer):

- Active - conversion of the sun's radiated power (energy) to other useful carriers (e.g., electric power and hotter water).
- Passive (passive solar) - the direct use of the sun's

thermal [electromagnetic] power for [passive] heating (of architecture and liquids).

## 10.1 The solar radiation supply

**NOTE:** *The available solar energy increases with altitude due to lower atmospheric absorption.*

**Irradiance** is a measurement of solar power and is defined as the rate at which solar power is falling onto a given surface. In other words, solar irradiance is a measure of how much solar power is contacting a specific location. The unit of power is the Watt (W). Solar irradiance is usually measured as power per unit area, so irradiance is typically expressed as $W/m^2$, or for larger amounts, $kW/m^2$. The irradiance falling on a surface can and does vary from moment to moment, which is why it is important to remember that irradiance is a measure of power - the rate that energy is transferring, not the total amount of energy.

"Total solar irradiance" is defined as the amount of radiant energy emitted by the Sun over all wavelengths, not just visible light, "falling" each second on a 1 square metre perpendicular plane outside Earth's atmosphere at a given distance from the Sun. It is roughly constant, fluctuating by only a few parts per thousand from day to day. On the outer surface of the Earth's atmosphere the irradiance is known as the 'solar constant', and it is equal to ~1367 Watts per square meter. Solar irradiance at sea level on the equator at noon on a sunny day is ~1000 $W/m^2$.

The solar irradiance integrated over time is called solar irradiation, solar exposure, or insolation. However, insolation is often used interchangeably with irradiance in practice. **Solar irradiation** is a measure of the total amount of solar energy accumulated on an area over a period of time. Solar irradiation is expressed as a number of watt-hours per square metre ($Wh/m^2$), and for larger amounts, $kWh/m^2$.

**CLARIFICATION:** *The terms 'irradiance', 'irradiation', and 'insolation' are often used interchangeably to mean the same thing.*

**Insolation** is another term used to refer to the amount of solar irradiance received over time. The amount of solar energy that strikes a given area over a specific period of time varies with latitude and with the seasons, as well as the weather, and is known as the insolation (incident solar radiation). In other words, the total amount of solar energy that falls over a given time in a given location is called insolation. Whereas, insolation is a measure of solar energy, irradiance is a measure of solar power. Insolation is the power of the sun added up over some time period. For example, if the sun shines at a constant power of 1000 $W/m^2$ for one hour, then it has delivered 1 $kWh/m^2$ of energy. The amount of power is the product of the power (1000 $W/m^2$) times the length of time (1 hour) and the unit of energy is the kWh. Insolation (measured in kWh) is not the same as power (measured in kW) in the same way that kilometers per hour is not the same as kilometers.

Hence, the power and energy measurements for solar electromagnetic radiation are:

- Solar irradiance (power) - solar radiation every second is expressed as $W/m^2$ or $kW/m^2$.
- Solar irradiation - solar irradiance over time greater than a second is expressed as $Wh/m^2$ or $kWh/m^2$.
- Solar insolation - same meaning as solar irradiation.

When the Sun is directly overhead the irradiance (insolation), that is the incident energy arriving on a surface on the ground perpendicular to the Sun's rays, is typically 1000 Watts per square metre. This is due to the absorption of the Sun's energy by the Earth's atmosphere, which dissipates about 25% to 30% of the radiant energy. Irradiance increases with altitude since the radiation passes through less air mass, hence the energy absorption by the atmosphere is less. The amount of solar irradiation received at any particular location on or above the earth's surface varies due in part to atmospheric attenuation ("loss"). This loss of light is caused by contact with air molecules, water vapor, and dust absorbing and otherwise scattering the light. Some of the light is absorbed by atmospheric composition, including but not limited to ozone, water vapor, and carbon dioxide. The amount of light absorbed and scattered depends on atmospheric composition and thickness. The minimum amount of atmosphere the sun's rays have to go through is the condition in which the sun is directly above a given point on or above the earth. This is referred to as the sun's zenith.

Astronomical data is required to calculate how solar insolation varies with time and with the position of the solar device on the Earth's surface. Atmospheric an meteorological conditions impact how much solar radiation will contact a solar powered device. And, the configuration and operation of the solar system itself affect will also impact the ability to interface with the available solar irradiance.

**NOTE:** *The term* **peak sun hours***, refers to the energy received during total sunlight hours as defined by the equivalent number of hours it would take to reach that total energy value had solar irradiance averaged 1000 W/m2. In other words, peak sun hours are the number of hours per day that solar insolation equals 1000 $W/m^2$. This term is interchangeable with $kWh/m^2$ /day.*

Solar power systems operate within a set of three types of parameters: astronomical parameters; atmospheric and meteorological parameters; and [solar power] device parameters. The maximum transfer of energy between the sun and a solar power system occurs when parameters within these three sets are optimized. The set parameters under which a solar power system can produce the maximum power is called 'maximum power' and/or 'optimum power transfer'. For instance, the voltage at which photovoltaic module can produce maximum power is called 'maximum power point' (or peak power voltage). Maximum power varies with solar radiation, ambient temperature, and solar cell temperature.

## *10.2 Astronomical parameters*

The sun changes its position relative to any point on the earth from morning to night, and from one season to another. The following are astronomical parameters relevant to the positioning and orientation of the contact interface of a solar powered device.

1. **Relative solar positioning** - The position of the Sun in the "sky" relative to a point on earth is defined by its:
    - Altitude angle 'α' (solar elevation angle)
    - Azimuth angle 'Ψ'
2. **The Earth's orbit** - The Earth orbits the Sun with one revolution per year in an elliptical orbit with the Sun at one of the foci of the ellipse. The orbit's two foci are sufficiently close together such that the orbit is approximately circular (slightly elliptical) -- the distance to the sun from the perihelion (the point in its orbit closest to the sun, ~ January 2) is approximately 3% less than its distance from the aphelion (its furthest distance, ~July 3). The sun moves faster across the horizon at perihelion, than at aphelion. Because the orbit is approximately circular, the effect of the orbit on solar irradiance remains essentially constant throughout the year as the earth orbits the Sun. The actual energy received at any distance from the Sun is determined by the inverse square law. Thus a 3% change in distance gives rise to a 6% change in the irradiance.
3. **The Earth's rotation** - The earth rotates about its inertial plane, which passes through the north and south "poles" of the planet. The earth rotates about this axis once each "day" (approximately 24 hours). The earth's rotation of once per day defines this planet's day and night cycle. As the Earth rotates the insolation at any point on its surface rises to a maximum at mid day and falls to zero during the night as the earth presents a different region ("face") toward the sun. For maximum efficiency the orientation of a solar should follow the Sun as it passes through the "sky".
4. **Latitude** - A solar device placed on the ground will only receive the maximum insolation when the sun is directly overhead. Because the Earth is roughly spherical, the angle between the plane of the earth's surface and the incident solar radiation will gradually increase from 90° as the device is repositioned away from the equator toward the upper and lower latitudes by an angle 'Θ', equal to the latitude of the device's location on earth. At this point the altitude angle 'α' of the Sun will be (90 - Θ) degrees. Because of the increased inclination of the earth's surface the insolation received by a device placed on the surface will gradually decrease. This shift in the position of the sun relative to a point on earth can be overcome by inclining the interface plane of the device so that it is perpendicular to the incoming solar rays'. The amount of elevation from the horizontal, the tilt angle, should be equal to the latitude angle 'Θ' of the location of the device. For maximum interface, the axis of inclination should be relatively perpendicular to the polar axis.
    - Note that the polar axis ("true north" and "true south") is not the same as the compass bearing of north and south, because the magnetic poles do not necessarily line up exactly with the geometric poles. In other words, true north/south is not the same as magnetic north/south. The angle between the magnetic and geographical meridians at any place is called the magnetic declination or variation, which can be as much as 20 degrees or more in deviation. It is expressed in degrees east or west to indicate the direction of magnetic north/south from true north/south. If a compass is being used to orient a solar device, then the difference must be corrected for, which varies from place to place.
5. **The Earth's tilt** - The earth's rotational axis is tilted ~23.45 degrees from the plane of its orbit. This tilt is essentially constant, maintained in that direction due to the gyroscopic action of the earth's rotation, and always points in the same direction relative to the stars, so that the north pole points towards the star polaris, the north star. Over very long time periods however, measured in thousands of years, the direction of earth's axis slowly changes due to gyroscopic precession. The fixed orientation in space of the earth's axis as it orbits the Sun determines the length of the day and creates the world's seasons. As a result of the Earth's tilt, the intensity of the insolation varies during the year giving rise to the seasons. This is not because tilt causes a point on the earth's surface to move closer to or further from the sun. The change in distance is negligible. It is because of three factors, which together reduce both the intensity and daily duration of the insolation during "winter" months:
    - The earth's tilt changes the angle of incidence of the solar radiation, changing its insolation per unit area. The intensity of solar radiation is

largely a function of the angle of incidence, the angle at which the Sun's rays strike the Earth's surface.

- The tilt also changes the path length of the radiation through the atmosphere, which in turn changes the amount of the Sun's energy absorbed by the atmosphere.
- The tilt changes the number of sunlight hours.
- The declination in the elevation of the Sun varies during the course of the year between minus 23.45° in the summer and plus 23.45° in the winter. The angular position of the Sun at its highest point in the sky with respect to an observation point on the plane of the equator and is called the solar declination 'δ' (not to be confused with magnetic variation, also called the declination). Accounting for the solar declination, the altitude angle α of the sun is (90 - Θ ± δ) degrees. Hence, the inclination angle of a solar interface from the horizontal (for maximum efficiency) should therefore be (Θ ± δ) degrees, and the device should be able to follow this variation in declination throughout the year.

6. **Time** - Sunlight is only available during sunlight hours.

### 10.2.1 Atmospheric and meteorological parameters

During sunlight hours the magnitude and quality of solar radiation contacting the earth's surface is dependent upon atmospheric/meteorological conditions. These conditions affect not only solar radiation, but may affect the performance of the solar power system itself.

1. **Meteorological presence (weather)** - will significantly determine the amount of solar radiation available to a solar device. Cloud cover, dust, precipitation, and air pollution, as meteorological conditions, will impact air composition/density and interface clarity, and hence, the effective power output of a solar device.
2. **Air density (atmospheric density)** - the mass per unit volume of atmosphere. The greater the mass, the more likely absorption and scattering become.
3. **Air pressure (atmospheric/barometric pressure)** - the pressure exerted by the weight of air in the atmosphere of Earth as a meteorological condition.
4. **Temperature (atmospheric temperature)** - thermal quality of atmosphere.
5. **Humidity (atmospheric humidity)** - the amount of water vapor in the air.

**NOTE:** *In general, solar systems, particularly thermal, work in relatively cold weather, because the device interfaces with the Sun's radiation. However, ambient air temperature, and the design of the solar device, will impact functioning.*

### 10.2.2 Solar power system parameters

These are parameters specific to the solar powered system itself. The orientation of the interface of the solar device/collector/array with respect to the position of the Sun is a major determinant in the efficiency of a solar power system. The amount of energy transferred to/through (i.e., "captured by") a solar system can be maximised if the collector can follow the ecliptic path of the sun so that the plane of the collector or array is always perpendicular to the direction of the sun. In order to get the most power output from a solar device, it needs to point in the direction that captures the largest quantity of solar rays. In other words, the amount of irradiance contacting a collector or array is directly proportional to the area of the radiation wave-front it intercepts. For optimum energy capture the collector must be perpendicular to the Sun's rays (i.e., when the angle of incidence is 90°). For a flat plate on horizontal ground this occurs only when the Sun is directly overhead. Unless the solar device is located within the equatorial region of the Earth, a 90° angle of incidence is not possible due to the position of the sun relative to the system's position on Earth.

When the incident energy is not perpendicular to the collector, the angle of incidence is (90° - Θ) and the effective area of the collector is AcosΘ, where A is the area of the collector, and Θ is the deviation from perpendicular of the radiation.

If the Sun's radiation is not perpendicular to the Earth, the transit path through the Earth's atmosphere will be longer, and hence, the energy absorbed on the way to the collector or array will be greater, because it will encounter more air (as in, air mass).

**NOTE:** *The 'air mass' is a dimensionless quantity defined as the ratio between the actual path length of the solar radiation through the atmosphere and the vertical path length through the atmosphere at sea level.*

The effect of a longer route through the atmosphere is to increase the energy absorption (or lost energy) by a factor of 1/cosΦ, where Φ is the deviation from perpendicular of the radiation, also called the zenith angle. Thus, in the polar regions as Φ approaches 90 degrees (cosΦ>0), the insolation is very low, even if the collector is pointed directly at the sun, due to the longer path through the atmosphere.

In concern to a solar device's mounting orientation toward the sun, there are two types of orientation:

1. Fixed [static] mount (fixed tilt) - do not track the sun.

2. Automatic tracking [passive and active] - tracks the sun.

Note that a fixed tilt design can be adjusted (re-mounted) at least twice a year to give a meaningful increase in power output. There are two types of automatic tracking: passive and active (both are mechanical). Automatic mechanical tracking systems make it possible to track both the azimuth and the elevation of the sun's position to maximise energy capture.

Automatic tracking systems include:

1. **Azimuth tracking:** Azimuth tracking keeps the device's interface pointing at the sun as the earth rotates.
    A. **Passive systems** provide the simplest form of azimuth tracking. They have no motors, controllers or gears, and they don't use up any of the energy captured by the collector. They depend on the differential heating of two interconnected tubes of gaseous refrigerants, one on either side of the collector. If the collector is not pointing towards the sun, one side heats up more than the other and vaporises its refrigerant. The resulting change in weight is used in a mechanical drive mechanism to turn the collector towards the Sun where it will remain when the temperature and weight of the two tubes will be balanced.
    B. **Active tracking** is also possible by employing temperature sensors and a control system with linear actuating motors taking their drive power from the system.
2. **Altitude/elevation tracking:** Elevation tracking enables the interface to follow the seasonal variations in the sun's altitude, but alignment is less accurate than for azimuth tracking. Compared with the daily variations in insolation, the seasonal variations are slow and the range of the variation, due to the solar declination is much more restricted. Because of this, reasonable efficiency gains can be obtained simply by manually adjusting the elevation of a static mount every two months.
3. **Dual axis tracking:** Combining azimuth and elevation tracking enables the interface to capture the maximum energy using the smallest possible collectors.

#### *10.2.2.1 Maximum power point tracking (MPPT)*

**Maximum Power Point Tracking (MPPT)** is algorithm that included in charge controllers used for extracting maximum available power from power conversion module under certain conditions. Jacobi's Law states that a power source will deliver its maximum power to a load when the load has the same impedance as the internal impedance of the power source. Note that batteries are not generally designed for interconnection with power conversion systems, and the mismatch results in efficiency losses. Thus, a power point tracker is a form of voltage regulator that is placed between the power system and a battery. It presents an ideal load to the power system allowing it to operate at its optimum voltage to maintain its full power (wattage), regardless of the battery voltage. The voltage at which power module can produce maximum power is called 'maximum power point' (or peak power voltage).A variable DC/DC converter in the module automatically adjusts the DC output from the module to match the battery voltage. It is not enough however to match the voltage at the specified maximum power point (MPP) of the PV array to the varying battery voltage as the battery charges up. Due to changes in the intensity of the radiation falling on the array during the day as well as to changes in the ambient temperature, the operating characteristic of the PV array is constantly changing and with it the MPP of the PV also changes. For optimum power transfer, the system needs to track the MPP as the solar intensity and ambient temperature changes in order to provide a dynamic reference point to the voltage regulator.

### 10.2.3 Solar power interface types

The type of solar device will determine the type of interface. In general, either:

1. The material composition of the solar device itself acts as the interface (e.g., photovoltaic cells/panels or direct solar collector), or
2. A mirror-receiver system is used. In a mirror-receiver system, the mirrors concentrate/reflect the solar radiation onto a receiver that absorbs the radiation; e.g., solar concentrator).

A solar collector is a heat collecting surface that intercepts the sun's radiated energy and heats up a thermal working fluid. In practical thermal systems it is usually more convenient to focus the suns thermal energy onto a small receiver in order to obtain a higher temperature rise of the working fluid. Such collectors are called concentrators. Typically, concentrators are constructed from parabolic mirrors, which reflect the sun's parallel rays on to a single spot at the focus of the mirror.

> **UNITS NOTATION:** *Note that the units used to express the degree of concentration of the mirror system are similar to the magnification factor of a lens, and are called* **suns** *(this unit is not a precisely defined quantity).*

There are several types of concentrators:

1. **Parabolic dish** - a shaped mirror that redirects solar energy onto a suitable heat absorber/receiver

located at the focus.

2. **Parabolic trough** - a shaped mirrors that redirects solar energy onto a pipe-like heat absorber located running through the focus. Generally, this setup forms a type of "solar furnace" used to raise steam to drive a turbine generator.
3. **Power tower** - uses a large array of parabolic mirrors focused on a solar furnace mounted on the top of a tower. Because of the long focal length, the mirrors are almost flat. Generally, this setup forms a type of "solar furnace" used to raise steam to drive a turbine generator.
4. **Heliostats** - sun tracking mirrors used to reflect solar radiation in a fixed direction (such as toward a solar panel or thermal receiver).

**NOTE:** *For most of these systems, the amount of energy captured, and hence, the temperature rise of the absorber will be proportional to the area of the dish-like mirror.*

### 10.2.4 Solar power system monitoring

Solar devices require a "clear" (i.e., unobstructed) interface with the solar electromagnetic radiation to function optimally. If the device is covered with a material (e.g., dust, snow, debris), then the device will produce less power relative to the obstructing material type, and amount of material, covering the device. Hence, solar devices require periodic cleaning to ensure the device's interface surface is free of extraneous material.

Note that the solar interface itself may degrade with exposure to sunlight, and may require periodic replacement.

## *10.3 Photoelectric power: Direct transfer of solar electromagnetic energy to electric power*

**NOTE:** *These systems are sometimes referred to as* **photoelectric transducers***, wherein a transducer is a device that transfers ("converts") energy from one carrier ("form") to another carrier ("form"). The majority of these systems transfer electromagnetic power (energy) to mechanical displacement of charges, which produces electrical power. The other systems transfer a non-electrical physical quantity, such as temperature or sound, to an electrical signal.*

At the top level, the photoelectric and photovoltaic effect refers to the direct production of electric power (as direct current (DC) voltage) through the contact of electromagnetic radiation (energy) with a semiconducting material. Note here that the term 'photo' means 'light', which is another term for electromagnetic radiation. The photo-electric/-voltaic effect (or photoemission) refers to the observed movement of free charge carriers (or electrons) when light (electromagnetic radiation) contacts a material. Electrons "emitted" in this manner may be called "photoelectrons". The photoelectric effect is an electromagnetic, physical and chemical phenomenon.

The photoelectric and photovoltaic effects are closely related, and the terms are sometimes used interchangeably. In either case, light is absorbed, causing excitation of an electron or other charge carrier to a higher-energy state. In other words, "photons" (dielectric perturbations) carry the potential of moving electrons out of materials. Or, said another way, it is the direct conversion of light into electrical power (voltage and direct current) at the atomic level. In either case, an electric potential (or voltage) is produced by the separation of charges, and the light has to have a sufficient energy to overcome the potential barrier for excitation.

**CLARIFICATION:** *In general, the 'photoelectric effect' is the physical phenomenon responsible for the creation of an electrical potential difference (voltage) in a material when exposed to light. However, when speaking about specific occurrences of the photoelectric effect, the terms photoelectric and photovoltaic mean something different. In specific, the ways in which the electrons are emitted in the photoelectric effect and photovoltaic effect create the difference between them. They differ in definition as the steps of progression are different in each case. The main scientific difference between the two processes is that in the photoelectric effect, the electrons are emitted into a vacuum space (usually via ballistic conduction), whereas in the photovoltaic effect, the emitted electrons directly enter a new material (usually separation is via diffusion).*

There are several basic types of photoelectric device (i.e., photoelectric cell), corresponding to the different forms of the photoelectric effect that they employ. A **photoelectric cell** is defined as a device whose electrical characteristics, such as current, voltage, or resistance, vary when exposed to light.

Modules (a number of connected cells), are connected/arranged into arrays (connected modules/cells). The power production module/cell has no moving parts. All forms of the effect utilize semiconductor material in order to generate the effect. Solar electromagnetic energy may be directly converted to electric potential energy via the following effects/methods. Note that any devices employing these effects/methods could be referred to as a solar cell, although photovoltaic cells are most commonly referred to as solar cells:

1. **Photoconductive effect (photoconductive cell/ photoresistor)** - light "frees" electrons from their valence bonds in a semiconductor material, while reducing the materials resistance (increasing electrical conductivity). The photoconductive cell

is a two terminal semiconductor device whose terminal resistance will vary (linearly) with the intensity of the incident light. For obvious reasons, it is frequently called a photoresistive device.

2. **Photoemissive effect (photoemissive cell, photocell, electric eye)** - light knocks electrons from a cathode to an anode, making a current flow through an external circuit.
3. **Photoelectric effect (photoelectric cell) -** light makes electrons move out of semi-conducting material and into a vacuum space.
4. **Photovoltaic effect (PV cell, photovoltaic cell, or solar cell)** - light makes electrons move between layers of semiconducting material, producing a voltage and a current in an external circuit. A photovoltaic cell may also be used as a photodetector (e.g., infrared detectors), detecting light or other electromagnetic radiation near the visible range, or measuring light intensity. A solid state electrical device that converts the energy of light directly into electricity by the photovoltaic/ photoelectric effect. Photovoltaic cells (PV cells) are the building blocks of photovoltaic modules, otherwise known as solar panels. The operation of a photovoltaic (PV) cell requires 3 attributes:
   - The absorption of light, generating either electron-hole pairs or excitons.
   - The separation of charge carriers of opposite types.
   - The separate extraction of those carriers to an external circuit.
5. A **photo-electrochemical cell (photo-electrolysis cell)** - may either be a type of photovoltaic cell (like that developed by Edmond Becquerel and modern dye-sensitized solar cells), or a type of cell that splits water directly into hydrogen and oxygen using only solar illumination. Photo-electrochemical cells or PECs are solar cells that produce electrical energy or hydrogen in a process similar to the electrolysis of water. Photoelectrolysis is the process of using sunlight directly to decompose water into hydrogen and oxygen through the use of semiconductor material similar to that used in photovoltaics. In other words, by passing light (electromagnetic radiation) through water it is possible to split the water into its component parts.
6. **Photogalvanic effect (photogalvanic cell)** - a special case of the so-called Becquerel effect, in which the influence of light on the electrode potential is due to a photochemical process in the body of the electrolyte (as distinct from photochemical or photoelectric processes in the surface layer of the electrode, which are the basis of the original Becquerel effect).
7. **Photomagnetic effect (photomagnetic cell)** - a material acquires (and in some cases loses) its ferromagnetic properties in response to light. The current model for this phenomenon is a light induced electron transfer, accompanied by the reversal of the spin direction of an electron. This leads to an increase in spin concentration, causing the magnetic transition. (Mahmoud, 2015)

### 10.3.1 Photovoltaic cells

The most common effect used to create solar panels is the photovoltaic effect. Here, solar power converts sunlight into DC voltage electrical power using photovoltaics. Solar cells, also called photovoltaic (PV) cells get their name from the process of converting light (photons) to electric current (voltage), via a mechanistic effect known as the PV effect. Photovoltaic (PV) technologies may be divided into three generational categories:

1. **Wafer-based PV** (also called 1st generation PV, crystalline silicon, and bulk PV) - This first generation PV cell technology monocrystalline silicone (monosilicon) cells and polycrystalline silicone (polysilicone) cells.
2. **Thin-film cell PV** (also called 2nd generation PV or thin film solar cell, TFSC) - This second generation PV cell technology includes amorphous, protocrystalline, and nanocrystalline cells.
3. **Organic photovoltaic cell** (OPVC) - This third generation PV cell technology uses organic, electronic conductive polymers or small molecules for light absorption and electrical charge transport.

All photovoltaic cells utilize a semiconductor P-N junction. Photovoltaic cells contain p-type materials flush with n-type materials. Sunlight provides the energy to make the current flow from the n-type to the p-type.

In general, the photovoltaic process occurs as follows:

1. "Photons" in rays of sunlight contact a solar panel and are absorbed by semiconducting material.
2. Electrons in the semiconducting material are excited from their current molecular/atomic orbital.
3. Once excited an electron can either dissipate the energy as heat and return to its orbital, or travel through the cell until it reaches an electrode. Once an excited electron reaches an electrode a current is created. The chemical bonds of the material are vital for this process to work.
4. An array of solar cells converts solar energy into a usable amount of direct current (DC) electricity.
5. An inverter can convert the power to alternating current (AC).

Photovoltaic diodes (a.k.a., photodiodes, PV cells, or solar cells) generate an electric current when light of sufficient magnitude impinges on a semiconductor lattice connected to a P-N junction. If the photon energy in the light energy is less than the band gap (energy range in a solid where no electron states can exist), the energy is simply dissipated as heat, and no electrons are released into the conduction band and no current flows. However, if the energy level of the photons is equal to, or higher than, the band gap of the semiconductor material, it will cause the covalent bonds in the semiconductor to be "broken" as electrons jump the band gap into the conduction band. Both the electron and the vacant site left behind by the electron in the valence band (the hole) then act as free charge carriers and contribute to the possible current. Once a photon has caused the release of an electron, any photon energy it had in excess of the band gap energy will be dissipated in the form of heat. Photons pass through the crystal lattice until they are absorbed as heat or until they give up their energy by causing the generation of electron hole pairs and the release of an electron across the band gap.

Photovoltaic cells can be stand-alone systems, or incorporated into other useful materials. Hence, the structural design of photovoltaic cell/panel can take several forms:

- Flexible panels - a flexible stand-alone PV cell.
- Rigid panels - a rigid stand-alone PV cell.
- Shingle and tile panels - a tile (e.g., roof tile) could be a PV cell.
- Window panels - a window could be a PV cell.

### 10.3.2 Device specifics

Specific devices will be accompanied by the following referential data:

1. Manufacturer - Organization/company name; brand
2. ID - Specific solar module identification code; module name
3. Rating - standard testing conditions; nameplate rating under laboratory conditions
4. Efficiency (%) - Output per input light irradiance using STC; energy conversion efficiency; module efficiency
5. Tier - Solar panel efficiency Trier 1 is highest, 5 is lowest.

## *10.4 Solar non-photoelectric power: Direct transfer of solar electromagnetic energy to electric energy*

Solar radiation can be directly converted into electrical power without the use of the photoelectric effect, via five methods:

1. **Thermoelectric or thermophotovoltaic effect**- The conversion of temperature differences to electric voltage and vice versa. Thermophotovoltaic (TPV) cells involve a direct energy transfer through heat [mode] to electricity via photons (as in, generating electricity from infra-red radiation). A thermoelectric device creates voltage when there is a different temperature on each side. Conversely, when a voltage is applied to it, it creates a temperature difference.
2. **Thermionic emission effect** - The process by which free electrons are emitted from the surface of a metal when external heat energy is applied. Heat energy transfer induces the flow of charge carriers from a surface or over a potential-energy barrier. This occurs because the thermal energy given to the carrier overcomes the work function of the material. Thermionic emission occurs in metals that are heated to a very high temperature. In other words, thermionic emission occurs, when a large amount of external energy transferred via heat is supplied to the free electrons in the metals (i.e., raises the internal energy of the substance and causing the valence electrons to gain enough energy to break their bonding with the parent atom, whereupon they become "free" (i.e., acquire kinetic energy).
3. **Ferroelectric effect (ferroelectricity)** - Ferroelectricity is a property of certain materials that have a spontaneous electric polarization that can be reversed by the application of an external electric field. Certain solids exhibit spontaneous electric polarisation when exposed to light (Read: light has an electric field, as in electromagnetic field). The nonlinear nature of ferroelectric materials can be used to make capacitors with tunable capacitance.
4. **Magnetohydrodynamic effect** (MHD; also magneto fluid dynamics or hydromagnetics) - The study of the magnetic properties of electrically conducting fluids. Examples of such magneto-fluids include plasmas, liquid metals, and salt water or electrolytes.
5. **Electro-gas-dynamic effect** - The process of creating electrical power by converting the kinetic energy contained in a flowing, high-pressure, ionized combustion gas.

## *10.5 Solar heating electric power: Indirect transfer of solar energy to electric energy*

The production of electric power by solar heating (energy transfer via heat) requires two stages. First, solar radiation (thermal energy) heats a working fluid, which is then used in a second energy transfer stage to generate the electric power. A solar "thermal" power system usually involves an array of mirrors to concentrate the sunlight on to an absorber. The absorbed energy is then used to power a heat engine (and turbine), which in turn drives a rotary generator. In large scale systems, the heat engine includes a turbine driven by steam or other vaporous working fluid. The steam (or other vapor) is produced by the concentrated heating effect in the heat engine, which transforms the working fluid therein.

In other words, electric power via solar heating uses concentrated light from the sun to heat a working fluid in a heat engine (and turbine), which turns a generator to make electricity (AC voltage internally). The working fluid that is heated by the concentrated sunlight can be a liquid or a gas. Different working fluids include water, oil, salts, air, nitrogen, helium, etc. In small scale systems the heat engine may be a Stirling engine. Other engine types include steam engines, gas turbines, etc.

Hence, solar power can be indirectly/secondarily converted into electrical power through the thermodynamic process. The thermodynamic process occurs when energy in solar radiation is transferred via heat into shaft work/power through a heat engine (via the Rankine cycle, Stirling cycle, or Brayton cycle), and then, shaft work (mechanical power) is converted into electrical power through a generator (e.g., alternator).

Herein, devices can be constructed to reflect and absorb/collect solar energy. For instance, a **solar thermal collector** supplies heat by absorbing sunlight for the purpose of either direct heating or indirect electrical power generation from heat. Similarly, a **concentrating solar power (CSP) system**, concentrates the sun's radiated energy using reflective devices such as troughs or mirror panels to produce a focused super heated thermal power source that is then used to generate electricity.

Summarily, a solar "thermal" power system mainly consists of a: solar energy collector field, a fluid flow distribution system, a suitable working fluid, a heat engine (and turbine), an electric generator, and a control system. Amongst the many available systems, the two most generic and common are: the central receiver thermal electric power system and the distributed solar thermal electric power system. These two systems have a comparatively high efficiency. In the central receiver concept large arrays of sun-tracking mirrors known as heliostats reflect the solar flux on to the central receiver boiler at the top of the tower. Here concentration ratios power a turbine (steam type) that in turn powers a generator.

## *10.6 Solar heating (passive): Direct thermal heating*

Solar radiation can be used and concentrated for its heating ("thermal") properties. Uses of direct solar "thermal" energy include, but are not limited to:

1. **Solar water heating** - Solar water heating systems, which contain a black solar collector that faces the sun, and either heats water directly or heats a "working fluid" that, in turn, is used to heat water.
2. **Solar walls** - Transpired solar collectors, or "solar walls," which use solar energy to preheat ventilation air for a building.
3. **Solar evaporation** - Solar desalination and solar distillation has been in practice for a long time as a means for evaporating water.
4. **Solar drying** - Solar drying, dehydrating, evaporation, desiccating, and cooking has been in practice for a long time (e.g., food dehydration; salt evaporation ponds; clothes drying; solar oven/ cooker).
5. **Solar ponds** - Solar ponds are used for the collection and storage of thermal energy (as internal energy). The energy can be transferred from the solar ponds for any suitable heating ("thermal") application. Therein, solar pond systems may be used for thermal energy storage, desalination, and electricity generation. A solar pond is a large scale solar collector with an integrated arrangement for storage of heated water. A solar pond is a pool of water (generally, salt water) that collects and stores solar thermal energy (as internal energy). The saltwater naturally forms a vertical salinity gradient also known as a "halocline", in which low-salinity water floats on top of high-salinity water. The layers of salt solutions increase in concentration (and therefore density) with depth. Below a certain depth, the solution has a uniformly high salt concentration. When the sun's rays contact the bottom of a shallow pool, they heat the water adjacent to the bottom. When water at the bottom of the pool is heated, it becomes less dense than the cooler water above it, and convection begins. Solar ponds heat water by impeding this convection. Salt is added to the water until the lower layers of water become completely saturated. High-salinity water at the bottom of the pond does not mix readily with the low-salinity water above it, so when the bottom layer of water is heated, convection occurs separately in the bottom and top layers, with only mild mixing between the two. This hot, salty water can then be pumped away for use in electricity generation, through a turbine or as a source of thermal energy. There are ad-/dis-vantages with solar ponds:
   A. The accumulating salt crystals have to be removed and can be both a valuable by-product and a maintenance requirement.

B. No need for a separate collector for this thermal storage system.
C. The extremely large thermal mass means power is generated night and day.
D. Due to evaporation non-saline water is constantly required to maintain salinity gradients.

## 11 Geothermal power

**TERMINOLOGY:**

- **Geothermal heat pump:** Devices that utilize the relatively constant temperature of the Earth's interior as a source and sink of heat for both heating and cooling. When cooling, heat is extracted from the space and dissipated into the Earth; when heating, heat is extracted from the Earth and pumped into the space.
- **Geothermal plant/facility:** A combination of devices (forming a facility, or "plant") in which the prime mover is a steam turbine. The turbine is driven either by steam produced from hot water or by natural steam that derives its energy from heat found in rocks or fluids at various depths beneath the surface of the Earth. The energy is extracted by drilling and/or pumping.

Geothermal energy is defined as thermal energy (heat) from the earth. Geo means "earth," and thermal means "heat" in Greek. Heat flows outward from the earth's interior. The earth's heat content is about $10^{31}$ joules. This heat naturally flows to the surface by conduction at a rate of 44.2 terawatts (TW) and is replenished by radioactive decay at a rate of 30 TW. The earth has been emitting heat for approximately 4.5 billion years, and will continue to emit heat for billions of years into the future.

> **NOTE:** *According to archaeological evidence, geothermal resources have been used by humanity in the form of naturally occurring hot springs for more than 10,000 years.*

Heat emanating from the earth's interior generates magma (a molten and semi-molten rock mixture). This mixture is usually made up of four parts: a hot liquid base, called the melt; minerals crystallized by the melt; solid rocks incorporated into the melt from the surrounding confines; and dissolved gases. Magma exists in the mantle and lower crust, and sometimes bubbles to the surface as lava. However, the crust of the earth traps most of the mantle (and its heat) beneath it. The earth's crust effectively acts as an insulator, which must be pierced by fluid conduits (of magma, water or other) to release the heat underneath. Because magma is less dense than surrounding rock, it rises within the mantle and through conduits within the crust. As the magma rises, it heats the surrounding rock, as well as water contained in rock pores and rock fractures under the earth's crust. Heat is carried to the surface by fluid circulation, either through magma conduits, hydrothermal circulation, hydrocarbon wells, drilled water wells, or a combination of these.

> **NOTE:** *There are many natural geothermal features on the surface of the earth, including but not limited to: geysers; hot springs; volcanoes; steam vents; underwater*

*hydrothermal vents; and mud pots. When a volcano erupts, the mantle of the earth flows up through the crust to the surface as lava.*

Geothermal energy exists in different carriers ("forms") all over the Earth (by steam vents, lava, geysers, or simply dry heat). Magma, heated rock, and heated water are all sources of geothermal energy. In order for a geothermal power system to operate, the heat must be carried to the surface by fluid circulation, either through magma conduits, hot springs, hydrothermal circulation, oil wells, drilled water wells, or a combination of these. This circulation sometimes exists naturally where the crust is thin: magma conduits bring heat close to the surface, and hot springs bring the heat to the surface. Once at the surface or the system's location, the thermal energy can be captured and used directly for heating, or it can be used as (or converted to) steam, and directed through a turbine-generator to produce electrical power.

**NOTE:** *Geothermal steam and hot water can reach the surface in two ways: through naturally occurring surface features such as geysers and fumaroles, or through man-made wells that are drilled down into the reservoir to harvest the energy.*

Natural heat from within the Earth may be transferred through a geothermal power system for the production of electric power, space heating, or industrial steam. Geothermal power uses heat from geothermal fuel (i.e., the inner earth) to heat water or another working fluid. The working fluid is then used as space heating, as industrial steam, or to turn a generator, thereby producing electricity.

Unlike other renewable energy sources, geothermal systems are considered "baseload". This means they can continue to operate throughout all seasonal changes on the earth's surface, and are not dependent on changing surface factors, such as the presence of wind or sun. Geothermal electrical power systems are capable of producing energy continuously (i.e., 24/365 - 24 hours a day and 365 days a year, any time and every day).

**NOTE:** *Rock is considered a reasonably good conductor of heat. Conversely, air is considered a reasonably poor conductor of heat.*

In order to obtain enough energy to generate electricity, geothermal power plants rely on heat that exists a few kilometers below the surface of the Earth. In some areas, the heat can naturally exist underground as pockets steam or hot water. However, most areas need to be "enhanced" with injected water to create steam. The heat energy transferred from the mantle to the waters in the earth's crust can be harnessed to create electricity.

Geothermal power stations are similar to other steam turbine thermal power stations – heat from a fuel source (in the case of geothermal, the earth's core) is used to heat water or another working fluid. The working fluid is then used to turn a turbine connected to a generator, thereby producing electrical current. The fluid is then cooled and returned to the heat source.

## 11.1 Geothermal sources

**NOTE:** *Water boils underground and generates steam at temps of 165˚C and pressure of about 100 psi.*

The type of geothermal field/reservoir will determine the type of geothermal power system (plant or station) that can be built on the geothermal site. There are two primary carriers of geothermal energy, and hence two primary geothermal field types:

1. Water-based fields - including steam and hot water.
2. Hot and molten rock-based fields - including hot and molten rocks, but no water.

Therein, there are four common types of geothermal fields/reservoirs; three of which are water-based and the fourth is rock-based:

1. **Hot water fields/reservoirs** are geothermal aquifers that contain reservoirs of water between ~60°-100° C. In general, these fields are used for direct thermal heating or as part of a binary power plant.
2. **Wet steam fields/reservoirs** are geothermal reservoirs that contain pressurized water that is above boiling point (100° C), so that when the water is pumped to the surface it becomes steam.
3. **Dry steam fields/reservoirs** are geothermal reservoirs that contain pressurized and "superheated" water that is significantly above boiling point. The "superheated" water/steam is pumped to the surface for use. Dry steam fields are rarer than wet steam fields.
4. **Hot and molten rock fields** are geothermal locations with hot rocks.

Electricity production from each type depends on field temperatures, and when water is present, pressures also.

**NOTE:** *Most geothermal reservoirs are found deeper underground than groundwater reservoirs.*

## 11.2 Geothermal power Types

Geothermal power can be harvested in a number of different ways. Firstly, water can be used via steam to power a turbine and produce electrical power, or the hot water itself can be used for heating purposes. Secondarily, heated rocks can be used to power a closed-loop heat pump with an internal turbine system to produce electricity, or the temperature difference between an underground area and the surface can be used as part of a heating and cooling system.

There are five water-based geothermal power systems include:

1. **Dry steam power (plant/station)** - The direct use of natural underground sources of steam of 150°C or greater to power turbines. In this case, the underground source of steam (water) is from a dry-steam reservoir. The steam is piped directly into the turbine, which is connected to a generator that generates electrical power. Steam directly from the geothermal reservoir runs the turbines that power the generator, and no separation ("flashing") is necessary, because the geothermal wells only produce steam. Dry steam systems use water in the earth's crust, which is heated by the mantle and released through vents in the form of steam. Dry steam geothermal systems have pipes that are drilled into the site and used to trap and redirect the steam. The steam is then used to turn turbines connected to a generator to produce electricity. The underground water reservoirs that feed such a system is refilled when rain falls on the land. The rainwater eventually soaks back into the crust of the earth. Sometimes, however, dry steam reservoirs do not refill themselves in a very consistent manner.
2. **Wet steam power (a.k.a., flash steam plant/ station)** - This system is similar to a dry-steam power system, but water is recycled back into the thermal well. In this case, the underground source of steam (water) is a wet-steam reservoir. This systems use a well that is drilled into the geothermal site to release the steam. After the steam is piped up, and passes through the geothermal power system, it is sent into a condenser, which cools it. This cooled water is then pumped back into the well (i.e., recycled). The water is heated again by the geothermal source, and released as steam, and the process repeats. This process can happen over and over with a minimal loss of water. Wet steam power system use naturally occurring sources of underground hot water and steam, which is "flashed" into steam, used to power a turbine-generator, and then condensed and recycled. Hot water and steam are pumped into a low-pressure area on the surface known as a flash tank. The water evaporates rapidly (i.e., "flashes") into steam, which is funnelled through a turbine connected to a generator to produce electrical power. Any remaining water can be flashed in a separate tank to extract more energy. The water is then condensed and recycled back into the earth. Flash steam systems pull deep, high-pressure hot water into lower-pressure tanks and use the resulting flashed steam to drive turbines. They require fluid temperatures of at least 180°C (usually higher). This is the most common type of geothermal station in operation today. The hot water flows up through wells in the ground under its own pressure. As it flows upward, the pressure decreases and some of the hot water boils into steam.

   **NOTE:** *A 'condenser' is a heat exchanger, which condenses a substance from its gaseous to its liquid state.*

3. **Binary cycle power (plant/station)** - Water heated underground (at ~107°-182° C) is piped to the surface where it is passed through a heat exchanger, containing a pipe with a secondary working fluids (a fluid with a lower boiling point). After being heated by the water piped up from underground, the working fluid is flash steamed to power a turbine, which is connected to a generator, and produces electrical energy. The geothermal water is never exposed to the air, and is injected back into the periphery of the reservoir. The hot water from underground heats working fluid (e.g., a liquid organic compound) that has a lower boiling point than water (e.g., isobutane). The two liquids are kept completely separate through the use of a heat exchanger used to transfer the energy via heat from the geothermal water to the working fluid. The secondary fluid vaporizes into gaseous vapor and (like steam) the force of the expanding vapor turns the turbines that power the generators. In other words, the organic working liquid creates steam, which flows through a turbine and powers a generator to create electrical power. The water in the pipe is recycled back to the ground, to be re-heated by the Earth and provide future heat for the organic compound again. If the power system uses air cooling the geothermal fluids never make contact with the atmosphere before they are pumped back underground. These systems are the most recent development, and can accept fluid temperatures as low as 57 °C. The moderately hot geothermal water is passed by a secondary fluid with a much lower boiling point than water. This causes the secondary fluid to flash vaporize, which then drives the turbines. This is the most common type of geothermal electricity station being constructed today. Both Organic Rankine and Kalina cycles are used. The thermal efficiency of this type station is typically about 10–13%. In binary systems, water is only used as a heating

agent, and is not exposed or evaporated. It can be recycled, used for other purposes, or released into the atmosphere as non-toxic steam. In general, however, binary systems generally emit no visible steam or water vapor plumes. If the geothermal fluid is not contained and recycled in a pipe, it can absorb biologically toxic substances in the earth, such as arsenic, boron, selenium, mercury, and fluoride. These toxic substances can be carried to the surface and released when the water evaporates. In addition, if the fluid leaks to other underground water systems, it can contaminate clean sources of drinking water and aquatic habitats.

4. **Enhanced geothermal systems (EGS)** - EGS uses drilling, fracturing, and injection to provide fluid and permeability in areas that have hot, but dry, underground rock. To develop an EGS, an 'injection well' is drilled into the ground. Depending on the type of rock, this can be as shallow as 1 kilometer to as deep as 4.5 kilometers. High-pressure cold water is injected into the drilled space, which forces new fractures in the rock, expands existing fractures, and dissolves areas. This creates a reservoir for/of underground fluid. Water is pumped through the injection well, and absorbs the rocks' heat as it flows. This hot water, called 'brine', is then piped back up to earth's surface through a 'production well'. The heated brine is contained in a pipe. It warms a secondary [working] fluid that has a low boiling point, which evaporates to steam and powers a turbine. The brine cools off, and cycles back down through the injection well to absorb underground heat again. There are no gaseous emissions besides the water vapor from the evaporated liquid. Pumping water into the ground for EGSs can cause seismic activity.

   **NOTE:** *In 2009 an EGS Geothermal project in Basel, Switzerland, was cancelled after the injection process caused hundreds of tiny earthquakes that grew to more significant seismic activity even after the water injection was halted.*

5. **Hot water system (plant/station)** - This system uses a hot water reservoir that does not reach high enough temperatures to become steam, but is still a viable source of direct heating. The water is not used to produce electrical power, but is piped and exchanged to heat desired areas. The heat from the pipes (and venting systems) radiate heat into a surface and/or area. Pipes return the water to the hot water reservoir to be reheated and introduced back into the system. Applications include, but are not limited to: space heating and cooling; food preparation; hot spring bathing and spas (balneology); agriculture; aquaculture; greenhouses; snow melting; and production processes.

There are two rock-based geothermal power systems; one of which is designed specifically as a heating and cooling system, and the other is designed to produce electrical power:

1. **Geoexchange system (geothermal heat pump, GHP) for heating and cooling** - This is a type of heating and cooling system. Technically, this kind of system is not geothermal since it uses a combination of the ground's low relative heat and indirect solar energy, not the earth's geothermal energy. Geoexchange systems involve the drilling of a well 3 to 90 meters deep (shallower than most oil and natural gas wells). The system does not require the fracturing of bedrock. A pipe connected to a system is arranged in a continuous loop ("slinky loop") that generally circles underground and above ground. However, the loop can also be contained entirely underground, for instance, to heat a parking lot or landscaped area. In this system, a working fluid (such as water or glycerol, similar to a car's antifreeze) moves through the pipe (and accompanying heat exchanger and ductwork, if present). This system is mostly used for heating and cooling on a seasonal basis. During the cold season, the liquid absorbs underground thermal heat (from a geothermal and/or solar source). It carries the heat to its desired location. The pipe can be connected to the infrastructure of a building to give off heat into the building through a duct/heat exchange system. These heated pipes can also run through hot water tanks. During the warm season, the geoexchange system works the opposite way: the liquid in the pipes is warmed from the heat in the building (or ground heat source), and carries the heat to be cooled underground.

   **NOTE:** *Some animals burrow underground for warmth in the winter and to escape the heat of the summer.*

2. **Geoexchange system (geothermal heat pump, GHP) for electrical power** - Unlike geoexchange for heating and cooling, this system does use geothermal energy to do work, and must be placed in a location with a sufficiently high underground temperature. Geoexchange systems for electrical power are typically self-contained tubular units with two principal sections: the process section and the heat absorption section. The heat absorption

section is otherwise called the 'geothermal riser'. The riser has its own pump with an oil compound (biodegradable and non-toxic). The oil is sent downward through a coaxial system to where the geothermal heat exists. As the oil gets hot at the location of the thermal riser, it comes back up through the center tube. The hot oil is transferred to a heat exchange, which contains two chemicals (isopentane and isobutane). These chemicals are pressurized and in liquid form when they absorb thermal energy from the heat exchanger. Once they are heated from the exchange, they turn into a gas, which drives a turbine connected through a shaft to a generator, and produces electrical power. After the gas moves through the turbine it enters a condensing system, and becomes liquid again, which is then pumped back down to the heat exchanger. These systems typically require an operating temperature of at least 148˚C. The power generating system operates at ~10,000rpm and needs only 108˚C. Both sections of the device are closed cycles. One of the most well-known geoexchange electrical power systems is the Power Tube, which is available with the following specifications.

- 10 megawatt system = 55m in length, 142cm diameter (with a 30.48cm diameter riser).
- 5 megawatt system = 47m in length, 112cm diameter (with a 22.86cm diameter riser).
- 1 megawatt system = 43m in length, 92cm diameter (with a 12.7cm diameter riser).

There are also co-produced geothermal systems:

- **Co-produced geothermal power** - These systems use heat obtained from the steam and hot water produced as a by-product of petroleum and natural gas wells to power an electrical generator.

## 11.2.1 The Cooling subsystem

Most geothermal electrical power generating system include a cooling subsystem. Cooling can occur through air cooling (e.g., fans) and/or water/wet cooling (e.g., cooling towers and evaporative cooling). A cooling system is designed to prevent turbines from overheating and prolong system life.

**NOTE:** *A 'cooling tower' is a heat rejection/dissipation device that ejects waste heat to the atmosphere through the cooling of a water stream to a lower temperature.*

Wet/evaporative cooling used in water cooled systems requires a continuous supply of cooling water and creates vapour plumes (i.e., air emissions as water vapor emissions). Usually, some of the spent steam from the turbine (for flash- and steam-type plants) can be condensed for this purpose. Vapor plumes are unaesthetic and air cooled systems are preferred in areas where the viewshed is sensitive to the effects of vapor plumes. Vapor plumes can also introduce contaminants into the atmosphere, depending upon the purification of the water source.

Air cooled systems, in contrast to the relative stability of water cooled systems, can be extremely efficient in the winter months, but are less efficient in hotter seasons when the contrast between air and water temperature is reduced, so that air does not effectively cool the organic fluid. Air cooled systems emit no water vapor, and thus blend easily into the environment. Air cooled systems are beneficial in areas where extremely low emissions are desired, or in arid regions where water resources are limited, since no fluid needs to be evaporated for the cooling process.

## 11.2.2 Geothermal resource assessment

Different types of geothermal energy are available on different parts of the planet. Satellites are used to determine geothermal hotspots. Thermal satellite imagery usually provides a 10km x 10km view of the ground. With this information you can determine how large and/or how many geothermal systems can potentially be installed without extracting too much energy (i.e., without cooling the area down).

Geothermal plants are designed for a specific resource. In other words, after satellite imagery is analyzed, wells are drilled, and then, the thermal characteristics and material output (e.g., steam and/or water) of the well are measured. And then, a geothermal system is selected and designed for that specific resource.

The part of the planet known as "Iceland", for example, has abundant sources of hot, easily accessible underground water. Europe has a significant volume of hot dry rock as a source of geothermal energy.

## 11.2.3 Environmental impact

Before construction of a geothermal power generation system, an environmental assessment must be completed to determine potential social system and ecosystem effects.

#### *11.2.3.1 Environmental contamination and disruption*

- Drilling into the earth's crust produces 'sludge', which is often rich in zinc and sulfur (and other potential pollutants). If the sludge is directly released into the environment it can harm ecosystems.
- Water that flows through underground reservoirs can pick up trace amounts of toxic elements. These harmful substances can be leaked to water sources

or the atmosphere if the geothermal system is not properly insulated. Hence, the steam used at geothermal plants can become a source of air pollution if it is released into the atmosphere. Frequently it is heavily laced with salts and sulfur compounds that are leached from the earth's crust. If the steam is simply condensed and released into the natural waterways, the high levels of salts and sulfurs can be toxic to aquatic wildlife. If released into the air, the toxins, in the form of acid rain, can still find their way into surface water systems and kill aquatic animals. Geothermal plant operators often cool and condense the steam produced at their plants and recycle it into their wells for these reasons.
- Some geothermal reservoir fluids contain varying amounts of certain gases, including carbon dioxide, which may be emitted as steam into the environment (with any accompanying particulate matter). In concern to particulate matter, mercury for example, is not present in every geothermal resource. However, if mercury is present in a geothermal resource, using that resource for power production could result in mercury emissions, depending upon the technology used. Because binary plants pass geothermal fluid through a heat exchanger and then return all of it to the reservoir, binary plants do not emit any mercury.
- Natural geothermal fluids contain varying concentrations of potentially toxic minerals and other elements, and are extremely hot when they reach the surface of the Earth. For these reasons, geothermal fluids can be dangerous to humans and surrounding ecosystems. Hence, fluids from geothermal reservoirs are injected back into the earth and are not allowed to be released into surface waterways. However, geothermal effluents can sometimes (depending upon composition) be stored in evaporative ponds, rather than be injected back into the system. Again, depending upon composition, these ponds may be safe for bathing/swimming.
- During operation, there is the possibility of aquifer/groundwater contamination.
- Wells must often be dug, which may disrupt the natural flow of groundwater.
- Total non-condensable gas emissions (e.g., sulfur dioxide, methane, $CO_2$ etc.) from geothermal resources are calculated as a percentage of the total steam emitted (generally, less than 5%). Conversely, air emission from combustion (e.g., coal fired electrical plant) contain are a much higher percentage of emissions.

#### *11.2.3.2 Subsidence*

- Subsidence is the slow, downward sinking of a land surface. Other types of ground deformation include upward motion (inflation) and horizontal movements. In some cases, subsidence can damage infrastructure, such as roads, buildings and irrigation systems, or even cause tracts of land to become submerged by nearby bodies of water. Although it can occur naturally, subsidence can also occur as a result of the extraction of subsurface fluids, including groundwater, hydrocarbons, and geothermal fluids. In these cases, a reduction in reservoir pore pressure reduces the support for the reservoir rock itself and for the rock overlying the reservoir, potentially leading to a slow, downward deformation of the land surface. While subsidence can be induced by thermal contraction of the reservoir due to extraction and natural recharge, properly placed injection (see injection sections) reduces the potential for subsidence by maintaining reservoir pressures.
- Geothermal sights can experience subsidence (setting or sinking of land). Geothermal plants have been linked to subsidence, or the slow sinking of land. This happens as the underground fractures collapse upon themselves. In some areas of New Zealand, the ground under a geothermal power plant subsides at a rate of almost a half a meter every year. This can lead to damaged pipelines, roadways, buildings, and natural drainage systems.

#### *11.2.3.3 Water Depletion*

- Water-based geothermal system can/will deplete the naturally existing underground water (over time). In general, geothermal systems need additional replenishing sources of water, because the steam released exceeds the amount of water that naturally flows into the systems. To restore some of the former capacity, 'water injection' is used. Re-injecting water can sometimes help a cooling geothermal site last longer. However, this process can cause earthquakes. The process of injecting high-pressure streams of water into the Earth can result in minor seismic activity, or small earthquakes.
- In some geothermal power systems, when electrical power is generated [some amount of] steam is lost to evaporation.
- Depending upon how it is used and controlled, wastewater (from human or other animal waste) can be used as an alternative replenishing source of water. In other words, wastewater can be used for 'water injection'. Waste water injection projects serve the dual purpose of eliminating wastewater,

which would otherwise be dumped into local waterways, and rejuvenating geothermal reservoirs with new water sources.

#### *11.2.3.4 Heat depletion*

- Geothermal power is considered to be sustainable, because the heat extraction is small compared to the Earth's heat content. Extraction, however, must still be monitored to avoid local depletion. Although geothermal sites are capable of providing heat for many decades, individual wells may cool down or run out of water. Most wells that extract heat from the Earth will eventually cool, especially if heat is extracted more quickly than it is given time to replenish. Hence geothermal system require appropriate control/management over the amount of energy extracted.

#### *11.2.3.5 Aesthetics*

- Geothermal power plants can be designed to blend-in to their surrounding more so than other power generation methods, and they can be located on multiple-use land.

#### *11.2.3.6 Travel*

- The land around geothermal vents is often unstable, and unfit for human habitation. Hence, teams who work at geothermal stations may have to travel some distance from their place of habitation.

#### *11.2.3.7 Seismicity*

- Earthquake activity (seismicity) is generally caused by displacement across active faults in tectonically active zones. An earthquake occurs when a body of rock is ruptured and radiates seismic waves that shake the ground. Although it typically occurs naturally, seismicity has at times been induced by human activity, including the development of geothermal fields, through both production and injection operations.

# 12 Nuclear power

Nuclear power uses refined nuclear material, which has been turned into a fuel rod. The fuel rod is placed in water where the to heat created by fission turns the water into steam. The steam turns the blades of a steam turbine to produce electricity. Nuclear power is the process of capturing nuclear energy within a machine called a "nuclear reactors" to produce electricity by means of a turning a magnetic-electricity generator. Nuclear power typically enables electricity generation by creating massive amounts of heat. The heat is applied to water to produce steam, and the steam turns a turbine(s) to create electricity. Nuclear power is carbon emission free, but not steam emission free.

> **NOTE:** *Nuclear is not technically renewable because the process degrades atomic material. Modern nuclear reactors also are a very low environmental impact technology.*

There are several possible elements that can be used as the fuel inside nuclear reactors, which generate enough heat to move turbines and generate electricity:

1. Thorium
2. Uranium
3. Caesium
4. Plutonium

A nuclear power generation system achieves its function by two possible processes:

1. **Boiling water reactor (BWR)** - A boiling water reactor uses nuclear fuel (often in the form of rods of easily fissionable material) to boil water. This water turns to steam, which powers massive turbines that generate the electricity. A BWR nuclear power plant typically uses uranium ore in its fuel rods. The uranium fuel rods generate heat via the radioactive decay of uranium isotopes (types of uranium atoms). This is called nuclear fission. The "reactor's" core generates more heat than is needed to produce steam, so boiling water reactor designs feature massive cooling towers to expel the excess heat and steam.
2. **Pressurized water reactor (PWR):** Water needs to be pressured to stay in liquid form and effectively cool this type of reactor. A pressurized water reactor is a "light" water reactor that uses uranium fuel rods to heat water under high pressure. The water circulates from the reactor core to a steam generator, where it heats a separate supply of water that forms steam to turn turbines that generate electricity. Unlike a boiling water reactor, a pressurized water reactor design keeps boiling water away from nuclear fuel, thus reducing the

risk of a nuclear accident.

3. **Molten salt reactors** *(are in an experimental prototype phase of development)* - use molten salt as the medium. These reactors need no pressurization. The molten salt passively cools itself and will quickly solidify when exposed to air (thus, reducing the likelihood of contamination). Molten salt reactors can be powered by a variety of nuclear materials, including formerly existing nuclear waste.
   A. A molten salt reactor requires highly specialized materials and equipment, including but not limited to:
      1. Highly resistant to corrosion materials.
      2. High-temperature salt pumps.

   B. A thorium-powered molten salt reactor consists of two principal elements:
      1. The thorium fuel source - thorium is not fissile, and hence, cannot sustain a nuclear fission reaction. Instead, it is classified as fertile, and hence, can "capture" a neutron, and eventually decay into uranium-233. The Uranium-233 is fissile, and hence, can sustain a nuclear reaction.
      2. The molten salt. Molten salt is salt that has been heated to the point that it turns molten (liquid). A molten salt reactor uses molten salt for two functions:
         i. As a coolant.
         ii. As the medium into which fissionable and fissile material is dissolved.
      3. Starter nuclear chemical to start the chain reaction, such as uranium-235, because it emits high-energy gamma radiation (continuously).

   C. The benefits of thorium include, but may not be limited to:
      1. Its abundance over other nuclear materials.
      2. It is a waste product of rare earth mineral mining.

Nuclear power has multiple advantages compared to other electrical power generation sources:

1. Minimal carbon emissions: Nuclear power does not emit greenhouse gases like carbon dioxide (CO2) or methane (CH4) during electricity generation. Nuclear power does not emit combustion by-particles (e.g., ash). These characteristics sets it apart from the combustion of fossil fuels like coal, oil, and natural gas.
2. Abundant supply: The planet has many deposits of uranium that can easily accommodate existing nuclear energy systems.
3. High capacity factor: Nuclear power plants provide a strong return on the energy expenditure that goes toward building and operating them. Compared to fossil fuels like coal and natural gas and renewables like solar and wind, nuclear comes closest to exploiting the maximum possible energy generation for a plant at a given time.

There are four principal disadvantages to nuclear power:

1. Economics: The cost of extracting and transporting uranium, mixed with the cost of building and safely operating a plant, makes nuclear power less cost-effective than coal or natural gas. The cost of operating a nuclear power plant is high, both in terms of materials, labor, as well as safety and [planetary] security.
2. Nuclear waste: Nuclear power plants create electricity via nuclear fission, and the "spent" fuel from fission are radioactive waste. Nuclear waste must be stored on-site or transported to a secure location via railroad. This is an expensive and potentially dangerous process, and the nuclear waste storage tanks where the waste ends up may leak radioactive liquid into the soil.
3. Meltdowns: Nuclear power works via a set of interoperable conditions and processes (Read: chain reactions). Without proper cooling, these chain reactions can spiral out of control, overwhelming safety systems and leading to the melting of the nuclear reactor core in an event called a “core meltdown.”

## *12.1 Nuclear waste*

Spent nuclear fuel is still radioactive and must be stored appropriately for biological safety. Generally, spent fuel is placed in underground bunker-type environments made of concrete and lead, with "no dig" signs and symbols written there so that future generations do not accidentally dig it up.

## *12.2 Radiation risks*

Ionizing radiation can cause immediate damage to a person's body, including, at very high doses, radiation sickness and death. At lower doses, ionizing radiation can cause health effects such as cardiovascular disease and cataracts, as well as cancer. Because of the serious risk of ionizing radiation, nuclear power plants are costly and humans working in them require special, expensive equipment.

# 13 Energy from biomass and hydrocarbon

*A.k.a., Biomass energy.*

Hydrocarbons are different than carbohydrates. Hydrocarbons, per se, only contain hydrogen and carbon. The word "carbohydrate" means: carbo - carbon; hydr - hydrogen; ate - oxygen. Lipids (fats) are organic compounds that contain the same elements as carbohydrates: carbon, hydrogen, and oxygen. However, the hydrogen-to-oxygen ratio is always greater than 2:1. Proteins also contain carbon, hydrogen, and oxygen like carbohydrates and lipids, but they also contain nitrogen, and often, sulfur and phosphorus. All biomass is composed of some combination of carbohydrates, lipids, and/or proteins.

## 13.1 Biomass

Biomass is the term for organic matter derived from living organism, recently living organisms, and their waste that can be used as a source of energy. Biomass is "organic", meaning it is made of material that comes from living organisms and contains carbon atoms. Biomass may also be defined as biologically-produced matter based in carbon, hydrogen, and oxygen also. Biomass contains potential energy originating from the sun. Energy obtained from any biomass source is often called "bioenergy". Biomass can be combusted to turn a turbine and produce electrical power. Biomass can be composted to produce natural gas and soil.

As an energy carrier ("source"), biomass can either be used directly via combustion to produce heat and light, or indirectly after converting (concentrating and purifying) it to various forms of biofuel. Biomass can be used to produce heat (thermal energy), light (as visible EM radiation), mechanical power, electrical power, and fuel (as well as compost). Biomass can be transformed into usable carriers of energy through direct and indirect means. Biomass can be burned/combusted to produce heat and light (direct), converted into electrical and mechanical power (directly through heat), or processed into biofuel (indirect). In other words, as an energy source, biomass can either be used directly to produce heat and light, or indirectly after converting it to various forms of biofuel (i.e., an energy storage medium).

**NOTE:** *Biomass is thought to our oldest source of energy after the sun. Combustion (as fire) is understood to be the first controlled chemical reaction discovered by humans, in the form of campfires and bonfires. The ability to control fire (as a technology) led to dramatic changes in the habits (and potentially, the physiology) of early hominids. The combustion of biomass (plant material and animal waste) is the oldest known source of power production.*

Biomass generation is an integral part of Earth's carbon cycle. The carbon cycle is the process by which carbon is exchanged between all layers of the Earth: atmosphere, hydrosphere, biosphere, and lithosphere. Between periods of exchange, carbon is sequestered (stored as terrestrial/biologic or geologic). The carbon in fossil fuels has been sequestered for millions of years. Unlike plants, when hydrocarbons present in fossil fuels are extracted and burned for energy, their sequestered carbon is released into the atmosphere at a volume that cannot be immediately re-sequestered by the earth's natural carbon cycle. Fossil fuels take thousand years to form naturally. They cannot be replaced and sequestered as fast as they can be consumed.

In contrast to fossil fuels, biomass comes from recently living organisms. The carbon in biomass can continue to be exchanged by the carbon cycle. This is because biomass has a lower 'energy density' than fossil fuels. In order to ensure that the carbon cycle continues as trending and desired, biomass materials/resources must be sustainably farmed.

**NOTE:** *Biomass can be combusted or converted to biofuel.*

## 13.2 Biomass sources

**NOTE:** *Biomass is the same energy that makes fossil fuels. Fossil fuels are made through the concentration of biomass over time by heat and pressure within the earth.*

Technically, any plant or animal matter could be used as a source of biomass, because it will contain hydrogen, carbon, and oxygen. A wide variety of biomass forms are available on the planet, and biomass can be produced anywhere that plants or animals can live.

Well-known and highly effective sources of plant matter biomass include, but are not limited to: hemp, bamboo, corn, miscanthus, poplar, switchgrass, sorghum, sugarcane, and a variety of tree species, ranging from willow and eucalyptus, to oil palm (palm oil). Animal waste is another common form biomass.

Biomass resources can be classified as follows:

1. Biologically cultivated materials and residues (e.g., agricultural, aquaculture, permaculture, algae-culture etc.)
2. Forestry materials and residues
3. Food residues and by-products
4. Animal by-products (tallow, fish oil)
5. Animal/human solid waste
6. Landfill gases
7. Cellulose products (e.g., paper and cardboard)

### 13.2.1 Biofuel

Plant and animal matter, as an originating source of biomass, can be converted into biofuel. A **biofuel** is a fuel that is produced through natural biological processes, such as anaerobic digestion, rather than a fuel produced by geological processes, such as those involved in the formation of fossil fuels from prehistoric biological matter. Biofuels are classified into two primary categories:

1. First-generation biofuels - First-generation biofuels are derived from food-based biomass sources, which are fermented via sugars (carbohydrates/ starch) present in the biomass to produce bioethanol. Bioethanol is an alcohol fuel that can be used directly in a fuel cell to produce electricity, or serve as an additive to gasoline.
2. Second-generation biofuels - Second-generation biofuels utilize non-food-based biomass sources. These biofuels mostly consist of lignocellulosic biomass, which is not edible. Lignocellulosic is a chemically inert and structural rigid form of biomass. Advanced second-generation biofuels are generally made from non-food feedstocks (feedstock that could not also be used as food), such as municipal waste, algae, perennial grasses, and wood chips. These fuels include cellulosic ethanol, bio-butanol, methane gas (biogas), methanol and a number of synthetic gasoline/ diesel equivalents.

## *13.3 Biomass creation*

> **NOTE:** *The faster a plant grows, the more efficient it is as a source of biomass energy.*

Technically, all biomass (energy) is derived from plant- or algae-based material, which derives a significant portion of its energetic existence from solar electromagnetic radiation. Plants and other living organisms absorb the sun's energy, and use it to create the organic matter of their body. When biomass is burned, this stored energy is released as electromagnetic (and thermal) energy.

Through the use of solar electromagnetic radiation (energy), green plants convert carbon dioxide and water into carbohydrates and oxygen in a process called photosynthesis. It could be said that these plants "breath in" carbon dioxide and "breathing out" oxygen; however, in plants respiration is a different process. In green plants both photosynthesis and respiration occur as separate processes. During photosynthesis, water is broken down to form oxygen, and during cellular respiration, oxygen is combined with hydrogen to form water. Hence, plants, unlike other living things, produce oxygen. Essentially, photosynthesis is the opposite of [cellular] respiration.

> **DEFINITION: Photosynthetically active radiation (PAR)** *designates the spectral range (wave band) of solar radiation from 400 to 700 nanometers that photosynthetic organisms are able to use in the process of photosynthesis. This spectral region corresponds more or less with the range of light visible to the human eye. Other living organisms, such as Cyanobacteria, purple bacteria and Heliobacteria, can exploit solar light in slightly extended spectral regions, such as the near-infrared. These bacteria live in environments such as the bottom of stagnant ponds, sediment, and ocean depths. Because of their pigments, they form colorful mats of green, red and purple.*

In relatively bright light, photosynthesis is the dominant process. During photosynthesis, chlorophyll, the pigment that makes plants green, absorbs electromagnetic radiation (energy) from the sun and uses it along with carbon dioxide and water to make carbohydrate molecules (sugars). Carbohydrates are complex compounds composed of carbon, hydrogen, and oxygen. At night, or in the absence of light, photosynthesis essentially ceases (in most plants), and respiration is the dominant process. However, plants respire continuously, day and night -- respiration does not depend on light. Whereas photosynthesis absorbs energy (from sunlight), aerobic respiration yields energy (as a result of the oxidation of glucose (a carbohydrate molecule, $C_6H_{12}0_6$).

1. Photosynthesis:
   - $6CO_2 + 6H_20$ + energy/energy in > $C_6H_{12}0_6 + 6O_2$
2. Aerobic respiration:
   - $C_6H_{12}0_6 + 6O_2$ > $6CO_2 + 6H_20$ + energy/energy out

Biomass generation requires carbon dioxide; hence cultivated and combusted biomass in the appropriate ratio is carbon dioxide neutral. When the carbohydrates that plants have made are burned, they turn back into carbon dioxide and water, and release the energy they captured from the sun.

> **NOTE:** *Some plants absorb carbon dioxide at during the day, and release oxygen at night. Typically, desert plants, such as cactus and other succulents, and epiphytic bromeliads and orchids from the jungle absorb $CO_2$ during the day and release oxygen at night. These plants include, but are not limited to snake plants, Easter and Christmas cactus, aloe vera plants (a species of succulent plant), mother-in-laws tongue, areca palm, a variety of bromeliads, and orchids such as the moth and the dendrobium.*

Plant-based biomass is often specifically called 'lignocellulosic biomass'. Lignocellulose is composed of carbohydrate polymers (cellulose, hemicellulose), and an aromatic polymer (lignin).

> **NOTE:** *The efficiency of photosynthesis is low, about 5% maximum (solar energy to energy in sugar).*

In general, good biomass material is a combination of cellulose (~60%), lignin (~30%), and other organic materials (~10%). Cellulose and lignin start with simple sugars (glucose) made through photosynthesis. Cellulose is a fiberous organic compound used as structural material in plants (fibers). Cellulose is the most abundant organic polymer on Earth. Lignin is a class of complex organic polymers that form important structural materials in the support tissues of vascular plants and some algae.

Algae is a source of biomass energy. Some algaes produce energy through photosynthesis at a much higher rate than any other biomass source. Further, algae contains oils that can be converted into biofuels (and/or food). Algae can be fermented to produce biofuels such as ethanol, butanol, and methane, as well as biodiesel and hydrogen. Algae can be grown in salt and fresh water; it does not require soil. Algae takes up much less space to produce than other biomass/ biofuel crops; particularly because algae can be grown in bioreactors.

## *13.4 Biomass to biofuel conversion technologies*

Biomass can be converted into a more concentrated energy carrier/source known as biofuel (also known as 'direct energy' or a 'concentrated energy resource'). Biofuels are easier to transport and are more energy dense than their original biomass resource. Also, their combustion characteristics are more convenient and predictable than raw biomass. The conversion of biomass to biofuel can be achieved by different methods, which are broadly classified into: thermo-chemical, biochemical, and chemical. The conversion process leads to biofuel that can take any of the following three forms of matter: biofuel solid; biofuel liquid; or biofuel gas.

1. **Thermo-chemical conversion** is the application of heat and chemical processes in the production of concentrated energy products from biomass (i.e., biofuel).
2. **Biochemical conversion** involves use of enzymes, bacteria, or other microorganisms to break down biomass into liquid fuels. The primary processes are anaerobic digestion/decomposition, fermentation, and composting.
3. **Chemical conversion** involves use of chemical agents to convert biomass into liquid fuels.

Note that hydrocarbons (as hydrocarbon fuels) can be derived from some biomass. There are a variety of ways of producing hydrocarbons from biomass since biomass is a mixture of carbon, hydrogen, and oxygen, and a pure hydrocarbon consists entirely of hydrogen and carbon. For instance, gasification converts whole biomass into a mixture of carbon monoxide and hydrogen gases, which can then be used to synthesize hydrocarbons.

### 13.4.1 Thermo-chemical conversion

Thermo-chemical conversion involves the use of heat as a significant mechanism for the chemical conversion of biomass into biofuel. Pyrolysis, torrefaction, and gasification are the basic thermochemical conversion technologies.

1. **Torrefaction -** Before biomass can be combusted, it must be dried. Torrefaction, like pyrolysis, is the conversion of biomass to a drier and refined form with the application of heat in the absence of oxygen, but at lower temperatures than those typically used in pyrolysis. During torrefaction, biomass is heated to about 200°C - 320°C. The biomass dries out so completely that it loses the ability to absorb moisture, or rot. It loses ~20% of its original mass, but retains 90% of its energy. The lost energy and mass can be used to fuel the torrefaction process. Torrefaction produces a solid biofuel. During torrefaction, biomass becomes a dry (generally, black) material. It is then compressed into briquettes. Biomass briquettes are hydrophobic, meaning they repel water. This makes it possible to store them in moist areas. The briquettes have a high energy density and are easy to burn.
2. **Pyrolysis** - Heating biomass to 200°C - 320°C in a pressurized environment without the presence (or with a very low presence) of oxygen. The absence of oxygen prevents combustion, causing a different chemical alteration to the substance. Pyrolysis produces a dark liquid called pyrolysis oil, a synthesis gas called syngas, and a solid residue called biochar.
    A. **Pyrolysis oil (bio-oil or biocrude)** - a type of tar (a mixture of hydrocarbons and free carbons). It can be combusted, used as a component in other fuels, and used as a compound in plastic.
    B. **Syngas (synthesis gas)** - a fuel gas mixture consisting primarily of hydrogen, carbon monoxide, and often, carbon dioxide. It can be converted into fuel, such as, synthetic natural gas. And, it can be converted into methane (used as a replacement for natural gas).
    C. **Biochar** - a type of charcoal, which consists of carbon and any remaining ash, obtained by removing water and other volatile constituents from animal and vegetation substances. Biochar is high in carbon. It is used as a soil amendment/conditioner. Biochar enriches soil and prevents it from leaching pesticides and other nutrients into runoff. Biochar is also an excellent carbon sink. Carbon sinks are reservoirs for carbon-containing chemicals, including greenhouse gases.
    D. **Gasification** - A process that converts organic

or fossil fuel based carbonaceous materials into carbon monoxide, hydrogen, and carbon dioxide, producing syngas and slag. During the gasification process, a biomass feedstock is heated to more than 700° C with a controlled amount of oxygen. During gasification, syngas is purified of sulfur, mercury, and other polluting particulates. Slag, a by-product of the process, forms as a glassy, molten liquid, which can be used to make shingles, cement, or asphalt.

### 13.4.2 Biochemical conversion

Many highly efficient biochemical processes have developed in nature to break down the molecules of which biomass is composed. Biochemical conversion processes use the enzymes of bacteria and other microorganisms (e.g., fungi) to convert biomass to gas and liquid fuels. The primary processes are anaerobic digestion/decomposition, fermentation, and composting:

1. **Anaerobic decomposition/digestion to methane** - the process by which microorganisms break down organic material in an oxygen-free (or low oxygen) environment. Anaerobic digestion is widely used for the production of methane- and carbon-rich biogas from biomass (e.g., crop residues, food scraps, and human and animal waste). Anaerobic digestion is frequently used in the treatment of wastewater, and to reduce emissions from landfills. Controlled anaerobic digestion is usually a multi-stage process. First, the carbohydrates are broken down. The resulting sugars and amino acids are then converted into carbon dioxide, hydrogen, ammonia, and organic acids. Finally, these products are converted into methane and carbon dioxide. Microorganisms are used in each stage of the process. These mixed cultures allow digesters to be operated over a wide temperature range, for example, above 0° C and up to 60° C. Solid remnants of the original biomass input are left over after the digestion process. This by-product, or digestate, has many potential uses. Potential uses include fertilizer (although it should be chemically assessed for toxicity and growth-inhibiting factors first), animal bedding and low-grade building products like fiberboard. Methane production is most useful with animal and human wastes, as well as landfill wastes, where it happens naturally.
2. **Fermentation to biofuel** - a biological/metabolic process by microorganisms that converts carbohydrate (sugar) to acids, gases, or alcohol (e.g., ethanol). Fermentation generally involves multiple stages. The science of fermentation is known as zymology. Biomass is the only short-term renewable energy source that can be converted into liquid biofuels, such as ethanol and biodiesel. Ethanol is made by fermenting biomass that is high in carbohydrates, such as hemp, sugar cane, wheat, or corn through ethanol/alcoholic fermentation. Biodiesel is made from combining ethanol with animal fat, recycled cooking fat, or vegetable oil. Biofuels do not combust as efficiently as petrol. They can, however, be blended with petrol.
   A. **Ethanol fermentation** (alcoholic fermentation) - converts sugars such as glucose, fructose, and sucrose into cellular energy, producing ethanol and carbon dioxide as a by-product. Note that as a material resource, ethanol can be used as a consumable, as a disinfectant, and as a fuel.
3. **Composting** - the process by which organic matter is decomposed and recycled as a fertilizer and soil amendment. Bacteria requiring oxygen to function (aerobic bacteria) and fungi manage the chemical process by converting the inputs into heat, carbon dioxide and ammonium. Note that the composting process naturally produces heat (thermal energy).

### 13.4.3 Chemical conversion

The utilization of chemical processes to convert biomass into biofuel.

1. **Transesterification** - Transesterification is a chemical reaction through which fatty acids from oils, fats, and greases are bonded to alcohol. This process reduces the viscosity of the fatty acids and makes them combustible. It is an organic chemistry process wherein the organic group R" of an ester is exchanged with the organic group R' of an alcohol. The process refers to a reaction between an ester of one alcohol and a second alcohol to form an ester of the second alcohol and an alcohol from the original ester. It is the most common form of chemical-based conversion. Biodiesel is a common end-product of transesterification, as are glycerin and soaps. For instance, mixing methanol with sodium hydroxide will create sodium methoxide. This liquid can then be mixed into vegetable oil. When the mixture settles, glycerin is left on the bottom and methyl esters, or biodiesel, is left on top. The glycerin can be used to make soap (or many other products), and the methyl esters are washed and filtered. Almost any bio-oil (e.g., soybean oil), animal fat or tallow, or tree oil can be converted to biodiesel. Transesterification of algal oil is frequently accomplished with ethanol and sodium ethanolate serving as the catalyst.
2. **Black liquor production** - The kraft process (also known as kraft pulping or sulfate process) is a

mechanical-chemical process that converts wood into the main component of paper using a hot mixture of water, sodium hydroxide, and sodium sulfide, known as white liquor, that breaks the bonds that link lignin, hemicellulose, and cellulose. One of the by-products of the process is known as "black liquor", which retains more than 50% of the wood's biomass energy. Black liquor can be used as a biofuel feedstock.

3. **Hydrogen production** - Biomass has a high concentration of hydrogen, which can be chemically extracted and used as an energy source (e.g., hydrogen fuel cells).

## *13.5 Hydrocarbons*

**CLARIFICATION:** *Hydrocarbons are always named based on the longest carbon chain. When a hydrocarbon has a double bond we replace the -ane ending with -ene. When the hydrocarbon has more than three carbon the position of the double bond must be specified with a number. Hydrocarbons with triple bonds are named basically the same, we replace the -ane ending with -yne. Cyclic hydrocarbons with delocalized bonds are called aromatic hydrocarbons the most common of these is benzene.*

Hydrocarbon molecules have a high energy density relative to other molecules, and are "easy" to store and transport. Hydrocarbons are the simplest form of organic [lipid] compound, and contain only carbon and hydrogen (i.e., hydrogen + carbon only).

1. Biomass hydrocarbons
2. Fossil hydrocarbons

Hydrocarbons can be found in the forms of matter:

1. Gases (e.g. methane and propane)
2. Liquids (e.g. hexane and benzene)
3. Waxes or low melting solids (e.g. paraffin wax and naphthalene)
4. Polymers (e.g. polyethylene, polypropylene and polystyrene)

Hydrocarbons can be classified at a top-level as either open chain or closed chain:

1. **Aliphatic hydrocarbons (open chain)** - - formed by successive bonds between carbon atoms and may be branched or unbranched (linear or "normal"). Herein, the overall geometry of the molecule is altered by the different geometries of single, double, and triple covalent bonds. A normal/linear/unbranched hydrocarbon has one chain of consecutively bonded carbon atoms. A branched hydrocarbon has at least one carbon atom not bonded to the end carbon of a chain of consecutively bonded carbon atoms. Instead, at least one carbon atom forms a bond to an inner carbon atom in the chain of consecutively bonded carbon atoms. Aliphatic hydrocarbons (open chain) can be either saturated or unsaturated hydrocarbons, neither of which contain a benzene ring. Aliphatic hydrocarbons are classified based on the structure and bonding of the carbon skeleton into one of three groups: alkanes (saturated); alkenes (unsaturated double bond), and alkynes (unsaturated triple bond). Saturated hydrocarbons consist entirely of single bonds, wherein each carbon atom is connected to four other atoms. Unsaturated hydrocarbons have one or more double or triple bonds between carbon atoms. Aliphatic hydrocarbons tend to be flammable; they combust (undergo transformation) through which old bonds are broken, and new bonds are formed.

A. **Alkanes (a.k.a., saturated hydrocarbons; paraffins)** - Alkane molecules are those chemical structures that are based on carbon atoms having only single bonds, and that are completely saturated with hydrogen atoms. Each carbon atom is connected to four other atoms; either another carbon within the skeletal structure, or a hydrogen atom. Saturated hydrocarbons are the basis of petroleum fuels and are found as either linear or branched species. Alkanes can be described by the formula: $C_nH_{2n+2}$, where 'n' is the number of carbon atoms present.

B. Methane, where n=1, described by: $CH_4$

C. **Alkenes (a.k.a., olefins; unsaturated form of hydrocarbon)** - Alkene molecules contain at least one carbon-carbon double bond. Alkenes can be described by the one double bond formula: $C_nH_{2n}$ (assuming non-cyclic structures). Alkene hydrocarbons are present in most organic and biological molecules. Alkene compounds do not occur naturally in crude oil, but are produced by reaction during the refining process. Example alkenes include: ethylene; propylene; or butylene.

D. **β-Carotene carotenoids** (a.k.a., tetraterpenoids and terpenoids) - Carotenoids are organic pigments that are found in the chloroplasts and chromoplasts of plants and some other photosynthetic organisms, including some bacteria and some fungi. Carotenoids can be produced from fats and other basic organic metabolic building blocks by all these organisms. There are over 600 known carotenoids, which are classified into two classes: xanthophylls (which contain oxygen) and carotenes (which are purely hydrocarbons, and contain no oxygen). Carotenes typically contain only carbon and hydrogen (i.e., are hydrocarbons), and are in the subclass of unsaturated hydrocarbons. The term, carotenoid, is a misnomer and originates from a scientist (1831) who proposed the term “carotene” for the hydrocarbon pigment he had crystallized from carrot roots.

E. **Alkynes (unsaturated form of hydrocarbon)** - Alkyne molecules contain at least one carbon-carbon triple bond. Alkynes can be described by the one triple bond formula: $C_nH_{2n-2}$. Alkyne hydrocarbons rarely occur in biological molecules or pathways.

2. **Cyclic hydrocarbons (closed chain)** - formed by successive rings of carbon. Whenever the ends of a carbon chain are joined together, that molecule is said to be cyclic.
   A. **Cycloalkanes** (cycloparaffins or naphthenes, distinct from naphthalene) - are the cyclic analog of an alkane. Cycloalkanes are alkanes that consist entirely of single bonds with at least three carbon atoms linked together to form a structural ring (hence, the prefix ‘cyclo-’). In other words, cycloalkanes are alkanes in which all or some of the carbon atoms are arranged in a ring. Cycloalkanes are monocyclic saturated hydrocarbons, and hence, are arranged in a structure containing a single ring (monocyclic, possibly with side chains), and all of the carbon-carbon bonds are single. Note here that there are also polycyclic alkanes, which are molecules that contain two or more monocyclic cycloalkanes that are joined, forming multiple rings. If the carbon chain that forms the backbone of a straight-chain hydrocarbon is long enough, we can envision the two ends coming together to form a cycloalkane. One hydrogen atom has to be removed from each end of the hydrocarbon chain to form the CC bond that closes the ring. Cycloalkanes therefore have two less hydrogen atoms than the parent alkane. When a cycloalkane contains only one ring, the general formula is $C_nH_{2n}$. However, the complete chemical formula for cycloalkanes is $C_nH_{2(n+1-r)}$ , where n is the number of carbon atoms and r is the number of rings. Cycloalkanes are named analogously to their normal alkane parent counterpart of the same carbon count: cyclobutane; cyclopropan; cyclobutane; cyclopentane; cyclohexane; etc. The larger cycloalkanes, with more than 20 carbon atoms are typically called cycloparaffins.
   B. **Cycloalkenes** - are the cyclic analog of an alkene. Cycloalkenes are alkenes that consist of three or more carbon atoms linked together with at least one carbon-carbon double bond to form a structural ring (hence the prefix ‘cyclo-’). They have no aromatic character.
   C. **Cycloalkynes** - are the cyclic analog of an alkyne. A cycloalkyne consists of a closed ring of carbon atoms containing one or more triple bonds. Cycloalkynes have a general formula $C_nH_{2n-4}$.
   D. **Aromatic hydrocarbons (arenes or aryl hydrocarbon)** - have at least one benzene-like ring (i.e., aromatic ring) of alternate single and double bonds with delocalized pi electrons between carbon atoms forming the ring(s). A benzene ring is a ring of six carbons with alternating double and single bonds. As a result, the benzene has six hydrogens and the formula for a benzene molecule is $C_6H_6$. Aromatic hydrocarbons can be monocyclic (MAH) or polycyclic (PAH). These compounds possess unique properties due to the delocalized electron density in benzene, including additional stabilization. Note that the term ‘aromatic’, and was assigned before the physical mechanism determining aromaticity was discovered; the term was coined because many of the compounds have a sweet or pleasant odour.

Some sources of biomass contain hydrocarbon substances known as terpenoids, which are similar to petroleum. These plants and algaes are known as “hydrocarbon plants” (or “petro-plants”) and “hydrocarbon algaes”. Hydrocarbon plants use unique metabolic pathways to produce hydrocarbon products. For instance, some of these plants produce a type of natural rubber (e.g., latex) that contains liquid hydrocarbon terpenoids of a high molecular weight, which can be converted into fuel and other products. Natural rubber is a hydrocarbon that contains long chains of alternating C=C double bonds and C-C single bonds. Terpenoid hydrocarbons may be extracted from the bulk matter of such plants through the use of organic solvents.

Well known families of hydrocarbon plants include, but are not limited to: Apocynaceae, Asclepiadaceae, Dipterocarpaceae, Euphorbiaceae, Hardwickia Pinnata (family Leguminosae), Moraceae, Sapotaceae, and sunflower (family Composiae). The latex of Euphorbia Lathyrus contains a fairly high percentage of terpenoids. And, the carbohydrate (hexose) from such plants can be used for ethanol formation.

## *13.6 Power from biomass, fossil fuels, and*

### other hydrocarbons

Combustion is the primary way by which power is produced from biomass, biofuel, fossil fuel, and other hydrocarbons. Biomass (and its refined products) can be ignited and combusted for heat, light, and fluid [gas] pressure. Take note that when gases are combusted they generally expand irreversibly, and the fluid pressure which has been generated may be used to power a turbine or an engine.

1. **Combustion as direct firing/burning** - the direct burning of biomass or biofuel in the presence of oxygen. Fire can be used for heat, light, and/or fluid [gas] pressure.
   A. In a furnace, biomass burns in a combustion chamber converting the biomass into heat. The heat may be distributed in the form of hot air or water. A common type of furnace for area heating is known as a wood-pellet stove. A pellet stove is a stove that burns compressed wood or biomass pellets to create a source of heat. Wood pellets are the most common type of pellet fuel and are generally made from compacted sawdust and related industrial wastes from the milling of lumber, manufacture of wood products and furniture, and construction. The biomass (possibly in the form of pellets) are placed in a hopper, which feeds the mass into a furnace, where it is burned. The heat may used to boil water in a boiler. In a boiler, the heat of combustion is converted into steam. Steam can be used to produce mechanical energy through a turbine, electrical energy through a turbine-generator, or heating.
   B. In an engine, combustion occurs as a flame that propagates in a cylinder.
- **Combustion as co-firing/co-generation** - Biomass is combusted with a fossil fuel, often in pre-existing fossil fuel (coal) plants. Biomass can also be used in co-generation (a.k.a., combined heat and power, CHP), which is the simultaneous production of heat and electricity.

Some biofuel technologies can be directly converted into electrical power via electrochemical oxidation of the material. This electrochemical process can occur in carbon fuel cells, ethanol fuel cells, and microbial fuel cells. The fuel can also be consumed indirectly via a fuel cell system containing a reformer which converts the bio-mass into a mixture of CO and $H_2$ before it is consumed in the fuel cell.

## 14 Energy storage (secondary energy carriers)

**CLARIFICATION:** *Primary energy carriers include all of the natural resources like natural gas, crude oil, coal, uranium, solar radiation, wind power, hydropower, and geothermal energy. Secondary energy carriers are those carriers of for which the production of other energy was needed (i.e., they required charging/producing by another power source).*

Energy can be stored in a variety of different carriers. There are many different types of energy stored in materials, and it takes a particular type of reaction to release each type of energy. In order of the typical magnitude of the energy released, these types of reactions are: nuclear, chemical, electrochemical, and electrical.

**NOTE:** *Stored energy can be converted to power through the use of appropriate conversion/release technology.*

Energy storage refers to the storage of useful energy that may either be used directly or transmitted is input in an end-use application.

Energy can be stored only as potential energy. Storing energy requires mass. Today, the most common way of storing energy is in [a mass of] batteries. Energy storage usually means batteries, but there are other ways, like pumped hydro and molten salt. But whatever the technology, there are two primary performance parameters in concern to energy storage. And, the usefulness of an energy storage system depends on both of these quantities. The two quantitative parameters are:

1. How much total energy can the system store? (Think watt-hours)
2. How much power can it deliver at any moment? (Think watts)

Storage systems have to be able to store enough energy to last through the “blackout” periods, and they have to be able to deliver that energy fast enough to meet the electrical load.

Once you know both the energy storage capacity (say, in megawatt-hours) and the output power (say, megawatts), you can simply divide these numbers to find how long the backup power will last. For example, a 20 megawatt-hour storage facility delivering power at the rate of 2 megawatts will last for 20 ÷ 2, or 10 hours on a full charge.

- Fuel - Matter that stores energy is called a ‘**fuel**’. Materials that store energy for work are called fuels. The amount of energy a fuel or other energy carrying source contains is called ‘energy density’. To acquire energy, you must use energy.

The system uses all available energy from locally generated sources (such as photovoltaic cells) first, then 'fills in' with power from the grid or, when the grid is not available, from batteries. Batteries are used to provide electricity power when solar radiation (including, wind and water) is not available, which means for solar, every nights and on cloudy days when the PV array is not producing enough energy to serve the connected loads.

> **NOTE:** *The external energy of a collection of matter, or system, is related to the relative condition of the matter with respect to its environment.*

## 14.1 Measurement for energy storage

In general, energy storage is measured in Joules. The formula for energy storage is as follows:

- $J = \frac{1}{2}CE^2$ = 1 watt/second
- where, J = joules, C = farads and E = voltage of the charge.

## 14.2 Energy storage performance parameters

Energy is a quantity that can be calculated for a given static carrier. Therein, **capacity** is the measure of a system's potential to generate power (or in the case of batteries, both generate power and store energy).

All energy storage devices have:

1. A power rating
2. An energy capacity rating
   There are two main things to consider with the choice of energy storage. Directly,
3. Can it produce enough current to the application (e.g., a motor)?
4. Does it have enough stored energy to last a required amount of time (e.g., 1 hour)?

Batteries have:

- Capacity = amp-hours

Energy storage usually means batteries, but there are other ways, like pumped hydro and molten salt. But whatever the technology, there are two performance parameters of interest:

1. How much total energy can the system store? (Think watt-hours)
2. How much power can it deliver at any moment? (Think watts)
3. How much recover efficiency can the system restore

Once you know both the energy storage capacity (say, in megawatt-hours) and the output power (say, megawatts), you can simply divide these numbers to find how long the backup power will last.

There are two performance parameters of interest in energy storage:

1. How much total energy can the system store? (Think watt-hours)
2. How much power can it deliver at any moment? (Think watts)

The usefulness of a storage system depends on both of these quantities. A system that stored an enormous amount of energy wouldn't be very useful if it could only return that energy a few watts at a time. And a system powerful enough to light up a whole city wouldn't be good for much if its batteries died after a few minutes.

## 14.3 Carriers/sources/modes of energy storage (energy storage systems)

A widely-used approach for classifying EES systems is the determination according to the source/carrier/form of energy used. EES systems are classified into mechanical, electrochemical, chemical, electrical and thermal energy storage systems:

Take note that these energy storage systems are sometimes as [secondary] energy carriers.

### 14.3.1 Mechanical storage systems

Energy may be "stored" in a mechanical system. There are many different types of mechanical systems utilized for the storage of [mechanical] energy.

1. **Pumped hydro storage** - the storage of water at elevation, which is released when power is required.
2. **Compressed/pressurized air storage** - the storage of compressed gas, which is released when power is required.
3. **Flywheel energy storage** - the storage of rotational mechanical/kinetic energy in an accelerated rotor, which is released when power is required.
4. **Gravitational potential energy** - the storage of mass at elevation, which is released when power is required.
5. **Tension** - the storage of energy in a device that holds tension, which is released when power is required.

### 14.3.2 Pumped hydro storage (PHS)

> **NOTE:** *Technically, PHS and hydroelectric dam systems store gravitational potential energy - fluids stored at elevation.*

Pumped hydro storage is a method of keeping water in reserve at elevation. The water is pumped to a storage pool above the power generation mechanism at a time when power demand is low, such as during the middle of the night. The water is then allowed to flow back through the turbine-generators at times when demand is high and a heavy load is place on the system.

The reservoir acts much like a battery, storing power in the form of water at elevation when demands are low, and producing maximum power during daily and seasonal peak periods. An advantage of pumped storage is that hydroelectric generating units are able to start up quickly and make rapid adjustments in output.

Conventional pumped hydro storage systems use two water reservoirs at different elevations to pump water during off-peak hours from the lower to the upper reservoir (charging). When required, the water flows back from the upper to the lower reservoir, powering a turbine with a generator to produce electricity (discharging). There are different options for the upper and lower reservoirs. For example, higher elevation dams and ponds can be used as pumped hydro storage plants. For the lower reservoir, flooded mine shafts, underground cavities, and even the open sea are also technically possible. PHS has existed for a long time – the first pumped hydro storage plants were used in Italy and Switzerland in the 1890s. Advantages are the very long lifetime and practically unlimited cycle stability of the installation. Main drawbacks are the dependence on topographical conditions and large land use. The main applications are for energy management via time shift, namely non-spinning reserve and supply reserve.

### 14.3.3 Compressed air (compressed gas) energy storage (CAES), also pressurized air storage

This is an electro-mechanical storage solution where air (or gas) is compressed with electrical power, and can then be released again to drive a power generator. Electricity is used to compress air (or other gas) and store it in either an underground structure or an above-ground system of vessels or pipes. When needed the compressed air may be used for fluid power, or it may be mixed with natural gas, burned and expanded in a modified gas turbine to produce mechanical and electrical power. Typical underground storage options are caverns, aquifers or abandoned mines. If the heat released during compression is dissipated by cooling and not stored, the air must be reheated prior to expansion in the turbine. This process is called diabatic CAES and results in low round-trip efficiencies of less than 50%. Diabatic technology is well-proven; the plants have a high reliability and are capable of starting without extraneous power. The advantage of CAES is its large capacity; disadvantages are low round-trip efficiency and geographic limitation of locations.

Compression of air creates heat; the air is warmer after compression. Expansion requires heat. If no extra heat is added, the air will be much colder after expansion. If the heat generated during compression can be stored and used during expansion, the efficiency of the storage improves considerably. There are three ways in which a CAES system can deal with the heat. Air storage can be adiabatic, diabatic, or isothermal.

1. **Adiabatic compressed air energy storage (ACAES)** - Adiabatic storage continues to keep the heat produced by compression and returns it to the air when the air is expanded to generate power.
2. **Diabatic compressed air energy storage (DCAES)** - Diabatic storage dissipates much of the heat of compression with intercoolers (thus approaching isothermal compression) into the atmosphere as waste; essentially wasting, thereby, the renewable energy used to perform the work of compression. Upon removal from storage, the temperature of this compressed air is the one indicator of the amount of stored energy that remains in this air. Consequently, if the air temperature is low for the energy recovery process, the air must be substantially re-heated prior to expansion in the turbine to power a generator.
3. **Isothermal compressed air energy storage (ICAES)** - Isothermal compression and expansion approaches attempt to maintain operating temperature by constant heat exchange to the environment.

### 14.3.4 Flywheel energy storage (FES)

In flywheel energy storage, rotational energy is stored in an accelerated rotor, a massive rotating cylinder.
This type of energy storage system is also sometimes known as a mechanical battery. The main components of a flywheel are the rotating body/cylinder (comprised of a rim attached to a shaft) in a compartment, the bearings and the transmission device (motor/generator mounted onto the stator). The energy is maintained in the flywheel by keeping the rotating body at a constant speed. An increase in the speed results in a higher amount of energy stored. To accelerate the flywheel electricity is supplied by a transmission device. If the flywheel's rotational speed is reduced electricity may be extracted from the system by the same transmission device. Advanced FES systems have rotors made of high-strength carbon filaments, suspended by magnetic bearings, and spinning at speeds from 20000 to over 50000 rpm in a vacuum enclosure. The main features of flywheels are the excellent cycle stability and a long life, little maintenance, high power density and the use of environmentally inert material. However, flywheels have a high level of self-discharge due to air resistance and bearing losses and suffer from low current efficiency.

### 14.3.5 Gravitational potential energy storage

with solid mass

Changing the altitude of solid masses can store via an elevating system driven by an electric motor/generator. When power (energy) is required, the mass is released and pulled ("falls") toward the center of gravity.

### 14.3.6 Spring-Tension energy storage

Energy can be stored in a tension device, such as the winding of a spring in an pocket watch. Potential energy is stored in the spring's tension. When the tension on the spring is released, mechanical/kinetic energy (power) is released.

### 14.3.7 Chemical energy storage systems (secondary energy carriers)

The energy is stored in a static chemical medium (i.e., chemical fuel), such as petroleum fuel (e.g., coal, gasoline, diesel fuel, natural gas) or biofuel (e.g., biogas, char).

### 14.3.8 Solid fuel energy storage

Any solid fuel is a chemical energy storage medium.

### 14.3.9 Liquid fuel energy storage (a.k.a., power to liquid)

Any liquid fuel is a chemical energy storage medium.

### 14.3.10 Gaseous fuel energy storage (a.k.a., power to gas)

Power to gas refers to technology that converts electricity into a gaseous fuel such as hydrogen or methane. The main purpose of the following chemical energy storage systems is to use "excess" electricity (i.e., electricity when available) to produce hydrogen via water electrolysis. Once hydrogen is produced different ways are available for using it as an energy source/carrier, either as pure hydrogen or as SNG.

These chemical energy storage systems allow for the storage of large amounts of energy, up to the TWh range, and for greater periods of time – even as seasonal storage. Another advantage of hydrogen and SNG is that these universal energy carriers can be used in different habitat service sub-systems.

#### *14.3.10.1 Hydrogen ($H_2$)*

Hydrogen is the lightest of all chemical elements. It is odourless, colourless, and non-toxic. It has a high diffusibility, and boiling point of approximately -259.2°C, with ignition limits in air 4.0-75.0 Vol.%. Hydrogen can be stored as either compressed hydrogen ($CH_2$) in tanks at 200 bar and up to 700 bar in the near future, or as liquid hydrogen in cryogenic tanks, or as metal hydride. In order to increase storage density, hydrogen can be liquified. It is then called $LH_2$ (Liquid/Liquefied Hydrogen) and has to be stored and transported at -253°C (-423°F) in cryogenic tanks. Liquefaction is highly energy-consuming, and requires about one third of the energy content of the liquid hydrogen. Different approaches exist to storing the hydrogen, either as a gas under high pressure, a liquid at very low temperature, adsorbed on metal hydrides or chemically bonded in complex hydrides. However, for stationary applications gaseous storage under high pressure is the most popular choice. Smaller amounts of hydrogen can be stored in above-ground tanks or bottles under pressures up to 900 bar. For larger amounts of hydrogen, underground piping systems or even salt caverns with several 100 000 m³ volumes under pressures up to 200 bar can be used.

Hydrogen can be produced via water-electrolysis. Electrolysis itself is the separation of bonded chemical elements. Therein, water-electrolysis involves running an electric current through water to split the bonded chemical elements into its compounds hydrogen and oxygen, both of which may then be stored.

Hydrogen may be used in fuel cells for local electricity generation. Therein, a typical hydrogen storage system consists of an electrolyzer, a hydrogen storage tank, and a fuel cell. An electrolyzer is an electrochemical converter which splits water with the help of electricity into hydrogen and oxygen. It is an endothermal process (i.e. heat is required during the reaction). Hydrogen is stored under pressure in gas bottles or tanks, and this can be done practically for an unlimited time. To generate electricity, both gases flow into the fuel cell where an electrochemical reaction, which is the reverse of water splitting (i.e., reverse of electrolysis) takes place: hydrogen and oxygen react and produce water, heat is released, and electricity is generated. For hydrogen storage systems specifically, the oxygen is generally vented to the atmosphere on electrolysis, and oxygen is taken from the air for the power generation.

> **NOTE:** *In fuel cells electricity is generated by oxidizing hydrogen or methane. This combined electrolysis-fuel cell process is an electrochemical energy storage system. However, both gases are multi-purpose energy carriers. Electricity can be generated in a gas or steam turbine.*

#### *14.3.10.2 Oxygen ($O_2$)*

Oxygen can be produced via water-electrolysis. Electrolysis itself is the separation of bonded chemical elements. Therein, water-electrolysis involves running an electric current through water to split the bonded chemical elements into its compounds hydrogen and oxygen, both of which may then be stored.

The oxygen can be compressed and stored in a storage tank. It can then be combusted to produce heat or its combustion can be used to power a turbine generator to produce mechanical and electrical power.

#### *14.3.10.3 Methane and synthetic natural gas (SNG)*

Methane is the simplest hydrocarbon with the molecular formula $CH_4$. Methane is more easily stored than hydrogen and the transportation.

Synthesis of methane (also called synthetic natural gas, SNG or syngas) is the second option to store electricity as chemical energy. Synthetic natural gas (syngas or SNG) can be created in a multi-step process, starting with hydrogen and oxygen. Hydrogen is then reacted with carbon dioxide in a Sabatier process, producing methane and water. Here a second step is required beyond the water splitting process in an electrolyzer, a step in which hydrogen and carbon dioxide react to methane in a methanation reactor. As is the case for hydrogen, the SNG produced can be stored in pressure tanks, underground, or fed directly into a gas grid. Several $CO_2$ sources are conceivable for the methanation process, such as fossil-fuelled power stations, manufacturing/production installations, or biogas plants.

## 14.3.11 Biological energy storage

Technically, energy can be stored in biological systems via glycogen, starch, and lipid production. Mammals, for example, store energy in the form of fat (i.e., lipids) and liver glycogen. Many plants store energy in the form of starch.

## 14.3.12 Electrochemical storage systems

Energy may be stored within an electrochemical system.

> **NOTE:** *An* **uninterruptible power supply (UPS)** *is a device that allows an electrical (or other) system to keep running for at least a short time when the primary power source is lost. It also provides protection from power surges.*

Technically, a battery is a chemical potential energy storage system, however, they are classified herein under electrochemical storage because when the energy in a battery is released it is released into an electrical system. In thermodynamics, 'chemical potential' is defined as the time rate of change of internal energy of a system through changes in the number of particles in the system (or in the limiting case, the derivative of internal energy through the number of particles).

Chemical potential is characterized by the following abilities to do work in a chemical system:

1. To react with other substances (chemical reaction).
2. To move to another state (phase transition).
3. To reallocate the space (diffusion).

There are two types of non-flow batteries: primary batteries (disposable batteries), which are designed to be used once and discarded, and secondary batteries (rechargeable batteries), which are designed to be recharged and used multiple times.

Batteries come in many sizes, voltages, and amperes.

## 14.3.13 Primary batteries (non-rechargeable)

A primary battery is a portable voltaic cell that is not rechargeable. These batteries must be re-cycled after a single use. In general, the electrochemical reaction occurring in the cell is not reversible, rendering the cell non-rechargeable. As a primary cell is used, chemical reactions in the battery use up the chemicals that generate the power; when they are gone, the battery stops producing electricity and is useless. Primary batteries are used when charging is impractical or impossible (e.g., pacemaker). Primary batteries are designed for high specific energy, long storage times, instant readiness and/or long usage times.

The most common types of primary battery are listed below, but note that secondary batteries, such as lithium ion batteries, can be designed to function as a primary, and not secondary, battery.

### *14.3.13.1 Zinc Manganese oxide (alkaline battery)*

Alkaline batteries are dependent upon a chemical reaction between zinc and manganese (IV) oxide (Zn/$MnO_2$). The alkaline battery gets its name because it has the alkaline electrolyte, potassium hydroxide, instead of the acidic ammonium chloride or zinc chloride electrolyte of the zinc-carbon batteries. Other battery systems also use alkaline electrolytes, but they use different active materials for the electrodes.

### *14.3.13.2 Zinc-carbon (Leclanche)*

A zinc–carbon battery is a dry cell battery that delivers a potential of 1.5 volts between a zinc metal electrode and a carbon rod from an electrochemical reaction between zinc and manganese dioxide mediated by a suitable electrolyte.

## 14.3.14 Secondary batteries (rechargeable)

A rechargeable battery, storage battery, secondary cell, or accumulator is a type of electrical battery that can be charged, discharged into a load, and recharged many times, while a non-rechargeable or primary battery is supplied fully charged, and discarded once discharged. In a secondary cell, the reaction can be reversed by running a current into the cell with a battery charger to recharge it, regenerating the chemical reactants.

In conventional secondary batteries, the energy is charged and discharged in the active masses of the electrodes.

The most common types of secondary battery are listed as follows:

### *14.3.14.1 Lead acid (LA)*

Lead acid batteries are the world's most widely used battery type. Typical service life is 6 to 15 years with a cycle life of 1500 cycles at 80% depth of discharge, and they achieve cycle efficiency levels of around 80% to 90%. There are many sub-types of lead acid batteries. One disadvantage of lead acid batteries is usable capacity decrease when high power is discharged. For example, if a battery is discharged in one hour, only about 50% to 70% of the rated capacity is available. Other drawbacks are lower energy density and the use of lead, a hazardous material. LA systems are easy to recycle and the charging technology is simple.

#### *14.3.14.2 Nickel cadmium and nickel metal hydride (NiCd, NiMh)*

Compared to lead acid batteries, nickel-based batteries have a higher power density, a slightly greater energy density and the number of cycles is higher; many sealed construction types are available. From a technical point of view, NiCd batteries are a very successful battery product; in particular, these are the only batteries capable of performing well even at low temperatures in the range from -20°C to -40 °C. Large battery systems using vented NiCd batteries operate on a scale similar to lead acid batteries. Like lead, cadmium is a hazardous material. NiMH batteries have much higher energy densities (weight for weight). NiMH batteries are far safer than lithium ion batteries.

#### *14.3.14.3 Lithium ion (Li-ion, LiPoly)*

High cell voltage levels of up to 3.7 nominal volts mean that the number of cells in series with the associated connections and electronics can be reduced to obtain the target voltage. Another advantage of Li-ion batteries is their high gravimetric energy density, and the prospect of large cost reductions through mass production. Lithium ion batteries generally have a very high efficiency, typically in the range of 95% - 98%. Nearly any discharge time from seconds to weeks can be realized, which makes them a very flexible and universal storage technology. Standard cells with 5000 full cycles can be obtained on the market at short notice, but even higher cycle rates are possible after further development, mainly depending on the materials used for the electrodes.

Safety is a serious issue in lithium ion battery technology. Most of the metal oxide electrodes are thermally unstable and can decompose at elevated temperatures, releasing oxygen which can lead to a thermal runaway. To minimize this risk, lithium ion batteries are equipped with a monitoring unit to avoid over-charging and over discharging. Usually a voltage balance circuit is also installed to monitor the voltage level of each individual cell and prevent voltage deviations among them.

#### *14.3.14.4 Metal air (Me-air)*

A metal air electrochemical cell consists of the anode made from pure metal and the cathode connected to an inexhaustible supply of air. For the electrochemical reaction only the oxygen in the air is used.

#### *14.3.14.5 Sodium sulphur (NaS)*

Sodium sulphur batteries consist of liquid (molten) sulphur at the positive electrode and liquid (molten) sodium at the negative electrode; the active materials are separated by a solid beta alumina ceramic electrolyte. The battery temperature is kept between 300 °C and 350 °C to keep the electrodes molten. NaS batteries reach typical life cycles of around 4500 cycles and have a discharge time of 6.0 hours to 7.2 hours. They are efficient (AC-based round-trip efficiency is about 75%) and have fast response.

#### *14.3.14.6 Sodium nickel chloride (NaNiCl)*

The sodium nickel chloride (NaNiCl) battery, better known as the ZEBRA (Zero Emission Battery Research) battery, is – like the NaS battery – a high-temperature (HT) battery. Its operating temperature is around 270°C, and it uses nickel chloride instead of sulphur for the positive electrode. NaNiCl batteries can withstand limited overcharge and discharge and have potentially better safety characteristics and a higher cell voltage than NaS batteries. They tend to develop low resistance when faults occur and this is why cell faults in serial connections only result in the loss of the voltage from one cell, instead of premature failure of the complete system.

### 14.3.15 Flow batteries

A flow battery is also a rechargeable battery, but the energy is stored in one or more electroactive species which are dissolved in liquid electrolytes. The electrolytes are stored externally in tanks and pumped through the electrochemical cell that converts chemical energy directly to electricity and vice versa. The power of a flow battery is defined by the size and design of the electrochemical cell, whereas the energy depends on the size of the electrolyte storage tank(s). Flow batteries can be fitted to a wide range of stationary applications. Flow batteries are classified into redox flow batteries and hybrid flow batteries.

#### *14.3.15.1 Redox flow*

In redox flow batteries (RFB) two liquid electrolyte dissolutions containing dissolved metal ions as active masses are pumped to the opposite sides of the electrochemical cell. The electrolytes at the negative electrode are called 'analytes', and the electrolytes at the positive electrodes 'catholytes'. During charging and discharging the metal ions stay dissolved in the fluid electrolyte as liquid; no phase change of these active masses takes place. The anolyte and catholyte flow through porous electrodes, separated by a membrane which allows protons to pass through it for the electron transfer process. During the exchange of charge a current flows over the electrodes, which can be used by a battery powered device. During discharge the electrodes are continually supplied with the dissolved active masses from the tanks; once they are converted the resulting product is removed to the tank. Theoretically, a RFB can be "recharged" within a few minutes by pumping out the discharged electrolyte and replacing it with recharged electrolyte.

#### 14.3.15.2 Hybrid flow

In a hybrid flow battery (HFB) one of the active masses is internally stored within the electrochemical cell, whereas the other remains in the liquid electrolyte and is stored externally in a tank. Therefore hybrid flow cells combine features of conventional secondary batteries and redox flow batteries: the capacity of the battery depends on the size of the electrochemical cell. Typical examples of a HFB are the Zn-Ce and the Zn-Br systems. In both cases the anolyte consists of an acid solution of $Zn^{2+}$ ions. During charging Zn is deposited at the electrode and at discharging $Zn^{2+}$ goes back into solution. As membrane a microporous polyolefin material is used; most of the electrodes are carbon-plastic composites.

### 14.3.16 Electrical storage systems

> **NOTE: Capacitance** *is a measure of ability to store electric charge.*

Electrical storage refers to the ability to store electric charge. Capacitance is the property that describes the storage of energy electrostatically (i.e., in an electric field). In other words, **capacitance** is a measure of ability to store electric charge. There are two closely related notions of capacitance, both of which are usually designated by the same term capacitance, and have the same SI unit of capacitance, the farad (F).

1. **Self capacitance** - Any object that can be electrically charged exhibits self capacitance. In a circuit, self capacitance is defined as the capacitive load, relative to circuit ground, that an electrode presents to the measurement system.
2. **Mutual capacitance** - the capacitive coupling between objects. The notion of mutual capacitance is particularly important for understanding the operations of the capacitor, one of the three fundamental electronic components (along with resistors and inductors).

A material with a large self capacitance holds more electric charge at a given voltage, than one with low capacitance.

- A 1 farad capacitor, when charged with 1 coulomb of electrical charge, has a potential difference of 1 volt between its plates.

In a mutual capacitance system, capacitance is a function only of the geometry of the design (e.g. area of the plates and the distance between them) and the permittivity of the dielectric material between the plates of the capacitor. For many dielectric materials, the permittivity and thus the capacitance, is independent of the potential difference between the conductors and the total charge on them.

#### 14.3.16.1 Mutual capacitance

In a capacitor, the ratio of magnitude of charge on either conductor relates to the potential difference (voltage) between the conductors. Therein, for any given voltage (supplied by some power source), the amount of Q (charge that can be stored) increases with the amount of capacitance (which is the measure of the capacitor):

- Capacitance in farads = charge on either conductor / potential difference
- $C = Q / \Delta V$

The energy stored in a capacitor is found by integrating the value of work (W):

- $W = .5CV^2$

### 14.3.17 Capacitors

A capacitor (originally known as a 'condenser', and prior to that known as a permittor) is a passive two-terminal electrical component used to store energy electrostatically (i.e., in an electric field). Practical capacitors vary widely, but all contain at least two electrical conductors (plates) separated by a dielectric (i.e., insulator). In other words, a capacitor is (generally) two metal plates separated by an insulated material (i.e., non-conductive material). A capacitor can store electric energy when disconnected from its charging circuit, so it can be used like a temporary battery, or like other types of rechargeable energy storage systems. Conventional capacitors are commonly used in electronic devices, and the more recent supercapacitor technology has some ability to replace batteries.

Capacitor operation may be understood via analogies:

1. Beaty, W.J. (1996). *Capacitor complaints*. Amasci. [amasci.com]
2. Moffitt, B. (2014). *Capacitor pipe water flow analogy : DC*. Brandon Moffitt Channel. [youtube.be]

Capacitors store energy in an electrostatic field between their plates. Given a potential difference across the conductors (e.g., when a capacitor is attached across a battery), an electric field develops across the dielectric, causing positive charge (+Q) to collect on one plate and negative charge (-Q) to collect on the other plate, until the capacitor is fully "charged". The charges want to re-combine with one another, but they cannot because the insulator is preventing them from reaching each other. If a battery is attached to a capacitor, then no current will flow through the capacitor.

When capacitors are connected across a direct current DC supply voltage they become charged to the value of the applied voltage, acting like temporary storage devices and maintain or hold this charge indefinitely as long as the supply voltage is present. When a capacitor is connected to a circuit with a direct current (DC) voltage source, two processes, which are called "charging" and "discharging" the capacitor, will happen in specific conditions. By connecting the capacitor to the power supply, the charging phase occurs. Once the charging phase has finished, no more current flows through it. When the capacitor is disconnected from the power supply and connected to a load, then discharging occurs until the voltage between the capacitor's plates drops to zero, $V_c$=0.

When an alternating current is supplied to a capacitor, it will alternately charge and discharge at a rate determined by the frequency of the supply. Therein, the capacitance in AC circuits varies with frequency as the capacitor is being constantly charged and discharged, and a 'displacement current' will appear across the capacitor.

The greater the collection of charge on one surface of the capacitor, due to various parameters, such as surface area, the greater the energy capacitance of the capacitor.

#### *14.3.17.1 Electrolytic capacitors*

An electrolytic capacitor is a capacitor that uses an electrolyte (an ionic conducting liquid) as one of its plates to achieve a larger capacitance per unit volume than other types, but with performance disadvantages.

Electrolytic capacitor is the generic term for three different capacitor family members:

1. Aluminum electrolytic capacitors
2. Tantalum electrolytic capacitors
3. Niobium electrolytic capacitors

All electrolytic capacitors (e-caps) are polarized capacitors whose anode (+) is made of a particular metal on which an insulating oxide layer forms by anodization, acting as the dielectric of the electrolytic capacitor. A non-solid or solid electrolyte which covers the surface of the oxide layer in principle serves as the second electrode (cathode) (-) of the capacitor.

Like other conventional capacitors, electrolytic capacitors store the electric energy statically by charge separation in an electric field in the dielectric oxide layer between two electrodes. The non-solid or solid electrolyte in principle is the cathode, which thus forms the second electrode of the capacitor. This and the storage principle distinguish them from electrochemical capacitors or supercapacitors, in which the electrolyte generally is the ionic conductive connection between two electrodes and the storage occurs with statically double-layer capacitance and electrochemical pseudocapacitance.

#### *14.3.17.2 Double-layer capacitors (DLC; supercapacitors)*

**NOTE:** *Electrochemical capacitors go by a variety of names, including but not limited to: supercapacitor, super condenser, pseudocapacitor, electrochemical double layer capacitor, electric double layer capacitor, and ultracapacitor.*

Electrochemical double-layer capacitors (DLC) exist between classical capacitors used in electronics and general batteries. Electrochemical capacitors consist of two electrodes, a separator, electrolyte, two current collectors, and packaging. Within the electrochemical capacitor, charge is stored electrostatically, not chemically as in a battery. It has, as a dielectric, an electrolyte solvent, typically potassium hydroxide or sulfuric acid, and is actually two capacitors connected in series via the electrolyte. It is called a dual layer capacitor because of the dual layers within the structure, one at each electrode. The surface area is directly related to the amount of capacitance. The higher the surface area, the higher the capacitance of the capacitor.

There are two types of electrochemical capacitor technology, symmetric and asymmetric designs:

1. Symmetric designs are designs where both positive and negative electrodes are made of the same material with approximately the same mass, and which are available with aqueous or organic electrolytes.
2. Asymmetric designs uses a different material for the two electrodes, with one of the electrodes having much higher capacity than the other. Currently, asymmetric designs can use aqueous or organic electrolytes.

There are significant differences in the characteristics and performance of the four types which leads to a wide variety of products with many different possible applications. The fourth type is not included in this table since the type has active research programs directed toward its development, but it is currently not available as a commercial product.

The two main features are the extremely high capacitance values, of the order of many thousand farads, and the possibility of very fast charges and discharges due to extraordinarily low inner resistance which are features not available with conventional batteries.

Still other advantages are durability, high reliability, no maintenance, long lifetime and operation over a wide temperature range and in diverse environments (hot, cold and moist). The lifetime reaches one million cycles (or ten years of operation) without any degradation, except for the solvent used in the capacitors whose disadvantage is that it deteriorates in 5 or 6 years irrespective of the number of cycles. They are environmentally friendly and easily recycled or neutralized. The efficiency is typically around 90 % and discharge times are in the range of seconds to hours.

They can reach a specific power density which is about ten times higher than that of conventional batteries (only very-high-power lithium batteries can reach nearly the same specific power density), but their specific energy density is about ten times lower. Because of their properties, DLCs are suited especially to applications with a large number of short charge/discharge cycles, where their high performance characteristics can be used. DLCs are not suitable for the storage of energy over longer periods of time, because of their high self-discharge rate, their low energy density.

### 14.3.18 Superconducting magnetic energy storage (SMES)

Superconducting magnetic energy storage (SMES) systems work according to an electrodynamic principle. The energy is stored in the magnetic field created by the flow of direct current in a superconducting coil, which is kept below its superconducting critical temperature. 100 years ago at the discovery of superconductivity a temperature of about 4°K was needed. Much research and some luck has now produced superconducting materials with higher critical temperatures. Today materials are available which can function at around 100°K. The main component of this storage system is a coil made of superconducting material. Additional components include power conditioning equipment and a cryogenically cooled refrigeration system.

The main advantage of SMES is the very quick response time: the requested power is available almost instantaneously. Moreover the system is characterized by its high overall round-trip efficiency (85 - 90%) and the very high power output which can be provided for a short period of time. There are no moving parts in the main portion of SMES, but the overall reliability depends crucially on the refrigeration system. In principle the energy can be stored indefinitely as long as the cooling system is operational, but longer storage times are limited by the energy demand of the refrigeration system.

### 14.3.19 Thermal storage systems

Thermal (energy) storage (TES) systems store available heat by different means in an insulated repository for later use, including space heating or cooling, hot water production, and electricity generation. Thermal storage systems are deployed to overcome the mismatch between demand and supply of thermal energy, and thus, they are important for the integration of renewable energy sources. Second, utilization of waste heat in production processes by thermal energy storage reduces the final energy consumption (i.e., increases energy efficiency if the thermal energy is used or has the possibility of being used).

> **NOTE:** *Thermal energy is challenging to store, due to the ease of heat dissipation in physical systems.*

TES is applied in the field of power generation, production process heat, space heating and cooling, as well as the management of thermal energy processes in vehicles. These classifications of storage characteristics and applications result in specific operation parameters and designs of TES systems.

Thermal energy storage is achieved by different techniques, and can be subdivided into different technologies:

1. Storage of sensible heat - sensible
2. Storage of latent heat - phase change material
3. Thermo-chemical ad- and absorption storage - chemical sorption reaction

### 14.3.20 Sensible heat storage

The term ‘sensible heat’ indicates that the storage process can be *sensed* by a change of the temperature. The relation of the change in temperature and the stored heat is given by the heat capacity $C_p$. The storage of sensible heat is one of the best-known and most widespread technologies, with the domestic hot water tank as an example. The storage medium may be a liquid, such as water and solar ponds, thermo-oil, or a solid such as concrete or the ground. Thermal energy is stored solely through a change of temperature of the storage medium. Herein, the capacity of a sensible heat storage system is defined by:

1. The specific heat capacity, $C_p$.
2. The mass of the medium used.

Sensible heat can be stored in either solids and/or liquids:

1. *Solids:* metals, stones, salts, ceramics.
2. *Liquid:* water, thermal oil, molten salt.
3. *Liquid with solid filler material:* water with stones/ pebbles, oil with cast iron, molten salt with stone.

#### *14.3.20.1 Solar Ponds*

Water-based ponds may be used to capture the sun’s radiative energy. A solar pond is a pool of salt water that serves as a form of solar energy collection and sensible heat storage. A solar pond uses the principle of energy transfer by convection to heat saline water. This heated water solution may then be used for various purposes.

In general, a solar pond is a mass of shallow water about 1 or 2 metres deep with a large collection area, which acts as a heat trap. The pond contains dissolved salts to generate a stable density gradient. They are generally filled with saline water made with NaCl, $MgCl_2$, sodium carbonate, or sodium sulfate. Part of the incident solar radiation entering the pond surface is absorbed throughout the depth, and the remainder is absorbed at the very dark, black bottom. If the pond were initially filled with fresh water, the lower layers would heat up, expand and rise to the surface. Because of the relatively low conductivity, the water acts as an insulator and permits high working temperature (over 90 ˚C) to develop in the bottom layers. Hence, a gradient is maintained at varying densities. The bottom is the most dense and is used as a storage zone. Above the bottom layer is a non-convective zone, or insulation zone, with a density gradient which facilitates a temperature gradient as well. This layer functions as insulation. There is no convection in the gradient layer because even though the warm water would normally rise, the high salt concentration at lower levels does not allow the water to be light enough to float up as it warms. This prevents heat in the bottom from reaching the top of the pond. The top layer, or surface zone, is convective due to wind-induced mixing and daily heating and cooling. The hot brine, or salt water, on the bottom may be extracted and used for direct heating and low-temperature production uses like drying crops and agricultural shelter heating.

The problem with solar ponds is that it is essential to have a controlled saline density gradient, which is quite difficult to maintain. Additionally, the pond must be kept free of dirt and other light-absorbing materials. Thus, for large scale operations, the difficulties are too great to rely upon solar ponds for efficient heat production.

Here is one possible system for converting the heat energy from the salt water in the pond to electricity. The hot brine is pumped from the bottom of the solar pond through an evaporator (where it transfers heat to an organic 'working fluid,), and then, returned to the pond. The organic working fluid is heated in the evaporator, turns into a vapor, thereby producing sufficient pressure to spin a turbine connected to a generator. Therein, the vapor transfers some of its kinetic energy to the turbine. The cooler vapor is pumped to the condenser where it is condensed to a liquid as it transfers energy to the cold water being pumped through the tubes of the condenser. The organic liquid is now pumped to the evaporator to continue the process. As the gradient layer diffuses as time passes, new freshwater and salt water can be pumped into the pond to maintain a sufficient gradient layer.

#### *14.3.20.2 Inter-seasonal thermal storage*

Seasonal thermal energy storage (STES) allows heat or cold to be used months after it was collected from waste energy or natural sources. The material can be stored in contained aquifers, clusters of boreholes in geological substrates such as sand or crystalline bedrock, in lined pits filled with gravel and water, or water-filled mines. STES systems can be divided into:

1. Underground systems
2. Surface and above ground systems

### 14.3.21 Latent heat storage

In contrast to the storage of sensible heat, latent thermal energy storage (LHTES) cannot be sensed: The energy which is absorbed or released is stored by a *phase transition*, which takes place at a constant temperature, and therefore, appears to be latent. Materials used for latent heat storage are called PCMs (phase change materials), because the heat storage is achieved by a phase change of the storage medium. In other words, 'latent heat' is the energy exchanged during a phase change, such as the melting of ice. It is also called "hidden" heat, because there is no change of temperature during energy transfer.

Latent heat storage is accomplished by using phase change materials (PCMs) as storage media. PCMs include, but are not limited to the following, which are divided by in-/organic, and then, solid-solid or solid-liquid:

1. Organic phase change materials (organic PCMs)
    - *Solid-liquid:* paraffins
2. Inorganic phase change materials (inorganic PCMs)
    - *Solid-solid:* salt
    - *Solid-liquid:* water/ice, salt hydrates, salt/molten salt

The best known latent heat – or cold – storage method is the ice cooler (ice box), which uses ice (an inorganic PCM) in an insulated box or room to keep food cool during hot days.

Currently, most PCMs use the solid-liquid phase change, such as molten salts as a thermal storage medium or concentrated solar power (CSP) plants. The advantage of latent heat storage is its capacity to store large amounts of energy in a small volume and with a minimal temperature change, which allows efficient heat transfer.

#### *14.3.21.1 Solar molten salt system*

Molten salt is salt which is solid at standard temperature and pressure (STP) but enters the liquid phase due to elevated temperature. In this system, salt becomes molten once heated by a concentrated solar radiation system. It is then transported to a hot salt storage tank. To produce electricity, the hot salt passes through a steam generator that powers a steam turbine. Subsequently, the cold salt (still molten) is stored in a second tank before it is pumped to the solar tower again. The main disadvantages are the risk of liquid salt freezing at low temperatures, and the risk of salt decomposition at higher temperatures. In solar trough plants a dual-medium storage system with an intermediate oil/salt heat exchanger is preferred. Typical salt mixtures, such as $NaK\text{-}NO_3$, have freezing temperatures >200°C, and storage materials and containment require a higher volume than storage systems for solar tower plants.

### 14.3.22 Thermo-chemical heat storage

A thermochemical heat storage (TCS) system uses the enthalpy of a reaction $\Delta H$. In reactions featuring a positive change of $\Delta H$ (endothermic reaction) heat can be stored. The energy can be released by a backward reaction ($\Delta H < 0$) afterwards. This chemical reaction always involves gas phase reaction:

1. *Solid - gas reaction:* dissociation reactions and adsorption processes
2. *Liquid - gas reaction:* absorption in alkaline or acid solution
3. *Gas - gas reaction:* methane reforming and ammonia dissociation

Sorption (adsorption, absorption) storage systems work as thermo-chemical heat pumps under vacuum conditions and have a more complex design than sensible or latent heat systems. Herein, heat from a high-temperature source heats up an adsorbent (e.g. silica gel or zeolite), and vapour (working fluid; e.g., water) is desorbed from this adsorbent and condensed in a condenser at low temperatures. The heat of condensation is then withdrawn from the system. The dried adsorbent and the separated working fluid can be stored as long as desired. During the discharging process the working fluid takes up low-temperature heat in an evaporator. Subsequently, the vapour of the working fluid adsorbs on the adsorbent and heat of adsorption is released at high temperatures. Depending on the adsorbent/working fluid pair the temperature level of the released heat can be up to 200°C and the energy density is up to three times higher than that of sensible heat storage with water.

Because of the possibility of storing the sorption compounds separately without the loss of energy, thermochemical storage is appropriate for thermal energy storage over large period of times.

## *14.4 Grid/network connectivity and power quality*

Energy storage systems can be on-grid (network connected) or off-grid (network dis-connected).

## *14.5 Battery technology as energy storage*

> **NOTE:** *If electric current is like water, then in application, a battery is like a water pump. A pump takes in water at low pressure and does work on it, ejecting it at high pressure. A battery takes in charge at low voltage, does work on it and ejects it at high voltage. Batteries, however, do not store electric charges, and hence, they are not analogous to a water balloon shooting out water.*

A battery is a device that converts chemical power (energy) into electrical power (energy), and vice versa. Batteries supply electricity by producing voltage and delivering direct current (DC). Batteries do not produce AC voltage. Also, batteries do not store electricity, but rather store a series of chemicals, and through a chemical process electricity is produced. Hence, it is inaccurate to say that batteries store DC or DC voltage. Although a current can be described as moving electrical charges, it is not true that these charges are "stored in a battery". Batteries store chemical potential energy, which is released as DC voltage when connected to an electrical circuit. Batteries are an electrochemical storage carrier. The energy is stored chemically, but released as electricity. Through a chemical reaction process the battery creates and releases electricity as needed by the electrical system or devices. Batteries are sometimes considered electron pumps.

> **CLARIFICATION:** *Electrical current is the movement of charged particles, such as electrons or ions, through a conductor.*

In composition, a battery is a technological device consisting of one or more electrochemical cells (voltaic cells). A voltaic cell is an electrochemical cell that uses a chemical reaction to produce electrical power (electrical energy). Simplistically, batteries contains atoms and molecules separated into ions that generate a voltage drop across their terminals.

> **CLARIFICATION:** *A* **cell** *is the smallest, packaged form a battery can take and is generally on the order of one to six volts. A* **module** *consists of several cells generally connected in either series or parallel. A battery* **pack** *(battery bank) is then assembled by connecting modules together, again either in series or parallel. The term 'battery' and 'cell' are often used interchangeably; technically, however, a battery is made up from a group of cells.*

A battery releases energy at a more or less constant or flat voltage until depleted. A battery is used where a constant potential difference has to be maintained.

### 14.5.1 Battery components

All batteries have at least the following components, including two terminals (i.e., electrodes):

1. **The anode (terminal)** - an electrode where oxidation occurs (in a voltaic cell). This is generally a metal material.
2. **The cathode (terminal)** - an electrode where reduction occurs (in a voltaic cell). This is generally a different metal material than the anode material.
3. **The electrolyte (the ionic conductor)** - provides the medium for transfer of charge as ions inside the cell between the anode and cathode. The electrolyte is typically a solvent containing dissolved chemicals providing ionic conductivity. It should be a non-conductor of electrons to avoid self discharge of the cell.
4. **The separator** - electrically isolates the positive and negative electrodes. It is a permeable membrane placed between a battery's anode and cathode.

The main function of a separator is to keep the two electrodes apart to prevent electrical short circuits while also allowing the transport of ionic charge carriers that are needed to close the circuit during the passage of current in an electrochemical cell.

**CLARIFICATION:** *In a galvanic (voltaic) cell, the anode is considered negative (-ve) and the cathode is considered positive (+ve). This seems reasonable as the anode is the source of electrons, and the electrons flow to the cathode. However, in an electrolytic cell, the anode is positive (+ve), while the cathode is negative (-ve).*

#### 14.5.1.1 Anodic index-galvanic corrosion (anodic index

The anodic index is a table showing the compatibility of different metals. This parameter is a measure of the electrochemical voltage that will be developed between two different metals. To find the relative voltage of a pair of metals it is only required to subtract their anodic indices. (Wheeler, 1972)

For example,

- The potential difference between iron and copper is approximately 0.4v.
- The potential difference between zinc and carbon is approximately 1.5v.

### 14.5.2 Battery operation

Batteries use a chemical reaction to do work on charge and produce a voltage between their output terminals. This voltage can be connected to an electrically conductive circuit (a load) to produce direct current (DC) electrical power. When a load completes the circuit between the two terminals, the battery produces electricity through a series of electromagnetic reactions between the anode, cathode, and electrolyte. Batteries operate based on the separation of [electric] charge in a chemical solution (i.e., an energy gradient), which produces an electromotive force (voltage) between their terminals. When the terminals are connected by means of an appropriate electrical conductor, then direct current will flow between the terminals powered by the pressure of the voltage (and, electrochemical discharge will occur).

Charging and discharging refer to the direction of current through a battery cell, and the type of chemical reaction that follows the current. Batteries are discharged or charged due to oxidation and reduction reactions therein.

1. **Charging** - the process of separating charge within a battery by providing DC electrical power to the battery.
2. **Discharging** - the process of releasing DC electrical power and reuniting charges via a conductive circuit.

Some batteries, due to their system's composition, cannot be recharged. Rechargeable batteries pump the charges back to their separate sides during charging, strengthening the electric field all over again. By reversing electrical current flow in a rechargeable battery, the chemical process is reversed, thus charging the battery. The cycle of discharging and charging is repeated continuously and is called **battery cycling**. All rechargeable batteries have a cycling lifespan (i.e., they can be cycled, discharged and recharged, a certain number of times before they need will no longer function without maintenance). Further, energy density decreases as a battery wears out.

**NOTE:** *A battery charger, or recharger, is a device used to put energy into a secondary cell (or rechargeable battery) by forcing an electric current through it.*

During discharge operation, the anode (terminal) experiences an oxidation reaction in which two or more ions (electrically charged atoms or molecules) from the electrolyte combine with the anode, producing a compound and releasing one or more electrons. In other words, the internal chemical reaction within the battery between the electrolyte and the negative metal electrode produces a build up of free electrons, each with a negative charge, at the battery's negative (-) terminal - the anode. At the same time, the cathode goes through a reduction reaction in which the cathode substance, ions and free electrons also combine to form compounds. In other words, the chemical reaction between the electrolyte and the positive (+) electrode inside the battery produces an excess of positive (+) ions (atoms that are missing electrons, thus with a net positive charge) at the positive (+) terminal - the cathode of the battery. The reaction in the anode produces a direct flow of electrons, and the reaction in the cathode absorbs them. The net product is electricity. The electrical (pump) pressure or potential difference between the + and - terminals is called voltage or electromotive force (EMF).The battery will continue to produce electricity until one or both of the electrodes run out of the substance necessary for the reactions to occur.

Batteries create electron flow in a circuit by exchanging electrons in ionic chemical reactions, and there is a limited number of molecules in any charged battery available to react, hence there is a limited amount of total electrons that any battery can propel through a circuit before its energy reserves are exhausted.

**CLARIFICATION:** *Reactants in a battery are separated internally by an electrolyte that provides for ion transfer, and externally by an electrical conductor (between the terminals), which provides for electron transfer. When a load is connected to the battery via the external conductive circuit, excess charges present in the* *negative ions of electrolytes on negative terminal (deposited during charging process) flow through the conductor, until they reach the positive terminal where they combine with positive ions, neutralizing the charge (the equilibrium condition). Under normal equilibrium conditions the electrical potential inside the battery exactly equals the chemical potential, and hence, there is no voltage and no electron flow. Normally, a battery which is not shorted out or connected to a load is under equilibrium conditions, meaning the chemical potential inside the battery exactly equals the electrical potential. Under these conditions, no charge carriers flow. If the positive terminal of the battery is connected to the negative terminal through some load, then the charge carrying electrons at the negative terminal of the battery will flow through the conductive load to the positive terminal.*

A battery is a chemical reactor where red-ox reaction happens. In the battery there is some medium, called an electrolyte, which can conduct only ions, but not electrons. Each voltaic cell consists of two half-cells connected in series by a conductive electrolyte containing anions and cations. One half-cell includes electrolyte and the negative electrode, the electrode to which anions (negatively charged ions) migrate; the other half-cell includes electrolyte and the positive electrode to which cations (positively charged ions) migrate. Redox reactions power the battery. Cations are reduced (electrons are added) at the cathode during charging, while anions are oxidized (electrons are removed) at the anode during charging. During discharge, the process is reversed. The electrodes do not touch each other, but are electrically connected by the electrolyte. Some cells use different electrolytes for each half-cell. A separator allows ions to flow between half-cells, but prevents mixing of the electrolytes. The reaction is driven forward by the chemical potential, an energy gradient. If the battery is not at 0 charge ("flat"), there will be a voltage between the electrodes.

**INSIGHT:** *When a battery is connected to a circuit, charges moves in the direction which diminishes the chemical potential energy in the battery.*

Because a battery is a system of separated charge, it has a static electric field. When a battery is powering an electrical load (i.e., discharging), over time, the separated charges get reunited via the conductive circuit, and the electric field between the positive and negative electrodes becomes weaker. Hence, as a battery is discharging (i.e., providing electrical power), its voltage (EMF) will drop over time. In a discharing battery, the chemical process is a decoupled redox reaction. As charges move around the circuit, the electrical potential inside the battery is reduced until equilibrium between the chemical potential and electrical potential is once again achieved.

Different metals have different affinities for electrons. When two dissimilar metals (or metal compounds) are put in contact or connected through a conducting medium there is a tendency for electrons to pass from the metal with the smaller affinity for electrons, which becomes positively charged, to the metal with the greater affinity which becomes negatively charged. A potential difference between the metals will therefore build up until it just balances the tendency of the electron transfer between the metals. At this point the 'equilibrium potential' is that which balances the difference between the propensity of the two metals to gain or lose electrons.

**INSIGHT:** *If you have two different metals in your body, particularly in your mouth, there will likely exist an electrical [galvanic] current between them. Such currents can and will interfere with the body's natural processes, potentially leading to states of dis-ease.*

### 14.5.3 Electrochemical cell types

Many types of electrochemical cells have been produced, with varying chemical processes and designs, including galvanic cells, electrolytic cells, fuel cells, flow cells and voltaic piles.

1. **Wet cell** - A wet cell battery has a liquid electrolyte. Other names are flooded cell, since the liquid covers all internal parts, or vented cell, since gases produced during operation can escape to the air.
2. **Dry cell** - A dry cell uses a paste electrolyte, with only enough moisture to allow current to flow. Unlike a wet cell, a dry cell can operate in any orientation without spilling, as it contains no free liquid, making it suitable for portable equipment. The common zinc–carbon battery (dry Leclanché cell) and zinc-manganese dioxide (alkaline cell) are both dry cell batteries.
3. **Molten salt** - Molten salt batteries are primary or secondary batteries that use a molten salt as electrolyte. They operate at high temperatures and must be well insulated to retain heat.
4. **Reserve battery** - A reserve battery can be stored unassembled (unactivated and supplying no power) for a long period (perhaps years). When the battery is needed, then it is assembled (e.g., by adding electrolyte); once assembled, the battery is charged and ready to work.

### 14.5.4 Battery condition parameters

This section describes some of the variables used to describe the present condition of a battery.

1. **State of Charge (SOC in %)** – An expression of the present battery capacity as a percentage of

maximum capacity. SOC is generally calculated using current integration to determine the change in battery capacity over time.

2. **Depth of Discharge (DOD in %)** – The percentage of battery capacity that has been discharged expressed as a percentage of maximum capacity. A discharge to at least 80% DOD is referred to as a deep discharge.
3. **Terminal Voltage (V)** – The voltage between the battery terminals with load applied. Terminal voltage varies with SOC and discharge/charge current.
4. **Open-circuit voltage (V)** – The voltage between the battery terminals with no load applied. The open-circuit voltage depends on the battery state of charge, increasing with state of charge.
5. **Internal Resistance** – The resistance within the battery, generally different for charging and discharging, also dependent on the battery state of charge. As internal resistance increases, the battery efficiency decreases and thermal stability is reduced as more of the charging energy is converted into heat.

## 14.5.5 Battery energy and power units

Average power determines how long a battery lasts. Batteries have a limited amount of energy they can supply before they need to be replaced or recharged. The energy is typically measured in units of Joules. Batter capacity may be specified in Joules, or in amp-hours. If a 12 volt battery is rated at 100 amp-hours, then it means that - at least theoretically - it can supply 100 amps of current at 12 volts for one hour. Or, again theoretically, it can supply 1 amp of current at 12 volts for 100 hours. Either way, the total energy stored in the battery is S=3600VA Joules, where V is voltage in volts and A is the amp-hour rating, and 3600 is the number of seconds in an hour, and S is the number of Joules of energy the battery can supply. Power is measured in Watts, which is Joules/second. If a battery has S Joules of energy, and the average power you are drawing from it is P Watts, then the battery will be discharged in S/P seconds.

## 14.5.6 Battery technical specifications

This section explains the specifications you may see on battery technical specification sheets used to describe battery cells, modules, and packs.

**CLARIFICATION:** *In describing batteries, discharge current is often expressed as a C-rate in order to normalize against battery capacity, which is often very different between batteries. A* **C-rate** *is a measure of the rate at which a battery is discharged relative to its maximum capacity. A 1C rate means that the discharge current will discharge the entire battery in 1 hour. For a battery with a capacity of 100 Amp-hrs, this equates to a discharge current of 100 Amps. A 5C rate for this battery would be 500 Amps, and a C/2 rate would be 50 Amps. Similarly, an* **E-rate** *describes the discharge power. A 1E rate is the discharge power to discharge the entire battery in 1 hour.*

1. **Nominal Voltage (V)** – The reported or reference voltage of the battery, also sometimes thought of as the "normal" voltage of the battery. All batteries will be damaged (if not explode and catch fire) if they are charged significantly above their nominal voltage.
2. **Cut-off Voltage** – The minimum allowable voltage. It is this voltage that generally defines the "empty" state of the battery. Some batteries will be damaged if they drop significantly below their cut-off voltage (e.g., lithium polymer batteries).
3. **Capacity or Nominal Capacity (Ah for a specific C-rate)** – A battery's [electric current] capacity is the amount of electric charge it can deliver at the rated voltage. The coulometric capacity, the total Amp-hours available when the battery is discharged at a certain discharge current (specified as a C-rate) from 100 percent state-of-charge to the cut-off voltage. The amp-hour is a unit of battery energy capacity, equal to the amount of continuous current multiplied by the discharge time, that a battery can supply before exhausting its internal store of chemical energy. Therein, capacity is calculated by multiplying the discharge current (in Amps) by the discharge time (in hours), which decreases with increasing C-rate. For example, a battery rated at 100 A·h can deliver 5 A over a 20-hour period at room temperature. An amp-hour battery rating is only an approximation of the battery's charge capacity, and should be trusted only at the current level, temperature and time specified by its technical specification.
   - Continuous current (amps) = amp-hour rating/ charge to discharge time (in hours)
   - Charge to discharge time (in hours) = amp-hour rating / continuous current (in amps)
4. **Energy or Nominal Energy (Wh - for a specific C-rate)** – The "energy capacity" of the battery, the total Watt-hours available when the battery is discharged at a certain discharge current (specified as a C-rate) from 100 percent state-of-charge to the cut-off voltage. Energy is calculated by multiplying the discharge power (in Watts) by the discharge time (in hours). Like capacity, energy decreases with increasing C-rate. A 12 volt battery rated for/ producing 100 amps of current has a 1200 watt-hour supply (12V · 100amp = 1200 W-h).

5. **Cycle Life (number for a specific DOD)** – The number of discharge-charge cycles the battery can experience before it fails to meet specific performance criteria. Cycle life is estimated for specific charge and discharge conditions. The actual operating life of the battery is affected by the rate and depth of cycles and by other conditions such as temperature and humidity. The higher the DOD, the lower the cycle life.
6. **Specific Energy (Wh/kg)** – The nominal battery energy per unit mass, sometimes referred to as the gravimetric energy density. Specific energy is a characteristic of the battery chemistry and packaging. Along with the energy consumption of the vehicle, it determines the battery weight required to achieve a given electric range.
7. **Specific Power (W/kg)** – The maximum available power per unit mass. Specific power is a characteristic of the battery chemistry and packaging. It determines the battery weight required to achieve a given performance target.
8. **Energy Density (Wh/L)** – The nominal battery energy per unit volume, sometimes referred to as the volumetric energy density. Specific energy is a characteristic of the battery chemistry and packaging. Along with the energy consumption of the vehicle, it determines the battery size required to achieve a given electric range.
9. **Power Density (W/L)** – The maximum available power per unit volume. Specific power is a characteristic of the battery chemistry and packaging. It determines the battery size required to achieve a given performance target.
10. **Maximum Continuous Discharge Current** – The maximum current at which the battery can be discharged continuously. This limit is usually defined by the battery manufacturer in order to prevent excessive discharge rates that would damage the battery or reduce its capacity. Along with the maximum continuous power of the motor, this defines the top sustainable speed and acceleration of the vehicle.
11. **Maximum 30-sec Discharge Pulse Current** –The maximum current at which the battery can be discharged for pulses of up to 30 seconds. This limit is usually defined by the battery manufacturer in order to prevent excessive discharge rates that would damage the battery or reduce its capacity. Along with the peak power of the electric motor, this defines the acceleration performance (0-60 mph time) of the vehicle.
12. **Charge Voltage** – The voltage that the battery is charged to when charged to full capacity. Charging schemes generally consist of a constant current charging until the battery voltage reaching the charge voltage, then constant voltage charging, allowing the charge current to taper until it is very small. If a charger cannot detect when the battery is fully charged, then overcharging is likely. Overcharging will damage the battery, possibly causing it to catch fire and/or explode.
13. **Float Voltage** – The voltage at which the battery is maintained after being charge to 100 percent SOC to maintain that capacity by compensating for self-discharge of the battery.
14. **(Recommended) Charge Current** – The ideal current at which the battery is initially charged (to roughly 70 percent SOC) under constant charging scheme before transitioning into constant voltage charging.
15. **(Maximum) Internal Resistance** – The resistance within the battery, generally different for charging and discharging.

# 15 Energy demand requirements and usage monitoring

**INSIGHT:** *After electrification, sleep became a disadvantage to feeding your family...because you could still be working for money.*

## 15.1 Reserve to production

The **reserves-to-production ratio** (**RPR** or **R/P**) is the remaining amount of a material resource, expressed in time. The reserve portion (numerator) of the ratio is the amount of a resource known to exist in an area and to be recoverable (proved reserves). The production portion (denominator) of the ratio is the amount of resource produced in one period (year) at the current rate.

1. RPR = (amount of known resource) / (amount used per year)
2. Units are time = amount / (amount/time)

This ratio is used to forecast the future availability of a resource to determine project life, and to determine whether more cultivation, harvesting, and/or exploration must be undertaken to ensure continued supply of the resource. Annual production of a resource can usually be calculated to quite an accurate number. However, reserve quantities can only be estimated to varying degrees of accuracy, depending on the availability of information and on the methods used to evaluate them.

Note that reserve and production rates are dynamic (constantly changing), and hence, this isn't a static calculation/analysis, but a dynamically recorded calculation. Also, reserves and production rates are not independent.

**Renewable energy sources:** *energy sources that are capable of being renewed (in a sufficient timeframe), and for which the demand rate (or use rate) is less than or equal to the production rate.*

## 15.2 Gross and process energy requirements

*Note: The* **embodied energy** *of a material refers to the amount of energy consumed in providing/producing that material. It is the energy consumed up to the end of the manufacturing process (cradle to gate). However, it may include delivery to the manufacturing site (cradle to site) or even the manufacturing processes into the completed product. This measurement can be used in comparing different materials.*

Technically, all energy inputs and energy outputs can be entered into a matrix, and have analyses run for any type of energy inquiry (i.e., the data can be parsed and analysed). Two of the most common analyses are known as 'gross energy requirement' and 'process energy requirement'.

The energy used in productive systems is measured based upon:

1. Gross energy requirement (GER) - the total amount of energy required for a system, project, object, service, or material. A measure of all the energy inputs that went into its creation and/or sustainment. The total energy consumed.
2. Process energy requirement (PER) - the energy consumed in the process directly undergone by building/creating a specified product (object, service, or material). A measure of the energy directly consumed in the process of producing the product, but not that of the second and higher generation consumption of the facility, transportation, etc.

## 15.3 Electrical energy demand

**QUESTION:** *How do we know how much electric charge flow (i.e., electricity) to produce?*

Electrical generation and distribution equipment are designed and deployed to meet the maximum demand that all users/loads may require at one time. Hence, peak demand measurements are used to properly size the electric service ensure that there is sufficient generating capacity available (at all times).

1. The term kilowatt-hour (kWh) refers to the quantity of energy used; energy is signified by kWh. The kWh is a 'unit of energy'. Electrical energy actually used.
2. The term kilowatt (kW) refers to the electric power or rate (a.k.a., pace) at which this energy is used; demand is signified by kW. The kW is a 'unit of power'. The rate at which a load transforms electrical energy. Electrical energy moment by moment demand by a device.

The kilowatt hour (kWh, kW. h, kW-h) is how most home energy usage costs are calculated. The kWh measures [electrical] energy usage - equivalent to one kilowatt (1 kW) of power sustained for one hour. How much "energy" is in something or how much energy is used over a certain period of time.

- Watts * Time Used (in hours) = Wh
- Watts * Time Used / 1000 = kWh

Generator (if, then)

- If a device is rated to generate 1 kW of power (and it operates for one hour at that level), then it sustains

1 kWh of energy.

Load (if, then)

- If a device uses 100 watts over 10 hours, then it would utilize 1kWh of energy (100x10=1,000=1kW).
- For example, if a 40-watt bulb is used for 25 hours (40x25=1,000 watts = 1 kW), then it would use 1 kWh (at the 25 hour mark).

### 15.3.1 Load and supply

The balancing of load and supply on an electric power system is usually centrally controlled by a system operator or "Dispatch Centre". The dispatch centre continually how much generation is needed at each instant of time and issues orders (dispatch) to individual generating stations in merit order to supply the demand. The dispatch centre has a pretty good idea from forecasts of what will be required but they monitor frequency on an ongoing basis to ensure the balance is maintained.

Very rapid changes are dealt with automatically by stations which have some local frequency control. These stations respond very rapidly to changes in frequency by increasing power generated if frequency begins to drop. Those stations will need to keep some of their generating capacity in reserve for emergencies and the often receive payment just for being available to provide such a reserve.

Power generated must exactly equal power consumed. You have a few seconds to balance it, but frequency will start to rise or fall if there is any imbalance. However, voltage is not dependent on active power generated or consumed, frequency is.

A mentioned above the frequency (electrical cycles per second) is tied to the rotational speed of the generators (mechanical revolutions per second). In the USA the frequency is nominally 60 Hz but it varies slightly around this perhaps (59.97Hz to 60.03Hz). When extra power is drawn from the grid the generators feel the strain and slow down a bit - so the frequency slows down by a fraction of a Hz. This is the signal to put in more gas or steam and increase the power to your generators.

In the past control rooms that actually had big charts on the walls and dials that people turned. Nowadays the whole system is computerised. The longer term decisions still have human oversight but short term decision have to be made automatically because there isn't enough time for human intervention. In fact the fastest responding element is a speed controller on some of the generators (called a governor) which acts like cruise control on your car. When demand for electricity exceeds generation the generators start to slow down and the governors kick in and increase the gas.

To control the spin rate of the generators the system/ technicials will, for example: apply more coal; turn on another turbine; in hydroelectric dams, open another gate and start another dynamo; in nuclear plants, pull out a couple of rods.

Some generators could alter their MW output, and some couldn't.

The frequency must stay the same as well. The frequency of the generator(revolutions per minute) goes up, as a result, the energy frequency at the generator output (Hz) goes up. Then it goes through a regulation circuit to synchronize it with the grid, to match the 50Hz(or 60Hz, if that's your thing).

### 15.3.2 Demand in a DC system

No content here yet.

### 15.3.3 Demand in an AC system

In an AC system, voltage doesn't vary with demand - frequency does.

1. If generation equals demand, then frequency will stay constant.
2. If generation is less than demand, then frequency goes down.
3. If generation exceeds demand frequency goes up.

## *15.4 Manufactured product energy usage label*

The wattage listed is the maximum power drawn by the appliance. Every device, whether it is printed on the device itself or the transformer that powers the device, should have a label indicating the power consumption in Watts. The Watt number on the device may represent the device's maximum power rating, and not be representative of the amount of energy it is actually using when running. For instance, a computer's power supply may have a maximum rating of 400 watts, but someone uses the device at lower than 400 watts 100% of the time.

Take note, that in general, it is not possible to accurately calculate real world energy usage based on a manufacturer's label.

## *15.5 Market-based billing*

> *Note: In general, electric meters record consumption (kWh).*

Typically, consumers in the market are charged for their electricity in terms of energy: the more energy used, the more they pay. A high-power appliance uses energy more rapidly than a low-power one, and therefore, costs more to operate (i.e., "run").

Your energy charges are based only on the total amount of energy you consume. Your demand charges are based on the highest level of electricity supplied at one time during the billing period and at the time of day it's needed by your business. In the market, electrical power companies use an electrical meter connected to a building to determine the power used, from which the total cost is calculated among a number of additional variables;

1. Time of day - peak hours (more cost); off-peak (lower cost)
2. Seasonal differentiated - e.g., more people using AC because of heat, more energy usage (more cost)

# 16 Energy density and power density

**IMPORTANT:** *Modern physics is still confused over the concepts herein as is visible in the circularity of their definitions: (1) Energy is possessed by mass due to its motion and/or potential motion; (2) and, mass is a form of energy ($E=mc^2$).*

Energy density refers to the energy content/quantity of an energy carrier based on a mass or volumetric unit. Any material or energy resource (as a region of space) can be measured for its ability to release energy and do work. Similarly, any energy conversion system can be measured for its rate of transferring energy. These measures may be used as metrics for evaluating and comparing the performance of different energy technologies, materials and systems; or, they may be used as parameters for these design [specifications] for a new energy supply system.

**CLARIFICATION:** *'Energy density' is sometimes known as 'work density'.*

If a system has a high 'potential energy density' or 'potential energy specificity', then it is able to contain ("store") a lot of energy in relatively little spatial area or mass. If a system has a 'high power density' or 'specific power', then per a given amount of time, it can output/ transfer relatively large amounts of energy based on its spatial area or mass. An energy resource with a lower 'energy density' or 'specific energy' means it takes more volume or mass to produce the same amount of work as a higher 'energy density' resource. Similarly, an energy system with a lower 'power density' or 'specific power' means it takes more time per volume or mass to transfer the same amount of energy as a higher 'power density' system.

The quantified presence of 'energy density' does not give information on how quickly this energy can be used/ transferred. This knowledge is contained in the term 'power density', which describes the rate at which energy can be put in and/ or transferred out. A high 'energy density' or 'energy specificity' does not necessarily mean a high 'power density' or 'power specificity'. Typically, having a high energy density means the presence of a low power density. In fact, in practical applications, a high energy density often equates to a low power density.

To better understand 'energy density' and 'power density' the case of a campfire could be used. To start the fire, kindling is used, because its high surface area-to volume ratio means that it burns quickly - a high 'power density'. However, once the fire is stable, kindling is no longer an optimal fuel source, because it burns too quickly. Hence, the fuel source is switched to logs, because they have a high 'energy density' and will burn for a longer period of time.

Metaphors are a useful way of understanding power density. For instance, dumping water out of a mug has a high power density, because it is capable of emptying all its contents almost instantaneously. Comparatively, if a jug with a 2cm spout is upended, it would take awhile to release its contents, giving it a low power density. For example, a tiny capacitor may have the same power output as a large battery, but because the capacitor is smaller, it has a higher power density.

> **NOTE:** *Magnetic energy density is the density of energy conveyed to the part of space occupied by the magnetic field.*

Just as energy can be separated at a top-level into potential energy and kinetic energy, energy density can be separated into potential energy density and kinetic energy density. Potential and kinetic energy can be released and transferred in the following ways:

1. Potential energy can be *released* from a system by a reaction (as 'energy density' or 'specific energy'), and *transferred* at a specific rate (as 'power density' or 'specific power').
2. Kinetic energy can be *extracted and/or released* from a flowing material by a device/system (as 'energy density' or 'specific energy'), and *transferred* at a specific rate (as 'power density' or 'specific power').

## *16.1 Energy [release] in relation to spatial region*

Energy in a given region of space may be classified as potential or kinetic. Whether potential or kinetic, there is a maximum available energy per unit of space (volume or mass) that can be released or extracted. Therein, there are two calculated classifications for the amount of *available* energy within said region of space (measured as volume or mass), which create a total of four classifications:

1. [Potential or kinetic] 'energy density' - volume is the unit-region of space.
   A. Potential energy density
   B. Kinetic energy density
2. [Potential or kinetic] 'specific energy' - mass is the unit-region of space.
   A. Potential specific energy
   B. Kinetic specific energy

'Potential energy density' and 'potential specific energy' are applicable to a material potential energy resource, such as fuel or an energy storage medium (i.e., battery). 'Kinetic energy density' and 'kinetic specific energy' are applicable to a material kinetic energy resource, such as wind or flowing water.

'Energy density' is the amount of energy per unit weight (gravimetric energy density) or per unit volume (volumetric energy density). Note that the volume of a three dimensional space (i.e., spatial area) can be given in either metric cubic units (e.g., $m^3$) or liters (L). And, weight is otherwise known as mass. Energy density and specific energy are measures of the direct use/release of an energy source per spatial area unit as volume or mass. Energy density and specific energy answer the question: How much energy can be (or is being) stored in a volume/mass of space?

1. **Energy density (volumetric energy density)** - how much energy a system contains in relation to its volume. In other words, 'energy density' refers to how much work a given region of space (as a volumetric spatial unit) is capable of releasing (or exerting). It is typically expressed in watt-hours/volume or joules/volume: watt-hours per liter (Wh/L), joules per cubic centimeter ($J/cm^3$), joules per cubic meter ($J/m^3$), gigajoules per cubic meter ($GJ/m^3$), or megajoules per liter (MJ/L).
   - Potential energy density = energy output per volume of space derived as a result of a reaction (as chemical, thermal, nuclear fission or decay, electrochemical, or electrical).
   - Kinetic energy density = energy output per volume of space as a result of motion (as mechanical).
   - Energy density (Ed) is energy per volumetric spatial unit.
   - $E_d = E / V$
   - where, E is the energy released during utilization (e.g., combustion or energized circuit), and V is the volume of the fuel (as $m^3$ or liter).

2. **Gravimetric energy density (specific energy)** - how much energy a system contains in relation to its mass. In other words, 'specific energy' refers to how much work a given region of space (as mass unit) is capable of releasing (or exerting). It is typically expressed in watt-hours/mass or joules/mass: watt-hours per kilogram (Wh/kg), joules per gram (J/g), megajoules per kilogram (MJ/kg), gigajoules per ton (GJ/t).
   - Potential energy density = energy output per mass of space derived as the result of a reaction (as chemical, thermal, nuclear fission or decay, electrochemical, or electrical).
   - Kinetic energy density = energy output per mass of space as the result of motion (as mechanical).
   - Specific energy (Es) is energy per unit mass:
   - $E_s = E / m$
   - where, E is the energy released during utilization (e.g., combustion or energized circuit), and m is the mass of the fuel (as kg).

Energy density in an electric field is given by:

- Energy density = potential energy / volume = $1/2\epsilon_0 E^2$

Electric and magnetic fields "store" potential energy. In a vacuum, the (volumetric) energy density (in SI units) is given by:

- $U = (\varepsilon_0/2)E^2 + (1/2\mu_0)B^2$
- where, E is the electric field and B is the magnetic field. And, U is expressed in Joules per cubic meter ($J/m^3$).

In normal (linear and nondispersive) substances, the energy density (in SI units) is:

- $U = 1/2\ (E \cdot D + H \cdot B)$
- where, D is the electric displacement field and H is the magnetizing field.

There are many different types of potential energy contained ("stored") in materials, and it takes a particular type of reaction to release each type of energy. A material (substance or system) can release [potential] energy in four types of reactions: nuclear; chemical; electrochemical; and electrical. In other words, these types of reactions are capable of releasing [potential] energy from a material.

Generally, only the useful (or releasable/extractable energy) is measured/quantified. For instance, in concern to chemical energy, chemically inaccessible energy is not applicable when accounting and calculating for energy density.

> **NOTE:** '*Energy density' (how much energy a region of space carries) does not provide sufficient information about 'energy conversion efficiency' (net output per input), or about 'embodied energy' (what the energy output requires in terms of harvesting, refining, distributing, and dealing with pollution, which all use energy themselves). However, the 'energy density' of a system can be calculated relative the inclusion or exclusion of [external] components required to express that energy (e.g., oxidisers, heat sink, temperature, and/or the energy output interface).*

Chemical reactions take in energy to break bonds and give off energy when they make bonds. Relatively large organic molecules like those of hydrocarbons have lots of weak carbon-carbon and carbon-hydrogen bonds which don't take a lot of energy to break. But when these molecules redox ("burn"), then the combustion products make lots of strong carbon-oxygen and hydrogen-oxygen bonds that give out a lot of energy when they form. However, a liquid fuel, for example, is only on chemical combination with Oxygen, that energy is released (converted) to heat. The output energy is more dependent on the bonds that form to make the products, than the bonds in the initial fuel.

> **CLARIFICATION:** *The amount of thermal energy released in a chemical reaction can be calculated through thermodynamic equations. The 'heat of combustion' is the total energy released as thermal energy (heat) when a substance undergoes complete combustion with oxygen under standard conditions (this information is often presented in units of kj/mol). Therein, the amount of energy released by the combustion of a given fuel is the result of the subtracting the energy required to break the bonds of the reactants from the energy released by the formation of bonds in the products. One measure of the chemical energy of a fuel is the 'heat of combustion'.*

When chemical reactions take place and bonds form, break, and reshape, the atom nuclei don't change in any way. What happens is that the electrons jump between atoms or groups of atoms and change orbits. The different orbits are bound by different energies and you can start with a configuration of atoms and electrons and end up with another configuration but the total energy stays the same. This is really all there is to it, and thinking about that will give you a lot of intuition in particular with "energetic" chemistry. The potential energy in the bonds becomes kinetic [thermal] energy.

> **NOTE:** *The energy density of a fuel (e.g., hydrocarbon) will vary depending upon its molecular makeup.*

Of note, energy per unit volume has the same physical units as pressure, and in many circumstances, it is a synonym for pressure. One could go so far as to say that energy, in every form, is simply pressure mediation. For example, the energy density of a magnetic field may be expressed as (and behaves as) a physical pressure. Similarly, the energy required to compress a compressed gas a little more may be determined by multiplying the difference between the gas pressure and the external pressure by the change in volume. Hence, pressure [in a fluid] may be considered to be a measure of energy per unit volume (energy density).

Using a battery as an example, 'energy density' is a measure of how much energy the battery can store, in a given size or mass, a characteristic of the battery chemistry and its packaging. A battery with a higher 'energy density' can power a load for longer than one with a lower 'energy density' and the same physical size or mass (and composition). Its units are in Wh/kg or Wh/$cm^3$. Note the use of hours in the unit: power x time = energy. Also, it has to be stressed that the calculated 'energy density' is related to a given discharge rate, temperature, battery size, average discharge voltage, and cut-off voltage. A battery can, for instance, have a higher 'energy density' when discharged at a lower discharge rate or to a final lower cutoff voltage:

1. Energy density of a battery = ((drain in amperes x service hours = capacity in amp-hours) x average

discharge voltage) / volume of battery in liters = Watt-hours/liter

2. Specific energy of a battery = ((current amperes x service hours = capacity in amp-hours) x average discharge voltage)/weight of battery in kilogram = Watt-hours/kilogram

## 16.2 Rate of energy transfer [power] in relation to spatial region

> **NOTE:** *Power is not sub-classified as potential or kinetic. Power is the rate of energy transfer. Power is measured in units: Watts = joules/ seconds*

Having a measure for 'energy density' or 'specific energy' does not give information on how quickly the energy can be used/transferred. This information is contained in the measure of 'power density' and 'specific power', which describes the rate at which energy can be released and/ or transferred. Hence, whereas 'energy density' refers to the capacity to do work, 'power density' refers to the speed at which work can be done. 'Power density' and 'specific power' are measures of power output as a time rate of energy transfer per spatial unit (volume or mass). Power density answers the question: How fast can a volume/mass of space deliver energy? There are two calculated classifications for the rate at which energy can transfer between regions of space (measured as volume or mass):

1. 'Power density' - volume is the unit-region of space.
   - Power density ($W/cm^3$ or $W/m^3$) = power / volume
2. 'Specific power' - mass as the unit-region of space.
   - Specific power (W/g or W/kg) = power / mass

'Power density' (a.k.a., volume power density) and 'specific power' (a.k.a., mass specific power) are the power correlates of 'energy density' and 'specific energy' -- the amount of power (time rate of energy transfer) between regions of space. 'Power density' and 'specific power' refer to the ability of a given system or region of space to deliver, or to take on, power. Power is transferred between regions of space via energy transforming systems (a.k.a., energy conversion devices), such as turbines, turbine-generators, batteries, fuel cells, motors, power supplies, combustion systems, and photovoltaic panels. Energy transformers convert a volume (volume power density) or mass (mass specific power) of energy at a specific rate.

> **NOTE:** *Since they release their energy quickly, in general, high power density systems can also recharge quickly.*

In terms of electrical energy, 'power density' (volume) and 'specific power' (mass) refer to the maximum current that can be drawn from a region of space (e.g., battery as volume and mass).

#### 16.2.3.1 Power density and lasers

The power density of a laser beam can be determined by:

- Power density ($W/cm^2$) = $250/d^2$ • power
- where, d is the diameter of the laser beam in millimeters. Assuming that the beam profile is uniform.

#### 16.2.3.2 Power density and batteries

For a battery, 'power density' refers to the rate of energy release per unit of battery volume or weight (typically W/ dm3 or W/kg).

> **NOTE:** *A battery system can only supply the maximum power for a restricted period of (seconds or less) over the total amount of time it is supplying energy.*

#### 16.2.3.3 Power density and radio

Power density is used by radio engineers to express power densities of isotropic antennas as a quotient of the transmitted power and the surface area of a sphere at a given distance ($W/m^2$).

#### 16.2.3.4 Power density and heat engines

Power density of heat engines in kW/L (the second common use as volumetric power density of energy converters).

#### 16.2.3.5 Power density and energy flux

A broader approach is to measure power density through the more universal measure of 'energy flux' as $W/m^2$ of horizontal area of land or water surface, rather than per unit of the working surface of a converter. In other words, power density is expressed as electricity generated per m2 of the area occupied (per period of time).

Wind power density, for example, refers to the energy flux across a turbine or to diffusion rates in fuel cells. Power density has been used recently in this sense in order to calculate a flux across the (vertical) area swept by a wind turbine (more on this in the wind power density section).

In terms of combustion to electrical energy, power density (as $W/m^2$) refers to the volume of raw material that would have to be extracted (relative to the material's specific energy) in order to meet the combustion system's desired production capacity (per period of time). The power density of the material could be calculated (per period of time), and then the power density of the entire system (including the technical combustion system and raw material) could be calculated.

In terms of a solar panel to electrical energy, power density (as $W/m^2$) refers to the power output of the panel relative to the surface area of the panel.

Subsequently, the power density of the entire arrayed system can be calculated. Note that the power density of solar installations must also account for space between panels, either for servicing in solar farms or for spacing between houses in rooftop solar installation.

In terms of a wind turbine, power density measures the flux of wind's kinetic energy moving through the working surface (the area swept by blades).

# 17 Energy and power safety

## *17.1 Warnings*

No content here yet.

## *17.2 Failures*

No content here yet.

## *17.3 Incidents types*

Types of energy/power incidents include, but are not limited to:

1. All types of power:
   A. Fire
2. Electrical power:
   A. Shock and/or electrocution
3. Electromagnetic power:
   A. Electromagnetic burn
4. Mechanical, fluid, and combustion power:
   A. Suffocation
   B. Crushing
   C. Dismemberment
   D. Thermal burn
5. Nuclear power:
   A. Radiation burn (electromagnetic burn)

### 17.3.1 Native and non-native electromagnetic radiation

Native (i.e., "natural") electromagnetic radiative energy is all around us. The three primary source of native EMR for us on earth are: 1) the earth; 2) the sun; and 3) the cosmos. All life on earth needs this native electromagnetic radiation (or at least a portion of it), and cannot function without it. In addition to native EMR, humankind has begun engineering electromagnetic radiation (i.e., non-native EMR or EMF). Biological organisms on earth have learned how to use EM radiation from the sun, and our species has learned how to use electromagnetic processes from reality to expand our functioning (e.g., radio telecommunications).

Humans are salt water, and they present a low-resistance path for electrical current, which will preferentially redirect through their bodies rather than through other substances.

1. Skin effect, inductances and capacitance are negligible at 60hz.
2. Emergency de-energization

"System Emergency" means the condition in the Electricity System when, due to the occurrence of one or more incidents, a part or the whole of the Electricity System experiences excessive frequency deviations or transmission voltage deviations, and in the opinion of the System Operator circumstances exist such that: (a) the safety of the Transmission System is at risk; (b) the reliable transmission of electricity is at risk; or (c) there exists a danger to life or property as a consequence of (a) or (b).

> **NOTE:** *The effects of EMR upon biological systems (and also to many other chemical systems, under standard conditions) depend both upon the radiation's power and its frequency.*

Hazardous energy is defined by the Canadian Standards Association (CSA) as: "any electrical, mechanical, pneumatic, chemical, nuclear, thermal, gravitational, or other energy that can harm people" (CSA Z460 "Control of Hazardous Energy - Lockout and Other Methods"). Some energy sources are obvious, such as electricity, heat in a furnace, or something that might fall. Others may be hidden hazards such as air pressure in a system or a tightly wound spring.

Not properly assessing and dissipating stored energy is one of the most common causes for workplace incidents that involve hazardous energy. Control of hazardous energy includes isolating the system from its primary power source and residual energy.

1. Hydraulic potential energy is the energy stored within a pressurized liquid. When under pressure, the fluid can be used to move heavy objects, machinery, or equipment. Examples include: automotive car lifts, injection moulding machines, power presses, and the braking system in cars. When hydraulic energy is released in an uncontrolled manner, individuals may be crushed or struck by moving machinery, equipment or other items.
2. Pneumatic potential energy is the energy stored within pressurized air. Like hydraulic energy, when under pressure, air can be used to move heavy objects and power equipment. Examples include spraying devices, power washers, or machinery. When pneumatic energy is released in an uncontrolled manner, individuals may be crushed or struck by moving machinery, equipment or other items.
3. Chemical energy is the energy released when a substance undergoes a chemical reaction. The energy is normally released as heat, but could be released in other forms, such as pressure. A common result of a hazardous chemical reaction is fire or explosion.
4. Radiation energy is energy from electromagnetic sources. This energy covers all radiation from visible light, lasers, microwave, infra red, ultraviolet, and X-rays. Radiation energy can cause health effects ranging from skin and eye damage (lasers and UV light) to cancer (X-rays).
5. Gravitational potential energy is the energy related to the mass of an object and its distance from the earth (or ground). The heavier an object is, and the further it is from the ground, the greater its gravitational potential energy. For example, a 1 kilogram (kg) weight held 2 metres above the ground will have greater gravitational potential energy then a 1 kg held 1 metre above the ground.
6. Mechanical energy is the energy contained in an item under tension. For instance, a spring that is compressed or coiled will have stored energy which will be released in the form of movement when the spring expands. The release of mechanical energy may result in an individual being crushed or struck by the object.

In most cases, equipment or systems will have safety devices built in. These safety devices include barrier guards and safeguarding devices to help protect workers during normal operations. However, during maintenance or repairs, these devices may have to be removed or by-passed. In these situations, a hazardous energy control program is needed.

A hazardous energy control program is used to maintain worker safety by preventing:

1. Unintended release of stored energy.
2. Unintended start-up.
3. Unintended motion.
4. Contact with a hazard when guards are removed or safety devices have been by-passed or removed.

Lockout is generally viewed as the most reliable way to protect an individual from hazardous energy because you are bringing the system to a zero energy state. When a system is in a zero energy state the hazard has been eliminated; thus, no hazardous energy exists. However, in some cases, using lockout is not practical because of its impact on operations and various other functions. Therefore, other controls can be implemented as long as adequate risk reduction of the hazard is obtained. This type of control means following a full set of steps to determine the hazards and risks of each task being performed, and determining what controls can be used to minimize and reduce risk to an adequate level. If an adequate level of risk cannot be achieved, then lockout will be the default method of control.

A voltage applied to a human body causes an electric current through the tissues, and although the relationship is non-linear, the greater the voltage, the greater the current. The threshold for perception varies with the supply frequency and with the path of the current, but is about 0.1 mA to 1 mA for mains-frequency electricity, though a current as low as a microamp can be detected as an electrovibration effect under certain conditions. If the current is sufficiently high, it will cause muscle contraction, fibrillation of the heart, and tissue burns. The lack of any visible sign that a conductor is electrified makes electricity a particular hazard. Death caused by an electric shock is referred to as **electrocution**.

### 17.3.2 Does it hurt more to be shocked by 110v or 240v AC?

One reason AC is more deadly is that any path which cause the current to pass through the body and cross the heart (i.e., left-hand-to-right-hand or hand-to-foot) will cause the heart to attempt to synchronize its beat to 60 Hz. The heart goes into fibrillation, and unless someone gets an AED on you within a couple minutes, that's the end. Heat is also generated by the flow of electrical current through body tissues, resulting in direct thermal injury (electrical burns) and possibly physical injury (entrance and exit wounds). In addition, the alternating current locks the muscles in a spasm, so you can't pull away. With DC, your greatest danger is thermal-physical injury at very high voltages, or just thermal injury at lower voltages. The reason DC feels much worse is that it causes the muscles to contract abruptly (whereas AC causes them to lock), so the physical effect is more painful. AC will freeze your muscles while DC will contract them. So if you hold a wire in your hand, DC will make you hold it even stronger, while AC will just "freeze" your muscles.

A higher voltage breaks down a poor insulator (e.g., the thin layer of non-conductive dry skin that covers the body), and once that insulator breaks down, the inner layers of the skin, and the muscles, are highly conductive. 15 mA is the lethal dose. That is why ground fault circuit interrupters (GFCI) can help prevent electrocutions, and are set to trigger at a 5 mV differential.

> **"***I have not tried the experiment, but I have read that a 9 V battery connected to two sharp needles will, if the needles are stuck into the skin, be very painful."*

Higher voltages are more dangerous because they break down poor dielectrics faster. Remember, at all times, 15 mA across the heart is all it takes. Current pushed/fed through the human body by voltage causes the body to react unpleasantly. Current is measured in amps, A. In the energy storage technology known as a battery, 'capacity' indicates how much power the battery pack can hold and is indicated in milliamp hours (mAh). In other words, mAh describes the measurement of how much load or drain (measured in milliamps) can be put on the battery for 1 hour, at which time the battery will be fully discharged.

However, DC tends much more to arcing than AC at points where current-carrying contacts are separated. The danger of fire and burning is significantly higher with DC compared to AC. The reason: an AC arc will be more efficiently extinguished due to the zero-crossings of current, 100 to 240 times a second (50 / 60 Hz). DC has no zero crossings, so an arc will form even at low voltages, around 40 - 50 volts. 250 VDC can easily cause an arc of one or more inches in length, if current is interrupted. Hybrid mechanical/electronic circuit breakers have only recently been developed for these DC current contact connections.

Of note, DC tends much more to arcing than AC. Any mechanical DC current connector, relay -- basically a mechanical current interrupter -- is dangerous, because of the DC arc, which will happen during the opening or closing of any DC current contact. Hybrid mechanical/ electronic circuit breakers have been developed for these connections.

## 18 Power symbols

A power symbol is a symbol indicating that a control activates or deactivates a particular powering or powered device. Universal power symbols are described in the International Electrotechnical Commission 60417 standard, Graphical symbols for use on equipment, appearing in the 1973 edition of the document (as IEC 417) and informally used earlier.

The well known on/off power symbol was the result of the logical evolution in user interface design. Originally, most early power controls consisted of switches that were toggled between two states demarcated by the words On and Off. As technology became more ubiquitous, these English words were replaced by the universal numeral symbols 1 and 0 (typically without serifs) to bypass language barriers. This "1" and "0" standard is still used on toggle power switches.

To create the symbol for a single on/off button, the "1" and "0" symbols were super-imposed onto each other to create the universally recognized power symbol used today. Because of widespread use of this symbol, a campaign was launched to add the set of characters to Unicode. February 2015, the proposal was accepted by Unicode and as of late 2015 the IEC power symbol family was in Stage 7 of Unicode character development and either in ISO approval ballot or pending ISO publication.

## 19 Energy and power fundamentals

Energy is a quantity that a given substance or system state/ dynamic contains. An energy system is a sequence of energy calculations and energy transfers ("conversions"). The components of an energy (power) system must work together to transfer energy and [transform] power in such a way as to provide for higher functioning and the fulfillment of energy/power requirements.

> **NOTE:** *If energy were defined as the ability of a system to cause external action, then such action becomes sensible by force (displacement), heat (temperature), and light (EM radiation).*

In any given service system, energy has the following characterizations:

1. Energy is *expressed/experienced* as: effect, change, action, movement (or motion), behavior.
2. Energy is *carried/possessed* by: substances and systems.
3. Energy is *transferred* as: work or heat.
4. Energy is *required* for all: structures, processes, operations, functions.

Energy systems involve [at least] the following process stages/phases:

1. **Harvesting, harnessing, and/or collecting** natural energy sources/carriers.
2. **Transferring/transceiving** between different carriers of energy in order to store the energy or produce power. These transferring/transceiving processes are sometimes, and inaccurately, referred to as energy "transformation" and/or "conversion" processes. In actuality, the energy does not change form, it simply transfers carriers.
3. The **distribution** of energy carriers to their end-use application.
4. The **utilization** ("consumption") of energy by a service application.

Energy is a unifying abstract quantitative property that may be assigned to any region, system, object or substance in space-time (existence) via calculation, indicating a change to space-time (existence). The value of the property 'energy' is derived via a measured formulaic (algebraic) expression relative to the region of space (system) under consideration and the theorized principles-attributes that make up existence. The quantized value that is 'energy' indicates the relative degree to which motion is present and/or change of motion is possible in a given area of space-time. The formulas for deriving energy are human inventions -- the description of the natural law of energy conservation by means of a set of algebraic formulas is a human invention. Objects and systems have energy that can only be indirectly observed - by observing what the object or system does.

> **NOTE:** *Although 'energy' may be the most important concept in physics to define, it is also the most difficult to define, because it is axiomatic to the study of existence, which is not yet fully understood.*

Energy is not a thing; it is not matter and it cannot be reified. But, existence may be said to "carry" a property called 'energy'. 'Energy' is an abstract value of a system, and when calculated in "appropriate" ways, always turns out to be conserved.

> **INSIGHT:** *When energy is present, change is occurring or is possible.*

It is incorrect to conceive of energy as a substance-like entity that occupies space, but there are entities called "fields" which occupy space. There are electric and magnetic fields which occupy space, and are described by the "classical" electromagnetic theory of Clerk Maxwell and others, way back in the 19th Century. To conceptualise energy as having form or substance, you should be aware that such conceptualisations are not required by the mathematical structure of physics. There is nothing in the equations or laws which says that energy has either form or substance. It is nothing more than an abstract entity which can be calculated according to rules which it is the business of physics to discover.

> **NOTE:** *Magnetic fields are really electric fields under a Lorentz transformation. Electric fields do not occupy space in the sense that matter does. Instead, they occupy "counterspace". You cannot put two matter-objects (e.g., clay bricks) in one place, but you can superimpose two magnetic fields in the same space to get a total magnetic field (in "counterspace").*

Characteristics of a broad conception of energy:

1. Energy is associated with the action of organisms.
2. Physical systems and objects possess and expend energy.
3. Energy of itself does not cause anything.
4. Energy is associated with activity.
5. Energy is transferred/exchanged between carriers by processes.
6. Energy is a generalised kind of fuel associated with making life comfortable.
7. Energy is a kind of fluid which is transferred in some processes.

There is an inaccuracy in the following commonly seen definition of energy: **"**Energy is the ability to do work, where work is force times distance." The concept that energy is the ability to do work dates back to the seventeenth century and was put into question when energy was defined quantitatively as a conserved quantity in the 1840s. Within ten years, the enunciation of the second law of thermodynamics had shown this definition to be false. In thermodynamics, 'work' takes on a meaning which is broader than the "force times distance" concept of classical mechanics. Therein, work refers to either (1) a process of energy transfer, or (2) the energy being transferred. Not all energy can produce work -- according to the second law of thermodynamics there is always some part of the energy of a system (disordered) that cannot produce work. Hence, there does not seem to be much information content in the statement that "energy is the capacity to be energy that is being transferred (by some process or other)" or "energy is the ability to do force times distance".

**ENERGY AS WORK AGAINST ENTROPY**

If energy is the ability to do work, then without energy there is no ability to maintain structure against the entropic randomization of the universe -- without energy there is no ability to do anything. Here, we take high energy molecules or molecules in motion that ultimately derive their energy from the sun (i.e., the basic economy of the planet is energy from the sun, is photosynthesises) and transformationally redirect it into something we can use. In other words, we take that high potential environmental energy and convert it through a process of some kind into directed high potential [information] energy that allows our habitat (and bodies) to be powered. At a biological level this occurs through a quantum transducer known as 'mitochondria'. Biologically speaking, our organisms strip electrons off food in a similar, though significantly more complex, manner to the functioning of turbines in a hydroelectric dam through which water flows. When water goes through the turbines electrons are taken [by us] and fed into an electric grid through electron transmission. In fact, our mitochondria is a miniature example of this electron transport chain seen in hydroelectric or nuclear generating power systems. Our organisms take high energy [macro] nutrients as proteins, lipids, and carbohydrates and process them through an energy "powerhouse" we know as mitochondria to produce a set of high-energy intermediaries (e.g., atp, nadph) that are then directed and delivered to regions of the cell(s) that maintain function (i.e., muscles to contract or neurons to fire or digestive juices to be released or cells to replicate. This process is technically known as mitochondrial bioenergetics. At a practical level our diet and lifestyle play an important role in functionally maintaining the ability of these powerhouses to do that work. Fundamentally, matter is a form of coalesced energy (remember e = mc2), and molecules are essentially information rich "data packets" of energy.

**INSIGHT:** *Spurred by the burgeoning industrial revolution, the theoretical physicists between 1840 and 1860 developed the "laws of thermodynamics". The first law (conservation of energy) told the industrialists that they could not get anything for nothing; the second law (increase in entropy) said that they could not even break even.*

Every time energy is transferred, some of its ability to do "work" is irretrievably lost. However, no such limitation applies to the conversion of work to heat; if a simplified definition of energy is needed, it might be described as the ability to produce heat (heating). While this definition is neither elegant nor useful, at least it is true. It is therefore misleading to leave heat out of any definition of energy. Thus, in every transfer of energy, there is energy available [given appropriate technology] to do "work", and energy not available to do "work" -- energy is the capacity to do 'work' and/or supply 'heat'. Therein, the specific expression/definition of 'work' is dependent upon the contextual medium possessing or transferring energy, and 'heat' is energy transfer between two objects of different temperatures:

- **Available energy**, that is energy which can, in principle, be transferred between systems by the process called "work".

Additionally, without the idea of "conservation", energy would mean nothing. Conservation of energy means that energy calculations, correctly performed, always balance to give a constant total. Note that the term 'conservation' does not mean the "saving of energy" or "not wasting energy".

The amount of work that can be obtained from energy depends on the degree of organization of the energy. Organization means all the molecules are moving in the same direction. If the same amount of energy is added to the random motion of the molecules, the result will be a rise in temperature.

Energy and mass are two different ways of expressing a certain property of a system, and that property is a conserved quantity. The equation $E = mc^2$ does not state that mass can be converted into energy. What it does say is that the total energy of a system can be found by multiplying its mass by a universal constant (or consistent). In a frame of reference affixed to the object, multiplying its mass by $c^2$ yields a quantity called 'rest mass energy'. All mass carries energy.

**INSIGHT:** *Mass can only be determined when a particle is at rest. This is called 'rest mass'. Electromagnetic emissions cannot be put to rest, and therefore, the mass of these "particles" (if they even have mass) cannot be determined.*

Mass and energy are scalar quantities, while momentum is a vector quantity. Kinetic energy is scalar, it does not have direction. A scalar quantity has only magnitude, while a vector quantity has both magnitude and direction. Momentum is a vector quantity, because it has magnitude and direction. Although a scalar quantity may be separated into components, that doesn't make it a vector quantity. A vector is defined by how those components add up to a total. Vectors also follow specific coordinate transformation laws. As viewed from different coordinate systems, the magnitude of a vector would be the same, but the values of its components would be different. There are requirements for a physical quantity to be a vector: 1) it should have a direction; and 2) it should be added by laws of vector addition.

**INSIGHT:** *We understand that matter is made of "atoms". We understand that atoms have "mass". We understand that there is a relationship between mass and energy. We understand that there is a relationship between vacuum and energy.*

At the center of all things with magnitude (e.g., magnetism), there is not that force (or inertia) modality. At the center of gravity there is zero gravity. At the center of magnetism there is zero magnetism. At the center of charge there is zero charge. Where there is not that force there is a "plane of inertia". There is no midsection to any magnet. Each new slice of a magnet will have its own plane of inertia. That tells you that there is no thing that is a plane of inertia. That tells you that the "block wall" or plane of inertia is not located there.

## *19.1 Energy and systems*

The concept of energy can be applied to any existent system, wherein the following principles apply:

1. Energy is a derived quantity that may be assigned as a property of any existent system.
2. The total quantity of energy in a closed system is fixed.
3. The total quantity of energy in an open system is not fixed. In an open system, energy is brought into the system from the environment.
4. More 'energy' is required to transfer something across a system boundary, than within the system boundary.
5. Systems maintain themselves by cycling energy and matter. Ecosystems maintain themselves by cycling energy and material nutrients [obtained from external sources].

An 'energy process' is any change that a system undergoes from one equilibrium state to another. Therein, a 'path' is the series of states through which a system passes during a process. To describe a process completely, one should specify the initial and final states, as well as the path it follows, and the interactions with the surroundings.

### 19.1.1 Energy and thermodynamic systems

Thermodynamics does not have a direct etymological meaning, but it could be named the study of heat transfer. Anything in physics related to heat is classified [at least] as part of study of thermodynamics, and follows thermodynamic principles. There are four principles (or "laws") of thermodynamics (zero through three):

1. **The zeroth law of thermodynamics** - if a system A is in equilibrium with system B, and system B in turn is in equilibrium with system C, then systems A and C are in equilibrium with each other.
2. **The First Law of Thermodynamics** - the change in internal energy of a system is equal to the sum of the energy transferred to the system by "heat" and the "work" done on the system. This principle claims that energy is conserved.
3. **The Second Law of Thermodynamics** - the efficiency of heat engines must always be < 1.
4. **The Third Law of Thermodynamics** - the temperature of a system cannot reach absolute zero (0 K); as the system approaches absolute zero, entropy approaches a constant.

Thermodynamics divides the universe/reality into two parts: a system and its environment. Therein, there are three distinct types of thermodynamic system:

1. **Isolated systems** - no transfer/exchange of energy or matter with the environment.
2. **Closed systems** - transfer/exchange only energy, but not matter with the environment.
3. **Open systems** - transfer/exchange both energy and matter with the environment.

Thermodynamics concerns equilibrium states. Thermodynamic equilibrium is an axiomatic concept of thermodynamics. It is an internal state of a single thermodynamic system, or a relation between several thermodynamic systems connected by more or less permeable or impermeable boundaries. In non-equilibrium systems, by contrast, there are net flows of matter or energy. Equilibrium is a state of balance (no change). In an equilibrium state there are no unbalanced potentials (or driving forces) within the system.

1. **Thermal equilibrium** is if the temperature is the same throughout. The point at which heat transfer stops.
2. **Mechanical equilibrium** is if there is no change in pressure at any point of the system with time.
3. **Phase equilibrium** is if a system involves two phases and when the mass of each phase reaches an equilibrium level and stays there.
4. **Chemical/atomic equilibrium** is if the chemical/atomic composition of a system does not change with time, that is, no chemical or atomic reactions occur.

The prefix iso- is often used to designate a process for which a particular property remains constant.

1. **Isothermal process** - a process during which the temperature remains constant.
2. **Isobaric process** - a process during which the pressure remains constant.
3. **Isochoric (or isometric) process** - a process during which the specific volume remains constant.
4. **Cycle** - A process during which the initial and final states are identical.

### 19.1.2 Thermodynamic energy flow types

A system and/or region of space can "gain" energy from its surroundings or "lose" energy to its surroundings. Technically, the system or region of space isn't actually gaining or losing some real thing called 'energy'; instead, the property, 'energy', which is assigned to that region of space or system is increasing or decreasing in value. As energy flows through systems it acquires different qualities:

1. **Enthalpy** - The amount of heat content used in a system at a constant pressure. In any system how much heat is used at the constant pressure termed as enthalpy. Enthalpy (h) is the measure of total energy content of a substance in a thermodynamic system. The SI unit for 'specific enthalpy' is joule per kilogram. It can be expressed in other specific quantities by $h = u + pv$, where u is the 'specific internal energy', p is the pressure, and v is specific volume, which is equal to 1ρ, where ρ is the density.
2. **Entropy** - Entropy is the measure of disorder, or a measure of "randomness". Entropy is a quantitative measure of the unavailability of a system's energy [to do work]. When a system receives an amount of heat (ΔQ), the system gains an entropy in the amount given by ΔQ/T, where T is the absolute temperature at which the heat transfer takes place. Entropy is a measure of the disorder of a thermodynamic system. Enthalpy is a measure of the total energy of a thermodynamic system. Entropy is a quantitative measure of the molecular disorder of a system. Entropy of the system increases when temperature gradients disappear or dissipate. Entropy of the system increases when concentration gradients disappear or dissipate. As energy is expended to do work, entropy decreases. If no energy is available in the system, its entropy level will remain constant or increase.

- There are at least two kinds of entropies - thermodynamic and information-theoretic entropies. Thermodynamic entropy should not be confused with the so-called 'information theoretic entropy' (a.k.a., intropy). 'Information theoretic entropy' is a measure of variety of message sources in communication systems.

3. **Exergy** - The generic name for the amount of work obtainable when some matter is brought to a state of [energetic] equilibrium with its surroundings by means of reversible processes. In thermodynamics, the exergy of a system is the maximum useful work possible during a process that brings the system into equilibrium with a heat reservoir. When the surroundings are the reservoir, exergy is the potential of a system to cause a change as it achieves equilibrium with its environment. Exergy is the energy that is available to be used. After the system and surroundings reach equilibrium, the exergy is zero The maximum useful work which can be obtained in a process in which system obtains dead state. For example, when a new source of energy, such as geothermal well, is discovered, the first thing the team does is estimate the amount of energy contained in the source. However, this information alone is of little value in deciding whether to build a power plant on the site. Additional information is needed in order to determine the work potential of the source; that is, the amount of energy that can be extracted as useful work. This property is called exergy. Note that destroyed exergy has been called anergy.
4. **Emergy** - is defined as the available energy of one kind required directly and indirectly to make a product or service. It is measured in emjoules (a unit referring to the available energy consumed in transformations). In energy systems, energy sources and components are connected with energy flows and arranged from left to right (generally), thus describe the order of increasing transformity. The transformity is defined as the emergy (in emjoules) of one kind of available energy required directly and indirectly (through all the pathways required) to make one joule of energy of another type. Transformity is the ratio of emergy to available energy.

## *19.2 The physics perspective on energy*

> **INSIGHT:** *Energy is a mathematical principle, not a description of a mechanism or anything physical.*

'Energy' is a physics term describing a mathematical principle - something that cannot be held or seen. Energy is simply a value that is algebraically calculated. Therein, energy is an abstract and quantized value (a property) that may be assigned to any given region of space-time, implying the presence of change or the possibility for change. The property, 'energy', is the result of mathematical expression and calculation, and cannot be reified. There is no such thing as "a form of energy", because energy does not have form - it is not an existent substance. Energy does not come in different forms. Hence, 'energy' is not capable of being transformed or converted. Instead, energy is an abstract, calculated value implying the transformation of existence, or potential for the transformation of existence, but it itself does not have existence or form. All systems in existence "carry" energy (i.e., have energy as a property assignable to their existence).

> **CLARIFICATION:** *Energy is not a physical substance; it is not made of atoms. Matter is made of atoms. The distinctive names of energy, such as kinetic energy, potential energy, electrical energy, mechanical energy, thermal energy, arise because of the different systems by which energy is assigned as a property, not because there are different forms or types of energy. Energy is just energy. Different physical "storehouses" result in the different names, not different kinds of energy. Many papers cite the approach in the Feynman Lectures: there are a number of different physical quantities whose sum is always constant (as a physical law), so we call that sum "energy". These various physical quantities are typically called "forms of energy".*

The value of the property, 'energy', can be calculated for any region of space-time and/or system given the data available to complete the calculation. 'Energy' cannot be calculated in isolation, or measured directly. Conceptually, energy only exists in the context of two or more objects and the occurrence of a change (i.e., in the context of a system).

Energy is a universal property of every existent system that implies the calculated ability to change [given a cause in the real world]. And, all change in the universe implies the transfer of energy. A change in a system's state implies a transfer of energy, and a transfer of energy implies a change in a system's state. The presence of energy and its transfer underlies all change of existence in the universe. Its presence, as an expressed property, is a calculable necessity for the existence of movement, heat, electricity, and all life.

> **NOTE:** *In physics, the presence of energy is required for change, but energy does not cause change. Differences in the real world (e.g., pressure and temperature gradients) cause change, and when change occurs, energy transfers (i.e., is recalculated). In other words, differences in pressure concentration and unbalanced forces cause change, not energy. But, when change occurs, energy is transferred. And, the quantity that is 'energy' can be*

*calculated to determine the value required for an expressible change to occur. For instance, the energy requirement for lifting an object a set height can be calculated.*

Energy is not made of anything, energy is a term used to describe a trait of matter and non-matter fields. When matter has velocity, for example, it is said to have kinetic energy. Energy isn't 'stuff', it is a calculated quantity based on an equivalence relation; a property that systems have. It is a scalar value that is assigned to the state of a system, (i.e., energy is a tool or mathematical abstraction of a property of physical systems). This quantity is involved in (i.e., can be associated to) all processes of change.

Mathematically, energy is a conserved quantity, and hence, it is not possible to create new energy that is not already present (mathematically speaking) in the universe. Many different kinds of change take place in the real world, and for each kind of change the total energy before is calculated to equal the total energy after.

**NOTE:** *In common parlance, the terms "energy generation" and "energy utilisation" are confusing because, in fact, no energy can be created or destroyed.*

A classic textbook definition of energy is "the ability (or capacity) to do work". Even though this definition is now deprecated, it seems to have enduring power "Energy is the capacity to do work" is not only incomplete, but incorrect, because it ignores the 2nd Law of thermodynamics, which states that not all energy has the ability to do work. The 1st law says that energy is conserved, yet the 2nd law says that the ability to do work is not conserved, so this definition of energy leads to a logical contradiction. Further, although at a conceptual level the idea that energy is "the capacity to do work" makes sense for mechanical energy, but not for thermal and other "forms" of energy.

## *19.3 Energy classification contexts*

The total energy of a system can be classified in a variety of ways. Hence, there are multiple "types" of energy, which depend upon the context of the classification. As a measure/property of the expression of something that exists, the presence of energy can be classified according to:

1. Spatial motion (of carrier/system)
2. Spatial length (of carrier/system)
3. Spatial medium (of carrier/system)
4. Pressure gradient (within carrier/system)
5. And, any combination thereof

### 19.3.1 Classified by: Spatial motion

Stating that an object "possesses" energy means that it is moving right now or has the ability to move due to its position [in a force field]. The part of the measure that is not currently represented as motion, but stays in the form of an ability to move due to its position is called, potential energy. While, the part corresponding to the motion right now is called kinetic energy.

In general, motion and the potential for motion is described as mechanical energy. Mechanical energy is the total energy an object has (when building up energy or when using it). The two known types of energy as per motion are: kinetic energy (current motion) and potential energy (potential for motion). Hence, the sum of potential energy and [macroscopic] kinetic energy is called mechanical energy.

Hence, from the perspective of spatial motion, energy can be classified in two fundamental ways:

1. As a flow: Energy expressed as motion is called **kinetic energy (mass and velocity)**. Kinetic energy is the energy an object "possesses" due to its motion. A force, driven by a cause, is required to accelerate a mass to its stated velocity. Kinetic energy is "gained" during acceleration and remains during motion. Kinetic energy represents explicit change.
2. As a potential for flow: Energy associated with position [in an electric or magnetic field] or condition is called **potential energy (position and condition)**. Potential energy is the energy associated with an object as a result of its position or condition inside a "force" field. Note here that potential energy is not stored energy. Energy can be stored in motion just as well as it can be stored in position. Potential energy represents a potential for future change (or motion). Energy due to position in space.

And yet, this arrangement of motion associated energy concepts could also be viewed from the following perspective classification:

1. How energy flows: electromagnetic energy, electrical energy, heat, work, etc.
2. How energy is stored: internal energy, kinetic energy (stored in motion), potential energy (stored in condition), energy density (stored in fuel), etc.

Simplistically, kinetic energy is energy "in motion" and potential energy is energy "at rest". Potential energy is often measured as positive or negative depending on whether they are greater or less than the energy of a specified base state or configuration, such as two interacting bodies being infinitely far apart.

When energy is present, then there ongoing change (i.e., movement) or the possibility of future change (i.e., future movement). That potential for future change can be "absorbed" by some sort of reservoir-like capability in existence (as potential energy), retained for a length of time (permittivity), then released again in the future as explicit change (as kinetic energy).

A existent\material system can have any combination of kinetic and potential energy, and both potential and kinetic energy can be "stored". Over time, energy is transferred from potential energy to kinetic energy, and then, back to potential energy constantly. This is referred to as the "conservation of energy" (or, "conservation of ether").

Potential energy only exists in the presence of a system. When a brick, for instance, is lifted, its potential energy is not increased. Instead, the potential energy of the system that consists of the two objects: the earth and the brick. Potential energy is not stored in either Earth or the brick, nor is it possible to apportion the potential energy between the two interacting objects. The first step to enlightenment is to learn not to speak or think about gravitational or electrical potential energy of electrons (or of any other kind of particle) and think instead of energy as a property of the whole system.

> **NOTE:** *Technology takes forms of potential energy and turns them into kinetic energy. Whenever energy is "used", it is kinetic energy.*

The material expression of kinetic and potential energy can take multiple forms. These forms represent a contextual measure (quantity) of the ability of a system or object to do work on another system or object in material reality. The interaction between energy and matter is described by its multiple forms of energy.

> **QUESTION:** *Energy is not a thing, it is a property of something; hence, how can it exist in different forms? Simply put, a "form" of energy is a mathematical expression, an equation that evaluates a quantity of energy in a given context. Thermodynamics is the study of any energy transformation that involves heat.*

Kinetic energy is calculated using the following formula:

- $E = 1/2mv^2$
- where, E is energy, measured in joules (J)
- where, m is mass, measured in kilograms (kg)
- where, v is velocity, measured in meters per second (m/s)

Notes about the expression:

1. The more mass a moving object has, the more kinetic energy it will possess at the same speed.
2. Because the velocity term in this formula is squared, velocity has a much larger effect than mass does on kinetic energy.
3. The larger an object (m) is and the faster it moves (v), the more kinetic energy (KE) it has.

Ways of harnessing macroscopic kinetic energy include, but are not limited to:

1. Wind power harnesses the kinetic energy possessed by moving bodies of air (wind) as they flow between atmospheric pressures.
2. Hydropower harnesses the kinetic energy of moving water as it moves (i.e., falls) in a "gravitational force" field.

Potential energy is calculated using the following formula:

- $E = gmh$
- where, g is the acceleration due to "gravity"
- where, h is height above inertial ground plane
- where, m is the mass of a body.

Notes about the expression:

- The larger an object is (m) and the more displaced it is (h) in a "force" field, the more potential energy (PE) it possesses.

### 19.3.2 Classified by: Spatial length

All energy types detectable in space-time may be classified by the length-dimension of the system or object (i.e., mass) under observation. Generally speaking, there are two principal categories of length: the macroscopic and the microscopic. The prefixes "micro-" and "macro-" come from Greek words that mean "small" and "large," respectively. The suffix "-scopic" originates with the word "scope," which in turn originates with the Latin word "scopus," which can mean aim, target or object of attention.

> **NOTE:** *The terms 'microscopic energy' and 'macroscopic energy' could be replaced here with 'microscopic viewpoint or approach' and 'macroscopic viewpoint or approach'.*

The macroscopic context considers a certain quantity of matter without considering the events occurring at the molecular level. The macroscopic approach is based on the study of the overall behaviour or gross behaviour of a number of molecules. Hence, the macroscopic "forms" of energy are those a system (or object) possesses as a whole with respect to some outside reference frame (e.g., the earth). The macroscopic viewpoint maintains:

1. The energy expressed/possessed by the gross or average behavior of multiple molecules that can be explained based on the continuum assumption.
2. Time average influence of multiple molecules.
3. Effects can be perceived by senses and/or measured by instruments, such as the effects of pressure and temperature.
4. Substances perceived as infinitely divisible or

existing along a continuum.

The microscopic "forms" of energy, on the other hand, are those related to the molecular structure (architecture) of a system, its molecular bonding, and the degree of the molecular activity, which are independent of outside reference frames. The microscopic context maintains:

1. The energy expressed/possessed atoms or molecules are considered based upon statistical considerations and probability theory in connection with a model of the atom.
2. The 'internal energy' of a system is the sum of its microscopic forms of energy.

The macroscopic and microscopic energy value of a system can be combined to express the 'total energy' of a system - the sum of its macroscopic energy and microscopic energy.

Kinetic energy and the spatial length of a system in question can be combined in value. Kinetic energy is the energy of motion: the motion of large objects (macroscopic kinetic energy), or the movement of small atoms and molecules (microscopic kinetic energy). Macroscopic kinetic energy is sometimes referred to as "high quality" energy, while microscopic kinetic energy is more disordered and "low-quality". Macroscopic kinetic energy can become microscopic kinetic energy through 'friction'.

### 19.3.3 Classified by: Spatial medium

It is customary to say that energy exists in different forms which are transformed or converted into one another during physical processes. However, using the term "energy form" for the respective categories is unsatisfactory because it easily leads to the misinterpretation that there are different kinds of energy. The term 'energy carrier' more accurately accounts for the well-known but little recognized natural law that energy always flows simultaneously with at least one other existent (physical) quantity. Hence, the term 'energy carrier' is able to provide clear language of how energy is transported, exchanged, and stored. The substance-like physical quantity which flows while energy is flowing, "carries" the energy. It is imprecise to speak about the forms of something that itself does not change, but rather, which only changes carriers.

Of course, there are limits as to how literally the expression "energy carrier" should be understood. The word "carry" implies here only a temporal relationship between the flow of energy and the flow of an energy carrier. It is not meant to imply that energy and its carrier necessarily occupy the same position in space or even flow with the same velocity. An energy carrier can be "loaded" with more or less energy in the same sense that a carrier of commodities, say a pickup truck, can be loaded with more or less of a commodity.

The picture of energy carriers and energy load factors is especially useful to describe devices which are traditionally called "energy transformers" or "converters." Traditionally speaking, energy flows into an energy transformer in one form and out in another. Unfortunately, this way of speaking suggests that one physical quantity is transformed into another within such a device. Actually, however, the energy simply changes its carrier within the device. In other words, the energy is transferred from one carrier to another within the device. Accordingly, the name energy transceiver is more appropriate to the actual function of such a device.

It is easy to graphically represent the energy transport from one device or region of space to another with the help of an energy flow diagram. Such diagrams provide the means for a simple, graphical calculus applicable to the solution of energy-related problems. A

### 19.3.4 Energy carriers, mediums, and forms

**CLARIFICATION:** *Energy can be absorbed by carriers and transferred between carriers.*

Energy can be classified according to the spatial medium (form or source) for which the quantity is being calculated. The following are not different forms of energy -- in physics, there is just energy, not different forms of energy. In particular, in physics, the conservation law states that there are no sources and there are no sinks of energy. There is such a thing as 'dissipation', which is covered by entropy per a thermodynamic system.

Energy may be classified for the following systems:

1. **Mechanical energy** - energy possessed by the mass of an object due of its motion and/or potential to move. Energy in the mass of an object due to its motion and gravitational position - the sum of the kinetic energy and potential energy of a mass.
    A. Mechanical kinetic energy - energy due to motion (moving objects)
    B. Mechanical potential energy - energy due to tension of objects.
2. **Chemical energy** - energy possessed by the composition of a chemical substance due to the condition and/or potential condition of its atoms. Energy in the chemical bonds of atoms and molecules. Chemical energy is released out of the reaction taking place between elements/molecules to form a more stable compound.
    A. Chemical potential energy - energy due to molecular position in a chemically-bonded "force" field (i.e., due to chemical bonds).
3. **Nuclear energy** - energy possessed by the composition of an atom due to the condition and/or potential condition of its binding nucleons. Energy in the nuclear bonds of an atom. Nuclear

energy is the energy released by either a fission or a fusion process. Here again the resulting products assume a more stable condition.

- Nuclear potential energy - energy due to dielectric position in an atomically-bonded "force" field (i.e., due to nucleus of atoms).

4. **Electric[al] energy** - energy possessed by the electric composition of an atom due to the condition and/or potential condition of its polar charge. Energy expressed in/as charged motion is electrical energy.
   A. Electric[al] potential energy - energy due to atomic position in an electrically-bonded "force" field.
   B. Electric[al] kinetic energy - when matter that carries a charge moves in an electric field it carries kinetic energy.
5. **Electromagnetic energy** - energy possessed by the composition of ether (electric and magnetic fields) due to the condition and/or potential condition of its dielectric inertial plane. Electromagnetic energy is a dynamic form of energy that is caused by the acceleration or oscillation of a charged particle. All substances above absolute zero (0 Kelvin) emit a range of electromagnetic energy.
   - The acceleration/oscillation of electrical charges produces dielectric radiation.
6. **Gravitational energy** - energy possessed by the mass of an object due to its motion and/or potential to move toward a zero inertial plane.
   A. Gravitational potential energy - energy due to mass position in a gravitationally-bonded force" field (i.e., due to height and weight in gravity field).
7. **Thermal energy** - the total energy of motion, rotation, and vibration of the atoms and molecules inside an object. Thermal energy is not the energy of a whole object itself (mass) moving. In a gas or gas mixture, like air, the motion (and rotation) of individual gas particles makes up this energy. In a solid, like a table, the thermal energy exists as vibration of atoms or molecules. Note that total thermal energy also includes some atomic forms of potential energy. The temperature of an object is determined by its total microscopic kinetic energy. Thermal energy is the result of molecular agitation causing rise in temperature. It is the basic energy form, in the sense all other forms of energy can be completely converted into thermal energy. The other way, i.e., the complete conversion of thermal into other forms of energy is not possible and is governed by the Second law of thermodynamics. Thermal energy is the energy of a vibrating molecule in all degrees of freedom (translational, vibrational, rotational, potential).

## 19.3.5 Movement and Oscillation of energy carriers

The oscillation and/or acceleration of an energy carrier will produce a related type of energy transfer:

1. Atomic and molecular oscillation generates thermal radiative electromagnetic energy (heat).
2. Mechanical oscillation generates acoustic/cymatic radiative energy (sound).
   A. Linear acceleration of matter results in force (thrust or propulsion).
   B. Circular acceleration of matter results in torque.
   C. Divergent acceleration of matter results in pressurization or explosion.
   D. Convergent acceleration of mater results in depressurization or implosion.
3. Electric [charge] oscillation generates electromagnetic radiative energy (light).
   A. Moving charges have a magnetic field.
   B. Linear acceleration of electric charge generates a pulse of electromagnetic radiative energy.
   C. Circular acceleration of electric charge generates electromagnetism.
4. Magnetic oscillation [in the presence of a conductor] generates electrical radiative energy [around the conductor].
5. Changing magnetic fields generate electric currents in a conductor.

**NOTE:** *All digital communications and wireless charging, at the present, are based on electron oscillation. Therein, the term 'signal' is another word for the propagation of energy conveying communicative information (i.e., a communication)***.**

## 19.3.6 Sub-classified by: Pressure gradient

**NOTE:** *There are pushing pressures and there are pulling pressures.*

Every aspect of power production and/or energy transfer in the world is about moving pressures from one place to another. Therein, flow exists because of a difference in pressure -- a difference in pressure between one point\location [in a conduit/medium] and another point\location [in the conduit/medium]. When there is no pressure [gradient], there is no flow of energy, and hence, no power.

**INSIGHT:** *Without pressure, there is no movement. Without cause, there is no pressure. Without intention, there is no cause. Without movement, there is no intention. Without desire, there is no suffering.*

When a pressure gradient has been established, energy always flows spontaneously, and without the need for work, from areas of high to low pressure (given a conducive medium for flow).

Pressure gradients:

1. Mechanical pressure gradient (strain)
2. Molecular pressure gradient (temperature, thermal)
3. Atomic pressure gradient
4. Electrical pressure gradient (voltage)
5. Magnetic pressure gradient (gauss)
6. Electromagnetic pressure gradient (electron-volt)
7. Electrochemical pressure gradient

Pressure types:

1. Electrical pressure (voltage) = energy / unit charge
2. Mechanical pressure (stress) = force / unit area
   A. Acting parallel (shear stress, the force is termed 'shear force')
   B. Acting perpendicular (normal stress\fluid pressure)
   C. The degree of mechanical deformation is termed 'strain'
3. Fluid pressure = energy / unit volume

Absence of pressure:

1. No hydro pressure = no flow of water = no hydro current = no hydro power
2. No electric and/or magnetic pressure = no flow of charge = no electric current = no electricity or electrical power
3. No mechanical pressure = no force or torque = no change of position = no mechanical power
4. No molecular pressure = no temperature = no thermal current = no thermal power

Water analogy describing the same principle, but different processes:

1. Matter flowing as water molecules (water molecules are flowing) - There are "excess" water molecules on one end of a conduit that are able to flow to the other end that has less molecules.
2. Matter flowing as charged particles (electron or proton particles are flowing) - There are "excess" charged particles (electrons) on one end that are able to flow to the other end that has less charged particles (electrons).
3. Ether flowing as dielectric fields - There are "excess" fields on one end that are able to flow to the other end that has less dielectric fields.

## 19.4 Energy Transfer modes

> **CLARIFICATION:** *It is not "the energy" being transported through the electromagnetic field, a fuel line, or a house wall which has different characteristics, but rather, a substance-like physical quantity which flows simultaneously with the energy in each case. Consequently, energy is not actually transformed or converted within a so-called "energy transformer" or "energy converter." Rather, it is correct to say that the other substance-like physical quantity that flows along with the energy is exchanged/transferred/converted within such a device. For example, energy is brought into a power plant together with coal and oxygen or, scientifically speaking, together with the amount of substance (the quantity measured in moles) of coal and of oxygen, and energy always flows out of the power plant simultaneously with electric charge.*

Energy transfer refers to the movement or flow of energy from one area of space-time to another without changing its form. There are different processes that allow for the transfer of energy; these different processes are otherwise referred to as 'modes of energy transfer' (or 'energy transfer modes'). These transfer modes (processes) are generally signified linguistically as gerunds (verbs functioning as nouns). The presence of the process (or mode) means the transfer of energy. Recall that the time rate of energy transfer is called 'power'.

> **NOTE:** *Although every transfer will mean some conversion to heat, the transfer of energy may or may not mean the complete conversion of the medium participating in the transfer. Whereas a combustion system involves some conversion of the input medium, a wind turbine system does not involve conversion of the wind to some other medium. Energy can be transferred without changing carrier, such as when [electrical] energy "moves" along a wire, or [thermal] energy "moves" from the inside of a hot cup to the outside.*

The mechanisms of energy transfer at a system boundary are:

1. Temperature (heat or heating) - heat transfer
2. Pressure (work or working) - work transfer
3. Volume (mass flow or permeating) - mass transfer

> **NOTE:** *In a closed systems (i.e., systems with a fixed mass), energy can only transfer across the boundary as heat and/or work, not mass flow. The boundary of an open systems allows for energy transfer by mass flow, as well as temperature (heat) and pressure (work).*

Systems may be said to "possess" energy, but they cannot be said to "possess" heat or work. These are modes of transfer, otherwise known as 'boundary phenomena', because they are recognized at the boundary between the two or more systems. The transfer modes are associated with a [boundary] process, not a state of the system. Also, they are path dependent functions (i.e., their magnitudes depend on the path followed during a process as well as the end states).

Heat and work are energy in transit. Thus, heat and work are not properties of state, but energy that is in transport across system boundaries, to or from the environment. It is not possible to measure how much heat or work are present in an object, but rather only how much energy is transferred among objects in certain ways during the occurrence of a given process. Work and heat are, in a way, transport concepts for energy.

Heat and work are measured as positive (additive) or negative (subtractive) depending on which side of the transfer they are viewed.

These transfer processes can be viewed from several perspectives. From the perspective of gradient flow, there are two primary transfer modes:

1. Differences in temperature lead to the transfer of energy.
2. Differences in pressure lead to the transfer of energy.

The are a fixed number of ways that energy can be transferred (i.e., "exchanged"). These transfer processes can be viewed from the motion of a medium:

1. **Displacing matter** - by accelerating matter through a pressure differential.
2. **Permeating matter** - by displacing the location of some matter into other matter through pressure differential.
3. **Pressurizing matter** - by compressing matter through pressure differential.
4. **Heating matter** - by [rapidly] accelerating the atoms and molecules of matter through pressure differential.
5. **Waving matter (mass radiation)** - by colliding matter, creating compression and rarefaction of mass (i.e., "waves"). By accelerating an interface to a closed and non-displaced system.
6. **Waving ether (electromagnetic radiation) -** by accelerating charges, creating compression and rarefaction of ether (i.e., "waves").

   **NOTE:** *Waving is transfer of energy without the transfer of matter. A wave is a vibration (vibratory pressure as compression and rarefaction) that transfers energy from one place to another without transferring matter (solid, liquid or gas).*

Energy can be transferred into our out of a system in several ways:

1. Through mechanical interactions - energy transferred mechanically as work (i.e., in a coherent manner)
2. Through thermal interactions - energy transferred thermally as heat (i.e., in an incoherent manner)
3. Through radiation interactions - energy transferred

**NOTE:** *Any of these transfers increase the system's internal energy (per ΔE).*

Energy can be transferred into our out of a system in several ways:

1. **Working - work transfer mode**: The coherent and directed transfer of energy by a force causing a displacement at the point of application of the force. Work transfer (working) may be contrasted with heat transfer (heating). Work transfer refers to all transfers that do not involve a temperature difference. May be viewed as the flow of "non-thermal energy transfer". If work is *done on* a system, then the energy of the system increases (input energy transfer). If work is *done by* a system, then the energy of the system decreases (output energy transfer).
2. **Heating - Heat transfer mode:** The transfer of energy driven by a temperature difference between two regions in space. Heat transfer takes place due to the presence of a difference in temperature. Heat always flows from the system with a higher temperature to the system with a lower temperature. Heat is the quantity of energy which crosses the boundaries of a thermodynamic system. When added to a system heat transfer causes the energy of a system to increase, and heat transfer from a system causes the energy to decrease.

There are several important principles to note when discussing these two transfer modes:

1. Work transfer can be completely converted into heat transfer.
2. Heat transfer cannot be completely converted into work transfer, because some of the "energy" will disperse irrecoverably. The degree to which the "energy" is dispersed is known as the entropy of the system.
3. Work transfer will always produce some heat transfer.
4. Both heat and work are path functions, and vary with the manner in which the process is carried out.
5. A system cannot contain or store either heat or work.
6. Heat into a system and work out of a system are considered positive quantities.

Energy can be transferred into our out of a system in several ways (modes) - it must flow or it is not energy transfer:

1. **Mechanical radiative transfer (wave flow)** - energy is "transferred" by the propagated disturbance of a physical medium (flow of "mechanical energy" as wave collisions). The flow of a propagating [contraction and rarefaction] disturbance of space. Matter does not flow with the transfer of energy.
2. **Matter transfer (mass flow)** - energy is transferred by the movement of physical matter through the boundary of a system, carrying energy with it. The flow of matter as volume transfer. As mass flows into a system, the energy of the system increases by the amount of energy carried with the mass into the system. Mass leaving the system carries energy with it, and the energy of the system decreases. Since no mass transfer occurs at the boundary of a closed system, energy transfer by mass is zero for closed systems.
3. **Electromagnetic transfer (field flow)** - energy is transferred by the propagation of an electromagnetic field (Read: electromagnetic induction or radiation). The flow of "electromagnetic energy". Or, the flow of ether as a propagating [contraction and rarefaction] disturbance of counterspace. The transfer processes are known as:
   A. Electromagnetic induction.
   B. Electromagnetic radiation.
4. **Electrical transfer (charge flow)** - energy is transferred by electric charge/current propagating through conductive matter. The flow of "electrical energy". The transfer process is known as:
   A. Electrical [charge] conduction.

### 19.4.1 Transfer types

Energy can be transferred from one point in space-time to another in three ways:

1. Through the action of forces.
   A. **Electric and magnetic force fields** - Charged particles, upon which electrical fields exert forces, possess potential energy in the presence of an electric field in a way similar to that of an object in a gravitational field. These force fields can accelerate particles, converting a particle's potential energy into kinetic energy. Likewise, charged particles can interact via the electric and magnetic fields they create, transferring energy between them, and in the case of an electrical current in a conductor, cause molecules to vibrate, i.e. converting electrical potential energy into heat.
   B. **Frictional Forces** - The macroscopic (large-scale) energy of an object, that is, the potential and kinetic energy associated with the position, orientation, or motion of the entire object, not counting the thermal or heat energy of the system, can be converted into thermal energy (heat), whenever the object slides against another object. The sliding causes the molecules on the surfaces of contact to interact via electromagnetic fields with one another and start vibrating.
   C. **Gravitational force (possibly, magnetic)** - When gravity accelerates a falling object it converts its potential energy to kinetic energy. Likewise, when an object is lifted, the object stores the energy exerted by the lifter as a potential energy in the earth-object system.
2. When atoms absorb or emit electromagnetic radiation (i.e., photons of light). When light falls on an object, an incident photon may either pass through the object, be reflected by the object, or be absorbed by the atoms making up the object. If most of the photons pass through, the object is said to be transparent. Depending on the smoothness of the surface on the scale of the photon's wavelength, the reflection may be either diffuse (rough surface) or coherent (smooth surface). If the photon is absorbed, the photon's energy may also be split up and converted in the following ways:
   A. **Photothermal effect:** the energy absorbed may simply produce thermal energy, or heat in the object. In this case the photon's energy is converted into vibrations of the molecules called phonons, which is actually heat energy.
   B. **Photoelectric effect:** the energy absorbed may be converted into the kinetic energy of conduction electrons, and hence electrical energy.
   C. **Photochemical effect:** the energy may bring about chemical changes which effectively store the energy.
3. When nuclear reactions occur, that is, when there are rearrangements of the subatomic particles that make up the nuclei of atoms. There are two basic types: **Fission** - when nuclei combine, and **Fusion** - when nuclei split apart.

### 19.4.2 Transfer (carrier) interactions

Electromagnetic waves (light) and mechanical waves (sound) interact with physical materials in various ways that impact their "transfer" of energy. There are three principal ways in which waves (compression and rarefaction of space or counterspace) interact with matter; these are known as wave behavior interactions:

1. **Transmission (light wave transmission or mechanical wave transmission):** The passing of a wave through a material. For instance, light passes through an object - an object is either transparent (the light passes straight through), or translucent (the light passes through, but its direction "scattered" by the material). Light rays that pass through an interface are transmitted rays. These rays bend. This bending is called refraction. The direction and magnitude of refraction depends on the relative densities of the two media and the angle of incidence.
2. **Reflection (light wave reflection or mechanical wave reflection):** The bouncing back of a wave after it strikes a barrier. For instance, light bounces off a surface. Reflection can either be coherent (the angle of incidence equals the angle of reflection) or diffuse (the reflected direction is scattered).
3. **Absorption (light wave absorption or mechanical wave absorption):** The transfer of energy from a wave to matter as a wave passes through it. For instance, light enters a material and does not pass through. Instead, its energy is converted into "thermal energy" as microscopic vibrations of the material, or is absorbed by chemical reactions triggered by the light (the photochemical effect).

Consider a passive solar home in the winter with sunlight propagating to a window on the home. The following may be said about the system:

1. Light is transmitted through the window (which is either translucent or transparent) .
2. The light contacts the floor and is either reflected or absorbed (after several reflections around the room, almost all is eventually absorbed. A tiny bit is reflected back out the window.
3. The floor (and other surfaces where the light contacts), are "heated" by the absorption of light.
4. Some of this heat conducts into the material.
5. Some of this heat is re-radiated (at infrared wavelengths), back into the room.
6. Air near the surfaces is "heated" by this re-radiation and by contact (conduction) with the wall.
7. The "heated" air rises (convection).

### 19.4.3 Work transfer mode

**IMPORTANT:** *Modern physics is still confused over the concepts here as is visible in the following: Work and energy are in the same units (joules), but work is always a change in energy.* Work describes a transfer change in energy; it's not a conserved quantity in itself unless embedded in the concept of energy, which is conserved. With the above said, the "ability/capacity of a system to perform/do work" is a common and imprecise definition of energy. As a measure, energy is the total amount of work that can be done.

Work is the difference in energy between when you started, and when you're done. "Work" is just the amount of energy added (the amount of energy it has at the end, minus the amount of energy it had when you started).

In physics, it is said that whenever a force is applied that causes motion, then "work" is done. Work is a mode of transferring energy; it is an energy interaction between a system and its surroundings. Work is the use of force to act on an object in order to move that object in the same direction as the force. As a principle, work has two expressed attributes. Firstly, work is a transfer of directed/ordered energy, as contrasted with "disordered" energy (i.e., heat). Work refers to an activity involving a force and movement in the direction of the force.

Work is done on something or by something. Another way of understanding work is that work is a change in energy via a force. There are other ways of changing energy, such a through thermal contact. The point is that work changes the energy of something and the change is through application of a force (or torque).

Hence, if there is force, but no movement of distance/displacement, then there is no work. Here, a '**force**' is an action that pushes or pulls (applies a pressure to) an object or material substance or physical system.

- Work (J) = force (N) x distance (m)
- 1 Joule = 1 newton x 1 meter
- In units energy = joules (J)
- Work = joules (J)

Work is scalar. Work is not a vector, but force and displacement are vectors. Work is the product of a component of a force on an object times the displacement of the object, while the force is being exerted in the direction of displacement.

- $W = {}^{+}F \times {}^{+}d$ - when force causes a displacement, work (energy) is positive (F x d = work)
- $W = {}^{+}F \times {}^{-}d$ - when force hinders a displacement, work (energy) is negative ($F \times {}^{-}d = {}^{-}$work).
- $W = {}^{+}F \times {}^{0}d$ - when force results in no displacement, there is no work (F x 0 = 0 work).

Secondly, work (W) is accomplished by a force (f) acting through a distance (d).

- $W = \int f_i \cdot \Delta x_i$ (i.e., Work = Force x Distance)
- $W = F \times \Delta x$
- where, x is displacement

For a constant force; the work done formula as force x distance, only applies if you have a constant force:

$W = f_i \cdot \Delta x_i$

From a systems perspective, work is the amount of directed energy transferred into or out of a system. Work can increase or decrease energy. In most classical scenarios, work will change either the kinetic or potential energy. In concern to work as a factor of potential or kinetic energy:

- W = ΔK (kinetic)
- W = -ΔU (potential)

### 19.4.4 Heat transfer mode

**IMPORTANT:** *Modern physics is still confused over the concepts herein as is visible in the circularity of their definitions: (1) Energy does work or produces heat; (2) but, heat is a transfer of energy.*

Heat, like work, is neither a thing, nor a form of energy. Heat is not a substance that is being transferred [between any two things]. Heat is the energy in transit from one body to another under the influence of a temperature gradient. Heat cannot be stored as such. Heat flowing into a body merely changes the internal energy of the body. The internal energy of the carrier is increased after heating. The temperature of a body gives a measure of the intensity of heat.

**NOTE:** *The enthalpy of a system is the sum of the internal energy and the pressure-volume of the system. It is a function of the state of the system and depends on the temperature and pressure of the system. The absolute value of the enthalpy of a substance cannot be calculated, but values relative to some arbitrary chosen reference state can be determined.*

When a temperature difference exists across a boundary, the second law of thermodynamics indicates the natural flow of energy is from the higher temperature body to the lower temperature body.

**DEFINITION:** *The* **specific heat capacity** *of a substance is defined as the amount of heat required to increase its temperature by one degree. Specific heat capacity is measured in joules per kilogram degree-celsius.*

Before it is transferred, the energy which remains within the boundary of the system is not heat, but 'internal energy' or 'total available energy'. Once a system absorbs heat, the latter is no longer heat, but internal energy of the system. In other words, it stops being heat because heat is no longer being transferred between two systems at different temperatures. For it to be heat it must be in the process of being transferred from one system to another system. Heat cannot be stored nor contained by any system because heat is a process function.

**NOTE:** *An adiabatic process is one in which the system is perfectly insulated and the heat transfer is zero.*

A process function, or process quantity, is a physical quantity that describes the evolution or shift through which a thermodynamic system passes from an initial equilibrium state to another equilibrium state. It is a category error to use the expression "heat stored" if one does not clarify that it is not heat (a process) which is being stored, but energy which has been transferred from one system to another transposing the boundary of the acceptor system. The proper expression for this is "energy stored by heat transfer"; or simply "energy stored".

The energy emitted or released by the system becomes heat the moment it crosses the boundary of the system (i.e., the moment it becomes energy in transit). Remember, process quantities cannot be stored or contained because they describe the trajectory by which a system acquired an equilibrium state. A process function or process quantity is not a state function. A state function is a property of a thermodynamic system which depends only on the current state of the system. Internal energy is a state function.

There is no such identifiable thing as "heat energy" in an object. Hence, "hot" is not a substance. Instead, heat is a mode of energy transfer representing the flow/transfer of energy spontaneously (across systems or within a system) due to temperature differences. When a suitable physical pathway exists, energy flows spontaneously from a hotter to a less hot (i.e., "colder") body. The name of the transfer process is heat transfer. What gets transferred is a quantity of energy. Heat describes what energy is doing at a given time. Essentially, heat is any energy transfer that is not macroscopically ordered (i.e., an energy transfer expressing all degrees of freedom; it "disperses"). When energy disperses, it is not destroyed, but rather, that it is lost for useful purposes.

### 19.4.5 Temperature (direction of heat transfer)

**Temperature** is a property of matter that determines the direction heat will flow when two mediums are brought into contact. The direction of heat transfer is based on temperature. In order to have a change in temperature there must be a transfer of energy between systems.

Temperature is a property which is directly proportional to the kinetic energy of the substance under examination.

Temperature is measured in either:

1. Kelvins (K) with zero motion as its reference point (0°K).
2. Celsius (C) with the freezing point of water as its

reference at (0°C).

The Celsius scale is a derived scale, defined in relation to the Kelvin temperature scale. The Celsius scale is an interval system, not a ratio system; it follows a relative scale and not an absolute scale. This can be seen because the temperature interval between 20 °C and 30 °C is the same as between 30 °C and 40 °C, but 40 °C does not have twice the air heat energy of 20 °C. A relative scale adds an unnecessary degree of abstraction (generating the potential for confusion) over an absolute scale. An absolute scale represents as close [an expressed] alignment with reality as is possible given what is presently known.

Heat is energy in transit, it is dynamic in nature and heat flow stops only at their equilibrium temperature state (i.e., thermal equilibrium).When two bodies are in thermal equilibrium with a third body, then they must be in thermal equilibrium with each other. This is called the Zeroth Law of Thermodynamics and is the basis for temperature measurements, since the thermometer must come to thermal equilibrium with the object being measured.

### 19.4.6 Modes of heat transfer

Heat transfer is energy in transition across the system boundary due to a temperature difference, there are three modes of heat transfer at the boundary that depend on the temperature difference between the boundary surface and the surroundings. These are:

- Conduction
- Convection
- Radiation

There are three types of heat transfer (i.e., three mechanisms by which energy is transferred via heat). The first two (conduction and convection) refer to the direct transfer of energy, whereas the radiation is a conversion of energy to a different form (electromagnetic radiation, light), and the subsequent travel (transfer/transport) of that radiation. These heat transfer processes may also be referred to as modes:

1. **Conduction (conductive heating/thermal conduction)** - transfer of thermal energy through an object/substance by atomic movement. Direct transfer by contact through a solid or stationary fluid. When a temperature gradient exists in a stationary medium, which may be a solid, liquid, or gas, the term “conduction” refers to the heat transfer that will occur across the medium.
   A. A **thermal/heat conductor** is a substance/material that allows thermal energy to move through itself easily. Materials that do not allow thermal energy to move through them easily are called **thermal/heat insulators**. Similarly, electrical conductors allow electrical energy to move through easily, while electrical insulators do not allow electrical energy to move through easily.
2. **Convection (convective heating/thermal convection)** - transfer of thermal energy from a surface to a moving fluid by movement of groups of molecules. Convection refers to the heat transfer that occurs between a surface and a moving fluid when they are at different temperatures. Simplistically, convection is the movement of a fluid in response to heat. A substance experiencing convection will move in the form of a [convection] current. Convection takes place through advection, diffusion, or both.
   A. **Advection** is the movement of some material dissolved or suspended in the fluid. For instance, if pure water is heated, there will occur convection of the water. Advection cannot occur because there is nothing dissolved or suspended in the fluid to advect. If silt is suspended in the water, and the liquid mixture is heated, then there will occur convection of the water and advection of the silt.
   B. **Diffusion** is the net movement of particles from high concentration to low concentration.
3. **Radiation (radiative heating/radiant heat/ thermal radiation)** - transfer of thermal energy through space-time from the emission and absorbance of electromagnetic waves - the emission of electromagnetic radiation and its absorption. All objects, even those that are in equilibrium (at equal temperature) with their surroundings, continuously emit/radiate electromagnetic waves (i.e., “light waves”) into their surroundings. The source of this radiation is the thermal energy of the materials, the movement of the object’s molecules. Radiation does not require matter, unlike convection and conduction.

### 19.4.7 Electromagnetic transfer mode

Electromagnetic transfer mode is the transfer of energy as electromagnetic fields at near the speed(s) of light. Electromagnetic energy can be reflected or emitted from objects through electric and/or magnetic waves traveling through space. The electromagnetic spectrum is the range of all types of electromagnetic radiation (electromagnetic radiation being a type of electromagnetic energy). Electromagnetic radiation is a kind of energy that travels and spreads outward as it travels. The electromagnetic spectrum is a categorization of all electromagnetic waves by frequency, wavelength or photon energy. Electromagnetic frequencies are produced where electricity flows. One does not exist without the other. Electricity, understood as the movement of electrical charges, generates an EM-waves, relative to the geometric conditions of the circuit and frequency conditions in the current flow. Conversely, an electromagnetic wave can generate electricity (photoelectric effect). Electromagnetic radiation can be described in terms of its wavelength — the distance between the crests of the waves — or its frequency — the number of crests that pass by a fixed point during a fixed time interval.

> **DEFINITION: Coupling** *is the transfer of energy from one medium, such as a metallic wire or an optical fiber, to another medium (which may be of the same composition, but separated by space). In an electrical circuit, coupling is the transfer of electrical energy from one circuit segment to another.*

Electromagnetic transfer mode refers to the transfer of energy between two spatially separated objects -- the energy is transferred without contact. Electromagnetic "wireless" power (wireless energy transfer) techniques fall into two categories:

1. Radiative (radiation-based)
2. Non-radiative (induction-based)

Therein, there are three kinds of wireless power transfer technology (wireless transmission of electricity and/or "energy") in accordance with its working principles (technically, these are all forms of electromagnetic transfer):

1. **Electromagnetic and electrodynamic induction (non-radiative)**
   - **Magnetic induction** - magnetic field coupling mode
2. **Electrostatic induction (non-radiative)**
   - **Electric induction** - electric field coupling mode
3. **Electromagnetic radiation (radiative)** - electromagnetic field coupling mode

> *Take note that each mode/method listed above has multiple different names in the literature and in application.*

## 19.4.8 Magnetic induction mode

> *A.k.a., Magnetic field coupling mode; direct induction; electromagnetic induction*

This is a method of producing electromotive force (voltage) and/or heat across an electrical conductor due to its dynamic interaction with a magnetic field. The magnetic field may come from either moving permanent magnets or alternating current electromagnets.

Electromotive force causes the movement of electric charge. How much electromotive force is present between two points in a circuit is measured in units of 'volts'. The electrical current that flows in this situation is known as an 'induced current'. Electromagnetic induction occurs when a changing (moving/dynamic) magnetic field induces an electrical current in a closed loop. Note that any change in the magnetic field around a conductor will induce a voltage. The more voltage induced, the more electrical current produced (if an electrical circuit is present).

> **CLARIFICATION:** *Induction refers to energy transfer without contact (versus conduction, which is by contact). The basic process of generating electrical power with magnetic fields (and without contact) is known as* **induction***. This specific type of induced current process is also called magnetic induction to distinguish it from charging by induction, which utilizes the Coulomb force. Inductive charging is also known as wireless charging.*

Electromagnetic induction relies on 'magnetic flux'. Magnetic flux refers to how a conducting material (or any material) is affected by a magnetic field. Magnetic flux is the product/strength of the magnetic field multiplied by the conductive surface area perpendicular to that magnetic field. Electromagnetic induction occurs when there is a change (change only) in the magnetic flux (over time). By continuously varying the magnetic field or surface area (angle or volume) a continuous electromagnetic induction will occur. Wrapping/coiling wire is a good way to increase magnetic flux.

> **CLARIFICATION: Electromagnetic flux** *can be classified into 2 types: (1) Electric flux is defined as the number of field lines or the concentration of field lines of an electric field perpendicular to a surface. (2) Magnetic Flux is the number of magnetic field lines or the concentration of magnetic field lines perpendicular to a given surface.* **Electrodynamics** *is the branch of physics which deals with rapidly changing electric and magnetic fields. A current moving through a conductor creates both magnetic and electric fields. A time-varying current will produce time-varying fields. Time-varying currents are nothing more than a macroscopic series of charges undergoing time-varying acceleration.*

Magnetic induction is used in the following energy transfer applications:

### *19.4.8.1 AC electricity (in conductive coils)*

**AC electrical generators (alternators)** - devices that use [electro]magnetic induction to produce electricity (as the flow of electric charge, electric power).

### *19.4.8.2 Heating (in ferrous metals)*

**Induction heating** (e.g., induction cooking) - the process of heating an electrically conducting object (usually a metal) by electromagnetic induction (specifically, magnetic inductive coupling), through heat generated in the object by eddy currents (also called Foucault currents). Induction heating occurs due to electromagnetic force fields producing an electrical current in a part. By applying a high-frequency alternating current to an induction coil, a time-varying magnetic field is generated. The parts heat due to the resistance to the flow of this electric current. An induction heater consists of an electromagnet, and an electronic oscillator that passes a high-frequency alternating current (AC) through the electromagnet. The rapidly alternating magnetic field penetrates the object, generating electric currents inside the conductor called eddy currents. The eddy currents flowing through the resistance of the material heat it by Joule heating. Induction heaters are used to provide alternating electric current to an electric coil (the induction coil). The induction coil becomes the electrical (heat) source that induces an electrical current into the metal part to be heated (called the workpiece). No contact is required between the workpiece and the induction coil as the heat source, and the heat is restricted to localized areas or surface zones immediately adjacent to the coil. This is because the alternating current (AC) in an induction coil has an invisible force field (electromagnetic, or flux) around it. Furnaces (as an alternative method of heating) tend to be large, have long start-up and shut-down times, and emit fumes and by-products of combustion, both a pollutant and a potential safety hazard. The induction heater can be small and, as all electric devices, is immediately turned on and off. It is a "clean" process and safer for those operating the system. It also has fewer maintenance costs than furnaces. As with conduction heating, induction heating has the benefit that all of the power supplied goes directly into the workpiece and heating times are short. They fit well into automated production methods, are easily controlled, and the process is highly repeatable. There are some surprising benefits to induction heating. For example, alloys are easily mixed in induction heating processes because the induced field automatically stirs the melted metal! Also, special techniques— precision melting, hardening of surface— can be implemented in the process. Induction heaters require electricity.

#### *19.4.8.3 Voltage transformation (between electrically conductive circuits)*

**Electrical transformers** (a.k.a., non-resonant inductive coupling; i.e., conventional transformer or electrical power distribution transformer) - devices that use electromagnetic induction to change the voltage of electric current. Electrical transformers transform one voltage into another voltage through electromagnetic induction. In other words, it is a device in which an input alternating current produces an output alternating current of different voltage. Note here that transformers work with AC, not DC. It is called an electrical transformer, because it transforms electrical energy into magnetic energy, then back into electrical energy again. A transformer's main purpose is to transfer electrical energy from the primary coil to the secondary coil. A transformer's basic operating principle: the transfer of power from the primary to the secondary circuit occurs via electromagnetic coupling. An electrical transformer is a form of wireless energy transfer. The primary and secondary circuit of ta transformer are not directly connected. Here, energy transfer takes place through a process known as mutual inductance (without any physical contact in between). In transformer theory, electromagnetic (EM) induction refers to the phenomena that electromagnetic changes in one place induce (EM) changes in another place.

### 19.4.9 Electrodynamic induction mode

> **Also known as:** *Magnetic field coupling mode (a.k.a., inductive coupling; magnetic coupling; magnetic inductive coupling; inductive power transfer; resonant magnetic induction; resonant inductive coupling*

This is the near field wireless transmission of [electrical] energy (by the transfer of electromagnetic energy) between two magnetically coupled coils that are part of resonant circuits tuned to resonate at the same frequency. The resonant inductive coupling process occurs in a resonant transformer, an electrical component which consists of two coils wound on the same core with capacitors connected across the windings to make two coupled LC circuits. Resonant transformers are widely used in radio circuits as bandpass filters, and in switching power supplies. Resonant inductive coupling is also being used in wireless power systems. Here the two LC circuits are in different devices; a transmitter coil in one device transmits electric power across an intervening space to a resonant receiver coil in another device. It is the transfer of energy between a current-carrying conductor and nearby conductors due to a time-varying magnetic field that is created by time-varying current in the energized conductor. Magnetic induction concerns electric currents generated by the motion of a magnetic flow along a conductor. In other words, magnetic field coupling is caused by the current flow in conductors. Magnetic field coupling is created by inductive means (inductive coupling). The magnetically induced current in each nearby conductor will be slightly different since it depends on the relative location of each individual conductor to the energized conductor. The coupling mechanism can be modelled by a transformer. According to the transfer distance, the magnetic field coupling mode can be mainly classified into short-range electromagnetic induction and mid-range strongly coupled magnetic resonance (SCMR). The transfer efficiency and transfer power of electromagnetic induction are normally high, but the transfer distance is limited to centimeter level. In contrast, the transfer efficiency and transfer power of SCMR are a marginally lower, but the transfer distance can achieve meter level to realize mid-range power transfer. Optimal for mid-range wireless power transfer. This technology is being developed for powering and charging portable devices such as cellphones and tablet computers at a distance, without being tethered to an outlet. Inductive power transfer works by creating an alternating magnetic field (i.e., an electromagnet; flux) in a transmitter coil and converting that flux into an electrical current in the receiver coil.

> **NOTE***:* **Non-dynamic magnetic induction (induced magnetism)** *is the production of a magnetic field in a piece of unmagnetized iron or other ferromagnetic substance when a magnet is brought near it. The magnet causes the individual particles of the iron, which act like tiny magnets, to line up so that the sample as a whole becomes magnetized. Most of this induced magnetism is lost when the magnet causing it is taken away.*

### 19.4.10 Electrostatic induction mode

> **Also known as:** *Electric field coupling mode capacitive coupling; electrostatic influence*

This is the near field transfer of energy between an energized conductor and the nearby conductors due to a time-varying electric field that is created by moving charge in the energized conductor. It pertains to magnetic flows produced by an electric charge (voltage). It is caused by an electric field gradient (voltage difference) or differential capacitance between conductors. The phenomenon of producing induced charges is known as electrostatic induction. The principle itself refers to the redistribution of the surface charges on the object. In other words, it is the production of an unbalanced electric charge (i.e., static electricity) on an uncharged conductor as a result of a charged body being brought near it without touching it. In other words, it is a redistribution of electrical charge caused by the influence of nearby charges. If the charged body is positively charged, electric charge in the uncharged body will flow toward it; if the opposite end of the body is then grounded, electric charge will flow onto it to replace those drawn to the other end, the body thus acquiring a negative charge after the ground connection is broken. A similar procedure can be used to produce a positive charge on the uncharged body when a negatively charged body is brought near it. Electrostatic induction is an efficient way of using a charged object to give something a charge, of the opposite sign, without losing any of the original charge. Electric field coupling is capacitive in nature (capacitive coupling). Hence, the coupling mechanism can be modelled by a capacitor (a capacitor is defined as two conductors separated by a dielectric, and may be used to store charge, "electrical energy"). A high-frequency and high-voltage driver source excites the resonant transmitter to generate an alternating electric field which can couple with the resonant receiver. Energy will be delivered as soon as this coupling relation is set up. The transfer efficiency of this mode is affected by surrounding objects. Optimal for short-range wireless power transfer.

> **NOTE:** *Electromagnetic resonance uses "antennas", and electromagnetic induction uses "transformers".*

### 19.4.11 Electromagnetic radiation mode (EMR)

> **Also known as:** *Resonant coupling; electromagnetic resonance*

This is the far field transfer and receiving of electromagnetic energy. Electrical energy is generally converted into electromagnetic energy, which can be radiated outward (as "EM waves"), which are then received and converted back into electric energy with using a silicon rectifier antenna in the receiver. Electromagnetic radiation (EMR) is the emissive transmission of electromagnetic energy between two bodies not in contact (source to receiver). Electromagnetic radiation is used to transfer electrical energy (which may carry power and/or data) without an electrical conductor or inductive coupling.

> **NOTE:** *An antenna can be designed to react with either the electric or magnetic field of a an electromagnetic radiative wave.*

The transmitter and receiver are tuned to the same resonant frequency (to a mutual frequency). In general, this is accomplished through "radio waves" or optical laser devices. Electromagnetic radiation (i.e., "light") propagates by itself in a vacuum at very high speed (the speed/s of light). Because of its high power density and good orientation features, electromagnetic radiation mode is usually suitable for the long distance transfer applications. However, its transfer efficiency is severely affected by the material conditions (e.g., meteorological or topographical conditions), and the impacts on creatures and ecological environment are unpredictable. Optimal for long-range wireless power transfer.

> **NOTE:** *In electric circuits, this motivating force is voltage (a.k.a. electromotive force, or EMF). In magnetic circuits, this motivating force is magnetomotive force, or mmf. Magnetomotive force (mmf) and magnetic flux (Φ) are related to each other by a property of magnetic materials known as reluctance.*

### 19.4.12 Electrical transfer mode

**Electrical conduction mode** (a.k.a., electrical transfer mode; electrical conduction coupling, electron mode) is the transmission of electrical energy (as electricity - flow of electric charge carried by electrons conserved in a circuit) from a power source to an electrical load, such as an electrical power grid or a electrically powered device with the use of a conductor (physical contact). An electrical conductor is a substance in which electrical charges (e.g., electrons) move easily with the application of voltage (i.e., contains movable electrical charges). Electrical conduction can occur in a "wired" or "wireless" manner. Wireless power transfer (WPT; a.k.a., wireless energy transfer, wireless energy transmission, and wireless electrical transmission) is the transmission of electrical energy (as electricity) without the use of a discrete human-made (synthetic) conductor (e.g., atmospheric plasma channel coupling - air method; ground channel coupling - ground method. Electrical power transfer (EPT; wired power transfer) is the transmission of electrical energy (as electricity) with the use of a discrete human-made (synthetic) conductor (e.g., hard-wire using a wire; resistive using a resistor).

Energy can be transferred by electrical transmission. Within a wire this is accomplished through electric fields associated with electrons in the metal wire. The electrons literally push on each other, and convey force through the wire, which thereby transfers energy. For example, the electro-chemical processes in a battery create positive and negative electric charges at the battery contacts which push on, and hence force, the movement of electric charge. Electrical energy is converted to heat when some of the electrons encounter resistance - that is, when the electrons are pushed through materials causing heat, that is, cause the atoms of the material to start vibrating. Alternatively, the movement of electrons may give rise to electric and magnetic fields (such as in coils of a motor), which do work, such as turning the motor shaft.

**NOTE:** *Bearings provide a convenient support for rotating shafts.*

Electrical energy can be transmitted by means of electrical currents made to flow through naturally existing conductors, specifically the earth, lakes and oceans, and through the upper atmosphere starting at approximately 35,000 feet (11,000 m) elevation — a natural medium that can be made conducting if the breakdown voltage is exceeded and the constituent gas becomes ionized. For example, when a high voltage is applied across a neon tube the gas becomes ionized and a current passes between the two internal electrodes.

**NOTE:** *Whenever an electric current flows through a conductor, a magnetic field is immediately brought into existence in the space surrounding the conductor. It can be said that when electric charges are in motion, they produce a magnetic field. The converse is also true (as in, when a magnetic field embracing a conductor moves relative to the conductor, it produces a flow of electric charge in the conductor).*

# 20 Units and formulas for: Energy

**CLARIFICATION:** *'Energy' is a concept that means 'capacity'. There is no physical stand-alone object called 'capacity'; instead, 'capacity' is a concept. Therefore, energy cannot be transferred; only objects can be transferred.*

In concern to watts, a quantity of energy is measured in watt-time (e.g., watt-seconds, or more commonly, watt-hours). Watt-hours means watts multiplied by the hours the watts are transferring energy (i.e., doing work) to form a total quantity of energy transferred, or potentially transferred. Similarly, watt-seconds means watts multiplied by the number of seconds the watts are transferring energy. Watt-hours are a measurement of energy, describing the total amount of energy (electrical, mechanical, etc.) used over time. Watt-hours are a combination of how fast the energy is used (watts) and the length of time it is used (hours).

**QUESTION:** *How much energy does a system require to operate for one second, and one hour? The answer will come in units of watt-seconds and watt-hours.*

Watt-time (e.g., watt-hours) is a quantity of energy -- the quantity of energy transferred (or, work done) in a given amount of time. For example, watt-hours is a combination of how fast the power (e.g., electricity) is used (watts) and the length of time it is used (hours):

- Watt-time = Watts x time
- Wt = W • t

In hours:

- Watt-hour = Watts x Hours
- 1 Watt-hour = 1 Watt x 1 hr
- 1Wh = 1W • 1hr
- Wh = W • hr

**NOTE:** *The unit for watt-hour may be abbreviated: Wh, W.h, or W-h (or in seconds, Ws, W.s, or W-s).*

More commonly, energy is measured in kilowatt-hours, the equivalent of 1000 watts of power for 1 hour.

- Kilowatt-hour = Kilowatts x Hours
- 1 Kilowatt-hour = 1 Kilowatt x 1 hour
- 1kWh = 1kW • 1hr
- kWh = kW • hr

In concern to the quantity of energy used by a load, for instance, a 60-watt (power) light bulb running for 1 hour (time), will have used 60 watt-hours of energy.

1. A 60W light bulb - requires 60W of power to run for 1 second.

2. Running for 1 hour.
3. Will use [a quantity of] 60 watt-hours of energy:
   - 60W x 1hr = 60Wh = .060kWh
4. 1 second is 1/3600 of an hour; hence, in 1 second a 60W light bulb uses:
   - .060kWh x 1/3600s = .00001666kWh

In other words, a light bulb with a power rating of 60 watts will use 60 watt-hours per hour, or 60 watt-seconds per second, or 60 watt-microseconds per microsecond, or 60 watt-centuries per century. However, watts do have an embedded reference time unit as part of their joule-based definition: 1 watt equals 1 joule in 1 second (W = J/s). Take note, however, that a joule is the amount of energy required to move an object against a static force of one newton, by the distance that light would travel in 1/299,792,458 second. Consequently, a watt is the amount of power required to push an object against a static force of one newton, at a constant velocity of 1/299,792,458 the vacuum speed of light.

As a measure of the most common unitized form, 1000 units (kilo units), energy is:

- Energy: 1kWH = 1000WH = 1000Wx3600sec = 3600kW−sec = 3600kJ1kWH = 1000WH = 1000Wx3600sec = 3600kW−sec = 3600kJ

# 21 Units and formulas for: Power

**CLARIFICATION:** *Joules per second (J/s) is a clearly signified unit of power. Joules per second makes it obvious that power is the rate at which energy is being generated or used. It's like how kilometres per hour (kph) makes it obvious that speed is the rate at which distance is being travelled. Watt as another unit of power; and, as a signifier of [a unit of] power, it does not make it obvious what power means. In other words, the usage of the term 'watt' as a signifier for power, does not make it obvious that power is the rate at which energy is transferred. But, the watt is actually just another name/signifier for Joules per second. J/s and W are the same thing.*

The units of power are units of energy (in a particular system or context) divided by time. The SI unit of power is the watt. The unit of power measurement, the watt, represents energy per unit time. As a rate of change of energy, power is:

- power = change of energy / change of time
- power (P) = $\Delta E / \Delta t$
- watt (W) = $\Delta E / \Delta t$

When the rate of energy transfer is constant, power is:

- power = energy transferred / time
- power (P) = E / t
- watt (W) = E / t

The unit of power is joules per second or J/s when work is measured in joules and time in seconds. A watt is the consumption of one joule of energy per second. One watt is equal to one joule of work done per second. Or, said another way, one watt is equivalent to an energy transfer rate of 1 J/second. When energy is measured in joules, then:

- Wattage as J/s = rate of power in Joules per second
- 1 Watt = 1 Joule in 1 second
- 1 W = 1J / 1s
- W = J/s

When energy is measured in newton-meters, then:

- Wattage as Nm/s = rate of power in Newton-meters per second
- 1 Watt = 1 newton-meter in 1 second
- 1W = 1Nm / 1s
- W = Nm/s

Take note that a joule is another term for a force of 1 newton over a distance of 1 meter:

- Joule = Force (1 Newton) x distance (1 Meter)
- 1 Watt = 1J/s = 1Nm/s

As a measure of the most common unitized form, 1000 units (kilo units), power is:

- Power: 1000 Watts = $10^3$W = 1kW = 1000J/s = 1kJ/s

## 21.1 Comparing energy and power in units and formula

Energy is an amount (i.e., quantity), while power is a rate at which energy is used.

- Energy = Watt (Power) x time
  - E.g., kWh = kW x t
- Power = Work (Energy) / Time
  - E.g., kW = kWh / t
- Time = Energy / Power
  - E.g., t = kWh / kW

In concern to units of energy and power:

- Energy is measured in watt-hours (W·h) or joules (J).
- Power is measured in watts (W) or joules per second (J/s).

Watts may be used for [at least] the following power measurements:

- Watts are used to measure the output of a power generating system.
- Watts are used to measure the power production capacity of a power generating system.
- Watts are used to measure the amount of power required by a power consuming system (load).

Watt-time (e.g., watt-hours) may be used for [at least] the following energy measurements:

- Watt-time measures the total amount of energy used over time -- watt-hours is a combination of how fast the energy is used (watts) and the length of time it is used (hours).

Power generating system can be said to produce watt-hours [of energy] per given timeframe (e.g., megawatt-hours per year, and not megawatts per year). Therein, power generating system may be said to produce a specific amount of energy (e.g., Wh) per a given timeframe.

The relationship between energy and power is a lot like the relationship between distance and speed:

- Energy is like distance - The amount of energy that is used over a specific period of time is like the distance that is travelled over a specific period of time. For example, the vehicle travelled 3 meters, or the electrical device used 3 joules (or 3 watt-hours).
- Power is like speed - Instantaneous power is like the speed at a specific instant in time (e.g. right now). The average power over a specific period of time is like the average speed over a specific period of time. For example, the vehicle travelled at a speed of 3 meters per second (m/s), or the electrical device used 3 joules per second (or 3 watts).

## 21.2 Electrical power

In general, electrical power is defined as the rate at which electrical energy is transferred via an electrical circuit. The SI unit of electrical power is the watt, which equates to:

1. An energy transfer rate of 1 joule per second.
   - One watt is defined as the energy consumption rate of one joule per second (J/s).
2. A current flow of 1 ampere through an electric potential difference of 1 volt.
   - One watt is one ampere of current flowing at one volt.
   - Hence, electrical power is described by the formula:
     - volts × amps = watts

**Table 22.** *Table of unit prefixes of watts (wherein, P = power).*

| Name | Symbol | Conversion | Example |
|---|---|---|---|
| Picowatt | pW | 1pW = $10^{-12}$ W | P = 10 pW |
| Nanowatt | nW | 1nW = $10^{-9}$ W | P = 10 nW |
| Microwatt | μW | 1μW = $10^{-6}$ W | P = 10 μW |
| Watt | W | - | P = 10 W |
| Kilowatt | kW | 1kW = $10^{3}$ W | P = 2 kW |
| Megawatt | MW | 1MW = $10^{6}$ W | P = 5 MW |

# 22 Power fundamentals

**INSIGHT:** *From the actualization of potential comes power.*

In the context of power, while 'energy' measures the total amount of energy transferred (i.e., work that is or can be done), it doesn't say how fast the energy is transferred (i.e., how fast the work is or can be done). Herein, power is the rate of transferring, producing, or consuming, energy (i.e., the rate at which energy is transferred, produced, or consumed). Take note that 'power' is not an amount of energy itself; it is a rate of change occurring to the presence of energy. Power is the rate at which a quantity of energy is transferred or otherwise changed in time. It could be the rate at which a quantity of energy is transmitted, as in the case of a power generator, or the rate at which it is received, as in the case of a load. It could also be the rate at which a quantity of energy is transferred between a transmitter and a receiver, such as across a power line between a transmitter and receiver. Thus, power can be described in the following ways, which all amount to the same definition:

1. Power = the [time] rate of energy transfer (or conversion) [within or between energy carriers].
2. Power = the [time] rate of change in energy [in a system].
3. Power = the amount of energy required or expended in a time interval (i.e., for a given amount of time).
4. Power = energy flow per unit time. In other words, power is the time rate of an energy flow. Power can be modelled as an energy flow, equivalent to the rate of change of the energy in a system(s) per period of time.
5. Power = energy "produced", "transformed", or "consumed" per amount of time (i.e., per time interval).

Take note that it is sometimes said that power is "a rate of *energy* generation (production) or consumption (utilization)". Technically, this is not accurate because energy cannot be generated or consumed, it can only be transferred. However, because power is a rate [of transfer], power can be said to be "generated" and "consumed". Power is generated, in the sense that energy transmission is occurring, and it is consumed, in the sense that an end device (load) is using it to function; and that transfer can be started and stopped, slowed or sped up. Hence, although it is not technically accurate to say that "power is a rate of *energy* generation and/or consumption", it is understandable.

**DEFINITION:** *In mathematics, a 'rate' is the ratio between two related quantities (e.g., A/B, where 'A' is the numerator and 'B' is the denominator). 'Rate' refers to a <u>rate of change</u>. The most common type of rate is "per unit of time" (time denominator), such as speed, heart rate and flux. Ratios (or rates) that have a non-time denominator include: exchange rates; literacy rates; and an electric field (in volts/meter). Often, 'rate' is a synonym of rhythm or frequency, a count per second (i.e., Hertz; e.g., radio frequencies or heart rate or sample rate). 'Power' is a ratio with a time denominator; it is energy per unit time (energy/time = power). Using the signifier "watt" for power is confusing since the "per hour" is not signified by the term itself; instead, it is inside the term "watt". Hence, to make the rate into an amount, it needs to be multiply by a time unit to cancel it out. It would be more intuitive if we worked in joules (energy) and joules per hour or joules/sec (power).*

When the quantity or location of energy changes, then power is present. Therein, as mentioned in the previous paragraph, it may be said that power is the rate at which energy is produced ("generated"), transferred ("transformed"), or used ("consumed") in a given amount of time. For instance, power is the rate at which an system (e.g., electrical) can produce, use, or transfer [electrical] energy. Hence, there are three basic power processes:

1. <u>Power is produced or converted</u> - how much energy is a system producing ("generating" or "transforming") or converting per time interval (e.g., second)? Or, how much power is a system producing from it source of power (energy)?
2. <u>Power is transmitted</u> - how much energy is a system transferring (or delivering) per time interval (e.g., second)? Or, how much power is a system transferring from its source to its usage point?
3. <u>Power is used or dissipated</u> - how much energy is a system using ("consuming") or dissipating per time interval (e.g., second)? How much power is a system using?

In every context, power includes a parameter for 'effort' (or energy) and for 'rate' (time). It is essential to recognize that power is a rate -- a time rate. Thus, regardless of the transfer process, the faster the transfer occurs, the more power is produced. A small amount of energy used extremely quickly can have a lot of power. Similarly, a large amount of energy used very slowly could have very low power. High energy does not necessarily mean high power. The power of any given energy transfer process depends on the time-rate (i.e., "how quickly") a given amount of energy can be transferred. The more energy transferred per time (e.g., /seconds), the greater the power of the transfer.

**NOTE:** *Power is a widely used measurement. When people speak of the loudness, volume, or level of a signal, they probably mean its power.*

Power is always delivered through pressure (force) and flow [rate] (speed or velocity). Hence, in both mechanical and electrical systems, power delivered may sometimes be calculated by multiplying pressure (force) times flow (speed or velocity). Herein, the rate is included in the flow (speed or velocity) measurement. In mechanical power systems, many terms describe the pressure or force (Newton, Newton per square meter, etc.) and many terms describe the speed or flow (meters per second, litres per second, etc.). In electric power, two terms [at least] describe the pressure or force (voltage and EMF) and two terms describe the speed or flow (current and amperes).

> **INSIGHT:** *All life in the solar system exists because of the power output of the sun.*

Power is absorbed (by a load) and/or transferred (to a load). Power may be dissipated. Power dissipation is the amount of energy per given time period emitted to the outside world by something. In physics, dissipation embodies the concept of a dynamical system where important mechanical modes, such as waves or oscillations, lose energy over time, typically due to the action of friction or turbulence. The lost energy is converted into heat, raising the temperature of the system. Such systems are called dissipative systems. A 60 watt light bulb "dissipates" ~60 watts of power.

There is an upper limit to how much power a power generating system (i.e., energy transformer or transceiver) can output. For instance, a 10 kW wind turbine (provided it has the optimum level of wind), can generate a maximum of 10 kW of power. Hence, 10 kW is the rate at which the wind turbine can generate power, and not the amount of energy that it can generate in a certain period of time. Frequently, the upper limit power output of a power generating system is simply referred to as its "output".

It is frequently said that an electrical device is a device that uses electrical energy. However, such devices are actually transferring the energy to other carriers (i.e., "converting it to other forms") such as heat, motion, electromagnetic radiation, etc., and in the process they are performing a useful function. The rate at which these devices "use" energy is their power [rating]. Depending upon the device and the context in which the power rating is being described, the terms 'load' and 'demand' are synonyms for power [rating]. Take note, however, that while the term 'power' can refer to the power that something is using or generating, the terms 'load' and 'demand' only ever refer to the power that something is using.

> **NOTE: Wattage** *is the maximum power drawn by a device.*

In concern to measurement, electrical devices "use" electrical power measured in units of watts or joules per second (i.e., are powered by watts). As a measure, the watts aren't affected by how long the device is running: a second, an hour, a day - no difference - as long as it's switched on it will be using a certain number of watts of power. If it's not switched on it won't be using any power (i.e., 0 W).

> **NOTE:** *A heat signature always indicates the presence of power (i.e., the presence of the time rate transfer of energy).*

Take note that for some devices it is more complicated to determine power usage/demand. For instance, the watts of power used by a laptop or other computing device may vary from moment to moment depending upon what the system is doing (e.g., how many programs are running). It may be using 50 W of power one moment, 30 W of power the next, and then 43 W of power the next. Hence, the need for a distinction between instantaneous power and average power.

> **HISTORICAL NOTE:** *Why is 'watt' a signifier for a unit of power? For equations, it is simpler for power to have its own unit (instead of being expressed using units of energy and time together). However, some idiot decided to name it after James Watt, the Scottish inventor who facilitated the development of the steam engine, with no relation to earlier energy-associated signifiers.*

Power can be measured (or calculated) in several ways. It can be measured at any instant in time, it can be averaged over a time interval, and its maximum value over a time interval can be determined:

1. **Instantaneous power** ($P_i$) - Instantaneous power is the power measured at a given instant in time. The instantaneous power (or instantaneous demand, or instantaneous load) is the power that something is using (or generating) at any one moment in time. For example, a 60W light bulb uses 60W every second, and a 60W power generating source can generate a maximum of 60W every second.
2. **Average power** ($P_{avg}$) - average power is the power measured over a long period (i.e., when t in the equation for power is very large). This is simply the mean, average of the instantaneous power over a longer period of time. Average power may also be referred to as "average load" ("mean load"), or "average demand" ("mean demand"). The average power represents the power that something uses or generates, on average:
   A. Over a specific period of time (e.g. yesterday); or
   B. Over multiple periods of time (e.g. across all the weekends on record); or
   C. Throughout a certain type of operation (e.g. typical laptop usage, or typical building usage - Monday to Friday 09:00 to 17:00, or typical efficiency for something that's generating power).
3. **Peak power** ($P_{pk}$) - Peak power is the maximum

value the instantaneous power can have in a particular system over a long period.

## 22.1 Power modes

Every energy transfer mode (or power generation/consumption system) has its equivalent calculation for power.

1. **Mechanical power** is the rate at which mechanical work is done. Mechanical power is the rate of change of mechanical energy. Mechanical power is the rate at which mechanical energy is converted. In a mechanistic sense, 'power' refers to how far an object can be moved in a given period of time, and hence, how much energy is transferred in that time period.
2. **Electrical power** is the rate at which electrical work is done. Electrical power is the rate of change of electrical energy. Electric power is the rate at which electrical energy is converted. Electrical power is the rate at which electrical energy is "produced" or "used" (or "consumed").
    - Since current is the rate of transport of charge, electric power is given by the above expression, but using current I instead of charge Q:
    - P = IV
3. **Electromagnetic power** is the rate of work done by the electromagnetic forces. Electromagnetic power is the rate of change of electromagnetic energy (Read: electric and magnetic fields).

### 22.1.1 Mechanical power mode (Work transfer)

In concern to work transfer mode, power is the amount of work done (or, can be done) per unit of time. Power is the time rate at which work is done -- power is the rate of doing/performing work. In other words, power is the amount of work that can be done in a certain amount of time, "the rate of working". Power is the rate of energy transfer by [doing] work per unit of time. Power is work over the amount of time it took to do that work. Regardless of the work being done, the faster the work is done, the more power is produced.

1. Working faster = more power
2. Working slower = less power

Whereas energy is the total amount of work that is or can be done, power is how fast the work is or can be done. Power is also often thought as the amount of work performed (or energy transmitted) in time.

Power is work (energy) per unit of time. Thus, as a rate of change of work done, power is:

- power = change of work / change of time
- power (P) = ΔW/Δt = ΔE/Δt
- where, work (W) and time (t)
- power = work done (J) / time (s) = energy used (J) / time (s).

When the rate of work is constant:

- power = work / time
- power (P) = W/t = E/t

### 22.1.2 Principal types of mechanical working power

There are two principal types of mechancal power, solid and fluid:

1. Mechanical power system (solid mechanics) - linear or rotational motion. Mechanical power systems are used for the generation, control, and transmission of power by the use of solid mechanical objects.
    A. Linear mechanical systems produce linear motion.
    B. Rotational mechanical systems produce angular motion.
2. Fluid power system (fluid mechanics) - linear or rotational motion. Hydraulics are used for the generation, control and transmission of power by the use of pressurized liquids. Pneumatics are used for the generation, control, and transmission of power by the use of pressurized gases.
    A. A hydraulic cylinder or pneumatic cylinder, provides force in a linear fashion.
    B. A hydraulic motor or pneumatic motor, provides continuous rotational motion or torque.
    C. A rotary actuator provides rotational motion of less than 360 degrees.

### 22.1.3 Linear working power

The full decomposition of the power formula for linear [solid] mechanical work transfer mode has the following sub-parts:

1. In [linear] work (W) transfer mode, energy (E) has the units of force times distance or displacement (F • d). In other words, linear work is force (F) times distance (d). Therein, power is force times distance over time:
    - P = E/t = W/t = (F•d)/t
    - Linear work = Force x Distance
    - W = F•d
    - power = linear work / time
    - P = W/t = F•d/t
    - where, work is in watts, force is in newton, and distance is in meters.

2. Force (F) is mass (m) times acceleration (a) is (m•a):
   - P = E/t = W/t = (F•d)/t = (m•a•d)/t

3. Acceleration (a) is an exponential increase in distance over time ($d/t^2$):
   - P = E/t = W/t = (F•d)/t = (m•a•d)/t = $(m \cdot (d/t^2) \cdot d)/t$ = $(m \cdot d^2)/t^3$

4. Alternatively to #2, distance (d) over time (t) is velocity (v): (note that speed is another word for velocity)
   - P = F•d/t = Fv
   - where, velocity is a length measurement per time (e.g., meters per second). The rate is included in the velocity measurement.
   - Note: (1) there must be both force and velocity, and (2) the force must be applied in the direction of the velocity. A static force without velocity does not require power to maintain itself, and velocity (including rotational velocity) without force also does not require power.
   - Note: in electrical systems, power = VI, which is the equivalent in mechanical systems to P = Fv. Therein, voltage (V; a.k.a., electromotive force, EMF) is the force (F), and current (I; a.k.a., amperage) is the velocity (v) .

### 22.1.4 Rotational working power

The full decomposition of the power formula for rotational [solid] mechanical work transfer mode has the following sub-parts. Note that torque causes objects to spin or rotate.

1. In [rotational] work (W) transfer mode, energy (E) has the units of force (F) times the swept angle (Θ) times the radius (r).
   - P = E/t = W/t = FΘr/t

2. Therein, force (F) times radius (r) is torque (T). Hence, energy (E) has the units of torque times the swept angle in radians (T • Θ).
   - P = E/t = W/t = FΘr = T•Θ/t
   - Rotational work = torque x the swept angle
   - W = T•Θ
   - Power = rotational work / time
   - P = W/t = T•Θ/t
   - where, work is in watts, torque is in newton-meters, and swept angle is in radians.

3. Swept angle (Θ) over time (t) is equivalent to angular velocity (ω).
   - P = E/t = W/t = FΘr =T•Θ/t = T•ω

### 22.1.5 Electrical power mode (Electrical transfer)

> **CLARIFICATION:** *The symbol for amperes is generally the letter 'I' (capital 'i'). Before being named amps, the letter 'I' traditionally stood for the "Intensity of current flow", hence, the first letter of the word intensity (I).*

Electric power is the rate, per unit time, at which electrical energy is transferred by an electric circuit (as electricity). In other words, electrical power is the rate of change of electrical charge (electrical energy). The electrical power drawn by an electrical device is expressed in Watts or Volt-Amps (VA). Electrical systems "draw" watts of power. Electric power systems are used for the generation, control, and transmission of power by the use of electricity.

> **NOTE:** *Many electrical devices that dissipate power, do so by converting the electrical power into thermal energy, or heat. This is true for wires and resistors.*

As a rate of doing electrical work in one direction (e.g., DC voltage), power is:

- power = volts x coulombs / time = volts x amps
- power (P) = VQ/t = VI
- where, electric current (I) consisting of a charge of coulombs (Q) every t seconds passing through an electric potential (voltage) difference of V.
- Note, the time interval required for the calculation of power (P=E/t), is included in the electric current parameter (I). Electric current (I) is measured in ampere, and one coulomb per second is equivalent to one ampere (1I).
- Herein, electrical work is done by a voltage (v) moving an amount of electrical charge (q).
  - Electrical work done = voltage difference x charge
  - W = ΔV • q
  - where, the rate of movement of electrical charge is current (I), measured in amperes (I = q/t).

Technically, power in electrical conduction is not transported through electrons pushing length ways just like water in a pipe. It is transported by electro magnetic fields which flow partly inside, partly outside the wire. Electrical energy flows wherever electric and magnetic fields exist together and fluctuate in the same place. The simplest example of this is in electrical circuits, as the preceding section showed. In the general case, however, the simple equation P = IV must be replaced by a more complex calculation, the integral of the cross-product of the electrical and magnetic field vectors over a specified area, thus:

- power (P) = $\int_S (E \times H) \cdot dA$
- where, the result is a scalar since it is the surface integral of the Poynting vector.

A system may take in power (power input) or put out power (power output):

- Input power (power in[put], $P_{in}$) = voltage x current
- Output power (power out[put], $P_{out}$) = voltage x current

### 22.1.6 DC voltage electrical power

In DC circuits, all voltages and all currents are constant, which makes calculation of power simple. A watt is defined as a current of one ampere, pushed by a voltage of one volt.

- Wattage = Volts x Amps
- 1 Watt = 1 Volt x 1 Amp
- 1W = 1V • 1I
- W = VI

In a resistor, the current, voltage and resistance are related by Ohms law as:

- Voltage = Amps x Resistance
- 1 Volt = 1 Amp x 1Ohm
- 1V = 1I • 1R
- V = IR
- where, V is voltage in volts, I is current in amps (traditionally stood for Intensity of current flow), and R is resistance in ohms.

Therein, the power dissipated by a resistor is:

- P = VI
- where, P is power in watts.

Take note that resistors are often rated in both ohms and watts. For a circuit with a single DC power supply, and a single resistor, the power dissipated by the resistor can be written as any of the following forms:

- $P = VI = I^2R = V^2/R$
- where, P is power in watts.

Power cannot be radiated without accelerated charges (i.e. time varying currents). Direct current is time invariant and cannot radiate power.

### 22.1.7 AC voltage electrical power

AC voltage has phases, and the number of phases may change how power is calculated:

- Single phase, P = IV
- Dual phase, P = IV
- Three phase, P = IV • 1.732
- where, 1.732 is the square root of 3.

### 22.1.8 Electromagnetic power mode (Electromagnetic transfer)

The watt specifies the rate at which electromagnetic energy is radiated, absorbed, or dissipated.

# 23 Fundamentals of: Force and motion

**NOTE:** *To precisely describe motion, the position of an object must be located within a given reference frame. When we say space is three dimensional, we mean we need three numbers to completely locate the position of an object or point. A system for assigning these three numbers, or coordinates, to the location of a point in a reference frame is called a coordinate system. Most frequently, a Cartesian (rectangular) system is used to describes the position in terms of x, y, z coordinates.*

Force is the ability to transfer energy (e.g., a push or pull, a pressure). It is frequently said that a force is a push or pull that one body exerts on another. Thus, a force is always an [inter]action, an influence. It represents the interaction of one body with another, which may be recognized by actual contact or by action at a distance. It is the influence of that which is a 'force' (or 'torque') that produces a change in a physical quantity (i.e., on an object or in a system). When forces are balanced they are said to be in a state of equilibrium. Force is a vector quantity - it has magnitude and direction. Hence, a force is has the following parameters (i.e., is characterized by its):

1. Magnitude
2. Point of action
3. Direction

**NOTE:** *Vector quantities are often represented by scaled vector diagrams. Vector diagram represents a vector by use of an arrow drawn to scale in a specific direction. Observe that there are several characteristics of this diagram: (1) a scale is clearly listed. (2) an arrow is drawn in a specified direction, therefore, the vector has a head and a tail. (3) the magnitude and direction of the vector are clearly labeled (the magnitude is 100 N and the direction is 35 degrees).*

It is commonly said that force is the "ability to do work". It must be noted that a force is required to do work, but every force does not necessarily do work. To apply a force, an amount of energy is required. This energy is then transferred to the object upon which the force has acted. This force does work on the second object. In this sense, force is a method to transfer energy, thus affecting the motion of a secondary object or system.

Newton's second law of motion states that a force, acting on an object, will change its velocity by changing either:

1. Its speed,
2. Its direction,
3. Or, both.

There are three principle types of motion due to force (i.e., all motion can be classified into three basic types):

1. **Translational/linear motion:** Object moves in a straight line. Translational motion is the motion by which a body shifts from one point in space to another. An object has a rectilinear motion when it moves along a straight line. Translational/linear motion is affected by force. Force causes linear acceleration. Note that "to translate" is "to have linear motion".
2. **Rotational motion:** Object spins. Rotational motion is the motion by which a body rotates in space. Rotational motion is affected by torque. Torque causes angular acceleration.
3. **Vibrational motion:** Object oscillates. Vibrational motion is the motion by which a body moves backwards and forwards (oscillates in two or more degrees of freedom) in space. Vibrational motion is affected by waves (compression and rarefaction). Waves cause vibrational acceleration.

An object can have any combination of these types of motion. For instance, the earth translates around the sun in an elliptical path, rotates about its axis, and vibrates during an earthquake. And, the three types of motion can be separated and analyzed.

In physics, a force is an influencing interaction that causes an object of mass (or charge) to change its velocity. Force can be categorically understood in relation to its physical application.

1. For a mechanical system, when force is applied, mass is displaced, and work is done (energy is transferred). Or, when torque is applied, mass is rotated, and work is done (energy is transferred). Therein, power is present as linear or rotational movement occurs.
   - Work (W) = force (F) x displacement (d)
   - Work (W) = F · rΘ = τΘ
2. For an electrical system, when force is applied, charges flow, and work is done (energy is transferred). Therein, power is present as charges flow.
3. For an electromagnetic system, when force is applied, electromagnetic waves (perturbations) propagate, and work is done (energy is transferred).

A force can cause any of the three types of motion. Therein, it could be said that there is one principal type of motion instantiation, and one principal sub-type of motion instantiation. The principal type [of motion] is force, and the principal sub-type [of motion], which is caused by the principal type (force) is torque.

1. [Principal type] **Force** as that which causes linear

(translational) motion. Translational motion is affected by force.
2. [Sub-type] **Torque** (twisting force, moment, moment of force) as that which causes rotational motion. Rotational motion is affected by torque. Torque is a measure of how much a force acting on an object causes that object to rotate. Torque is the counterpart of the force in angular motion.

A force can be acted as a force alone or as a torque. A force can be present without a torque, but a torque cannot be present without a force. A force is necessary in order to create a torque. Torque is created by a force. The specifics of the torque depend on the location of the force and the center of rotation (i.e., point about which an object rotates, the pivot point). One important distinction between force and torque is direction. Positive and negative signs are used to represent forces in the two possible directions along a line. The direction of a torque, however, is clockwise or counterclockwise, not a linear direction.

Take note that it is possible [for an object] to have a zero total torque with a non-zero total force. For instance, an airplane with four propeller engines -- two on either side of the fuselage, each side's propellers spinning in opposite directions to cancel out the total torque. Conversely, it is possible to have a zero total force and non-zero total torque. A merry-go-round's engine(s) need to supply a non-zero torque to bring the go-round object up to speed, but there is a zero total force on it. If there was not zero total force on it, its center of mass would accelerate.

**NOTE:** *The farther away from the center of rotation that the force is applied, the easier it is to rotate, the greater the torque.*

A simplistic way of classifying force is as follows:

1. **Applied force** is a push or a pull that is exerted on an object by another.
2. **Force of gravity** is the natural force that draws any object that is thrown to the sky towards the center of the earth.
3. **Normal force** is the magnitude of push that is brought about by an object's own weight.

A force is the fundamental result of an interaction between two objects, whereas power is an expression of the rate of energy transmitted over time (e.g., work), of which force is an element. Force and power can both be described and measured, but a force is an actual physical phenomenon, and power in itself is not.

**NOTE:** *Heat transfer by friction involves force. Heat transfer by conduction does not involve force. The definition of work could thus be restated as the amount of energy transferred by forces. No work is done without motion.*

## 23.1 Mechanical force

Mechanical force includes several possible sub-types of force.

### 23.1.1 Linear motion (linear/translational force)

Sum of all forces (f) = mass (m) x acceleration (a). Mass times acceleration (ma) is not a force. The sum of all forces on an object equals the product of its mass times its acceleration.

If every part of a system moves in a straight line at a constant speed, then it is in translational equilibrium (Note: this includes being at rest). For a body to be in translational equilibrium, the resultant forces in any two perpendicular directions must be zero.

- Force = Mass x Acceleration
- Newtons = kg x $m/s^2$
- where, the acceleration of gravity on earth is 10 $m/s^2$.

### 23.1.2 Torque (rotational force)

A force that produces a twisting or turning effect, or rotation, is called torque. Torque is also called a "rotational force" or a "twisting force". It is a "force" that makes anything rotate, twist, or turn. Any time anything rotates, there is a torque involved. Torque is the rotational equivalent of linear force. Torque can be used to create a force at a distance, but it does not cause an object (directly) to move along a distance. Torque is defined as a force around a given point (axis), applied at a radius from that point. A force applied at a non-zero distance from an object's centre will tend to rotate the object. This is easily seen in real life. If a wrench is placed on a bolt and a force is applied to the end of the wrench, the bolt will turn. If the same pulling force was applied directly to the bolt, it would not turn because the force's direction passes through the object's centre. The amount of torque is determined by multiplying the magnitude of the force by the force's distance from centre.

The ability of a force to rotate an object about an axis depends on two variables:

1. The magnitude of the force (F).
2. The distance (r) between the axis of rotation and the point where the force is applied.

The "turning ability" of a force is the product of F and r. The technical name for this "turning ability" is torque. Hence, the torque τ exerted by a force F that is applied at a point r relative to the origin is the cross product of r and F. Thus, the formula for torque is:

- torque (τ) = force (F) x perpendicular distance (r)
- $\tau = F \cdot r$

The magnitude of a torque depends on three quantities:

1. The force applied.
2. The length of the element (e.g., lever arm) connecting the axis to the point of force application.
3. The angle between the force vector and the lever arm.

Note that the units for both torque and work are the product of force and distance, yet torque and work are two different things. Torque is a force that tends to cause a rotation, which means that it does not actually cause an object to move along a distance. Work is a measure of energy transfer between systems, which may or may not have been done by a force from torque.

Mathematically, for rotation about a fixed axis through the center of mass, the formula is:

- $W = \int^{1}_{2} \tau d\theta$
- where, W is work, τ is torque, and ∫ (θ1 and θ2) represent (respectively) the initial and final angular positions of the body.

Whereas torque is measured, power is calculated. The power of a torque (rotational force) is a product of torque and rotational speed (i.e. cadence). The power (work per unit time) of a torque is given by:

- power (Pm) = torque (τ) · angular velocity (Ꞷ)
- where, Ꞷ is angular velocity or angular speed.
- Note, power herein is notated as a mechanical parameter, hence, mechanical power (Pm).

The terms “moment” and “torque” are often used interchangeably. By definition, however, moment is a quantity that represents the magnitude of force applied to a rotational system at a distance from the axis of rotation.

### 23.1.3 Pressure

Pressure is the force applied perpendicular to the surface of an object per unit area over which that force is distributed. Pressure is the ratio of force to area over which it is applied. Pressure is a scalar quantity as it has magnitude but no direction, while force is a vector quantity, because it has both magnitude and direction.

- pressure (P) = force (F) / area (A)
- F/A = ΔF/ΔA = work/volume = energy / volume

Pressure in a fluid can be seen to be a measure of energy per unit volume by means of the definition of work. This energy is related to other forms of fluid energy by the Bernoulli equation. Pressure in a fluid may be considered to be a measure of energy per unit volume or energy density. For a force exerted on a fluid, this can be seen from the definition of pressure:

## *23.2 Electrical force*

When two bodies of matter have charges and are near one another, an electric force (F) is exerted between them. The existence of such force, where current does not flow, is referred to as static.

The force of attraction or repulsion exerted between two charged bodies is directly proportional to the product of their charges (Q) and inversely proportional to the square of the distance (d) between them.

This relationship between attracting or repelling charged bodies was first discovered by a French scientist named Charles Coulomb and accordingly is known as Coulomb’s Law:

- $F = \hat{a} (Q_1 Q_2 / 4\pi\varepsilon_0 d^2)$
- Electric force $(F) = k (q_1 q_2 / r^2)$
- where, F is a vector quantity, which represents the electrical force acting on charge $Q_2$ due to charge $Q_1$ measured in newtons (N).
  - Wherein, F is the electric force.
- where, â is a dimensionless unit vector with a unity magnitude pointing from charge $Q_1$ to charge $Q_2$. k is coulomb's constant.
  - Wherein, q1 and q2 are charges (scalar values).
- where, $\varepsilon_0$ is a universal constant called the electrical permittivity of free space [$\varepsilon_0 = 8.854x10^{-12}$ farad per meter (F/m)].
  - Wherein, r is the distance of separation between the two charges.

# 24 Fundamentals of: Electricity

Electricity is the set of physical phenomena associated with the presence and flow of electric charge. Electricity gives a wide variety of well-known effects, such as lightning, static electricity, electromagnetic induction and electric current. In addition, electricity permits the creation and reception of electromagnetic radiation such as radio waves.

In electricity, charges produce electromagnetic fields which act on other charges. Electricity occurs due to several types of physics:

1. **Electric charge:** a property of some subatomic particles, which determines their electromagnetic interactions. Electrically charged matter is influenced by, and produces, electromagnetic fields, electric charges can be positive or negative. Electric charge is measured in coulombs.
2. **Electric force:** the force of attraction or repulsion between objects due to charge.
3. **Electric field:** charges are surrounded by an electric field. The electric field produces a force on other charges. Changes in the electric field travel at the speed of light. Electric fields are measured in kilovolts per metre (kV/m).
4. **Magnetic field:** these fields are toroidal/spiral in form, near instantaneous, and feedback into/onto themselves. They are not as well studied as electrical fields. A changing/fluctuating (in flux) magnetic field will induce an electric field [at a distance] in a material capable of conducting an electric field (i.e., in a conductive material). A magnetic field can be generated in one of two ways (either / or): directly through a permanent magnet; or indirectly by passing an electric current through conductive coils/windings to produce an 'electromagnet'. and Magnetic fields are measured in milligauss (mG).
5. **Electromagnetic field:** The synchronized and perpendicular propagation of electric and magnetic fields at a specific frequency. Electromagnetic field are typically measured in electron-volts (eV). The frequency is typically measured in hertz (Hz).
6. **Electric potential:** the capacity of an electric field to do work on an electric charge, typically measured in volts.
7. **Electric current:** a movement or flow of electrically charged particles, typically measured in amperes.
8. **Electric conductor**: a material that can carry an electrical current, and through which charges move freely. Conductivity is determined by the atomic makeup of a material. Materials with high electric charge mobility (many free electrons) are called conductors, while materials with low electron mobility (few or no free electrons) are called insulators. For electrons to flow continuously (indefinitely) through a conductor, there must be a complete, unbroken path for them to move both into and out of that conductor. Note that when a current carrying conductor is placed in a magnetic field it experiences a force (specifically, an electromagnetic force).
9. **Electromagnets:** moving charges produce a magnetic field. Electric currents generate magnetic fields, and changing magnetic fields generate electric currents.

In electrical engineering, electricity is used for:

1. **Electric power** where electric current is used to energise equipment.
2. **Electronics** which deals with electrical circuits that involve active electrical components such as vacuum tubes, transistors, diodes and integrated circuits, and associated passive interconnection technologies.
3. The **electromagnetic spectrum** is the range of all possible frequencies of Electromagnetic radiation and is sorted by frequency. The electromagnetic spectrum is a categorized spectral representation of electromagnetic waves by their wavelength (frequency) location within the whole set of known electromagnetic waves, which is most commonly measured in micrometers. Names are often assigned to regions of the electromagnetic spectrum, but there is no clear cut dividing lines from one region to the next. Electromagnetic waves can be characterized by either the frequency or wavelength of their oscillations, which determines their position in the electromagnetic spectrum, which includes, in order of increasing frequency and decreasing wavelength. The electromagnetic spectrum is a unified spectrum of photonic energy patterning that humans, for purposes of functional service specialization, have split into "frequency bands". Individual photon energies in the frequency band known as "radio frequency" (RF) are so small that its not useful to describe RF waves in terms of photons, but one could do so. Each "band" represents electromagnetic radiation along a continuous spectrum, split into wave segments with different, upper and lower, frequency boundaries (a.k.a., "bands"). So, visible light and RF are the same thing, EMR; its only a matter of how much energy each of them (i.e., each frequency instantiation) is carrying. Because of its frequency, the "RF" band is has lower photon energy than visible light.

## 24.1 Electricity in nature

Electricity is not a human invention, and may be observed in several forms in nature, a prominent manifestation of which is lightning. Many interactions familiar at the macroscopic level, such as touch, friction and chemical bonding, are due to interactions between electric fields on the atomic scale. The Earth's magnetic field is thought to arise from a natural dynamo of circulating currents in the planet's core. Certain crystals, such as quartz, and even sugar, generate a potential difference across their faces when subjected to external pressure. This phenomenon is known as piezoelectricity, and was discovered in 1880. The prefix "piezo-" is derived from the Greek piezein (πιέζειν), which means to press or to squeeze. The effect is reciprocal, and when a piezoelectric material is subjected to an electric field, a small change in physical dimensions takes place.

Some organisms, such as sharks, are able to detect and respond to changes in surrounding electric fields, an ability known as electroreception, while the ability of an organism to internally generate an electric voltage is termed electrogenic (such an ability often serves as a predatory or defensive weapon). The biological order Gymnotiformes, of which the best known example is the electric eel, is able to stun its prey via high voltages generated from modified muscle cells called electrocytes. It is important to note here that all animals transmit information along their cell membranes with voltage pulses called 'action potentials'. Action potentials are also responsible for coordinating activities in certain plants.

## 24.2 Principles of electrical theory

The following principles form the foundation of electrical theory, and hence, are the basis of electricity.

1. All charged particles (i.e., charges) have an electric field. There are no magnetically charged particles (if they existed they'd be called "magnetic monopoles").
2. There are two ways of creating an electrical field: introduce an electrically charged particle, or introduce a time-varying magnetic field.
3. There are two ways of creating a magnetic field: move an electrically charged particle (i.e., an electrical current), or introduce a time-varying electric field.
4. Under static conditions (i.e., not changing with respect to time), either electric or magnetic fields can exist without the other. Technically, this is not entirely accurate in concern to magnetic fields, because the electric field is still present, it is just being cancelled out.
5. Under dynamic conditions (i.e., changing with time), neither an electric or magnetic field can exist without the other. If one field is time-changing, the other must be non-zero.
6. Electromagnetic energy refers to the synchronous presence of electric and magnetic fields.
7. Electrostatics is the study of static (unchanging) electric fields, electric charges, and the rules governing their interactions.
8. Magnetism is the study of static magnetic fields, magnets, and the rules for their interactions.
9. These two areas of study are tied together with electrodynamics, which is the study of changing electric and magnetic fields, and electromagnetic (EM) waves (of propagation radiating as "radiation").
10. Electrical science is the study of electrical effects. Electrical effects are caused by electric charges and by the electric and magnetic fields associated with charges.
11. The theory of electric circuits is a subset of the theory of electrodynamics, which is a subset of quantum theory.

**INSIGHT:** *There is no physical object called 'wave'. Wave is not what something is, but what something does. For instance, wave is what a flag does. There is no waving without the flag. Similarly, there is no physical object called vortex. Vortexing is what something does.*

## 24.3 Electric charge

The 'electric charge' is a property of some subatomic particles, which determines their electromagnetic interactions. Charge is the quantity of electricity responsible for electric phenomena. It is one of the fundamental physical quantities in electric circuit analysis. A quantity of charge that does not change with time is typically represented by Q. The instantaneous amount of charge, which is time dependent (changes over time), is commonly represented by Q(t). The concept of an "electric charge" adheres to the following principles:

1. The physical property of matter that causes it to experience a force when placed in an electromagnetic field is called an "electric charge", and it has historically been called a "charge of electricity".
2. Electric current is a "flow of charge", rather than "a flow of electricity."
3. Electrons are "charge carriers", rather than "particles of electricity."

**CLARIFICATION:** *The speed at which energy transfer occurs, or signals travel, down a conductor is the speed of the electromagnetic energy (light), not the speed of movement of the electrons.*

The decomposition of the physical environment to charge is as follows:

1. Matter - all forms of matter are composed of molecules.
2. Molecule - molecules are composed of atoms
3. Atom - atoms are composed of particles, of which there are three: protons, neutrons, and electrons.
   A. Relative position - the center of the atom is called the nucleus, which is surrounded by orbits.
   B. Protons within nucleus.
   C. Neutrons within nucleus.
   D. Electrons in orbit.
4. Charge - a property of particles determining electromagnetic interaction.
   A. Electrons maintain a negative polarity (-ve), a negative charge.
   B. Protons maintain a positive polarity (+ve), a positive charge.
   C. Neutrons do not have a polarity, are neutral.
5. Atomic charge determination
   A. An excess of electrons creates a negative charge.
   B. The absence of electrons creates a positive charge.
6. Charge field vector
   A. Positive charge outward
   B. Negative charge inward
7. Charge interaction/dynamics
   A. Different charges attract each other (void space).
   B. Same charges repel each other (create space).

In physics, 'charge', also known as electric charge, electrical charge, or electrostatic charge (dielectric), and symbolized 'q', is a characteristic of a unit of matter that expresses the extent to which it has "more (-ion) or fewer (+ion) electrons than protons". The basic unit of electric charge is the "coulomb".

- 1 coloumb = 6.25 x $10^{18}$ electrons

Electric charge, also called "the Quantity of Electricity," is a fundamental component of everyday matter. Objects are made of molecules and atoms, atoms are made of protons, neutrons, and electrons, and the protons and electrons are made in part out of electric charge. Electric charge is substance-like. If you have a quantity of charge, you cannot destroy it, you can only move it from place to place.

> **NOTE:** *Electric forces are what hold together atoms and molecules, solids and liquids. In collisions between objects, electric forces push things apart.*

Matter can carry charge. However, it is not the charge of matter that transports energy; it's the electromagnetic field that is linked to the charge. Charged particles are expressed as propagating electromagnetic excitations in the field. In a charged particle's rest frame (static charged), the magnetic components is not expressed, and only the time-like ones (the electric field and the energy, respectively) remain. Charge itself gives rise to a 'divergence' in the electric field. Current (moving charge) gives rise to a curl/spiral in the magnetic field. In other words, in its rest frame, a charged particle appears to generate an electric field only and no magnetic field at all. From a different frame of reference (in particular one in relative motion), we'll see the charge moving, thus a current which generates a magnetic field as well. Fundamentally, charge produces a field that acts on other charges.

> **NOTE:** *Materials can be listed in the order of those "most likely to lose electrons" (gaining positive charge) to "those most likely to gain electrons" (gaining negative charge). This is called the 'triboelectric series'.*

Note, it is possible to let charges pass through a vacuum with no resistance, but that is not a reason to call the vacuum a conductor [of charge]. Conducting is associated with influence of the conductor on the motion of the conducted - directing the motion - which a vacuum does not appear to have. The vacuum (space) allows charged matter to pass trough it. Electromagnetic waves propagates (at the speed of light) in vacuum.

## 24.4 Charge and electric circuits

Moving charges represent an electric current. During operation, although charges are transferred between different parts of an electric circuit, the total amount of charge does not change. Electrons or protons are neither created nor destroyed when an electric circuit is operating.

In a neutral state (zero charge), electrons will neither leave nor enter the neutrally charged body should it come in contact with other neutral bodies. If, however, any number of electrons is removed from the atoms of a body of matter, there will remain more protons than electrons and the whole body of matter will become electrically positive.

Should the positively charged body come in contact with another non-charged body, or having a negative charge, an electric current will flow between them. Electrons will leave the more negative body and enter the positive body. This electron flow will continue until both bodies have equal charges. When two bodies of matter have charges and are near one another, an electric force (F) is exerted between them. The existence of such force, where current does not flow, is referred to as 'static'.

The force of attraction or repulsion exerted between two charged bodies is directly proportional to the product of their charges (Q) and inversely proportional to the square of the distance (d) between them.

## 24.5 Conductors

Conductors allow for charge transfer through the free movement of electrons (or protons). Conductors guide the flow of electric charge, and hence, the flow of electromagnetic energy.

Three factors determine whether or not the atom is a "good" or "bad" conductor:

1. The number of electrons in the outer orbit.
2. The distance of the outer orbit from the nucleus of the atom.
3. The density of the atoms within the element.

Therein,

1. If the atom has only one orbit, maximum number of electrons on orbit is 2.
2. If the atom has more than one orbit, maximum number of electrons on outer orbit is 8.

The following are good conductors:

1. Gold, silver, copper have 1 electron on their outer orbit.
2. Mercury has 2 electrons in its outer orbit
3. Aluminum has 3 electrons in its outer orbit.
4. Carbon has 4 electrons in its outer orbit.

> **NOTE:** *The net electric charge of a conductor resides entirely on its surface. The mutual repulsion of like charges from Coulomb's Law states that the charges be as far apart as possible, hence on the surface of the conductor. The electric field inside the conductor is zero.*

## 24.6 Electric current

> **NOTE:** *Electron theory states that the subatomic particle that does the work in electronics is the electron, which happens to be negatively charged. There is a subatomic particle that flows the other way, from positive to negative: the Positron.*

An electric current is a flow of electric charge, which transfers electromagnetic energy through conductive space. The particles that carry the charge in an electric current are called 'charge carriers'. There are a variety of charge carriers:

1. In metallic solids, electric charge flows by means of electrons, from lower to higher electrical potential.
2. In electrolytic solutions, electric charge flows by means of ions.
3. In gases and plasmas, electric charge flows by means of ions and electrons.
4. In a vacuum, electric charge flows by means of ions and injected free electrons.

Electric current is measured in coulombs per second (amperes or amps; A or I).

- Amperage = amount of electrical current
- Amperage = Coulombs / Seconds
- 1 Ampere = 1 Coulomb / 1 Second
- 1 Ampere is equal to 1 Coulombs per second
- 1A = 1C / 1s
- A = C/s

> *1 Coulomb is approximately $6.241 \times 10^{18}$ times the elementary charge (e or q). The elementary charge is the electric charge carried by a single proton, or equivalently, the magnitude of the electric charge carried by a single electron (-e or -q). This elementary charge is a fundamental physical constant.*

Current is rate of change in the electric field:

- current (I) = $\Delta q/\Delta t$
- wherein, q=charge

> **NOTE:** *Ampère's force law states that there is an attractive or repulsive force between two parallel wires carrying an electric current. This force is used in the formal definition of the ampere, which states that the ampere is the constant current that will produce an attractive force of $2 \times 10^{-7}$ newtons per metre of length between two straight, parallel conductors of infinite length and negligible circular cross section placed one metre apart in a vacuum.*

Electric current is measured using an instrument called an **ammeter**.

> **NOTE:** *Humanity cannot [with present technology] directly observe the electrically-charged particles that produce current.*

The energy in electric circuits is not carried by individual electrons, it is carried by the circuit as a whole. Current is defined as the rate of flow of charges through a medium. Current is the flow of charges, stationary charges cannot give any current. Charge gives rise only to an electric field, while current produces both electric and magnetic fields. The energy flowing through an electric circuit as an electric current is contained in electrostatic and the magnetic fields produced by the electrons.

> **NOTE:** *In an electric current, the electron particles are the "medium", wherein energy is transferred electromagnetically.*

Electricity (electrical energy) is the flow of electrical charge, and all flows of electrical charge (electric current) transfer energy electromagnetically. In metals, the electrically charged particles are electrons. Electricity cannot flow through air, except in the form of electrically charged particles of air - as in a spark or lightning stroke.

> **NOTE:** *Some elements in a circuit can transfer ("convert") energy from one carrier ("form") to another. For example, a resistor transfers ("converts") electromagnetic energy traveling through a conductor (i.e., "electrical energy") to heat (i.e., "thermal energy"), this is known as the Joule effect. In other words, electric currents cause Joule heating.*

> **NOTE:** *The flow of charge (i.e., an electric current) causes friction, which is called resistance. Resistance quantifies how much current you get across something per volt applied. Namely, if you apply a voltage V across a wire and measure current I, the resistance R is defined by: R = V/I. Resistance therefore has units of V/A, which get another name, ohms.*

#### *24.6.3.1 Current and the AC power grid*

In an AC electric power grid, a certain amount of energy is lost because it vectors off into space. This is well understood: electrical energy is electromagnetic waves travelling everywhere, and unless the power lines are twisted or somehow shielded, they will act as 50-60Hz antennas. Waves of 60Hz electrical energy can spread outwards into space rather than follow the wires. The power lines can even receive extra 60Hz energy from space, from magnetic storms in Earth's magnetosphere. Electric energy is gained and lost to empty space while the charges of electricity just sit inside the wires and wiggle.

## *24.7 Current and electromagnetic fields*

Any time current flows through a conductor, a magnetic and electric field are generated around the conductor. If that current is direct current (DC), then the resultant magnetic and magnetic fields will have a constant orientation/polarity (i.e., a constant electromagnetic field - DC magnetic field and DC electric field). If the current is alternating current (AC), then the electric and magnetic fields will vary in direction (polarity) and intensity with the alternation of the current (i.e., a varying electromagnetic field - AC magnetic field and AC electric field).

Any AC circuit propagates its signals using electromagnetic waves. The transmission of the signal between elements is done only by electromagnetic waves. But in a circuit, these waves are guided waves, the traces on a PCB or the wires of our circuit guide the waves along the desired path.

> **NOTE:** *An antenna is a transceiver/transformer of sorts. The antenna is a device that transforms guided electromagnetic waves into propagating electromagnetic waves (and vice-versa). So all it is doing is taking the guided wave that is sent to the antenna and providing it a means of going into open space.*

## *24.8 Electromagnetic fields*

An **electromagnetic field (EMF** or **EM field)** refers to the field created by static (electric field) or moving (magnetic field) charges. Note that a constant electric or magnetic field filling a space is not a wave (i.e., not an electromagnetic wave). In physics, a field is a space together with a set of values for every point in the field, which generates a time-space coordinate system. An electromagnetic field is a set of values for electric and magnetic vector orientation and magnitude (strength), one for each point in space time. The components of the field depend on a reference point for the coordinate system (the observer), even though the field itself has a definite physical existence. Technically, a classical field is a function whose domain is space-time, and a wave is a configuration of the field that satisfies a [differential] wave equation. Note that a quantum field is more complicated. Note that the term 'field' is challenging to define because it is a fundamentally assumed/axiomatic form of existence in physics. Hence, it cannot be defined by saying what it is made of. Electric fields are measured in kilovolts per metre (kV/m) and magnetic fields are measured in milligauss (mG).

An electric field can be created by:

1. The presence of a changing magnetic field.
2. The presence of a charge[ed particle] (e.g., ion).

A magnetic field can be created by:

1. The presence of a changing electric field.
2. The presence of a dielectric charge[d particle] (e.g., permanent magnet).

### 24.8.1 Alternating current and electromagnetic fields

The electromagnetic fields produced by an alternating current can be categorized as follows:

1. *Near fields* allow for electromagnetic induction. The near-field is a reactive power field. Inductive coupling is the coupling of elements with near fields.
2. *Far fields* allow for electromagnetic radiation.

### 24.8.1 Alternating current and near field electromagnetic induction

In a coil of wire, AC produces fluctuating fields that can induce currents on another coil without any physical contact. This process is known as electromagnetic induction, and it uses near field electromagnetic reactance radiation (vs. far field propagating radiation). The electric and magnetic fields produced for electromagnetic induction are not in a constant ratio of strengths to each other, and are not phase (i.e., there is a reactance). Electromagnetic induction is a particular form of the more general electromagnetic field (EM Field), which is produced by moving charges. If an AC current is fed through a piece of wire, the electromagnetic field that is produced is constantly growing and shrinking due to the constantly changing current in the wire. This growing and shrinking magnetic field can induce electrical current in another wire that is held close to the first wire. The current in the second wire will also be AC and in fact will look very similar to the current flowing in the first wire. One can generate a magnetic field by letting an alternating current flow through a wire or coil. That is what happens in the primary coil of a 'transformer'. The other way around, a change in a magnetic field will generate a current in a coil - that's what happens in the secondary coil. These properties of magnetic fields and current are called electromagnetic induction.

> **NOTE:** *The near field and far field are regions of the electromagnetic field around an object, such as a transmitting antenna, or the result of radiation scattering off an object. This difference between picking up a magnetic field and magnetic radiation is known as the difference between near and far field. [wikipedia.org]*

In a general electromagnetic induction setup, the secondary coil exists inside one wavelength of the wave that is produced by alternating current on the first coil (i.e., in the near field). This means that the current in the secondary coil does not exist because of electromagnetic radiation (self-propagating EM fields), but because of electromagnetic induction (reactance EM fields). In an electromagnetic induction circuit, the electric and magnetic fields don't [re-]create each other and propagate outward.

### 24.8.2 Alternating current and far field electromagnetic radiation

Electromagnetic radiation (EMR) is a particular form of the more general electromagnetic field (EM Field), which is produced by moving charges. The electric and magnetic fields in EMR exist in a constant ratio of strengths to each other, and must also be in phase. In electromagnetic radiation, the magnetic field will create an electric field (just assume that), but further away from the conductor that began with making the electromagnetic field. The electric field will create a magnetic field, even further away, and so on. It just goes on and on, due to specific properties of the field. It can vary in frequency, from extremely low frequency all the way up to extremely high frequency.

Electromagnetic radiation (EM radiation or EMR or far field) is the radiant electromagnetic energy released by certain electromagnetic processes. Electromagnetic radiation is a transverse wave where an electric and magnetic field oscillate perpendicular to each other and in the direction of propagation. The energy of the wave is in the electric and magnetic fields. Electromagnetic radiation is associated with those EM waves that are free to propagate themselves ("radiate") without the continuing influence of the moving charges that produced them, because they have achieved sufficient distance from those charges. Thus, EMR is sometimes referred to as the **far field**; versus, the near field, which refers to EM fields near the charges and current that directly produced them, specifically, electromagnetic induction and electrostatic induction phenomena.

> **NOTE:** *In general, electromagnetic radiation from an antenna comes from alternating current flowing in a linear conductor.*

### 24.8.3 Direct current and electromagnetic fields

A direct current (DC) electromagnetic field refers to a constant or static DC electric or DC magnetic field emission, which has a frequency of 0 Hz. In a coil of wire, DC produces electromagnetism, and does not produce electromagnetic induction (near field) or electromagnetic radiation (far field). A DC magnetic field (constant polarity) cannot be used to induce current in any other conductor. Only a varying magnetic field can do that (to generate that you need varying current). You can use this unidirectional field in a way similar to how you can use permanent magnets. For example - closing and opening electromechanical relays. The only way to produce an electromagnetic field is to somehow change the current with time. So, even if the source of the current is constant (DC), then it is possible to produce an EM field by frequently changing the physical properties of conductor along its length, such as changing the cross-section of the conductor frequently along its length, or modifying the electrical parameters of the conductor frequently. The electric field of a direct current (DC electric field) is measured in are measured in Volts per meter (V/m). The magnetic field of a direct current (DC magnetic field) is measured in milliGauss mG with a DC gaussmeter.

## *24.9 Electromagnetic radiation*

Electromagnetic radiation (in the shape/geometry of a wave) are produced by accelerating electrical charges. The current carrying charged particles in AC circuits are continuously accelerating (at a frequency) and always emit electromagnetic waves. These emissions may be limited to reduce energy losses with the use of shielding, twisting, and coaxial cables. An EM wave is present when there is an oscillation of charge (as in, an oscillator produces a periodic, oscillating electron signal, an AC signal).

In a DC circuit operating with a constant current, the electrical charges, usually electrons, only experience a brief initial acceleration when the circuit is energized, and negligible energy is radiated as electromagnetic waves. In other words, the DC hasn't been DC forever, there was a time when it turned on, and that put out a small electromagnetic click, but just for an instant. A DC wire puts out a steady magnetic field, not a propagating electromagnetic field. Direct current is also capable of producing a varying magnetic field (by turning it on and off at a certain frequency, for example), So, it may emit an electromagnetic wave, if it's varying in some way.

The electric and magnetic fields produced by direct current (DC) lines are referred to as static fields because their sources, voltage and current, do not alternate over time. Thus, DC fields are qualitatively different in nature than the alternating current (AC) electric and magnetic fields (often called EMF) produced by AC transmission lines. While AC EMF can cause the induction of currents or voltages in nearby objects, this does not occur with DC fields.

Stable AC produces a constant "vibration" in the conductor, while DC doesn't vibrate the conductor at all. If the electron flow in 60Hz AC power signal were converted to a sound, then it would sound like a low hum -- specifically, a 60 Hz hum, between a B and a Bb, right below the C two octaves below middle C. DC current sounds like a single click when it starts and another when it ends. This is because what we call sound consists of vibrations.

Electric and magnetic fields surround any electrical circuit, whether it carries AC or DC power, including appliances, electrical wiring and power lines. Both electric and magnetic fields diminish rapidly as the distance from the source increases. Electric and magnetic fields from DC transmission lines are commonly referred to as static fields because they do not alternate in direction. Static electric fields occur as a result of voltage. Static magnetic fields are created by a magnet or by the steady flow of electrical current (DC).

The fields associated with the operation of a DC line are static, which is the same as having a frequency of zero, and do not induce voltages or currents in nearby conducting materials in the environment. Note that in certain weather conditions, both AC and DC transmission lines may produce an electric field associated with electric charges in the air and not just those on the conductors.

An electric field applied to an electric circuit causes a flow of electric charge, which transports/moves electromagnetic energy and generates consequential heat as thermal energy due to resistance (friction). All charges have an electric field. When you accelerate a charge you also get a magnetic field. To get EM waves you need to accelerate the charges - like wiggling them back and forth or turn them in a circle for acceleration. Electrons accelerating in a conductor do emit EM waves out of the conductor - that is how radio transmitters work. A DC circuit does not emit significant EM waves while it transports/moves electrical energy from source to load.

In electronics and telecommunications engineering, a "transmitter" or "radio transmitter" is an electronic device which, with the aid of an antenna, produces EMR (as radio waves). The electronics of the transmitter device generate a radio frequency alternating current, which is applied to a part of the device known as an antenna. When excited by this alternating current, the antenna radiates EMR (as radio waves). The term transmitter is usually limited to equipment that generates radio waves for communication purposes, or radiolocation, such as radar and navigational transmitters. Generators of radio waves for heating or industrial purposes, such as microwave ovens or diathermy equipment, are not usually called transmitters even though they often have similar circuits.

The electromagnetic fields that we measure radiating from AC electric currents in the circuits in the walls of a building have a frequency of about 50 to 100 cycles per second. If we increase the frequency to 500 or 1000 kilocycles (1 kilocycles = 1000 cycles) per second, we are "on the air", for this is the frequency range which is used for radio broadcasts.

All accelerated charges radiate electromagnetic energy (i.e., electromagnetic radiation). So, everything that conducts alternating current acts as an antenna. However, in order to achieve efficient radiation the antenna must be designed appropriately. The antenna itself, when connected to a transmitter, is both the positive, 0, and negative pole at different times. This movement of charge creates a changing electric and magnetic field, which becomes an electromagnetic wave, capable of radiating energy from the antenna or aerial (see Maxwell equations and Hertz definition). As the [alternating] current from the transmitter approaches the end of the wire [antenna], but has no place to go, the charges pile up until they are pushed back in the other direction. By the time the charge is back at the transmitter, it's travelled $\lambda/2$ or experienced a 180° phase shift. The voltage at V1 has also changed by this point, and so the current is constructively adding to the new currents being produced by the transmitter, as an alternating current that form a sine wave. If it were not for some of this energy being "lost" as radiation, the energy in the antenna would grow without bound. The radiation of energy from the antenna is presently understood in the form of a set of equations named after a human being, "Maxwell's equations". Essentially, the equations state that the current in an antenna is associated with a magnetic field, and the voltage is associated with an electric field -- an antenna is an arrangement such that at some distance away from the antenna (the far field) these two fields are mutually perpendicular and in phase, and the output of their integration [in a medium] is a self-propagating EM [field] wave.

**INSIGHT:** *An equation may be true, but not* *factual.*

The electric field is produced by stationary charges, and the magnetic field by moving charges (currents; or, permanent magnetic substance); these two concepts are often described as the sources of the field. The way in which charges and currents interact with the electromagnetic field is described by Maxwell's equations and the Lorentz force law. The alternating voltage from the transmitter is moving (accelerating) the [electron(ic)] charge backwards and forwards. Standing waves that impact the functioning of the antenna are the result of a miscalculated antenna, and they represent lost energy. The standing wave is the pattern you get (in voltage or current) when the power travelling to the antenna is superimposed on the power reflected back from the antenna due to mismatch of antenna and transmission line. Power is travelling in both directions at once and when you sum the instantaneous voltage at all points along the line you get a steady pattern of highs and lows. This is the "standing wave".

However, in transmission of charge through a wire, the wire is a poor "antennas" and doesn't radiate well. To make a functional antenna, power (i.e., the energy contained in voltages and currents) must be transferred effectively into electromagnetic radiation, where the energy is contained in the electric (E) and magnetic (H) fields [travelling away from an antenna].

A magnetic field, as the result of a moving charge, can also be thought of as the flow of water in a garden hose. As the amount of current flowing increases, the level of magnetic field increases. Magnetic fields are measured in milliGauss (mG). Electric fields are created around appliances and wires wherever a stationary charge, a "voltage", exists. Electric voltage can be thought of as the pressure of water in a garden hose – the higher the voltage, the stronger the electric field strength. Electric field strength is measured in volts per meter (V/m). The strength of an electric field decreases rapidly as you move away from the source. Electric fields can also be shielded by many objects, such as trees or the walls of a building.

Antenna absorbs radio waves and turns them into electrical signals. Antennas are sometimes called receivers. A transmitter an antenna setup that radiates radio waves (i.e., signals; electromagnetic radiation; invisible light). Electron oscillations on the antenna produce electromagnetic radiation in the form of radio waves. To make a good antenna you have to transfer power (the energy is contained in voltages and currents) into electromagnetic radiation (where the energy is contained in the electric field "E" and magnetic field "H") travelling away from the antenna. Antennas can emit radiation and can receive radiation.

The distance from one peak to the next is the wavelength, and the number of peaks passing through a fixed point per unit time is the wave frequency. Electromagnetic radiation is electromagnetic energy in motion. Electrodynamics is the physics of electromagnetic radiation, and electromagnetism is the physical phenomenon associated with the theory of electrodynamics. The electromagnetic field generated from currents and charges (i.e., "sources") is called electromagnetic radiation (EMR), since it radiates from the charges and currents in the source, and has no "feedback" effect on them, and is also not affected directly by them in the present time (rather, it is indirectly produced by a sequences of changes in fields radiating out from them in the past). EMR consists of the radiations in the electromagnetic spectrum, which has been split for government control and commercial application into a series of "bands", including radio waves, microwave, infrared, visible light, ultraviolet light, X-rays, and gamma rays.

## *24.10 EM radiation and EM waves*

The following is a list of notes on EM radiation/waves

1. Radiation is the transfer of energy by way of electromagnetic waves. Waves are what something does, not what something is. Hence, what is waving?
2. Frequency: The frequency of the wave is the number of "crests" (and troughs) [of the wave] that pass a given measurement point within 1 second. In other words, it is the number of complete waves passing a given point in 1 second. And, it has the unit [measurement] of 'Hertz'.
3. Unit: Hertz - 1 wave or cycle, per 1 second, is call a 'hertz'.
4. Energy transfer: The higher the frequency (i.e., the higher the hertz as cycles per 1 second) the higher the amount of energy transferred. Gamma are the shortest (highest) energy "waves" in the current spectrum.
5. Compression and rarefaction: Wavelength is the distance between two consecutive compressions or rarefactions.
6. Note: In general, human vision can detect electromagnetic radiation waves (light) from ~400nm to ~700nm (the visible light region or band of the spectrum).
7. Objects appear to have color because em waves from 400-700nm interact with their molecules. Some wavelengths in the visible spectrum are reflected, and other wavelengths are absorbed. In the case of a green leaf, EM waves from 492-577nm a reflected (which the human eye interprets as green) and the rest of the wavelengths in the visible spectrum are absorbed. Seeing a leaf as green does not give enough information to determine how the leaf reflects UV, microwave, or IR. Everything emits, absorbs, or reflects electromagnetic radiation differently based on its composition. A spectral

signature is a graph showing these interactions across a region of the EM spectrum. Characteristic patterns all for the identification of an object's chemical composition, and determine such physical properties as temperature and density.

8. Sound waves are longitudinal waves - sound travels quickest through a solid.
9. EM waves have a transverse (right angle) and longitudinal (parallel) component.

## *24.11 Electromagnetic waves*

**NOTE:** *Electromagnetic waves are the geometry taken for the transfer of electromagnetic energy. Mechanical waves (longitudinal for sound and transverse for water) are the geometry taken for the transfer of mechanical energy. A wave is a compression and rarefaction of a medium. It is sometimes said that mechanical waves have a spatial medium (mass), whereas electromagnetic waves have a counterspatial medium (ether).*

**Electromagnetic waves (EM Waves)** are the oscillating electrical and magnetic fields, acting perpendicular to each other, and propagating through space. EM waves retain their total energy in accordance with the law of conservation of energy. The EM wave spreads out as it travels, which reduces both the field strength and the energy of any section of the EM wave. Total energy of the wave remains the same, however. The relationship between the electrical and magnetic fields at any given point in space is given by Maxwell's equations. An accelerated charge radiates electromagnetic energy in the form of electromagnetic waves. The speed at which energy or signals travel down a cable is actually the speed of the electromagnetic wave, not the movement of electrons. Electromagnetic wave propagation is fast and depends on the dielectric constant of the material. In a vacuum the wave travels at the speed of light and almost that fast in air. An electromagnetic wave is a certain configuration of the electromagnetic field. EM waves carry energy, momentum and angular momentum away from their source particle and can impart those quantities to matter with which they interact. It could also be said that an electromagnetic wave travels through fields and changes them. A field is not the same thing as a wave, but a changing field is experiencing a wave passing through it. And people shortcut this by speaking as if a changing field is a wave. When electric and magnetic fields fluctuate together they lead to formation of the propagating waves called electromagnetic waves. An electromagnetic wave is not constant - it oscillates with time. When an electric (or magnetic) field oscillates, it generates an oscillatory magnetic (electric) field. This oscillatory magnetic (electric) field then generates its own electric (magnetic) field, and back and forth they go until the EM energy in the field is absorbed by matter. This oscillatory electric-magnetic field is an electromagnetic wave. An EM wave can be traveling (e.g. radiation from an antenna) or it can be confined in what is called a standing wave (e.g. the radiation inside a microwave oven). It is the oscillation that makes it a wave. An electromagnetic wave is electromagnetic radiation, is electromagnetic energy in motion, which is described by wave theory. In other words, an EM wave is any EM field that obeys the differential equations governing waves. Technically all EM fields obey this equation, so the definition is usually restricted to fields which have a non-zero frequency component -- that is, fields that oscillate.

An electromagnetic radiation will travel forever, or until it contacts something, in accordance with Newton's first law -- just like any other object in motion.

Electromagnetic waves propagate in vacuum at a maximum speed of 299,792,458 meters per second . For a 12-gauge copper wire carrying a 10-ampere DC current, the speed of electric current (average electron drift velocity) is about 80 centimeters per hour or about 0.0002 meters per second. The speed of electric (electromagnetic) field propagation in copper wire is slower than in vacuum by a factor referred to as the velocity factor. The speed of electromagnetic waves propagate in vacuum is 299,792,458 meters per second. The velocity factor for a 12-gauge copper wire copper wire is about 0.951 (according to this source). Therefore, the speed of electricity in a 12-gauge copper wire is 299,792,458 meters per second x 0.951 or 285,102,627 meters per second. This is about 280,000,000 meters per second which is not very much different from the speed of electromagnetic waves (light) in vacuum.

## *24.12 Electrical circuits*

Electrical circuits provide a means of guiding the transfer of electromagnetic energy (power) via charge carriers in the conductive conduit (i.e., the wire/circuit path).

Electrical circuits in which charges oscillate continuously (alternating currents) will continuously produce both:

1. EM energy through the wire/circuit path, and
2. EM energy that takes the vector path of the magnetic field.

**DEFINITIONS: Reactance** *is the opposition of a circuit element to a change in current or voltage, due to that element's inductance or capacitance. A built-up electric field resists the change of voltage on the element, while a magnetic field resists the change of current. The electrical* **resistance** *of an electrical conductor is a measure of the difficulty to pass an electric current through that conductor. An ideal resistor has zero reactance, whereas ideal inductors and capacitors have zero resistance – that is, respond to current only by reactance. Note that The magnitude of the reactance of an inductor rises in proportion to a rise in frequency, while* *the magnitude of the reactance of a capacitor decreases in proportion to a rise in frequency (or increases in proportion to wavelength). As frequency goes up, inductive reactance goes up and capacitive reactance goes down.*

## 24.13 Voltage

A voltage (electromotive force) is required for charges to flow as an electric current. If the voltage difference between two points is zero, there can be no net current between the two points. In other words, charges will flow (as electrical current) through a conductor by applying a voltage across two separated points. The amount of current that flows when voltage is applied is known as amperage.

**ANALOGY:** *If you have a garden hose and you are trying to push water through it (voltage), you can push as much as you want, but there is a limited amount of flow because the hose is a particular size. Increase the size [of the conduit] and you can increase the amount of flow (amperage).*

Voltage (a.k.a., electric potential difference, electric pressure, electric tension, or electromotive force) is the difference in electric potential energy between two points per unit electric charge. Therein, electrical potential energy is the energy that a charge has when it is at a certain location in an electric field. Each potential difference in a system describes the system's ability to do work. The voltage between two points is equal to the work done per unit of charge against a static electric field to move the test charge between two points and is measured in units of volts (joule per coulomb). A voltage may represent either a source of energy (electromotive force), or lost, used, or stored energy (potential drop). An electromotive force (EMF) is a force that causes electrons (electricity) to flow in a conductor. In a power system, voltage is a measure of the "strength" of an electrical supply.

**NOTE:** *The higher the voltage, the stronger the electric field.*

Voltage is similar to pressure -- the presence of a potential difference (pressure gradient) drives the electric current, just as the pressure of a pump drives a flow of water. Hence, voltage could be called electrical pressure.

Voltage exists if charges are moving [through] a distance. It is sometimes said that a voltage may exist even when no current is flowing. For example, a disconnected battery has a voltage between its terminals, but because it is disconnected there is no current between the terminals. However, to determine the presence of voltage one must first establish a current; current is required to get/measure voltage. Thus, it is somewhat inaccurate to state that voltage drives the current. From this view, it could be said that a potential difference does not "drive" the current; instead, coulomb force and/or energy is what drives the current. Therein, coulomb force (on a charge) and/or energy can be directly calculated from the potential difference.

**NOTE:** *Besides superconductors, which can maintain eddy currents flowing in rings with no externally supplied voltage, there can't be currents without voltages, because if there is a current there is a charge moving due to the presence of an electromotive force.*

Unless there is a difference in charge between two points, no field can be established, and hence there is no potential.

The electric charges will gather at the two poles. Positive charges at the cathode and negative charges at the anode. If the two electrodes are not connected by an external conductor they will not be able to leave the surface of the electrodes and they simply accumulate over there producing an open circuit voltage. As soon as the two electrodes are connected by a conductor the charges will flow by the forces of the electric field in the appropriate direction. If the connecting wire has no resistance or almost zero resistance then it will be a short circuit and a huge current will flow only limited by the internal resistance of the battery. If the electrodes are connected by a conductor through a resistance then the current will be limited according to the Ohm's law.

- current (I) = V / (R+r)
- where I is the Current, V is the voltage between the electrodes, R is the external resistance and r is the internal resistance of the battery.

In a battery, the electric field is maintained by the chemical reaction. When connected to a conductor, the charges move through the conductor since it is the path of least resistance.

**ANALOGY:** *The flow of water through a pipe does depends principally on the pressure difference at the two ends. The flow of charge through a conductor does depends principally upon the charge (pressure) difference at the two ends. It is the pressure (voltage) difference between the two endpoints matters that is of principal significance.*

If electrical work can be done (i.e., there is electrical power), then there is a voltage -- voltage has units of J/C (joules per coulomb). Voltage is expressed and calculated as the difference in electrical energy between two points [in space] per unit electric charge. Voltage is electric [potential] energy per unit charge, measured in joules per coulomb ( = volts).

- Voltage (V) = *energy* in joules (J) / *charge* in coulombs (C)
- Voltage (V) = joule (J) / coulomb (C)

- 1V = 1J/C
- Potential = the *ability* to do work.
- Electric potential is the ability to do [electrical] work per electric unit.
- similarly, the electric field is electric force per charge. E = f/q \ f=qE

Notes on voltage:

1. The word "drop" in the term 'voltage drop', comes from the analogy of current being the flow of water and each difference in height that makes the water flow is a drop, a voltage difference. So voltage drop is just a difference in voltage across a component that makes a current flow.
2. A "voltage difference" is the electric potential difference between two points on the circuit, and the current flows in a direction in which the potential difference can be minimized.
3. The second of Kirchhoff's laws tell us that the sum of all the voltages in a circuit must be zero (so, in a simple circuit, the initial voltage from the battery minus all the voltage drops from all the resistors is zero).

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# TABLES

**Table 23.** **Life Support > Power > Primary**: *Primary energy "generating" sources accompanied by a description of where the energy is derived from.*

| Primary Energy Generating Sources | | | |
|---|---|---|---|
| **Energy source generators** | **Energy from / transport by** | **Conversion process** | **Power depends on** (Conversion rate of generator and ...) |
| Geothermal (thermal) | Heat from inside the earth | Turbine | Temperature |
| Wind (atmospheric current) | Atmospheric currents derived from the earth's rotation and exposure to radiant energy from the sun | Turbine | Wind speed ~$v^3$ |
| Wave (water + wind) | Wind waves in a body of water | Wave device / Turbine | Wave height ($H^2$) and wave period |
| Tidal (water + solar system gravity/electrostatic force) | Daily cyclical movement of a body of water | Tidal device / Turbine | Height squared ($H^2$) and flow speed (cubic) |
| Hydro (water + planetary gravity/electrostatic force) | Uni-directional flowing movement of water | Dam / Turbine | Height squared ($H^2$) and flow speed (cubic) |
| Hydrolysis (water) | Chemical reaction of an organic molecule breaking down in water | Reactor | Delocalization across the C9-N15 bond and steric effects |
| Solar (radiation) | Solar non-thermal radiation from the sun | Photovoltaic | ~ annual radiation |
| Solar (thermal) | Solar thermal radiation from the sun | Collector | ~ annual radiation |
| Animate (animal) | Animal movement | Animal movement | Species, sex, and strength/health of organism |
| Coal (solid hydrocarbon) | Combustion of organic rocks | Combustion | Heat content of the fuel |
| Oil (liquid hydrocarbon) | Combustion of organic liquids | Combustion | Heat content of the fuel |
| Gas (gas hydrocarbon; a.k.a., "natural gas") | Combustion of organic gases | Combustion | Heat content of the fuel |
| Biomass (plants & animal waste) | Combustion of plant-derived materials | Combustion | Heat content of the fuel |
| Nuclear (atomic) | Heat from fission of large atoms or fusion of small atoms | Reactor | Temperature |

**Table 24.** **Life Support > Power > Energy Conversion**: *Example conversions with efficiency notation.*

| Energy Conversions | | | |
|---|---|---|---|
| **Converter** | **Form Of Input Energy** | **Form Of Output Energy** | **Efficiency** |
| petrol engine | chemical | mechanical | η |
| diesel engine | chemical | mechanical | η |
| electric motor | electrical | mechanical | η |
| boiler & turbine | thermal | mechanical | η |
| hydraulic pump | mechanical | potential | η |
| hydro turbine | potential | mechanical | η |
| hydro turbine | mechanical | electrical | η |
| generator | mechanical | electrical | η |
| battery | chemical | electrical | η |
| solar cell | radiation | electrical | η |
| solar collector | radiation | thermal | η |
| electric lamp | electrical | light | η |
| waterpump | mechanical | potential | η |
| water heater | electrical | thermal | η |
| gas stove | chemical | thermal | η |

# TABLES

**Table 25.** Life Support > Power > Energy Type *Elaborated list of energy forms and energy types with accompanying descriptions. Note that wave energies (such as radiant or sound energy), kinetic energy, and rest energy are each greater than or equal to zero because they are measured in comparison to a base state of zero energy: "no wave", "no motion", and "no inertia", respectively.*

| Types of energy | Description of energy Type |
|---|---|
| **Kinetic** | (≥0), that of the motion of a body. |
| **Potential** | (≥0), that of the position of a body relative to the zero plane of inertia of that body. |
| Forms of Energy | Description of energy Form |
| **Mechanical** | The sum of (usually macroscopic) kinetic and potential energies. The energy of motion (every moving object). Usually visible. |
| *> Mechanical [wave]* | (≥0), a form of mechanical energy propagated by a material's oscillations -- 'acoustic energy' is called sound. |
| **Chemical** | That contained in molecules (molecular bonds). |
| **Electric** | That from electric fields. |
| **Magnetic** | That from magnetic fields. |
| **Electromagnetic** | (≥0), that of electromagnetic radiation including light -- 'optical energy' is called light; 'radiant energy' carried by light. |
| **Nuclear** | That of binding nucleons to form the atomic nucleus. |
| *> Ionization* | That of binding an electron to its atom or molecule. |
| **Thermal** | A microscopic, disordered equivalent of mechanical energy. Expressed as heat. |
| *> Heat* | (≥0), the microscopic motion of molecules. An amount of thermal energy being transferred (in a given process) in the direction of decreasing temperature -- heat is a form of energy; temperature is a measurement of heat. |
| Forms of power *(Thermodynamically, only 2 forms of power)* | Description of power type |
| **Mechanical power (work[ing])** | The rate at which "work" is done. Mechanical energy used per unit time. |
| **Thermal power (heat[ing])** | The rate at energy is transferred via heat. Thermal power is the measure of thermal energy used per unit time. It is the rate of heat transfer or heat flow rate. |

**Table 26.** Life Support > Power > Energy Kinetic*: Forms of kinetic energy (classified by type of motion).*

| Kinetic Energy Forms | Motion | Examples And Subtypes Of This Form Of Energy |
|---|---|---|
| **Mechanical [motion]** | motion of macroscopic objects/substances; | machines, muscles, projectiles, wind, flowing water, mechanical waves, sound (acoustic, longitudinal waves), ... |
| **Thermal [motion]** | vibratory motion (vibration) of microscopic particles of matter (molecules, atoms, ions) -- | heat, fire, geothermal, ... |
| **Electrical [motion]** | flow of charges (electrons, protons, ions) | electric current, AC and DC circuits, ... |
| **Electromagnetic [motion]** | disturbance propagating through electric and magnetic fields or the motion of photons | the electromagnetic spectrum [banded into radio waves, microwaves, x-rays, ...] |

**Table 27.** Life Support > Power > Energy Potential*: Forms of potential energy (classified by type of mathematical field).*

| Potential energy forms "Forces" | Quantity in field | Examples and subtypes of this form of energy |
|---|---|---|
| Gravitational [force field] | mass | roller coaster, waterwheel, hydroelectric reservoir, ... |
| Electromagnetic [force field] | charge | electric, magnetic, chemical, elastic, ... |
| Strong nuclear [force field] | color charge | nuclear reactors, nuclear weapons, ... |
| Weak nuclear [force field] | lepton number | radioactive decay, mass change, ... |
| Chemical [force field] | ion[ic charge] - atoms and molecules separated into ions (ionic bonds) | endothermic and exothermic reactions |

# TABLES

**Table 28.** **Life Support > Power > Energy Flow**: *Energy flow breakdown examples.*

| Energy Flow Breakdown Examples | | |
|---|---|---|
| **Energy Stage** | **Technology Used** | **Example of objects in stage of flow** |
| Primary | - | coal, wood, hydro, dung, oil, etc |
| - | Conversion | power plant, kiln, refinery, digester |
| Secondary | - | refined oil, electricity, biogas |
| - | Transport/Transmission | carriage, pipes, wires |
| Final | - | diesel oil, charcoal, electricity, biogas |
| - | Conversion | motors, heaters, stoves |
| Useful | - | heat, shaft power |

**Table 30.** **Life Support > Power > Energy Transformation**: *Energy transformation: coal fired power plant example.*

| Coal-Fired Power Plant Example Of Energy Transformations | |
|---|---|
| **Energy Transformation** | **Description Of Transformation** |
| Chemical energy | coal converted to thermal energy in the exhaust gases of combustion |
| Thermal energy | the exhaust gases converted into thermal energy of steam through the heat exchanger |
| Thermal energy | steam converted to mechanical energy in the turbine |
| Mechanical energy | turbine motion converted to electrical energy by the generator, which is the ultimate output |
| In such a system, the first and fourth step are highly efficient, but the second and third steps are less efficient. The most efficient gas-fired electrical power stations can achieve 50% conversion efficiency. Oil- and coal-fired stations achieve less. | |

**Table 29.** **Life Support > Power > Energy Transformation**: *Energy transformation types and descriptions.*

| Energy Type | Description of Energy Transformation |
|---|---|
| Thermoelectric | Heat > electric energy |
| Geothermal power | Heat > electric energy |
| Heat engine | Heat > mechanical energy |
| Ocean thermal power | Heat > electric energy |
| Hydroelectric dams | Gravitational potential energy > electric energy |
| Electric generator | Kinetic energy or mechanical work > electric energy |
| Fuel cells | Chemical energy > electric energy |
| Battery | Chemical energy > electric energy |
| Fire | Chemical energy > heat and light |
| Wave power | Mechanical energy > electric energy |
| Wind power | Mechanical energy > electric or mechanical energy |
| Piezoelectrics | Mechanical ("strain") energy > electric energy |
| Acoustoelectrics | Mechanical ("acoustic/sound") energy > electric energy |
| Friction | Kinetic energy > heat |
| Heater | Electric energy > heat |

# TABLES

**Table 31.** <u>**Life Support > Power > Physics**</u>*: Physics > Electrostatics > Charges. Opposite charges attract. When there is an equal # of opposite charges there is "balance", giving the atomic system an overall neutral (zero) charge.*

| Name | Signifier | Unit | Relationship |
|---|---|---|---|
| Proton | + (positive) | charge | |
| Electron | - (negative) | charge | |
| **Name** | **Signifier** | **Unit** | **Relationship** |
| Positive charge | | Cations | Possesses more protons than electrons; higher electric potential |
| Negative charge | | Anions | Possesses more electrons than protons; lower electric potential |
| Uncharged / electrically neutral | | Neutrino | Equal numbers of protons and electrons; no net electrical charge; equipotential throughout |

**Table 32.** <u>**Life Support > Power > Physics Energy**</u>*: This table depicts the different conceptualizations of energy, the incorrect and correct scientific conceptions, and their information analogues.*

| Conception | Incorrect idea | Scientific concept | Information Analogue |
|---|---|---|---|
| Energy as agent | Energy causes things to happen. It makes an action happen and can be stored inside a physical thing. | Energy does not cause events to happen. However, when events happen, there is always a transfer of energy between interacting physical things. | Information does not cause events to happen. However, when events happen, there is always a transfer of information between interacting physical things. |
| Energy as action | Energy is an action or activity, like burning, bubbling, running, and bouncing. | Actions are visible experiences that energy is transferring. | Actions are visible experiences that information is transferring. |
| Energy as form | Energy has multiple forms depending upon its location in the physical world. | Energy does not have different forms or location in the physical world, but there are different types (or modes) of energy transfer - energy is transferred within and between "carriers" in different ways. | Information does not have different forms or location in the physical world, but there are different types (or modes) of information transfer - information is transferred within and between "carriers" in different ways. |

**Table 33.** <u>**Life Support > Power > Prime**</u>*: Primer movers as types of work and power.*

| Prime mover | Type of work | Type of power |
|---|---|---|
| Force | Mechanical work | Mechanical power |
| Pressure | Fluid work | Fluid power |
| Voltage | Electrical work | Electric power |

# TABLES

**Table 34.** Life Support > Power > Types: *Power types and their properties.*

| | Power Type | | | |
|---|---|---|---|---|
| **Property** | **Electrical** | **Mechanical** | **Pneumatic** | **Hydraulic** |
| **Energy transition** | Turbine | IC engines, electrical energy is used to drive motors | Electrical energy is used to drive compressors and other equipment | IC engines, electric motor, air turbine used to drive hydraulic pump |
| **Medium** | Energy is transferred wirelessly or wired | Energy is transferred through levers, gears, and shafts | Compressed air/gas in pipes and hoses | Pressurized liquid in pipes and hoses |
| **Energy storage** | Batteries | Variable frequency drives | Reservoir, air tank, pneumatic valves | Accumulators, hydraulic valves |
| **Transmitters** | Wireless and wired transmitters | Transmitted through mechanical components like levers, gears, cams, screws, etc. | Transmitted through pneumatic cylinders, rotary devices, and rotary actuators | Transmitted through hydralic |
| **Leakage** | Stray voltage and ground currents | N/A | Contamination relative to gas used | Contamination relative to liquid used |
| **Energy transmission/ distribution** | Unlimited with power loss | Short distance | Up to 100m<br>flow rate v = 2-6 m/s<br>signal speed up to 1000 m/s | Up to 1000m<br>flow rate v = 20-40 m/s<br>signal speed 20-40 m/s |
| **Operating speed** | | | v = 0.5 m/s | v = 1.5 m/s |
| **Power supply input** | Low | Variable | High | Very high |

**Table 35.** Life Support > Power > Circuit/Ground: *Grounding system comparison table. In the 1999 Edition of the NEC, impedance grounded systems were considered to be ungrounded systems.*

| Grounded Systems | | | | |
|---|---|---|---|---|
| **NEC reference** | **Required grounded systems** | **Pros** | **Cons** | **Use** |
| Article 250.20(A) | (Solidly grounded) ac systems less than 50V | Greater safety<br>Prevents insulation damage from over-voltages from line-to-ground faults during resonant ground faults<br>Easy detection; faster mean time to repair | Higher fault levels; validate circuit breakers rated for bolted fault | Equipment such as window shades, BAS, and some fire alarm systems |
| Article 250.20(B) | (Solidly grounded) ac systems 50V to 1,000V | | | Residential single-phase 120V/240V<br>Commercial and light industrial facilities with 3-phase, 480V:208 Y/120Vsystems |
| Article 250.20(C) | (Solidly grounded) ac systems 1,000V and above | | | Medium-voltage transmission lines |
| Article 250.20(D) | Impedence grounded systems | Provides operational continuity during a line-to-ground fault; equipment doesn't shut down<br>Introduction of the resistance can control the higher fault levels present in the solidly grounded system | Must be engineered to match facility capacitance | Industrial plants; mills<br>Large data centers<br>Medium-voltage cables |
| **Ungrounded Systems** | | | | |
| **NEC reference** | **Allowed ungrounded systems** | **Pros** | **Cons** | **Use** |
| Article 250.21(A) | General: systems deemed to be a higher safety risk to automatic shut down, suich as blast furnaces | Provides operational continuity during a line-to-ground fault. Equipment doesn't shut down<br>Cheaper to install | Primary line-to-ground transietns are passed through transfomers unattenuated | Steel manufacturing<br>Industrial plants<br>Pulp and paper |

# TABLES

**Table 36.** Life Support > Power > Mechanical Electric: *Difference Between Induction and Synchronous motors and generators is explained with the help of various factors.*

| Basis Of Difference | Synchronous Motor | Induction Motor (Asynchronous Motor) | Synchronous Generator (Alternator) | Induction Generator (Asynchronous Generator) |
|---|---|---|---|---|
| **Type of excitation** | A synchronous motor is a doubly excited machine. | An induction motor is a single excited machine. | - | - |
| **Frequency** | - | - | Frequency is determined by the rotational speed of the generator's shaft -- faster rotation of the shaft generates a higher frequency. | - |
| **Supply system** | Its armature winding is energized from an AC source and its field winding from a DC source. | Its stator winding is energized from an AC source. | - | - |
| **Speed** | It always runs at synchronous speed. The speed is independent of load. Synchronous motors are used where constant running speed is the governing factor. In a synchronous motor the rotor and magnetic field rotate at the same speed. | If the load increases, the speed of the induction motor decreases. It is always less than the synchronous speed. The operation of the induction motor depends on relative motion as the difference in speed between the rotor and the rotating magnetic field. This relative motion induces and EMF in the rotor. | - | - |
| **Starting** | It is not self starting. It has to be run up to synchronous speed by any means before it can be synchronized to AC supply. | Induction motor has self starting torque. | - | Usually not started without an energized connection to the electric power grid, unless they are designed to work with a battery bank energy storage system. |
| **Operation** | A synchronous motor can be operated with lagging and leading power by changing its excitation. | An induction motor operates only at a lagging power factor. At high loads the power factor becomes very poor. | - | - |
| **Usage** | It can be used for power factor correction in addition to supplying torque to drive mechanical loads. | An induction motor is used for driving mechanical loads only. | - | - |
| **Efficiency** | It is more efficient than an induction motor of the same output and voltage rating. | Its efficiency is lesser than that of the synchronous motor of the same output and the voltage rating. | - | - |

**Table 37.** Life Support > Power > Solar Electric: *Direct solar to electric conversion types.*

| No | Types | Characteristics |
|---|---|---|
| **1** | Photoemissive | Light interacting with a cathode causes electrons to be emitted from the cathode surface. |
| **2** | Photoconductive | The resistance of a material is changed when it is illuminated. |
| **3** | Photovoltaic | Light interacting with the junction of two exposed substances generates an output voltage proportional to light intensity. |
| **4** | Photomagnetic | Light interacting with a dynamic magnetic field causes a voltage. |
| **5** | Photogalvanic | Light interacting with a material produces a chemical action that causes voltage. |
| **6** | Photoelectrochemical | Light interacting with a material produces a chemical action that causes voltage. |
| **7** | Bio-photoelectrochemical | Light interacting with an organic material produces a chemical action that causes a voltage. |

# TABLES

**Table 38.** Life Support > Power > Storage*: Typical values of specific energy and energy density.*

| Common storage materials (fuels) | | | | |
|---|---|---|---|---|
| **Energy source** | **Energy reaction type (to release)** | **Density Kg/m3** | **Specific energy mj/kg** | **Energy density Mj/m3** |
| Coal (anthracite) | Chemical | 1350 | -27 | -36,450 |
| Coal (lignite) | Chemical | 801 | -15 | -12,015 |
| Wood | Chemical | 600 | -15 | -9,000 |
| **Common storage hydrocarbons (fuel alkanes)** | | | | |
| **Hydrocarbon (alkane) storage** | **Energy reaction type (to release)** | **Density Kg/m3** | **Specific energy mj/kg** | **Energy density Mj/m3** |
| Methane (ch4) | Chemical | 423 | -55.5 | -23,529 |
| Ethane (c2h6) | Chemical | 545 | -51.8 | -28,246 |
| Propane (c3h8) | Chemical | 585 | -50.3 | -29,449 |
| Butane (c4h10) | Chemical | 601 | -49.5 | -29,729 |
| Pentane (c5h12) | Chemical | 621 | -48.7 | -30,223 |
| Hexane (c6h14) | Chemical | 655 | -48.3 | -31,633 |
| Heptane (c7h16) | Chemical | 680 | -48.1 | -32,690 |
| Octane (c8h16) | Chemical | 698 | -47.9 | -33,433 |
| Decane (c10h22; kerosene) | | | | |
| **Common storage alcohols (fuels)** | | | | |
| **Alcohol storage** | **Energy reaction type (to release)** | **Density Kg/m3** | **Specific energy Mj/kg** | **Energy density Mj/m3** |
| Methanol (ch3oh) | Chemical | 787 | -22.7 | -17,855 |
| Ethanol (ch3ch2oh) | Chemical | 785 | -29.7 | -23,278 |
| 1-Propanol (ch3(ch2)2oh) | Chemical | 800 | -33.6 | -26,902 |
| **Common storage devices (battery-like devices)** | | | | |
| **Device storage** | **Energy reaction type (to release)** | **Density Kg/m3** | **Specific energy Mj/kg** | **Energy density Mj/m3** |
| Lithium battery (non-rechargeable) | Electrochemical | | 1.8 | 4.32 |
| Lithium-ion battery (rechargeable) | Electrochemical | | 0.36–0.875 | 0.9-2.63 |
| Alkaline battery | Electrochemical | | 0.5 | 1.3 |
| Lead-acid battery | Electrochemical | | 0.17 | 0.56 |
| Nickel-metal hydride battery | Electrochemical | | 0.288 | 0.504-1.08 |
| Supercapacitor (EDLC) | Electrical (electrostatic) | | 0.01-0.036 | 0.06-0.05 |

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**Table 39.** Life Support > Power > Storage: *Functional differences between a battery and capacitor.*

| Function | Capacitor | Battery |
|---|---|---|
| **Charge time** | 1-10 sec | 10-60min |
| **Cycle life** | 1 million or 30,000 h | 500 and higher |
| **Cell voltage** | 2.3 to 2.75V | 3.6-3.7V |
| **Specific energy (Wh/kg)** | 5 (typical) | 100-200 |
| **Specific power (W/kg)** | Up to 10,000 | 1,000-3,000 |
| **Service life (in place) in years** | 10-15 years | 5-10 years |
| **Charge temperature (between two values)** | -40 to 65˚C | 0 to 45˚C |
| **Discharge temperature (between two values)** | -40 to 65˚C | -20 to 60˚C |

**Table 40.** Life Support > Power > Storage: *Overview of sensible, latent, and thermochemical processes using salt.*

| Temperature level | Salt type | Test type |
|---|---|---|
| <0 ˚C | Water-salt mixtures | PCM slurry |
| 0-100 ˚C | Melting of salt hydrates in crystallization water | PCM |
| 40-300 ˚C | Dehydration of salt hydrates | TCS |
| 40-150 ˚C | Absorption in concentrated salt solutions | TCS |
| 120-500 ˚C | Solid–liquid conversion in anhydrous salts | PCM |
| 100-800 ˚C | Anhydrous molten salts | Sensible |
| 100-800 ˚C | Anhydrous solid salts | Sensible |
| 100-800 ˚C | Solid–solid conversion in anhydrous salts | PCM |

**Table 41.** Life Support > Power > Storage: *Electrochemical capacitor types.*

| Electrochemical capacitor type | Symmetric aqueous | Symmetric organic | Asymmetric aqueous | Asymmetric organic |
|---|---|---|---|---|
| Energy density | | | | |
| Power performance | | | | |
| Self discharge rate | | | | |
| Low-temp discharge | | | | |
| Packaging | | | | |
| Voltage balance | | | | |
| Cell voltage | | | | |
| Operating temperature limits | | | | |

**Table 42.** Life Support > Power > Conversion: *Energy "transformation".*

| **Energy Resources** | >>> | **Technological Equipment** | >>> | **Usable Energy** |
|---|---|---|---|---|
| For example, moving water, biomass, wind, sunshine, the Earth) | | For example, hydroelectric and wind turbines, stoves and furnaces, photovoltaic panels) | | For example, electricity, steam, heat, biofuels |

# TABLES

**Table 43.** Life Support > Power > Load*: Energy requirements of a device/load.*

| Device/load (examples) | Instantaneous power requirement/ demand/usage "rating" P=E/t | Energy requirement/usage: | | |
|---|---|---|---|---|
| | | If run for 1 second (energy consumed) | If run for 1 minute (energy consumed) | If run for 1 hour (energy consumed) |
| 60W light bulb | 60w<br>60J/s | 60w<br>60J/s | | |
| Laptop | 40-80w<br>40J/s - 80J/s | 0-80w<br>40J/s - 80J/s | | |

**Table 44.** Life Support > Power > Load*: Example electrical energy demand profile.*

| Name and amount of device | x | Device's required POWER (rate of demand in 1 minute in Watts) | x | TIME the device is used (in hours) | = | Total energy consumption of device (in watt-hours) | Power usage in time |
|---|---|---|---|---|---|---|---|
| 1 Light bulb | x | 100 Watts (1x100 = 100W or .1kW) | x | 10 hours | = | 1,000 Watt-hours or 1kWh | 1kW used in 10 hours |
| 10 Light bulbs | x | 100 Watts (10x100 = 1000W or 1kW) | x | 1 hour | = | 1,000 Watt-hours or 1kWh | 1kW used in 1 hour; 10 times more demand than 1 light bulb over 10 hours |

**Table 45.** Life Support > Power > Conversion Electric*: Electric power conversion classified according to whether the input and output are alternating current (AC) or direct current (DC). A power converter is an electrical or electro-mechanical device for converting electrical energy.*

| Electric power conversion | | | |
|---|---|---|---|
| DC to DC | DC to AC | AC to DC | AC to AC |
| Dc-to-DC converter | Inverter | Rectifier | Transformer / autotransformer |
| Voltage regulator | | Mains power supply unit (PSU) | Voltage converter |
| Linear regulator | | Switched-mode power supply | Voltage regulator |
| | | | Cycloconverter |
| | | | Variable-frequency transformer |

**Table 46.** Life Support > Power > Electricity*: AC and DC device differences.*

| AC Devices (~1950) | DC Devices (~2000) |
|---|---|
| Electric typewriters and adding machines | Computing and printing equipment |
| Teleprinter | Telecommunication systems |
| Early fluorescent lighting | Advanced fluorescent lighting with electronic ballast, gas discharge lighting, LEDs |
| Radios, early televisions | HDTV's, CD Players, smartphones |
| Record players | CD players and game consoles |
| Electric ovens | Microwave ovens |
| Fans and furnaces | Electronically controlled HVAC |

# **Life Support:** Medical Service System

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**Acceptance Event:** *Project coordinator acceptance*

**Last Working Integration Point:** *Project coordinator integration*

**Keywords:** medical, health service, first response, first aid, lifeform restoration

## Abstract

Human life, like all biological life, is composed of consciousness animating a biological life [organism] form. In this dimension of reality, given the technologies available, the human biological form can be injured and will not become whole again instantly [and through mental thought alone]. Injury and dis-ease can degrade the quality of life of an individual at the same time degrading the quality of life of those in interrelationship with the injured and/or intensely suffering individual. Even in a community-type society, it is still possible for social conflict to emerge such that medical services may need to include individuals trained to stop violence. A community-type society perceives violence as an accident in society to be individually recovered from and socially restored to a dynamic where the violence is unlikely to present itself in the future. Violence is a medical issue, as are physical injuries, skills and knowledge are similar in some regards and different in others. Here, there are no police-type roles as seen in the market-State. Issues that cause harm and trigger life-oriented restorative processes and protocols are likely to be handled different depending on what values (on a values circumplex) are being actively encoded within that society. Some values are more likely to engage punitive-type behaviors; whereas other values are more likely to engage restorative-type behaviors. A medical service is, by definition, of the restorative type. A medical service provides the capability of dealing with medical problems. A medical service is, in part, a disaster recovery plan for life forms. A medical system involves medical knowledge, medical procedures, and medical drugs, but healthy well-being is primarily achieved by facilitating individual happiness with respect to whatever might have distressed them into illness. Thus, good health-care places enormous emphasis on dealing with the cause of illness, as opposed to remedial treatment of the symptoms. Humans can be injured physically and mentally, together.

## Graphical Abstract

Image Not Yet Associated

# 1 Introduction

In its scientific context, medicine is the science of creating and restoring healthy functioning and facilitation of biological resilience. Pain means something is wrong; pain has a function. Pain is a signal of something, often, tension. The more a source of pain continues to generate the pain, the more disease there will be. There are emergency cases of pain, such as a vehicular accident where humans are physically injured, and there are cases of pain, such as overeating and arthritis. Some medical problems are life-threatening, and others are not. Because there are life-threatening medical problems, there is the necessity for a medical service to be continuously operative and available to respond. Some medical procedures can be carried out remotely, but others require structures and technologies positioned at fixed locations.

A proper medical system restores the individual and the social to wholeness, together. Science and ancestral wisdom can be used together to address the whole personal, and their experience throughout time.

Human performance can be compromised by many aspects of a task, including:

1. Body posture
2. Physical and biomedical composition
3. Sleep restoration (awakeness)

## 1.1 *Disease and the environment*

Dis-ease can come from intentional re-arrangement of the environment. For instance, there is no moderation when humans are surrounded by, and consume, hyper palatable, which they are wired to eat more of. It is basic biological wiring to eat the available and to overeat on highly palatable foods (especially hyper-palatable food that is also nutrient poor). In general someone where to make their meals enjoyable, full of real food, but not over the top palatable (i.e., to the point that overeating becomes more likely). In place of this type of food, some societal arrangement make food with hyper-palatability and low nutrients more accessible, thus leading to behaviors that generate dis-ease states within the environment, because real signals are being obstructed. Humans are designed to crave substances that are good for them (i.e., that the body needs). But when food service systems are designed outside of nature, then the bodies craving mechanism (taste) can quickly become misinformed and aberrant such that people crave foods and food-like substance that do not satisfactorily meet their bodies needs.

## 1.2 *Medical technology inventory*

Medical technology and inventory
Team coordination/control protocols

1. Emergency medical response
   - A. Pharmaceuticals
   - B. Decision support (for humans)
   - C. Semi-automated systems
   - D. Fully-automated systems
   - E. Medical studies
   - F. Operations
2. Equipment
   - A. Laboratory diagnostic equipment
     1. Clinical chemistry
     2. Hematology
     3. Pathology
     4. Microbiology
     5. Hematology, and endocrinology
   - B. Imaging diagnostic equipment
     1. Radiographic
     2. Magnetic resonance
     3. Ultrasound
   - C. Minimally invasive or non-invasive monitors
     1. Electrocardiograph, blood pressure, oxygen saturation, etc.
     2. Equipment and protocols to provide rescue, resuscitation, stabilization, and transport.
   - D. Surgery
     1. Microsurgery/micro-therapeutics equipment and protocols.
     2. Specialized surgery
   - E. Fluid therapy systems including infusion pumps, on-site production of fluids, nutritional support, blood, and blood component replacement.
   - F. Methods for biomonitoring
   - G. Medical waste management
   - H. Medical storage systems for samples, pharmaceuticals, and other perishable items.
   - I. Medical energy management

## 1.3 *Medical response*

**INSIGHT:** *People are more likely to heal faster when they have an aesthetic view from their window as opposed to a hospital bed with a view over the parking lot.*

### 1.3.1 The first responders

*A.k.a., The first responding intersystem team.*

Must account for proximity location. Availability of emergency medical equipment and personnel (locationing).

1. Emergency equipment access
2. Emergency personnel access

# **Life Support:** Cultivation Service System

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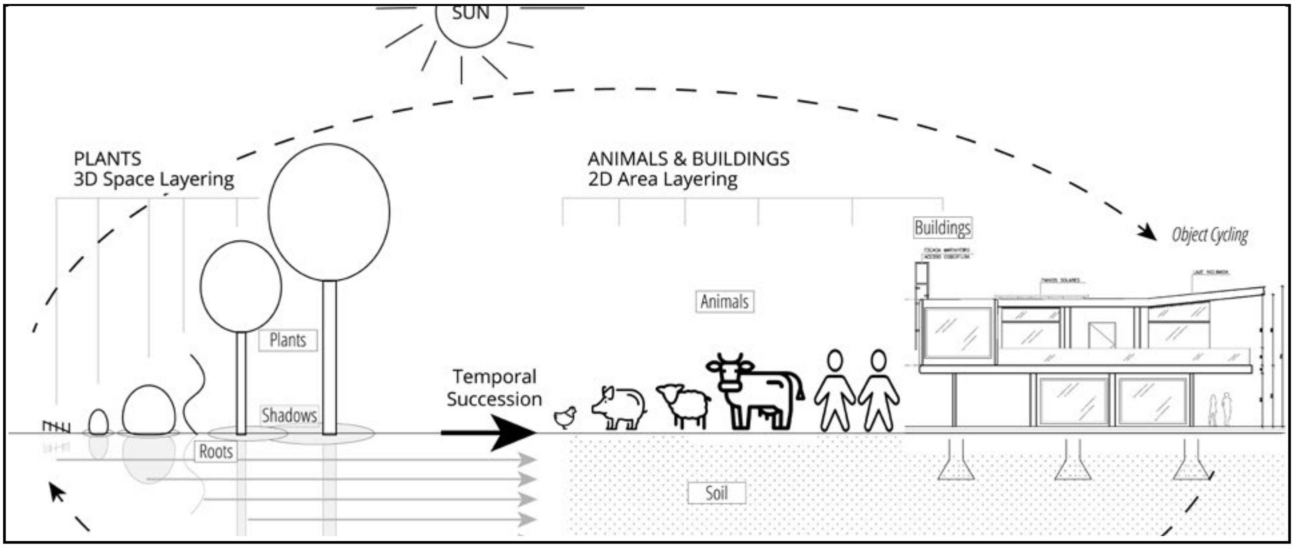
**Last Working Integration Point:** *Project coordinator integration*

**Keywords:** cultivation, biological cultivation, food cultivation, food service, food production, biological nutrition, materials cultivation, biological materials production

## Abstract

Human life, like all biological life, is composed of prior animated life and minerals. Food is organisms (i.e., their bodies), including animal, vegetable, fungal, and bacterial, or it is things that come out of the bodies of these organisms. In nature everything is food for something else. It is possible to produce a service that cultivates food and other useful materials from organisms (e.g., textiles). Here, the mimicking of natural patterns is often the optimal strategy. Technology can be used to provide means and timeframes for cultivation that are impossible without the technology (e.g., hydroponics). Food has flavor. Food can, or cannot, be appropriate in nutrient content for the consuming organism. Textile and food products are the output of the cultivation service. Some foods are processed prior to distribution and others are not. In a community-type society, individuals can prepare and cook their own food, or they can rely on automated services. Similarly, material cultivation system may rely on human effort (e.g., such as personal gardens), others may involve a combination of human team and machine interaction, and even others may be fully automated operations. In general, the cultivation service involves the cultivation of resources from other organisms. There is a second dimension to the cultivation service, mining. Mining isn't really a form of cultivation because it doesn't involve the cultivation of living organisms. However, it does involve the "cultivation" of minerals (including hydrocarbons) from the earth. Hence, the cultivation service involves both the cultivation of other organisms and the extraction (mining) of compounds from the earth. Mining may include the collection of matter in its various forms (e.g., gaseous, liquid, and solid). Humans are mutually dependent upon other organisms in their environment. These other organisms can be selected and cultivated to facilitate human fulfillment and ecological flourishing.

## Graphical Abstract



# 1 Life cultivation

Life cultivation is the act of caring for, raising, and harvesting life and life's organisms. Farming is growing, caring for, and harvesting plants and animals. Harvesting means to take the life of, and then use, some organism. The wise tending and cultivation of nature will lead to greater fulfillment and abundance of organisms in nature. Through habitat service system design (the master planning of cities), cities may become unique ecosystems that facilitate the caretaking of the total planetary ecological system, produce food, material resources, and beauty. By highly controlling and coordinating the flow of resources within the city (habitat service system), it is possible to utilize the principles of natural systems in to cycle and regenerate the continuous flow of resources upon the planet for global human fulfillment. It is possible to grow food embedded within the living habitat service system environment. It is possible to plan for the cultivation of organismal and mineral resources requirements for materials, for food, and for beauty around cities.

## *1.1 Organisms for cultivation*

On earth, the kingdom of organism has two views:

1. 4 Kingdoms (simple view):
   - A. Animals
   - B. Plants
   - C. Fungi
   - D. Bacteria
2. 6 Kingdoms (biological sciences):
   - A. Animals
   - B. Plants
   - C. Fungi
   - D. Eubacteria
   - E. Archaebacteria
   - F. Protista

The systematic cultivation of organisms for a habitat service system includes, but may not be limited to, the following types of organisms:

1. Animal culturing (heteroroph cultivation)
   - A. Pasture (normal) grazing *(and life placement in general)*
   - B. Pasture (woodland) grazing *(and life placement in general)*
   - C. Wilderness grazing *(and life placement in general)*
   - D. Grazing internal habitat service system land *(short duration placement, often to provide an ecological cleaning service)*
2. Plant culturing (horticulture, autotroph cultivation)
   - A. Annual culturing
   - B. Perennial culturing
   - C. Agroforestry
   - D. Hydroponics
   - E. Floriculture (flower farming), is a discipline of horticulture concerned with the cultivation of flowering plants.
3. Agriculture
   - A. Mono-agriculture
   - B. Poly-agriculture (mono- and perennial-agriculture)
   - C. Perennial agriculture (permanent agriculture)
4. Aquaculture
   - A. Plant culturing
   - B. Fish culturing
   - C. Amphibian culturing
   - D. Reptile culturing
   - E. Insect culturing
5. Fungal culturing
6. Insect culturing
7. Algae culturing
8. Bacterial culturing *(a secondary function/ requirement)*
9. Artificial photosynthesis *(not a technology yet accessible to humans)*

Note here that agriculture is the practice of cultivating plants and livestock. There are many different types of agricultural names and practices, which sometimes overlap. A farm is an area of land used for growing crops and raising animals.

The fundamental difference between animals and plants is the way animals and plants take in carbon to form organic compounds. Plants are autotrophs, which means that they meet their carbon requirements solely from carbon dioxide in the atmosphere, or from water in the case of water-dwelling plants. Animals, being heterotrophs, are unable to make their own organic molecules and so must take them in ready-made by eating plants and other animals.

### 1.1.1 Essential nutrients

All organisms have a quantity and quality of essential nutrients in order to maintain optimal functioning. Herein, essential means required for life and must be acquired/consumed from outside the body. All organisms have a bio-regional environment, including climate and available resources in which they are likely to thrive and/or survive.

## *1.2 Cultivation service location planning*

Places where food and other materials are cultivated may determine the flow of persons (or other animals) over a landscape. Food could be seen as 'place', and connection to 'place' - eating the landscape someone lives in. For example, fruit trees in an environment may cause humans to use those paths when they intentionally travel within the city to acquire that type of food on any given day at any given hour. The effect of cultivating specific organisms in specific areas may have an effect on human locomotion flow and ought to be accounted for at the level of the habitat service system.

## 1.3 Organismal control and harvesting

*A.k.a., Killing organisms, cultivation environmental control.*

There are several ways of controlling organisms, include:

1. Placing other organisms in the same environment.
2. Some organisms may be controlled with fencing.
3. Some organisms may be controlled by chemicals.
4. Some organisms may be controlled with light alterations.

The ways of killing, culling, and harvesting organisms, include:

1. Chemical "-icides":
   A. Pesticide - to kill insects.
   B. Fungicide - to kill fungi.
   C. Insecticide - to kill insects.
   D. Larvicide - to kill insects.
   E. Herbicide - to kill plants.
   F. Rodenticide - to kill rodents.
   G. Controlled burning - fire.
2. Light cover:
   A. Shade (i.e., cover that blocks out light).
3. Mechanical:
   A. Animals eating organisms.
   B. Crushing.
   C. Projectile.
   D. Human hands or robotic harvester.

### 1.3.1 Bioaccumulation of chemicals

Bioaccumulation means that the organism accumulates a higher concentration of that chemical than is found in the environment in which it lives. Most toxic metals, besides mercury and organic forms of lead, do not bioaccumulate. Something can be toxic and cause health problems without bioaccumulating.

Necessary terms for understanding bioaccumultion include:

1. Biomagnify - at each step along the food web, each tropic level, that chemical will accumulate to a higher concentration.
2. Persistence - how long a chemical remains in the environment.
3. Cycle of dependency - when you have to use more of it, and more chemicals because the pests evolve resistance to it.
4. Global distillation - for persistent organic chemicals, they can undergo long range transport in the atmosphere. Persistent means they persist in the environment for months to decades.

A common type of bioaccumulating chemical pesticide is:

- Organochlorin pesticides are lipophilic (fat soluble), which means they will bioaccumulate and biomagnify.

Identifying sources of bioaccumulation:

1. Identify sources of input of chemical.
2. Was there pesticide use on this land prior?
3. Is there pesticide drift? Drift refers to chemicals drifting or moving because of wind, water, and other forms of motion that migrate pesticides to locations other than originally indented.

Some pesticides remain on the skin and other get incorporated into the tissues. Pesticides cannot always be washed off plants. Some pesticides become systemic, often through uptake by the roots of the plant where up they are delivered throughout the plant by the plants circulatory system.

Pesticide residue has to do with pesticides use, the behavior of the farmer, the physiology of the plants, how quickly the pesticides break down and what are the environmental variables that influence the breakdown:

1. Temperature.
2. Humidity/moisture.
3. What is the concentration of the pesticide.
4. When is the harvesting taking place relative to the prior questions.

## 1.4 Food and materials cultivation

Plants, animals, and fungi, can be cultivated for food and materials.

There two primary reasons for cultivation, a secondary third:

1. Cultivation for food.
2. Cultivation for materials.
3. Aesthetics (for beneficial human feelings)

Therein, there are three types of cultivation (with the third being a combination of the two types):

1. There is cultivation for food.
2. There is cultivation for materials.
3. There is cultivation of some organism for both food and materials.

These different types of cultivation all include and can be sourced from:

1. Animals
2. Plants
3. Fungi
4. Bacteria

Parameters for food include, but may not be limited to:

1. Mass (kg/CD).
2. Water Content (%).
3. Volume (m3/CD).
4. Macronutrient profile (grams).
5. Micronutrient profile (primarily measured in milligrams or even micrograms).

# 2 Cultivation for food

*A.k.a., Food cultivation, nutrition service.*

Every ecosystem has a food chain. Food defines carrying capacity for a species. Any biological organism exists as long as a stream of nutrition (and energy) passes through it in the form of food for animals or electromagnetic radiation in combination with inorganic and organic compounds for plants. Food is lifeforms or things secreted by lifeforms. When humans eat food they eat the tissues of living, or recently living, things. Humans eat life and life eats life, and there is no present way around that. In terms of food, organisms can be bred for flavor, texture, nutrition, and disease resistance. Food is an instructor to the genome, to hormones, and to the microbiome.

> **INSIGHT:** *In the early 21st century, there is a profound separation of human beings from their food that pervades society, and includes its food cultivation, preparation, and consumption practices.*

When an organism eats food it is eating other organisms (their bodies), or it is eating things that come out of other organisms, as well as raw physical elements. Essentially, food is bodies or excretion from bodies (organisms). Life feeds on life. The human organism eats living things or formerly living things, necessarily, to remain alive. Material bodies consume and make use of material substances, and when the amounts are off or the substances are not right, then the conscious organism doesn't feel its best.

> **INSIGHT:** *No matter what you eat, you prey upon other species and make your body from them.*

In a closed ecosystem (the earth) nothing goes to waste; not even waste (e.g., excrement). Excrement is food for other organisms.

## *2.1 Simple food processing*

Humans are an omnivore and through various technologies they are able to render a lot of foods that would otherwise be inedible on the wild landscape, edible. Food processing technologies include both mechanical technologies and chemical technologies. Most wild food has to be processed for someone prior to consumption. Berries and other fruits not so much, but for most staple foods there is a process that must be gone through to render them edible. And, that is one of the unique things about the human animal. Humans can take foods that are otherwise inedible to them, and through technologies they have developed (e.g., mechanical or chemical technologies), they are able to render a lot of material (food) edible, and in some cases, more nutritious. Hence, humanity is no t just an omnivore, but a technological omnivore. Not highly complex technologies like smart phones and 3d printers, but basic technologies like grinding and cooking that humanity has had for millennia. These technologies allow humanity to prepare and consume foods that might otherwise be too tough, unpalatable, or have chemicals in them that need to be deactivated through heat for them to be safely digested.

**QUESTION:** *Why are particular foods cultivated?*

The following are kingdoms/types of life that humans can eat:

1. Insects (entamophagy).
2. Fish and other marine animals.
3. Land animals (meat comes from wild animals and from animal stewardship; meat consumption is a 200000 year practice).
4. Plants.
5. Fungi.
6. Bacteria

## 2.2 Cultivation for flavor and diet

**APHORISM:** *If you don't like what comes out - change what goes in.*

Humans are designed to crave the foods that bring them what they need in terms of micro and macro-nutrient profiles. And, flavor is the mechanism. Since the 1950s, the flavor of whole foods has been getting progressively blander and blander. At the same time, the flavor of the foods that are not good for humans, the processed foods, have been getting more delicious and more irresistible. When flavor is changed, so is the incentive to eat. It is no surprise in the early 21st century that people are eating the wrong foods. It is a perfect storm of making the healthy whole foods taste bland, and the unhealthy foods take delicious and taste such that many people just can't stop eating it. Often, if it wasn't for the added flavoring chemicals people wouldn't eat the substrate. In the early 21st century, a lot of what is called "food" has the appearance (flavor or look) of food, but not the substance of it. (Schatzker, 2015)

**NOTE:** *It was gas chromatography technology in the 1950s that allowed for the analysis of flavor and the creation of flavor technologies.*

It is a human requirement for optimal fulfillment to understand and experience food, which is through flavor. When humans eat, they don't experience nutrition, they experience flavor [as a signaling molecule that moves into a relational database that remembers past signals, and as input into a system that resolves a decision space into an auto-sub-conscious behavior (i.e., a behavior that requires a finitely resolving "will space" to override). Food seeking behavior is all about flavor. Flavor is the language of deliciousness and drive, and it is what makes food seem like, and is experienced as, food.

Those who experience out of control cravings have an relationship between desire and satisfaction (i.e., fulfillment) that is out of proportion. The desire/craving is spiked highly. Flavor is the cue to eat. In animal studies, you can get animals to eat a food they wouldn't normally eat by adding a flavor to it. Our behaviors are realized in a particular environment, a "cued" environment. Flavoring does cause the behavior; it is the imprinting of desire on something. It is what individuals become exposed to that ultimately determines their palate; it is the result of our experiences. Human genetics are realized in a particular environment, and flavor technology is one way in which the environment has changed in the early 21st century.

Flavor is a way of sensing for nutrients. Flavor is the language of nutrition. It is how humans identify where the nutrients are in nature. Flavors tell bodies where and how the nutrition of the physical body is. Flavors are human nutrition memory. The flavor system is a language, it is how humans identify where the nutrients are in nature. Flavor is the language of desire when it comes to food, because food is experienced on the part of consciousness as flavor. Human bodies associate flavor with nutrients. A craving for flavor is, in nature, a craving for something that will bring you the nutrient that you need. Flavor is the way the body remembers and knows where to find nutrients out there in nature. Humans evolved taste buds to find adequate nutrition in the world. The human body uses flavor as a desire/sense to indicate the presence of nutrition and signal to start and stop consuming food. Nutrition comes in a biologocial package with its evolutionary co-factors, with one of the most significant being flavor. (Schatzker, 2015)

Individuals crave foods by taste and flavor, in order to meet their bodies "needed" nutritional requirements. It is possible here to "mess up" this natural sensing-and-drive system by cultivating food without great flavor and an accompanying "quality/rich" nutrient profile. Humans can come to understand food through the same lens by which it is experienced: how it tastes, through taste flavor chemicals. It is relevant to note here that nutrients have no flavor (on their own), with the exception of vitamin C. And yet, the way humans analyze chemicals is with flavor, and subsequent [mental-bodily] sensation.

Modern society has begun adding signaling molecules, These signaling molecules are commonly known as "flavoring" (or, "aroma"),, to foods people would otherwise not eat. In some cases these signaling molecules isolated (e.g., terprnes) and sometimes macro-nutrient (e.g., sugar) form.

In general, individual humans who have not consciously negated (through will and bad information) the following of their flavor system can do a better job at feeding themselves. The human body tells its consciousness what is need as this or that, and therein, our body responds with a food seeking behavior. What individuals "love" about food is the projection of an image (desire of pleasure) that we know is going to bring us nutrition. Individuals know through an accurate sensing of flavor what their body needs. We follow the desire for flavor to identify foods that are nutritious, and the reading of the signaling molecules in the food tells an individuals consciousness us when to stop eating and stop searching. (Schatzker, 2015)

Humans have bodily equipment used to sense flavor, which is evolutionary and in DNA. It is how the body knows what is in its food before the body eats it. The preponderance of human DNA goes to the function of the human nose and tongue. A lot of human DNA is about the sophistication of the organism's senses of smell and taste, because it is important to the organism's daily, continued overall functioning, survival, and replication.

Humans experience taste as a combination of taste and smell. Humans are smelling when they are eating by means of retro-nasal olfaction (smell) receptors. This is a more powerful form of smelling than when someone sniffs through their nostrils. When someone eats, flavor molecules waft up the back of their throat, and move through a hole into the nasal cavity, which then connect with and stimulate olfactory receptors. Humans actually smell while they eat, and it is a process called, "retro-nasal olfaction". And, it is a more stimulating form of smelling than when they sniff through their nostrils. For consciousness, the identity of a food comes primarily from smell. Without smell, a natural food would only have some combination of the five "taste flavors" common to all foods (sweetness, sourness, saltiness, bitterness, umami). In other words, by degree, food would have a bland taste as there would be no signaling information for the sense of smell to identify the uniqueness of the food. It is the aroma (flavor) that gives a food its distinct body-sensation characteristics. And, it is someone's experience of aromatic flavors that allows them to predict the unique chemical composition of the food. It is relevant to note here that the brain, through consciousness training, can become more sensitive to the information (i.e., to detecting and analyzing chemicals and matching them with bodily needs). Which means, without good information while being exposed to bad information, individuals are more likely to make food choices that limit, or even harm, their bodily functioning.

The flavor of a tomato (or any organism) is telling the body "its delicious" come get your nutrients here. The flavor chemicals are intimately connected to the nutrients in the organism that may considered consuming. If humans take those flavors out if a tomato (or any food), and put them in a [processed food], for example, drink or chip; then, what has been done is created the sensation of nutrition, but delivered macro-calories (e.g., sugar) and/or isolated flavors (e.g., aromas) in place of the whole associable spectrum of nutrients.

> **QUESTION:** *What type of adaptation are you asking for from your body when you artificially flavor food?*

Since the 1950s flavorings have been introduced to the global society. At the macro-nutrient scale, its has been since the start of agriculture when humans began to cultivate separate food items and then mix them together to create hyperpalatable foods (e.g., wheat bread, cakes, etc.), with less nutrition. Thus, creating food that tells a lie, a nutritional lie that confuses the body's ability to sense food that is generally satisfying and leaves people feeling happy and vigorous. The consumption of "naturally" and artificially flavored foods and processed foods interferes with the way individuals naturally sense nutrition; it interferes with the way an individual would naturally sense it. Processing incentivizes people to eat food they wouldn't normally eat because the flavoring language that is sensed from the food has had "flavoring" molecules added to it to attract the body's desire (Read: food-seeking behavior). And thus, when people consume foods with flavor added, then food guidance behavior and eating can detract from optimal functioning.

Food that has "natural" or artificial flavors, or nutritionally deficient macro-nutrient sources, added together, tells a nutritional lie and disrupts the body's ability to feed itself properly, creating all sorts of seemingly irrational sorts of eating behaviors. (Schatzker, 2015)

Society in general, and habitat service systems in particular must grow food nutritionally dense and with flavor, for the local (and sometimes global) population.

In the early 21st century. agronomic performance as yield, and pest resistance, has increased significantly. But what was lost was flavor and nutrition. Selecting organismal DNA for for shell life and size, has bread out the flavor in food. Which is essentially a reverse evolutionary pressure. Food is now bread for size and flavor profitability. Companies got the market of consumers to eat more just by adding flavors. Nutritional wisdom is that what we want has some relationship to what we need. In general, we don't taste vitamin c, or minerals, for example. (Schatzker, 2015)

In general, the number one daily instinct in humans is for food, experienced as a pleasurable meal (i.e., a meal with flavor). Very few individuals have a strong enough will to overcome these cravings and desires. In community, it is understood that humans have a need to have access to real nutritions food that tastes flavorful.

Flavor is partially genetics and partially a factor of where and how something is grown. And, the flavoring added to processed foods makes them hyper-palatable, and so people overeat when they eat. Flavors added indiscriminately (Read: for profit) make people eat more food and eat food they wouldn't normally eat. People have a craving and their craving can't be met by what they are eating, and so they don't stop eating, or don't stop thinking about food. Experimentally, someone can get an animal to eat essentially whatever they want, by fooling it with flavor.

When flavor molecules are extracted or synthesized, and re-purposed, to what end and/or standards are they being re-purposed? Are they being re-purposed to manipulate consumers senses, or are they being re-purposed for our more optimized human fulfillment. When an essence (flavor) is taken and put in some other food product, then the body becomes confused and behaviors may not reflect an accurate sensory response toward fulfillment. When people fool their senses because of food choices, they change their food interface behavior.

Nature has endowed humans with their most sophisticated bodily system, because it requires daily (or, almost daily) human behavior to seek and consume nutrition for the body's, which is one of the body's most essential tasks: getting important nutrients to sustain and replicate. By manipulating this richest of senses, and most direct source of pleasure, early 21st century society has warped its relationship with the building blocks and energy source for human bodies, which require food. The market-State has taken a system designed to bring human bodies to a state of nutritional completion and turned it against humanity for profit and power. Flavor chemistry and bad information in the context of commercial profit artificially alters individuals relationship to food as that which in part individuals remake their bodies from.

When society incentivizes the wrong food, using flavoring and processing (over time), it sets up a negative cycle of eating where food loses its ability to satisfy the mental-body. The food tastes good in the moment, but over time the eating and craving experience becomes very unfulfilling. There is satisfaction in the moment, but not ultimate fulfillment in the nutrition and overall food experience and optimal bodily functioning. Food that cannot turn off someone's hunger will still make someone satisfied in the moment, but ultimately leave that individual wanting [ever more]. Industry wants the consumers' [satisfied] purchase, not their fulfillment. Its directive is not human fulfillment; its directive is profit.

Humans are moved to eat, motivated to eat, want to eat, desire to eat, and have a need to bring in nutrition; and, that eating [nutrition] need is a behavior made up of many decision, some individual and some societal. Importantly, however, what an individual desires (in the absence of sense manipulation) is needed by the body; here, the desire and the food are in alignment with optimal human functioning. (Schatzker, 2015)

What humans need is food that is being honest with them, so they can correctly interpret and respond with fulfilling behaviors. Human bodies will crave the nutrients they are deficient in, and flavor is the signaling language for that craving (Read: drive). The human flavor palate is critical in seeking out foods. At a fundamental level, humans don't make nutritional choices, they make flavor choices. That is how humans are genetically wired; they expect their food to be delicious, and they look forward to it.

Very often in the food environment of the 21st century, the foods eaten are the foods that should not be eaten. To a large extent, the cause of that behavior is the corruption of nutrition - nutrition signaling and nutrition structuring/cultivating. Society has corrupted nutrition by designing and producing foods that give people false signals, that give peoples bodies false information about the nutrients they contain. Flavorings incentivize food in an unnatural and deceptive way; they get individuals to eat food they wouldn't normally eat, and to overeat.

"Trust the child's intuition" when they are adverse to eating certain foods and favorable toward eating others (qualified, obviously, by flavoring and processing to make a food-like substance taste good). Food tastes good to an animal, because the food is good for the animal. Society ought to increase opportunities for free-choice food nutrition. The "free choice" calf experiment shows that animals make very different food choices when they have the free and natural choice. Calves did better at meeting their own needs than certified phds in animal nutrition. Eat when your hungry and listen to your cravings is a wise saying, that works when your cravings and hunger aren't being manipulated through artificially flavored food-like stuff (i.e., a different living environment) to which our body responds with behaviors that take away from our fulfillment. Eat something that tastes like it is and is both flavorful and nutritious, and you receive from your body "post-ingestive feedback" telling you to stop and that you are complete again (i.e., have all the building blocks until the next eat cycle). (Schatzker, 2015)

### 2.2.1 Food as nutrition

Nutritional fulfillment allows for the optimal functioning of all organisms, humans and plants alike. Therein, there is a species appropriate, species specific dietary framework for eating. Humans need a diet with enough energy and nutrition for each day's activities (with the exception of fasting days). Different organisms given different environments have different nutritional make-ups. Nutritional analysis can be done on any organism to reveal its breakdown of vitamins, minerals, and other bio-chemicals. It is important to note here that the scientific breakdown of molecules may not equate to how much nutrition any given human may acquire from its consumption. For example, a nutrient may be bound up by an anti-nutrient, making it unavailable for sufficient digestion and absorption. A basic nutrient analysis can be done on all food, plants, animals, and fungi, it can also be done for whole pastures/landscapes.

### 2.2.1 Food and self-connection

When individuals forage and hunt from a landscape, they find easily that they have an interest [in the health] of that landscape, and in the organisms that navigate that landscape. When someone has a relationship with a landscape, because one experiences the acquisition of food from that landscape, then one has a vested interest in that place. The same goes for the organisms themselves, the harvesting and hunting of a species gives the "predator" a relationship with that species that someone who thinks ill of harvesters and hunters might not have. There is a saying among traditional hunters:

> *"People who hunt deer love deer more than people who think hunters shouldn't hunt deer because it is not nice ... who think deer shouldn't be hunted. Hunters who hunt deer really come to know deer deeper, like they know themselves. Some people struggle psychologically with how ecology works, in that organisms eat other organisms. That is nature."*

### 2.2.2 The human [nutrient] diet

Humans ought to eat a species-appropriate diet. The introduction of lower quality food leads to the generation of lower quality potential for people. It is important for society to ensure the food selection is sending the right messages to the organisms genes and the right inputs for optimal functioning.

### 2.2.3 Food cultivation hygiene

Hygiene is a concern with food residue, bacteria and other potential disease causing organisms that may be on or near food.

### 2.2.4 Food storage

Food storage and preservation techniques include, but are not limited to:

1. Gas introduction
   A. Ozone
   B. Nitrogen
2. Vacuum
   A. Sterilization of vacuumed containers (e.g., cans)
3. Air depressor locks
4. Fermentation
5. Dehydration (desiccation)
   A. Freeze dehydration

### 2.2.5 Food preparation

Food preparation can be key to nutritional acquisition from it, and for removal of harmful chemicals.

# 3 Cultivation for materials

*A.k.a., Materials cultivation, materials cultivation service.*

Plants and animals can be selectively cultivated for material purposes.

# 4 Holistic cultivation of land

*READ: Holistic land cultivation.*

*A.k.a., Holistic pasture cultivation, holistic landscape cultivation, holistic land cultivation, ecological mimicking pasture cultivation of plants and animals, restoration agriculture, restorative agriculture, regenerative agriculture, intentional ecological cultivation, ecologically sustainable cultivation, ecologically regenerative cultivation, holistic cultivation, holistic land management, permaculture, perennial agriculture, perennial ecosystem, perennial polyculturing, perennial agriculture, permanent agriculture, syntropic farming, syntropy farming, syntropic/syntropy agriculture, circular symbiotic farming, agroforestry, pastoral agroforestry, agro-silvo-pastoral, whole eco-farm planning, etc.*

*NOTE: The techniques described here (ecologically-based, perennial crop[ping], pastoral livestock focused, agroforestry, organic, etc.) meet the definition for many of the above a.k.a. terms. All of these also known as (a.k.a.,) terms are essentially related.*

Holistic land cultivation includes, but is not limited to the cultivation of plants, animals, and fungi within a supportive ecological service environment. Herein, there is the intentional selection and cultivation of plants, animals, and fungi:

1. Pasture cultivation of plants.
2. Pasture cultivation of animals.
3. Pasture cultivation of fungi.
4. Ecological design for considerations for cultivation of wild insects and other animals.

Holistic land cultivation (i.e., permaculture) is an ecological design methodology whereby humans alter the landscape in such a way as to create relationships between materials, plants, animals, and humans so that their function and harvestable yield are optimized. Permaculture (permanent agriculture, permanent culture) is the use of perennials and animals on a landscape to produce a permanent culturing ecosystem. In other words, permaculture is the intentional design of perennial agriculture. Society can obtain staple foods from fully functional, perennial, ecological systems. The aim is to create systems that are ecologically sound and meet the needs of humans, while not exploiting or polluting. Holistic land cultivation is an approach to landscape cultivation that adopts arrangements observed in flourishing natural [perennial] ecosystems. It includes a set of design principles derived using natural ecologies and whole systems thinking. It uses these principles in fields such as regenerative agriculture, re-wilding, and community resilience. This is a approach to grow food, soil, and reforest landscapes simultaneously.

This is approach to create a sable staple food producing perennial ecosystem. Through the intentional repeating of patterns found in nature in an engineered cultivation system it is possible to design and develop a natural perennial ecosystem that performs ecosystem services effortlessly, optimally, and with minimal inputs, while simultaneously providing a portion of outputs to serve human nutrition and material needs. A cultivation system ought to restoring health and vitality to the earth, plant, animal system. It is important to question that once the system is planted, how long can it subsist there? Here, permanent means that they system continues year after year, that it is restorative, regenerative, and sustainable. Annual systems do not convey those characteristics. Currently, in order to farm annual plants on large scale, because of the growth context of annual plants, the farmer must destroy a 3D perennial ecosystem in order to expose the large land patches of soil. This can be done by mulching the environment, cutting, burning, ploughing, or using herbicides. In order to cultivate annual plants over a wide scale of land, the local perennial ecology must be destroyed. Over time, and by its very nature, annual cropping destroys the living resource base of the planet. However, it is possible to include annual plants in a perennial-based holistic land cultivation system. As the land size of this cultivation system increases, so will the amount of annuals, which could be designed and harvest to meet a populations actual needs.

Holistic cultivation refers, in general, to a permanent form of agriculture using perennial systems (primarily), instead of annuals. This methodology (Read: selection of methods) is sometimes known as permanent agriculture, perennial agriculture, and restorative agriculture. Herein, carbon farming comes naturally through woody plants that remove excess carbon dioxide and store it in the form of perennial woody vegetation, and organic matter, in the soil.

> **NOTE:** *All species require the support of others. A natural community is defined as an assemblage of interacting plants and animals and their common environment recurring across the landscape. Natural communities are what protect and spread biological diversity; they are units that repeat across the landscape.*

Holistic land cultivation uses [ecological] process-based agriculture, as opposed to [agrochemical] input-based agriculture, typical to industrial systems in the early 21st century. There would be no agriculture input industry if society does not need agricultural inputs. Early 21st century society needs agricultural inputs because the type of agriculture practiced is degrading the resource base. A holistic cultivation system is biologically diverse, and relies on the regenerative/restorative inputs of: animal husbandry, agroforestry, and perhaps editions of mined substances (e.g., calcium when deficient). It is possible to imitate nature's successional pathway.

There is a contribution-related section on the website. Coordinators generally recommend reading the standards and observing the models for the standards to gain a comprehensive understanding of the envisioned proposal.

In the context of food, agriculture means to produce staple (and, stable) food and forage crops for nutrition and material compounds for materialization. "Farms" coordinate agricultural operations.
In the context of food, agricultural products (for nutrition and calories) include, but are not limited to:

1. Fruit and nut bearing trees.
2. Fruit and nut bearing shrubs.
3. Fruit bearing vines.
4. Grasses (for herbivory)
5. Fungi

In the context of materials, agricultural products (for materialization) include, but are not limited to:

1. Wood.
2. Textiles and fabrics.
3. The breakdown products of carbohydrate bodies (fruit > juice > vinegar > alcohol).

A viable ecological cultivation system must be based on natural patterns and relationships that are perennial, and provides (produces) the following staple and societally required elements:

1. **Foods** - nutrition and calories [for humans and other organisms].
2. **Fuels** - power [for the habitat life support service system].
3. **Medicines** - medical [for the habitat life support service life ]
4. **Fibers (and other materials)** - materialization [for the habitat technological support service system]
5. **Ecological niches** for domestic and wild animals, plants and other organisms - ecological services [for the whole planetary biosphere].

It is possible, and likely more sustainable to obtain staple foods from fully functional, perennial, ecological systems. Humankind can achieve all of the benefits of natural perennial ecosystems. This can be done by creating agricultural ecosystems that imitate natural systems in form and function, while still providing for human nutritional needs. The design of farms to produce staple food crops with perennial plants and livestock. A farm is an area of land used for growing crops and raising animals. Ecological polycultures require animal polycultures. It is possible to design a farm that mimics natural ecological [perennial] service systems. It is useful to follow natural patterns and resource flows when designing a cultivation system. A cultivation system that is easy to maintain by humans is one that doesn't require weeding. A weed is a plant in the wrong place. Because the ecological cultivation system is fit for the ecological biome (through time) the system should be able to be planned for 100 years of harvests (and soil regeneration). (Shepard, 2013)

One way in which holistic land cultivation coordination (i.e., restoration agriculture) can produce more calories per acre than annual crops is by creating overyielding polycultures. Overyielding polycultures are intentionally designed plant and animal systems that may produce lower yields per item, but the total per hectare/acre yield exceeds that which any one crop would have produced. In perennial polycultures there will be fewer of each element than if that element were raised in a monoculture, and because of competition effects with neighbouring plants and animals, yields per plant may be less than in a mono-cropped system. The farmer's goal is to create a system where the total yield is greater in a polyculture than a monoculture and hence the name "overyielding polyculture." The average perennial polyculture farmer is not striving to grow the most of any one crop. A perennial polyculture farmer is striving to coordinate and optimize an ecological system for human cultivation purposes. The cultivation system is modeled after nature, and the system is designed to optimize its total system yield. (Shepard, 2013, p107)

> **NOTE:** *Herein, restoration does not mean what it commonly means in the early 21st century, which is, to take a piece of land and return it to some past state. Herein, then research a snapshot of the land in the past, and then, conform the land to the restorers idea of what nature was back in the snapshotted past, the plant species and spend money to force it to stay in that form I stead of living with the natural cycle.*

Every action taken in a holistic cultivation system is taken with thought to other systems, and the action often carries with it a, secondary useful purpose. The landscape produces food, but it also produces medicines and stabilizes the ecology, produces smells, and produce nutrients for the local ecology. Humans can design ecological cultivation systems that mimic what nature wants to move toward and allow the system to take care of itself, an automated agriculture system managed by nature.

## 4.1 Common holistic cultivation techniques

Holistic cultivation practices (e.g., restorative agriculture techniques) include, but are not limited to:

1. Permaculture **analysis and design.**
    A. Polyculture - plants that grow well together.
    B. Allelopath ("bad neighbors") - plants that do not grow well together.
    C. Perennial polyculture - perennial plants that will grow well together over time.
2. Aquaculture **analysis and design.**
3. Ecological aquaculture **analysis and design.**
4. Agroecology **analysis and design.**
5. Agroforestry **analysis and design.**
6. Soil food web **analysis and design.**
7. **Succession:** Polyculture and full-time succession planting of multiple and inter-crop plantings.
8. **Succession:** Natural sequence farming.
9. **Planting category:** Perennial crops (primarily).
10. **Planting category:** Organic annual cropping and crop rotations.
11. **Planting category:** Cover crops & multi-species cover crops.
12. **Planting category:** Borders planted for pollinator habitat and other beneficial insects.
13. **Breeding strategy:** Strategic, total and utter neglect (STUN) breeding.
14. **Livestock:** Well-managed grazing, animal integration and holistically managed grazing.
15. **Livestock:** Grassfed livestock.
16. **Livestock:** Silvopasture.
17. **Earthwork strategy**: Keyline subsoiling and keyline planning.
18. **Farming strategy**: Conservation farming, no-till farming, minimum tillage, and pasture cropping.
19. **Fertilization:** Compost, compost tea, animal manures and thermal compost (few supplements).
20. **Fertilization:** Biochar/terra preta.

## 4.2 Natural ecosystem mimicking food production systems

*A.k.a., Nature mimicking cultivation system for food and materials.*

Food production systems can be designed like natural ecosystems. These natural ecosystem food production systems should, in theory, show the same resistance to pests and diseases as wild landscapes, while conserving and increasing top soil, and increasing in fertility over time. Fertility (through fertilization) comes from livestock raised and grazed on the landscape. In the early 21st century, soil fertilization comes in a bag from an agrochemicals company. Using landscapes in this way it is possible to play an active part in restoring and healing land to a state of greater productivity.

The coordination of a perennial farm involves the following five main element:

1. Water coordination (i.e., water management).
    A. Earth shaping (by means of).
2. Maintaining perennial ground cover.
3. Diverse 3-dimensional perennial woody crop plantings.
4. Diverse animals.

It is possible to design a cultivation system when animals and plants are arranged according to lifecycle and strata, how they relate through the multiple effects of the influence of time, creating a dynamic environment, and then managing this through species succession, continually increasing the quantity and quality of useful life. Using this method, the inputs costs and growing period for a crop can be predicted precisely, and therein, farms can be built wherever people need fresh produce.

### 4.2.1 Ecological succession

*A.k.a., Natural succession.*

Ecological succession is the observed process of change in the species of an ecological system over time. Part of how ecosystems work is through ecological succession (or, natural success). For instance, if there is a bare land surface, that surface will generally be colonized by lichens first, then mosses, then grasses, etc. Annual grains and legumes have a place in the ecological succession of nature. They follow disturbances in the soil. They grow and colonize rapidly, while making hard seeds that last a long time to protect themselves from adverse environmental conditions. And then, eventually, thorny plants and shrubbery are likely to take over, slowly, sun loving trees will become established. After the sun loving phase is established, then shade-tolerant trees will grow underneath. Following ecological succession it may take more or less than 1800 years to get to a closed canopy growth, shade-tolerant forest. Humans can quicken the process of creating a closed canopy, shade-tolerant forest by planting specific species and harvesting (pruning and cutting) trees and other plants year after year.

Natural succession can start with a bare planet. It goes through a phase where it is colonized by lichen and mosses, then a grassland phase, then flowers and shrubs, then sun-loving trees, then shade-tolerant trees. This happens across the planet at different rates of speed based on local conditions, like water availability, temperature, pests, etc.

**IMPORTANT:** *Through natural succession, soil can be built quickly during the grassland phase with animals.*

It is possible to plant a landscape planned over time to mimic, though more rapidly the natural process of ecological success. Natural Succession is an ecological process. Natural success can be accelerated through "synchronization". "Synchronization" refers to the act of removing plant biomass, through harvesting and pruning, in order to obtain a yield, open up space for the next succession of species, and to encourage new growth through the release of different root hormones that occur after pruning.

It is possible to use the natural succession of plants for:

1. Fertilization
2. Irrigation
3. Pest control
4. Food production

It is possible to graph a successive plant species (that starts with bare ground) and extends out in time:

1. Bare ground (start)
2. "Pioneer plants" (1-3 years)
3. "Secondary plants" (3-30 years)
4. "Climax stage" (over 30 years)

### 4.2.2 Ecological stratification

Ecological stratification deals with the basic principle that limited space equals limited plant growth. Stratification is analyzed to make sure that every crop planted gets the right amount of light for that crop. Some crops need a lot more light than others, and a large part of the challenge in arranging plants (and possibly, rows) is making sure that every crop has adequate light. Stratification basically ignores all other differences plants have, and separates plants into five different categories, or strata, based only on sunlight needs. When planting crops together, farmers have to understand the amount of light taken up by each plant. Stratification divides all plants into 5 main categories, or “strata”:

1. **Emergent plants** - need constant or near constant sunlight. Emergent plants are also normally quite tall, because they are reaching up towards the sun.
2. **High plants** - need a lot of sunlight, but less sun than emergent
3. **Medium plants** - need occasional sunlight.
4. Low plants - need some sunlight, or scattered sunlight
5. **Ground cover plants** - need the least amount of sunlight.
6. **Vine-type plants** - plants that climb on other plants.

Emergent plants require the most sunlight and need constant sun to thrive. They are also typically tall plants, such as corn or eucalyptus, but there are always exceptions. Plants under the designation “high” need a lot of sunlight to survive, but less sunlight than emergent plants.

Some percentage of the total layering is taken up by emergent plants could take up about 20% of the space available to them. Plants with the designation high could take up about 40% of their available space. Plants with the designation medium require a medium amount of light and could take up around 60% of their available space. Plants can be arranged in space based on the principle of stratification, which refers to where a plant grows in its optimal habitat.

Practically, this means that you can’t plant an emergent plant next to a high plant, because the emergent plant will block out all of the sun for the high plant. However, you could plant an emergent plant with a low plant, because the sunlight filtering through the emergent plant would be enough for the low plant. In this scenario, the emergent would actually shield the low plant from getting too much sun, so they work together really well. The same relationship works for high plants and medium plants.

### 4.2.3 Plant-leaf photosynthesis and sunlight

Photosynthesis occurs under a fairly narrow band of temperatures, and when grasses are growing in the shade, their leaf temperature is lower than if they were in the full sun. Partially shaded grasses continue to photosynthesize and grow when their full-sun compatriots have shut down to wait for cooler temperatures. In addition to a longer growing season the partial shade cast by the evenly scattered trees helps the grass to grow more during the day.

Leaf temperatures aren't the only thing that shuts down photosynthesis in forages. The chlorophyll in a leaf can be thought of as a sponge. This green sponge soaks up sunlight as fast as it can while some of that sunlight is being used as the energy to manufacture basic carbohydrates. Once photosynthesis is happening as fast as it can and reaches its maximum, it can only convert sunlight into simple sugars at that fixed, maximum rate. If more sunlight is striking the leaf than the chloroplasts can use, then that leaf has become "light saturated." Additional light striking the leaf surface does not result in more photosynthesis. Some is reflected by the leaf and some is converted into heat which can further slow photosynthesis. Leaf temperatures can become so hot that moisture loss causes wilting and a further reduction in photosynthesis. (Shepard, 2013, p113)

### 4.2.4 Whole ecological farm planning

To plan the ecological integration of a cultivation (farming) system requires the following accountabilities:

1. Earth shaping for hydrological optimization.
2. Food system selection (plants and animals).
3. Crop and livestock development.
4. Farm installations and processing equipment.
5. Manuality and automaticity.

The following activities can be manual or automatic:

1. To spread out livestock manure when it becomes to concentrated in specific areas.
2. Finish mowing.
3. Moving the animals from paddock to paddock.
4. Observing paddocks for change.
   A. Adding plants and/or culling plants.
   B. Adding animals and/or harvesting animals.
   C. Changing the rotation of the animals.
5. Harvesting fruit and nuts and distributing it to the animals.
6. Giving supplemental feed and water. In some cases it is possible to not give any supplemental feed (during the grazing season).

### 4.2.5 The ecologically integrated design process

The ecological landscape must be planned as a whole, including plants, animals, and other organisms as a whole system.

An ecologically integrated cultivation system must complete the following planning objectives:

1. Identify the biome in order to select genetics (i.e., select keystone species).
2. Identify the landscape in order to perform earthworks which optimize the hydrological system on the land (i.e., earthworks for water management).
3. Build fences, roads, utilities and pipelines.
4. Establish edible woody polycutures, as well as other plants and animals, using agroforestry techniques.

## *4.3 Holistic landscape cultivation planning*

The holistic land cultivation planning process involves:

1. Identification of the local biome and key plant species.
2. Identification of the spatial and termporal layout of plants
3. Identification of data related to plant harvesting.
4. Accounting for ecological succession (where applicable).
5. Taking action with earthworks in conjunction with planting and livestock introduction.

Herein, it is desirable to identify the type and location of organism, and its breakdown) through time in space. The inputs, processes, and outputs of a cultivation system can be planned and visualized, for example:

1. Woody plants and animals produce **food** (fruit), juice, vinegar, alcohol (chemical process of rectification is also known as distillation).
2. Oil (nuts) + alcohol = **fuel**.

### 4.3.1 Water sources and distributions on the landscape

*A.k.a., Water flow through storage and distribution.*

Plants and animals live through water. A landscaped cultivation system must have some form of water distribution (Read: irrigation) system over the landscape. The source of that distribution system may be from (simplified view):

1. Rainwater directly.
2. Water body (or, bodies) on the landscape (e.g., ponds, wells, swales, springs, pools, etc.).
3. Water body (or, bodies) external to the landscape (e.g., municipality, river, etc.).

Water sources on a landscape include:

1. Natural rivers.
2. Natural ponds and lakes.
3. Natural springs.
4. Vertical wells - these come from deep holes dug in the ground.
5. Horizontal wells - are similar in concept to ancient "qanats" found in Persia and throughout the Middle East. The modern interpretation is to bore a hole into a mountainside and let gravity deliver the water for you. This method largely eliminates the need for vertical wells and pumps. Dig contour trenches on slopes at higher elevation and you can turn every hillside into a giant water collection system (much like a tent or a building roof). Every inch of rain will yield about 2/3 gallon of water per square foot of relatively impermeable surface area (like steep, rocky slopes). Capture this water with trenches (i.e., get it underground fast) and use horizontal bores to retrieve the water. Let Nature and gravity do the work.

## 4.3.2 Landscape modification using earthworks (land for agriculture)

> **READ:** *Terrain and micro-climate modification planning.*

The farm/landscape cultivation development process involves the following service steps:

1. **Whole farm planning and assessment**
   A. When doing earthworks that could significantly modify the microclimate of the whole farm, the whole farm and its environmental landscape must be consered.
      1. Where is the farm located and what are the environmental characteristics of the land and atmosphere?
      2. What are the goals of the farm, of the cultivation operation?
      3. What is the approach to cultivation, what tools are available and usable?

   B. In the case of most landscapes, there is an optimal earth and plant pattern; in general, the optimal pattern all around the landscape is:
      1. Create a swale, then berm, then position a tree downhill from the swale, and then an alley gap, and repeat: Swale > berm > trees > alley, then the pattern repeats, swale > berm > tree > alley,...
      2. Earth modification that changes hydrological flows (dynamics, including, dams, swales, and ponds) can significantly alter a micro-climate and dramatically increase forage production, but they aren't without risks.

   C. Landscape measurements that may be used to assess a landscape (for acquisition and continuous coordination) include, but are not limited to:

   D. Penetrometer testing - Look at soil compaction with a soil penetrometer.

   E. Conduct a soil mineral composition test.
2. **Earth shaping (a.k.a., land shaping, land re-shaping, earthworks)**
   A. The primary purpose of earth shaping systems is to coordinate the local hydrological cycle. Earth shaping systems can be used to spread water out and slow it down. They also make more water available to the livestock. Hydrological changes may occur to the flow of water when the landscape is changed. When the shape of the earth is changed, it will influence water movement. Water usually moves over a landscape at 90 degrees to a contour lines (i.e., perpendicular to contour lines). It is important to note here that changing the shape of land can lead to unforeseen future problems. The general goal is to evenly distribute water across the landscape.

   B. Transportation through the landscape should be accounted for when re-shaping earth. It is important to account for transportation roads when earth shaping. Roads can either be expensive to maintain, or they can be features that catch and move water passively from one place to another.

   C. In most locations it is important to consider fire mitigation techniques when re-shaping the landscape. Fire breaks can be composed of gaps in shrub and canopy vegetation, or they can be composed of fire-resistant woody crops.

   D. Ensure to design the landscape so that automated machines can harvest nuts and fruits between trees and/or within alleys (if such are to be used).
      1. This means considering the usage of automated harvesting machines in concern to plant placement.

2. This means considering the application of earthworks in concern to how they will affect harvesting machines' ability to do their job.

3. **Landscape modification for optimized site hydrology and production capacity (a.k.a., landscape water flows, storage, drainage, and irrigation)**
    - The limited water resources of land can be made better use of by first understanding the way rainwater runs across a slope, and then reshaping the land to control the water flow: both where it goes and the speed of flow. Land reshaping can also be used to collect excess water and direct it off the property, or into storage areas where it can be used during dry seasons. Changing the landscape will change the pattern of water flow. When water flows fast over a hard soil it does not soak in to any great degree, which can cause erosion. When water flows slower, more water will soak (infiltrate) into the soil and the potential for erosion will be reduced. Changes to the land structure can spread out, capture, and slow the movement of water over and through a landscape. The following are the types of modification that can be made to a landscape to change the water flows and dynamics therein:

    A. **Digging ditches/trenches (excavating lines in the landscape):**
        1. **Ditches (a.k.a., trenches)** - any excavated channel in the ground designed to change the flow of water, including the movement of water from one location to another and the infiltration of water. Note that the most common use of the term, ditch, refers to a channel that drains water away from an area quickly, thus limiting infiltration. Ditches can be used for irrigation and drainage.
        2. **Swale** - a long, level excavation along the landscape intended to capture surface water runoff (from rain, roof, road runoff, tank overflow, diversion drains, etc.) and then store and/or move it.
        3. **Absorption swales (a.k.a., absorption trench, water harvesting ditch, keyline swale, swale and berm, etc.)** - An absorption swale (sometimes just, swale) is a type of ditch that follows the contour of a terrain and acts as a drain; they are simple canals or ditches that are contoured with the landscape (i.e., made at the same height). A swale is the creation of long, level hollows, furrows or other excavations (which may also include barriers, such as berms) created across a slope. Swales and berms can be created via a number of methods, including: shovel and hoe, bulldozer, or excavator. A swale is an uncompacted ditch, dug on contour, to catch and infiltrate water and prevent runoff. As a swale infiltrates water deeper and deeper, tree roots follow the water downward. Swales are used to intercept overland water flow and then hold it for long enough to let it slowly infiltrate into the soil. This technique improves subsoil water storage. When it rains, water will accumulate in the swale and slowly drain into the soil. When the rainfall rate exceeds the soil infiltration rate, water sheets on the surface of the soil and begins to flow downhill. As this sheet of water encounters a swale, it collects in the swale and stops flowing. This gives the water more residence time in the landscape and allows the water to soak in. Swale formation is the process of reshaping the land on contour to collect/harvest rainwater. Swales are the most convenient way to store water in presence of a slope, on and in the slope. Without the swale, the rainwater will flow downhill, and with strong rain, it will usually remove the top soil and cause erosion. Swales can prevent water from running and eroding top soil. The primary purpose of a swale is to slow and sink the water into the landscape, which also allows for passive irrigation of crops/forage. A swale is placed "on contour" (i.e., level) so water shouldn't generally flow in (Read: within) it. However, the spillway of a swale can feed into a pond, rerouting runoff without having to have the "swale" falling off contour. Further, permeable pipes (e.g., french drains) can be placed in the swale at desired heights to drain the swale into a pond or elsewhere. In some cases, like in the tropics, mulching material

(e.g., dry grass) is placed on the swale to reduce evaporation and also to act as a sponge. Some plants that may be placed on the berm or near the swale may not like damp environments, so mulching material used for the absorption of water will reduce moisture level in surrounding soil. There are concerns with producing swale-type structures on the landscape. Swales and other permanent water features that will concentrate water into a very small part of the landscape for a long time. Swales under some conditions could lead to landslides. As a technique, swales generally work best in more arid climates.

4. **Spreader swales** - A spreader swale takes water away from wet spots slowly. Spreader swales move water downhill slowly, typically at a 1 percent slope (Read: .3 meters elevation drop over 30 meters distance, which approximately a 1% slope or 1 foot drop to 100 foot distance). This is the degree of slope at which water will just barely begin to move. Thus, unlike traditional ditches (which move water quickly away from an area), spreader swales intentionally move the water slowly across the landscape allowing it more time to soak in.
5. **On contour vs. off contour swales** - on contour swales are often for retention, whereas off contour swales are often for diversion.
6. **Collector swales** - A collector swale gathers water from a large area in order to create a surface pond.
7. **Fish scale swale and berm (fishscale swale and berm)** - These are not traditional contour line following swales. These swales are shaped like a "V", with the downward part of the V facing down the slop. They look a little like boomerangs. Often, the line of the "V" shape forms the bern and a small v shaped swale is created uphill, inside the "V" shape. The inner side of the "V" shape is the swale that collects water for infiltration.
8. **Swale and berm** (usage for excavated soil) - The soil acquired from excavating the swale can be placed on the downward side and serve as a berm. A berm combined with a swale will help reduce the likelihood of downward erosion. The berm will also keep the moisture level in the swale higher, as well as in the berm itself. A swale-berm is a water harvesting ditch with a soft earthen mound that is located immediately downslope from it. For some sites it is necessary to design an accurately measured series of swales and berms to capture rainfall and spread the water out evenly; instead, of allowing it to gathering together in waterways and valleys where is transported to unusable locations.
9. **Swale and dam** - Swales can be combined with dams.
10. **Spillway** - A spillway is structure in the landscape designed to control the release of water from a water body source.

B. **Digging holes type (excavating holes in the landscape):**

1. **Pocket ponds (a.k.a., vernal ponds, ephemeral ponds, small ponds)** - A pocket pond is used to capture overflow rainwater. These ponds are dug on the landscape to catch overflow rain. Pocket ponds can also be designed for stormwater treatment. These ponds are designed to hold water during large rain events and to make that water soak slowly into the soil. Pocket ponds are the "surge protection" for the swale system when a large rainfall event occurs. These small ponds are placed at the heads of valleys and at the ends of ridges to collect water. These ponds have several main purposes: to spread the water out and have it soak in more evenly, and for amphibians (which eat insect and act as insect control). This technique improves subsoil water storage. These are ponds that drain and eventually disappear and mimic ecological pond systems more commonly known as vernal pools or ephemeral ponds. Vernal ponds are wetlands that only exist for a period of a few weeks or months during and slightly after heavy rainfall (or, the area's rainiest season). These ponds can host a variety of insectivorous amphibians that provide pest control for the whole system. Note here that some pocket ponds do hold water throughout the season, even when that was not the original intention. Also, some ponds may be intentionally designed to do so throughout the driest months of the year.
2. **Ridge ponds** - when there is enough room on a ridge it is possible to place a ridge pond for the retention of water.
3. **Porous bottom ponds** - are designed to recharge aquifers. The idea is not to store surface water for any length of time but to get the water underground as quickly as possible.
4. **Keyline swales and pocket ponds** - With keyline swales designed to accept the excess

water during large rain events water is captured and moved to the pocket ponds and overall toward the ridges. Pocket ponds are designed to fill up with this "surge" water and then slowly drain it into the keyline swales. A properly designed keyline swale and pocket pond system should be designed to capture and hold a region's maximum rainfall event.

C. **Ridging/embanking types:**
   1. **Berm** - a berm is either, a temporary flat strip of land on a sloped landscape, or a raised bank (an artificial ridge or embankment), often adjacent to a water body. In the case of a swales, a berm is a low earthen wall adjacent to a ditch that can be used to help retain runoff in the designated swale area along the downhill side of the location. In general terminology, a berm is a mound or wall of earth or sand on a landscape. Berms help to keep water in swales and ponds.

D. **Piping types**
   1. Pipes can be installed that will allow for drainage, livestock watering, or irrigation. Pipes can be gravity-fed or use a pump.
      i. **Diversion drains (e.g., french drain, perforated drain pipe, drain conduit, water channel)** - A diversion drain is "on a falling contour" sometimes with a fall of 1:300, so that water will flow in an intended direction.

E. **Subsoil explosion (a.k.a., subsoiling, keyline subsoiling, keyline pattern cultivation, subsoil ripping, yeoman plow, etc.)**
   1. **Keyline plowing (a.k.a., subsoil plowing)** - Pull a keyline plough through the field; a hook-type (knife-type) instrument pulled behind a tractor. Pull the non-inversion rigid time plow through the ground, which explodes the subsoil, thus allowing air and water to infiltrate into previously compacted soil. Before this tool is used, go around the land and take samples with a penetrometer (a tool pushed into the ground that measures the compaction power as well as the depth pushed into the ground for reading the compaction of the ground). It is meant to penetrate the subsoil, to a depth of 2" below existing rooting depth without inverting the soil. The cultivation pattern uses keyline geometry to act as a micro-water management storage ditch as well, holding more water on ridges. The effect is to loosen compacted soil and open up micro-water harvesting & diversion ditches across the landscape. In some pastures, it is possible to increase the rooting depth of forage plants by breaking up hardpan and allowing root access into these micro-furrows. The roots of many plants, particularly grass plants, have a challenging time penetrating soil compacted at 300psi and higher. These ploughs can be used over and over again each year to reduce the compaction of the soil at lower and lower depths. This system creates soil that is capable of infiltration at a rate greater than before. This technique also allows grass and other plants to create deeper roots. This technique improves subsoil water storage. This technique will not work when there are rocks present in the soil or on the land. This technique requires a special plow and a tractor. Generally, keyline plowing is done once a year around springtime. This instrument can be pulled over the enter pasture, or just the alleys. The subsoiler hook cuts a slot in the ground and slightly lifts the soil on either side of it, which shatters compacted layers and reduces their psi. Tight soil can be loosened by the mechanical action of a subsoiler.
      i. Air can be introduced by various techniques including using a subsoiler, disc harrow, cultivators and plows, and suitable seedbeds can be created with disc harrows, tillers and spading machines.
      ii. Be careful of steeply sloped terrain that may not be safe for tractor use.
      iii. Poor timing of keyline plowing can op up soil to increased evaporation and could create compaction or tractor tire ruts.

F. **Hydological "keyline" landscaping (a.k.a., "keyline" system design, hydrological site design)** is a landscaping earthworks terrain modification technique of maximizing the beneficial use of the water resources on a landscape. Here, the "word" keyline is essentially synonymous with "water flow". The "keyline" represents a specific topographic feature related to the natural flow of water on the landscape. Keyline systems use a variety of techniques to capture rainfall, slow the water as it moves over the landscape, spread the water outward toward the ridges where it is needed (and tend to be dryer) and can soak in, and store excess water in the soil, ponds, and tanks. By slowing down fallen rainwater and spreading it out, it will have an increased time in the landscape. This gives the rain time to soak in rather than run away. An exception to this would be sites that are pre-existing [true] wetlands (although, not if they were created by improper water management in the first place). The concept of "keyline" planning (a.k.a., hydrological site planning is based on the natural topography of the land and its rainfall. Each land area has a "sweet spot" line representing a single, water-collecting swale, which impacts (or has the possibility of impacting) the water flow on a maximum number of hectares of that particular land with the least amount of earth shaping. On most properties this "sweet spot" will be located somewhere near the keyline of a slope. The "sweet spot" is an inflection point is at the place where the contour lines go from closer together on the convex slope to wider apart as the slope broadens and becomes more concave. It's called a "Keyline" because it's a contour line starting at the "Keypoint". Once the keylines are located, a laser level, transit or A-frame is used to accurately measure out where the water management swales will be located.

1. A contour map is essential in order to best understand the rise and fall, and flow of the land. The leading proponents of keyline design recommend the use of orthophoto maps (aerial photomaps which are available from keyline consultants) because of their increased contour detail.
2. Keyline design and planning (a.k.a., hydrological design and planning) involves the following three concepts related to water and the way water flows on a landscape):
    i. **Water source point ("keypoint" or "key point")** - every primary valley has a "keypoint". It is the point at which the primary valley gets suddenly steeper. This is a common location for a dam, pond, or swale placement. A keypoint is a position located along the centerline at the base of the steepest part of a primary valley. Keypoints are mostly about the storage of water at particular points (elevations) on a landscape. The transition between a convex shape (hill) and a proceeding a concave or high- slope shape that ends the hill is where the keypoint may be located. Imagine a steep slope merging with a more gentle grade. Where steep meets shallow is the "keypoint". Actually, the "key point" itself is not the point of inflection where a slope goes from convex to concave, but rather is located just below this inflection point. The "key point" is the highest point water will fill up to in a valley if that valley is dammed. The keypoint is important in terms of storing water. A dam placed above the keypoint will not collect nearly as much water as a dam placed below the keypoint. If a dam is placed below the keypoint, it will store much more water, because there is a larger volume of water present for it to store. In general, dams are placed below the keypoint. Functionally, the "keypoint" is the first place where it is practical to build a dam as far up a watershed as possible. Build the dam at higher elevation and you won't collect enough water (and engineering becomes painfully expensive). Build the dam lower and you will need a larger structure (which increases costs). Also: The lower in elevation you build a dam, the less "head" you have to work with = water pressure is lower and the amount of land that can be irrigated by gravity is greatly reduced. The water collected by the dam will reduce the water and moisture level on architectural structures below, and can also be directed via ditches or pipes for irrigation to crops/ forage below.
    ii. **Water source channel (a.k.a., "keyline", "key line", swale/trench)** - a line that runs through a keypoint and extends to where the contours of the valley start to become the sides of the ridge. Keyline swales spread out rainwater. Keyline (key line) is not so much about storing water, but is more about water dynamics (i.e., what is the behavior of rain water after falling on the landscape). On a hill, the water will mostly travel down the steepest part, and hence, in certain landscapes, certain parts of a hill may get less water because they are not as steep. Keylines are trenches (swales), and are excavated to more equally distribute the water over the surface of the landscape. From the "key point" on the landscape, a contour line is drawn, and this contour line becomes the "key line" (keyline). Water flows, but also collects in the trench. Hence, due to keylines, there is a greater distribution of water on the part of the hill that is usually avoided by the flow of water. Without the keylines, less water will hydrate certain

parts of a hill due to them having less of a slope than other parts.

1. Depending on the following factors, the channels capture and move water on the landscape (e.g., keyline swales) have to be different sizes and different distances apart:
    a. The rainfall patterns of the area.
    b. The soil types.
    c. The infiltration rate (how fast the water soaks into the soil).
    d. The slope of the land.
    e. How big the area is that rain is being caught from.

iii. **Keyline planning and cultivation rules (a.k.a., keyline cultivation patterns)** - The key idea behind 'Keyline' water management is to consciously slow, sink and spread rainwater by relieving compaction, opening up pore space in compacted soil and distributing excess water towards drier parts of the landscape. This has the effect of buffering the natural concentration of water towards valleys and reducing flooding. By maximizing the flow of water to drier ridges (using precise plow lines or mounds that fall slightly off contour), it is possible to infiltrate water across the broadest possible area. In this respect, keyline strategies can be both a flood and drought mitigation strategy. The basic keyline cultivation rule is that cultivation on ridges (above the keylines) should be parallel to and above the contour lines, whereas cultivation below the keylines should also be parallel, but below the contour lines. This means that water runoff above the keylines is directed towards the more gradual slopes for slower dispersal into the soil, and below the keylines it will be directed towards the greater slope for quicker dispersal, and hence will not result in swampy and therefore possible saline conditions. The basic idea here is that you create trenches that extend from the sides of a hill (i.e., valley centers) toward ridge centers to feed and store water there also. However, each landscaped must be analyzed individually because in keyline design planning it is not strictly (or, always) true that the best action is to take water from a valley high in the landscape and move it slowly towards a ridge(s).

2. **Keyline layout versus contour layout planting** - keyline layout differs from contour planting in that rows remain equidistant from one another. In reality, landscape contours are always irregular and never equidistant. Keyline layout seeks to optimize land usage while still maintaining equal distance in cultivation rows so as to maximize density and efficiency. Contour layouts leave irregular shapes that are difficult to maintain.

Sometimes the "key" terminology is difficult to understand. Instead of the word "key", one could just say, "important water points". It is possible to make the language here more precise using the following terms to identify the primary elements of a hydrological terrain design (rather than the word "key"):

1. **Water source point (key point; keypoint pond)** - the point at which the water collects before traveling down some water channel.
2. **Water source channel (key line; swale & berm)** - the water channel extending off of a water source point ("key point").
3. **Ridge source ponds** - ponds on ridges, if sufficient space.

There are three basic principles when it comes to intentional water movement over the landscape:

1. Water may flow from the valleys to the ridges [by means of the water source channels, a.k.a., key lines].
2. When there is a water channel network with ponds, then water may also flow from the ridges to a water source point pond (keypoint pond).
3. In general, the slope of the water source channel (i.e., the slope of the swale and berm structure) should always be 1% (as in, 1 meter over 100 meters or 1 foot over 100 feet).

#### *4.3.2.1 Additional swale and berm specifics*

The two primary purposes of a swale and berm system are to:

1. Facilitate infiltration of the water.
2. Move the water to where it is most needed.

There are several good practices when it comes to the application of swales:

1. Catchment area X maximum rainfall event ever recorded = "safest design" swale + pond volume.
   A. The capacity of the swale and outlet system must be able to intercept and disperse this catastrophic event volume to avoid system failure.
2. Swales in clay soils can be deper with steeper sides. This makes sense also, because ponds are often filled with a foot depth of clay all around that is tamped down by a back hoe machine, in order to hold water in.
3. Swales in sandy soils must be wider with gently sloping sides.
4. Safest design volume is influenced by measured water infiltration rate, saturation point, and soil type.

Additional water terrain "keyline" understandings include, but may not be limited to:

1. The main ridge line usually descends in elevation so that every primary ridge and primary valley shooting off from it is lower than the next.
2. Each of these primary valleys has a key point located within it and the different key points from valley to valley are in different spots.
3. Every equidistant line used for plowing, swales, tree belts, alleys, etc. above and below the key contour line runs parallel to the key contour line.
4. Running parallel to the key line will ensure that both the parallel lines above and below the key contour line will slope gradually off contour and carry water runoff from the higher valley points to the lower ridge points which would otherwise have water rush off them into the lower parts of the valley.
5. The slightly off contour parallel lines should be gradual at 1:100 or even 1:300 rise over run.

Risks of keyline and swale techniques include, but may not be limited to (i.e., there are a few important considerations to keep in mind when installing a swale):

1. During very heavy rainfall, swales can overflow. If flash floods are a possibility, and to avoid erosion – you should include a rock-lined spillway to a lower swale, drainage ditch or catchment dam.
2. Pools of water in the swales may result in mosquitoes in warmer climates, it is recommended to mulch in the swale to reduce standing water. Also, planting of water loving ground covers help to stabilise the soil and absorb excess water
3. Swales can be adapted to almost any environment but may not be appropriate for areas with a high water table or on extremely steep slopes.
4. Swales are most suited for deep rooted perennial plant species, trees, bushes & nitrogen fixing ground covers where regular access for maintenance or harvesting is not required.
5. Swales have the potential to cause landslides in tropical volcanic highlands where thick soil and underlying non-porous volcanic rocks become oversaturated with water causing land sliding and flooding.
6. Rotting of plant roots is a possibility when there is excess water collection below the swale. Woody plants on the bank may be ok, but below the swale and on the berm itself, woody plants may develop rotting roots.

"Keyline" design and planning was first by Yeoman's initial article, which included the following order of operations:

1. Water - calculation of key points and keylines in order to aid placement of dams and irrigation channels. Placement and size is decided by the contours and the surrounding suitability of flood irrigation land.
2. Roads - Roads should not cut across contours as this interrupts water runoff flow. Generally, road placement should be along the top of ridge lines and elevated contours.
3. Trees - Trees are crucial to sloping land in stabilizing the soil, providing shelter from the elements and controlling erosion.
4. Buildings - Buildings are placed on considerations of comfort, aesthetic attributes and practicality.
5. Fences - fencing can be applied to correlate with the planned subdivision of the property based on its production requirements. Fencing should also be used to protect trees and dam access from damage by livestock.

#### *4.3.2.2 Natural swales and berms*

Swale and berm structures can be made by human earthworks and sometimes by natural means. Sometimes swale and berms structures (non-keyline if course) are made by organisms naturally on the landscape. For example, a landscape where termites build homes above ground, which then once unoccupied dissolve into the ground and overtop grows grass. A landscape may have many of these grassy mounds all over the landscape forming a natural swale and berm type system. These swale and berm structures generally only support water infiltration and do not direct the way as a keyline design would.

#### *4.3.2.3 Mounds*

*A.k.a., Berms.*

Mounds are earthen surfaces that rise above the terrain. There are many different type of mound constructions:

1. Pure earth mounds - Mounds made of earth taken from somewhere else and deposited on another terrain, shaped into a line with a curved (mound-type) profile.
2. Hugel style mounds - Hügelkultur is a German word that means hill or mound. In Hugel style means no-dig raised beds constructed from decaying wood debris and other compostable biomass plant materials, which effectively creates a soil mound with logs and other material inside. These mounds rise above the terrain. They hold moisture maximize surface volume.

**NOTE:** *Whereas mounds rise above, swales dip below.*

#### *4.3.2.4 Swale and berm design*

There is an optimal way to construct a swale and berm system given a particular landscape (Leigh, 2022):

1. Design planning considerations:
   - A. Ideal landscape - 15% of the ground surface covered in water .
     1. Ponds.
     2. Swales to transport water to the ponds.
   - B. Design the system of swales and ponds for water to move:
     1. By the longest path.
     2. Over the longest time.
     3. With the least amount of friction.
     4. "The farther you lead water, the more storage you have."
   - C. Placement
     1. Place first swale at the property's highest elevation possible.
     2. Typically 1.2 to 1.8 meters (4-6 feet) below highest points.
   - D. Begin the plan by marking the level contours of the property. This will determine the pattern of the ponds and swales.
   - E. Spillways direct water flow from higher to lower storage features and prevent overflow.
2. Sizing:
   - A. Depends greatly on soil and climate.
     1. Wider and shallower in sandy soils.
     2. Narrower and deeper in clay soils.
     3. Up to 6 m (20 ft) wide in deserts.
   - B. Should allow for slow water movement.
     1. Often, the slower the better.
     2. Should be able to walk the speed of the flow.
   - C. Should be large enough to not blow out the spillways.
   - D. Width.
     1. Can be anywhere from wheelbarrow width to roadway width.
     2. Should not exceed crown spread of fringing trees.
   - E. Examples:
     1. Small, front yard size - 20 inches wide and 8 inches deep .
     2. Large, pasture size swales - 1.2 to 1.8 meters wide and .457 deepn (4-6 feet wide and 18 inches deep).
3. Spacing:
   - A. Swales typically hold moisture 30-40 feet down the slope.
   - B. Distance between swales can be 3-20 times the swale width depending on rainfall.
     1. Large swales can be spaced 12 feet apart with average rainfall exceeding 50 inches.
     2. Large swales should be spaced 60 feet apart with average rainfall less than 10 inches.
   - C. On slopes, use height of trees to judge distance between swales, where berms are level with the height of the treeline below.
4. Sloping:
   - A. In general, the slope of a swale and berm structure should be 1% (as in, 1 meter over 100 meters or 1 foot over 100 feet).
5. Construction:
   - A. Built on contour (i.e., they are level to allow even distribution of water).
   - B. Equipment:
     1. Firstly, depends on size and budget.
     2. Can be dug by hand with shovels.
     3. Tractor with turn plow, scrape blade, subsoiler, disc harrow.
     4. Backhoe or excavator.
   - C. Ground can be ripped first with subsoiler, for the planned width of swale and berm.
   - D. Often dug into the subsoil.
   - E. Material dug from the swale becomes the berm.
     1. Berms not compacted or sealed (unlike pond walls).
   - F. Swale floor can be sloped to encourage water drainage in a particular direction.
   - G. Can be constructed to be backflooded by ponds.
   - H. Spillways to direct overflow to another swale or pond in a series.
     1. Lower than berm height.
     2. Can be packed clay, rocks, grass, concrete,

anything that won't wash out.

6. Planting:
   A. Berm planting
      1. Essential for the long term functioning of the swale.
      2. Seeded or planted on either side after an initial soaking of rain.
         i. Grasses for herbivorous grazing.
         ii. Perennial shrubs and bushes.
         iii. Trees.
            1. Some of the collected water is stored in trees.
            2. Planted in the berm or above the swale (not in the swale).
            3. Highly recommended in arid climates to shade and reduce evaporation.
            4. Roots increase absorption efficiency
            5. Leaf drop adds nutrients and organic matter to the swale.
   B. Swale planting:
      1. Since the topsoil is removed, the swale itself is not typically fertile.
         i. Soil can be left to accumulate organic matter.
         ii. May be planted with grass.
         iii. May be filled with mulch or gravel, or nothing.
7. Living Swales:
   A. Living swales are planted swales, not earthwork swales.
      1. Constructed on contour of dense, clump grasses.
      2. The grasses stop and retain overland water flow, similar to dug swales.
      3. Common in regions with shallow or rocky soils.
   B. Over time, earthwork swales will fill in with plant and runnoff debris, and the planted berms will create living swales.

#### *4.3.2.5 Maintenance of swales and berms*

Basic swale maintenance includes:

1. Inspect swale after storms to make sure that rainwater has drained and there is no erosion.
2. Remove sediment and debris from in and around the swale.
3. Inspect pea gravel diaphragm for clogging, and correct the problem (if applicable).
4. Re-plant grass if the original grass cover has not been successfully established.
5. Keep grass at the appropriate height.

Seasonal swale maintenance includes:

1. Rototill or cultivate the bottom of the swale does not drain down within 48 hours.
2. Remove sediment build up within the bottom of the swale.
3. Repair eroded areas (as needed).
4. To complement the swale's water harvesting abilities, couple them with annual subsoiling.

Risks of using swales incluide,

1. Do not construct a fence or structure within the swale.
2. Do not over-mow or mow shorter than 7.6cm.
3. Do not mow or allow animals to forage on swale after rain event.
4. Be careful storing material or debris in the swale.
5. Be careful filling a swale.

An example watershed coordination process is as follows:

1. Identify the contour lines.
2. Observe the land when it rains. Watch where the water comes from and where it goes. The harder it rains the more may be learned.
3. Area and rainfall will give you a good approximation of how much water you can collect from a slope (watershed) of known dimension.
4. Concentrate on one (1) watershed at a time.
5. Keyline plowing is for flat areas and gentle slopes. A Keyline "plow" is a specialized tillage instrument similar to a chisel plow or subsoiler. Note that keyline plowing can be done with a common chisel plows. All that is required is a toolbar with 3/4 inch wide knives 12 to 16 inches long spaced 2 feet apart. Very simple = not expensive.
   A. Plow along contour lines once yearly for the first 5 years. Thereafter, plow only as necessary to keep range land healthy. Subsoiling creates slits in the soil that channel air and water into the subsoil stimulating underground micro-organisms, reducing compaction to improve water absorption and downward root area, and overall, improving plant growth.
6. Wherever the watershed is large enough, build a dam to retain water for flood irrigation of pastures at lower elevations. Alternatively, it is possible to build pocket ponds ("tanks") with porous bottoms designed to trap and store water temporarily until it can soak into the ground and recharge aquifer.

#### *4.3.2.6 What can be done using swales and berms to produce food, fuel, and fiber in a pasture environment on a slope of up to and more than 50 degrees?*

The landscape can be terrain modified to include a contour line swale and berm perennial culture with grazing plants in the alleys between swale and berm lines. Contour the elevated differential landscape with swale-berm lines. Here, the alleys between perennial plants are for forage for gazing animals, relative to what type of slope they can handle, with some grazing animals being more able to traverse steeper slopes than others. These swale and berm rows/lines of plants are spaced up and down the hills with grass for grazing animals in between. Here, the swale and berm lines are on contour; meaning, this type of swale keeps everything level, such that the path of the swale moves along the contour, or elevation curve, of a slope. Doing this means that the water absorbs evenly into the land below as opposed to flowing to the lower end of the swale.

The berm sits on the downhill side of the swale and is the perfect place to grow trees and deeper rooting plants. The deep roots will keep the berm stable, as well as suck up the moisture from below so that the newly hydrated soil doesn't become overly saturated.

Simply, plant trees in rows, and the second row offset in a diamond grid pattern, and place a small berm on the lower side of each planting. Thus, allowing for the tree berms to slow the water down, and retain it for a period, allowing it time to soak to the roots.

There may also be hedgerows with grazing alleys in between contouring the landscape (a.k.a., contour hedgerows). The distance between each successive swale and berm (or hedgerow) structure contouring the landscape will likely depend on the slope of the hill.

> **NOTE:** *Specific types of trees and other plants grow well on slopes and help reduce erosion and increase water retention.*

#### *4.3.2.7 How to create a swale and berm structure*

The creation of a swale and berm structure on the landscape requires:

1. Diagrammatic planning.
2. Laser levels can help find the contour lines of a property.
3. Digging equipment to excavate and move earth.
4. Planting of plants in alleys, berms, and swales (where appropriate).

#### *4.3.2.8 Most common earthworks pattern*

The most common earthworks pattern found on holistically cultivated land is:

- Fence, alley, swale, fence, berm, tree, fence, alley, swale, fence, berm, tree, fence, alley.
    - The fence before the berm is placed just as the berm starts so that animals do not walk on the berm.

## 4.3.3 Landscape modification using plants (plant agriculture)

**READ:** *Planted-landscape cultivation planning.*

The plant ecological sub-system must be planned. Forage and fodder should be diverse and support a resilient food supply for animals. Gives animals a more diverse and healthy diet that is not only nutritious, but potentially medicinal. In essence, the design of a diverse cultivation offers animals a habitat that might resemble their "original" experience grazing in the wild.

#### *4.3.3.1 Identify the local biome and key plant species*

*A.k.a., Identify the plants, plant selection planning.*

The following are the steps for designing a landscape based on the local biome:

1. Identify the local biome (Read: zoning and bioming). A biome is a region on planet Earth that has similar plants and animals, similar rainfall patterns, and relatively similar soil types. Biome are also defined by the successional pathway that occurs in that region. Identify the hardiness zone.
    A. The concept of a **biome** refers to an ecological nich, which is a position or role taken by an organism within its specific ecological environment. An nich may be defined in part by what resources are available in a particular location. Or, it may be defined by what resources are there during a particular time of the day or season. Or, it may be defined by a particular successional phase.
2. Find the key species that produce food by selecting first woody and long-lived plants, then select the other plants, for the biome. Often, the trees, which exist in the biome the longest. The largest and most dominant species often set the rules for the site. In other words, plants that are there for the longest period of time (often, the woody plants, trees) change/color the site -- they chemically change it with their roots, leaves, etc. For example, an oak or beech tree planted site will only allow oak or beech tolerant species to live there. Plants that don't like oak soil, which is soil that an oak tree is growing in won't grow around an oak tree.
    A. Identify the available plants, selected for function in a given biome. Plants that are adapted to a specific set of environmental conditions are the most likely to be the best producers on that site. If it doesn't want to grow, let it die.
3. Imitate the system (the biome) and work with what grows best there.
4. For a perennial farm, plant many seeds and select the plants that behave the best for our intended purposes (i.e., cull the rest). Select genetics

optimized for pest free and disease free with no significant human inputs whatsoever.

In concern to an ecological nich (a biome), resources include:

1. Food
2. Water
3. Shelter
4. Reproduction sites.
5. Etc.

#### *4.3.3.2 Plant disease control*

It is possible to use both plants and animals to control diseases in plants:

1. Using plants to control diseases in plants
   - In restoration-type agricultural systems, it is often optimal to choose known pest and disease resistant varieties of plants. Then, do not spray chemicals to kill pests and diseases, and cull weak genetics. Use sexual reproduction to breed pest and disease resistant food plants, instead of poison immune pests.
   - Use other plants under taller plants to act as catchers of disease organisms.
2. Using animals to control diseases in plants
   - Animals can be used as a plant disease control system. Animals can be used to break the lifecycle of diseases that effect plants. For instance, diseased leaves (infected leaves) fall to the ground and lie on the floor until the conditions are right appear for the disease organism to spread itself. Having animals (e.g., cattle) eat the leaves significantly reduces the potential for future infections and the spread of the disease causing organism. Also, by using the animals to prune the lowest hanging leaves, and raising the lowest branches to a higher height, the likelihood of potential diseases is further reduced.

#### *4.3.3.3 Identify the success of plants*

Identify which plants should be placed on the landscape first, and which plants should be planted over time.

#### *4.3.3.4 Identify the spatial (location) and temporal (time) layout of plants on the landscape*

The design process involves spatial and temporal layout information. Each plant has an identifiable lifetime within which it has requirements for light and fertilization. Each plant's relationship amongst other nearby species ought to be considered, as well as its physical structure and the structure of its leaves. Each plant will fit somewhere in a three-dimensional model of plant stratification over a two-dimensional land area. For each plant, given its lifetime, it is necessary to account for the time it will take a plant to occupy its strata, at maturity, and its physical space.

It is generally best to select primarily perennial plants that work in that biome and will produce useful food (and/or useful materials), and then position those plants appropriately.

An example planting arrangement might include,

> *Daffodils at the base of the trees eliminate sod while repelling rodents and providing early spring nectar and pollen for bees and cutflowers. Iris between the trees also provide sod control while yielding cutflowers and tubers used by a skin-care products companies. Comfrey (large green leaves) is used by a medicinal herb company and accumulates potassium and calcium while providing overwintering habitat for predatory insects and substrate for morels. This collection of compatible plants is only a small part of the larger system which includes chestnut, grape, hazelnut, rugosa rose, Siberian pea and currants and pears, with seedless grapes. The pattern then repeats itself across the landscape.*

#### *4.3.3.5 Identify plant harvest data*

Important considerations for placing species along a harvest succession timeline would be:

1. Time until it reaches mature size. Identify the plant's lifetime.
2. Time until harvest. Identify when the plant will have a harvest.
3. Time until removal. Identify weak genetics or intentionally planned removals.
4. Time until pruning. Identify if the plant and/or environment requires additional cutting.
5. Time until flowering. Identify when the plant can be pollinated.
6. Time until fruiting. Identify when the flower will become a fruit and when the fruit will be ready for harvest.
7. Seasonal weather patterns. Identify weather conditions.
8. Plant coordination issues. Continuously monitor and observe the plants to ensure health.

#### *4.3.3.6 Identify the location for each plant on the landscape in 3D space*

> *A.k.a., Plant elevation categorization, plant stratification.*

Once the plant species table has been created, the next step is to identify the exact location of each plant on the landscape (if not using the random seed dispersal technique). A map should be drawn that shows the approximate location of every plant. Here, it is important to determine how all ecological niches will be filled and the number of plants that will be required to be installed in the system.

1. Plant location planning will (generally) need to take into account the harvesting of plants, and the safety and health of the habitat teams (i.e., workers). For example, planting a pricker-filled raspberry bush directly beneath an apple tree may make human harvesting of the apples more dangerous, may also make the pigs less likely to forage for fallen apples. In the case of human harvesting the apples, the humans may get cut, and raspberries would be unnecessarily crushed. The gap between plants may need to be considered if there is heavy automated machinery that will done any of the harvesting.
2. Plant location planning may need to take into account the placement of "special" category plants, such as those that have spikes. For example, raspberries are normally planted along the outside edge of one row. This is because raspberries produce spikes along the stems, and if they were to be planted throughout the system, it would be unpleasant to harvest other crops, and to harvest biomass.
3. Plants of the same species may need to be planted specific distances apart. And therein, consideration needs to be given to growth and the volume of area that will be taken up by the mass of the plant and the canopy, over time.
4. Often times it is optimal to place woody-harvestable plants in places where their harvest is simplified for humans and other animals.
5. Some tree species that drop fruit represent a potential danger to those passing underneath them. For instance, trees with fruit that could drop on someone's head must be considered for maintenance and/or positioned in an area where fruit drops are unlikely to hurt pedestrians. These plants (e.g., durian) can positioned near the riparian areas of the watershed area as that is a location less frequently traversed (due to agroforestry preservation techniques to preserve the watershed).

It is possible to identify a three-dimensional plant layering over the whole of the landscape. It is possible to classify common plant types according to their stratified position on the landscape and their requirements for sun. There are distinct vertical elevation levels (layers) over any landscape (from tallest to shortest; a three-dimensional solar collector stratification model can be established):

1. **The emergent layer** - mature, exceptionally tall trees. These trees emerge above the general level of the forest.
2. **The canopy layer** - typically, the most photosynthetically active layer (in a forest). The upper most layer of tree foliage.
3. **The understory (sub-canopy)** - in a closed canopy forest, where the branches of the trees are almost touching, the understory is composed of trees of trees with varying degrees of shade tolerant trees. Some of these trees may take over as canopy trees and others not.
    A. A mixture of plants as an understory planting may including, for example:
        1. Clover to accumulate nitrogen.
        2. Diakon radish, root crops, squash
4. **The shrub/bush layer** - likely to be comprised of shade tolerant plants.
5. **The vine layer** - these vines usually climb trees.
6. **The ground layer (the forest floor, ground cover)** - these are the most shade tolerant plants. Many ephemeral plants are located here. Ephemeral plants are those that have a rapid life cycle, and grow and set seed in a few weeks or months.
7. **The underground/rhizosphere layer** - plants that live primarily underground.

Different plants have the ability to thrive in different light intensities. Optimal placement of plants depends on the species requirements for sun (in relation to hemispheric location), which involve the following two broad categories (i.e., in concern to light exposure, there is a range, a spectrum, of plant types from those that require a lot of sun to thrive and those that require very little):

1. **"Sun loving plants"** - plants that do well in full sun. In general, these plants are placed on the south (northern hemisphere) and north (southern hemisphere) side of slopes. What plants like sun on themselves throughout the day? These most often include trees and grasses (note that even sun loving plants, like grasses can be optimized with some shade throughout the day to reduce leaf temperature).
2. **"Shade tolerant plants"** - plants that do well in shaded conditions. In general, these plants are placed on the north (northern hemisphere) and south (southern hemisphere) side of slopes.

Analysis and planning will have to occur to design an any given 3D spatial cultivation location/position, throughout the day and the year. The following questions must be answered:

- What is the sun intensity and angle of radiance on a plant's position, throughout the day and throughout the year?

The common plant types included in a stratified solar collection model include (note that some species in each of these categories are sun-loving and others are shade tolerant):

1. Tall and medium stature trees.
2. Tall and short shrubs.
3. Canes (e.g., raspberries and blackberries).
4. Vines.
5. Herbaceous non-woody perennials.

> **NOTE:** *It is often possible to maximize photosynthesis by laying out tree rows from north to south.*

For example, a holistic land pasture may be laid out with rows of edible woody plants with alleys between each row. For example, a one-hectare field may be planted with 18 rows of edible woody plants with a 7 meter wide alley between each row (Shepard, 2013):

1. Canopy layer A - 10 of the 19 rows are planted with canopy trees (e.g., chestnuts) planted 3.6 meters apart within the row.
   A. Understory layer - Within the row, beneath each tree, plant a row of upright small sized deciduous shrubs or bushes (e.g., red currant) 0.6 meters apart.
   B. Vine layer - Within each row plant one vine (e.g., trellised grape vine) on each tree.
   C. Ground layer - often perennial grass, and other producing plants.
2. Canopy layer B - 8 of the 18 rows are planted with medium trees (e.g., apple) every 7.3 meters with another set of smaller trees or shrubs (e.g., hazelnut bushes) planted as an understory every 1.2 meters apart.
   A. Understory layer - Bushes (e.g., raspberry canes) are planted on the south (or north depending on hemisphere) side of the entire row every 0.6 meters apart.
   B. Vine layer - Within each row plant one vine (e.g., trellised grape vine) on each medium tree.
   C. Ground layer - often perennial grass, and other producing plants.

The above spatial arrangement would result in a total for each hectare of:

1. 172 canopy trees (e.g., chestnut trees).
2. 68 medium trees (e.g., apple trees).
3. 416 understory shrubs/bushes (e.g., hazelnut bushes).
4. 832 bushes (e.g., raspberry canes).
5. 1040 bushes (e.g., red currant bushes).
6. 120 vines (e.g., grape vines).
7. A ground layer covered by grass and other food produced for humans and livestock.
8. An underground layer where food is produced for humans and livestock.

A highly simplified example could be:

1. Canopy high layer of oak, chestnut or beech.
2. Understory of cherries, apples, Hawthorne, plum.
3. A shrub layer is hazelnuts.
4. Raspberries and black berries as a cane fruit.
5. Grape vine currents around trees, and gooseberries in the shade.
6. Forage for grazing animals on the ground layer.
7. Tubers for foraging animals below ground layer.

An important resource for selecting plants based on their stratified location is:

- One Community Global: Food forest [onecommunityglobal.org]. *Note that this source is highly incomplete in concern to plants for animal forage.*

#### *4.3.3.7 Identify where plants can play a role in protection*

Protective strips/rows of plants can be placed over the landscape in order to:

1. Act as a fence and security.
   A. Predator protective plantings.
2. Act as path protection from rain and erosion (when placed along both sides of the path).
3. Act as erosion prevention.
   A. Anti-erosion plantings are made from vegetation with a developed root system: willow, acacia, poplar, willow. Such landings should be provided on steep slopes, slopes, embankments, hills. Landings are made along horizontal lines.
4. Act as a wind break.
   A. Wind protective plantings.
5. Act as shade from the sun.
   A. Sun protective plantings.
6. Act as a privacy break (e.g., around personal dwellings or common-personally scheduled quiet access areas).
   A. Privacy protective plantings.
7. Act as sound protection (e.g., around a common access pool area where children may be screaming.
   A. Noise-protective plantings are created along streets and highways from trees and shrubs with a dense crown. A good noise-absorbing effect is given by landings stepped in height, i.e.,

lower ones closer to the noise source.

#### 4.3.3.8 *Example holistic landscape apple tree planting, comparing inputs as expenses to inputs as yields*

The input agriculture system can create the next problem in the landscaped cultivation system. For example, apple trees generally do not like to have their roots in dense sod (i.e., dense grass). Conventional growers will use herbicide and organic growers will use mulch or tillage. Mulch, tillage, herbicide are all inputs (as expenses in time, labor, and/or materials). Whenever there are expenses, it is often possible to turn that expense into an output (or, profit in terms of the market). To reduce sod around an apple tree, for example, it is possible to plant comfrey, daffodils, and irises, which will out-compete the sod. The grasses will die around the tree, the daffodils will bloom 3 week before the apples do, so all the wild pollinators will already there (likely, the second generation of wild pollinators will already be there by the time apples bloom). Iris roots and comfrey greens can be harvested and sold, generally to a medicinal herb company. University of Madison research shows that the number one overwinting habitat for beneficial insects is underneath comfrey leaf debris, than compared to other plants. Another benefit of having daffodils at the base of the trees is that they are toxic to rodents, which reduces the likelihood of rodents nibbling the bark off the trees. Here, all yields are accomplishing work, instead of being expenses. Apple scab is one of the biggest fungal disease in apples, apple scab spores infect the leaves, the leaves fall to the ground, and the next spring, when a raindrop hits the leaf at the right temperature, the spore is released upward, hitting the lower foliage and then climbing up the tree. It is possible to have a natural pruning process for apple trees up to about four or five feet, using livestock. After the natural pruning, any leave that falls with apple scab, if a raindrop hits it, if it splashes up the live leaf height on the apple tree is too high up to become contaminated. Alternatively, agrochemical fungicides, which is an input-expense, could be sprayed to reduce the disease. Another natural method of scab control may be applied in the fall, after the apple tree leaves have fallen, move the cattle through to clear space for harvesting. Then pick the apples by grading and harvesting the fruit. While harvesting, throw all the "bad" fruit with insects in them to the ground. Then send through the pigs to clean up all the fruit on the ground.

#### 4.3.3.9 *Methods of planting a landscape*

*A.k.a., Selecting a planting strategy, planting a restoration agriculture pasture, how to plant a landscape.*

There are two primary planting strategies, one based on annual care and the other based on genetic selection:

1. **The plant and care strategy** - Plant a specific number of plants in specific locations and then care for their survival. This strategy is more optimized for an annual ecology. The general purpose here to plant and then to help the plants survive, when challenged, through extra inputs (e.g., compost tea, herbicides, fungicides, etc.).
2. **The genetic selection planting strategy (the observe and cull method)** - Plant way too many food-producing trees and shrubs in the early years. Remove the ones that don't bear at a young age. Continue to remove the ones that are susceptible to diseases and that are attacked by pests and continue to plant new seedlings and varieties year after year after year. Let the dynamics of population ecology kick in and let pest and disease populations stabilize. The cultivation wants the specific genetics that are pest- and disease-resistant and need very little care. This strategy produces a better perennial ecology. Plant more trees to start, and then cull 60-90% of the trees that aren't thriving. Forget about taking careful care of the plants. Practice strategic neglect (a.k.a., strategic total utter neglect) to see which genetics are best, then cull the rest.
3. **Succession method** - Plant species in a manner that follows the natural succession of plants in the area.

There are several ways to plant trees and other plants on a landscape:

1. In terms of locating:
   A. Placing - The location can be pre-planned and designed, and then the selected plants are planted in specified locations.
   B. Dispersing - The seeds can be scattered randomly and the plants will grow when they find the right growing conditions. This method creates patches of naturalized vegetation. This is also one method for selecting for better plant genetics; those genetics that don't thrive won't survive.
2. In terms of pre-growing:
   A. Direct seeding - placing or dispersing seeds into the ground soil.
   B. Transplanting - growing out the seeds in a pot and then transplanting them in soil.

Under the "plant and care" strategy mentioned earlier, it is relevant to note that when transplanting young trees (and other woody plants), there will be a much higher tree survival rate when the weeds are managed correctly. Weeds when unchecked and uncontrolled can take up moisture and nutrients from young trees, they can also produce compounds that inhibit the growth of the trees. Restorative farming uses symbiotic plants planted beneath the trees. Conventional farming uses herbicides that are compatible and listed for use with both the woody crop and the alley crop. If herbicides are not to be used, then light cultivation on either side of the tree row often works well. Additionally, organic mulches, when applied thick enough, can smother out weeds around newly planted trees as well as help to retain soil moisture. Such organic mulches often contain wood chips and sawdust. Straw and hay work as well, but not as well as wood cuttings. Note that straw and hay also tend to provide a habitat for bark-eating rodents, which is undesirable. Plastic mulches are sometimes used, but can increase the heat under the plastic and cause stress to the tree (in these cases, white plastic is often preferable to black). Geotextile and spun-polyethylene landscape fabric works as well. The textile and plastic products must be removed when their purpose is complete. It is relevant to note here that mulches represent quite an up-front investment in materials, labor, and cost. Rarely is mulch an option on larger plantings of several acres or more.

#### *4.3.3.10 Methods of genetic selection*

When initially starting a holistic cultivation system it is preferable to use seedlings (or seeded plants) and not grafted cultivars, because only the ones that thrive will survive (and, the others will be culled). Every seed is a genetically unique individual and the planter has no idea whether it will thrive or not under the local conditions. Grafted cultivars all have the same genetics. Individual seed genetics allows for the selection of those that rive and the culling of those that do not. Therein, buy in wholesale quantities and sell the rest to other farms or locations. Then, plant high density, close together (not 30 feet apart), then choose the ones that are performing well and cull the rest. Herein it is significant to note that soil tests will, essentially, always show deficiencies. However, there will still be plants that thrive under those conditions. Everywhere on planet earth there are plant communities that live healthy, vigorous, and vibrant lives and they show no deficiency symptoms in them. Yet, do a soil test anywhere, and everywhere it is done there are deficiencies. Everywhere on the earth there are plants that are site-adapted to grow there well. In this, humans can mirror and then improve upon an ecology. Identify a selection criteria for keeping, and if a plant doesn't meet the criteria then cull it. Plant seeds in nursery first, then when sprouted, plant them in an agroforestry row.

A common selection criteria may be:

1. Will grow very fast.
2. Will produce seeds within three to five years.
3. Will be pest free.
4. Will be disease free.

This produces perfectly site adapted plans with no major inputs:

1. No soil amendments.
2. No pest control.
3. No fertility control.
4. No disease control.

Repeat this selection, culling, and seeding process each year and over time the site will have a perfectly adapted perennial cultivation ecology. Once these site adapted plants are producing their own seed, then it may be useful to buy a grafted variety for its pollen. Every once in a while bring in variety.

#### *4.3.3.11 Plant protection from livestock planning*

There are circumstances where plants need to be protected from animals. For example, young trees need to be protected from foraging animals, which is often accomplished by means of fencing. Many livestock will damage young trees, or scratch or dig in the understory. There are breeds of livestock more and less compatible with a fully diverse herbaceous understory. A newly planted row of trees will need to be protected from animal foraging. Animals need to be stopped from reaching over the fence to forage young trees. Young trees need to be protected from foraging for 3-4 years. Note, however, that some trees (e.g., male mulberries) can be trimmed severely and the tops thrown to cattle, sheep, or goats to consume. Cutting male mulberries, for example, will not damage them like the female berry-producing plants, and will instead stimulate them to send up numerous shoots, which can be consumed by the livestock.

Animals can be rotated frequently to avoid hoof damage to tree roots. A portable two-strand polywire fence with a solar charger is all that is needed. For pigs, both strands are lowered to nose and ear height.

From the perspective of perennial grazing-adapted plants, the question is, how can livestock help the plants be healthier. Relatively short periods of occupation in a paddock so that are not grazing so long that not grazing the too short or re-grazing the plants as they are starting to grow necessarily. How long do plants need to regrow. This statistic is not fixed, and livestock should not be reintroduced until the plants have reached the right growing stage. This requires constant observation and monitoring. Develop a plan, then assume you are wrong, because the landscape can go off-tack with the plan and the plan will need to be adjusted. Coordinating a dynamic (constantly moving) biological system requires real-time adjustments.

### 4.3.4 Landscape modification using trees (agroforestry)

**READ:** *Agroforestry cultivation planning; woody-plant cultivation.*

Trees should match the soil type and microclimate and have multiple functions. Therein, agroforestry is farming that incorporates trees and/or woody plants in a regenerative manner. Agroforestry is the general process of re-wooding (adding woody species to) an environment successionally in order to change an annuals-based landscape to a perennial cropping system. Agroforestry is a set of food-forest intercropping cultivation techniques that combines agriculture, pastoral, and forestry techniques in one area. Note that trees and shrubs are considered part of the forestry system. These techniques are sometimes used to transition from an annual to a perennial cropping system. Agroforestry may also be considered transitional because it includes (or, commonly includes) annuals, and is not made-up completely of perennials. Agroforestry is used to describe a set of agricultural practices in which woody plants, especially trees, are integrated with annual crops and/or livestock on the same piece of cropland. The intentional inclusion of woody plants (Read: forestry) is to modify, to varying degrees, the local microclimate. Changes to the landscape often cause microclimate modifications, which can be intentional planned. In concern to restoration agriculture, agroforestry represents a transitional system that helps transform an annuals-based commercial operation to a more perennial (or, completely perennial) system. In other words, agroforestry may be used to bridge the gap between commercial annual and perennial cropping systems. Annual crops will always have a yearly or seasonal planting "cost", or at least require more energy and resources, more inputs, than a perennial polyculture. Annual agriculture is, in general, hostile to animals, by humanity, for their production, having to necessarily exclude and/or exterminate them to maintain the annual crop.

The first step in the agroforestry transition is the planting of trees, often in rows (curved or linear), and the alleys are used for growing annuals. Then, once the trees become established and are producing forage, the alleys are converted from annual crops to perennials (with a lot of grass, but also many other forage and perennial crop plants) and livestock are introduced. In a restoration agriculture system, as opposed to a pure agroforestry system, the landscape is "managed" by the grazing animals. In a restoration agriculture system, the animals do the mowing, the animals do the fertilization, and the animals do the pest control. A lot of the inputs that are required for regular agriculture are completed by the livestock or other natural processes. Soil on planet earth is created by perennial ecological system, so it is important to design an agriculture that is a perennial ecological agriculture, which is what restoration agriculture is all about. An within that context, some annual agriculture can still be done using alleycropping (an agroforestry technique). Agroforestry methods are relatively simple and universally applicable in nearly all regions of the world. It is relevant to note here that woody crops can take several years to become fully established and the tree-crop system must be designed and managed so that both the trees and the crops gets sufficient water and nutrition.

Woody plant selection includes the following functional considerations:

1. Microclimate modification.
2. Nitrogen fixation.
3. Food for livestock.
4. Harvestable products.
5. Functional biodiversity
6. Conservation.
7. Aesthetics.
8. Woody plant must be adapted to the climate, site, and soil.
9. The establishment time of the plant.
10. Interaction with crops and/or other plants (e.g., shading, root habits, nitrogen fixation).
11. Pruning

Woody plant selection and placement for light availability includes the following considerations:

1. Placement and distance from one another.
2. Row orientation (if planted in a row).
3. Alley width (if using alleycropping).
4. Leaf canopy characteristics - trees with different heights and different canopy structures will cast different amounts of shade and alter the microclimate in different ways.
5. Leaf phenology - when do the leaves leaf out (i.e., produce leaves) and when do the leaves drop?
6. Pruning considerations.
7. Protection considerations - protection from livestock, especially when young

It is important to consider below ground competition for water and nutrients, and such considerations include, but are not limited to:

1. Alley width.
2. Root distribution.
3. Root pruning (e.g., tillage, subsoiling, etc.)

In agroforestry, trees are commonly arranged in the following ways:

1. In rows.
2. In grids:
   A. Linear grids.
   B. In a diamond shaped grids.
3. As contours.
4. Dispersed randomly.

There are two basic types of agroforestry systems:

1. **Agro-silvi-cultural system** - a system that combines trees with crops.
2. **Silvo-pastural system** - a system that combines trees with livestock.

3. **Agro-silvo-pastoral** - a system that combines all three (trees, crops, and livestock).

Agroforestry practices/techniques include, but are not limited to (note: these practices can be combined, and their applications usually overlap):

1. **Erosion reduction** - trees can reduce water and wind erosion. For example, trees placed along the side of a road/path to reduce water erosion on the path. Trees can be placed on slopes to hold soil together and reduce erosion on the slope.
2. **Windbreaks** - row(s) of trees (or woody plant). These linear plantings of trees or shrubs are intended to mitigate the effects of the wind. Simply, Windbreaks are plantings of trees and shrubs designed to enhance crop production, protect livestock, people and structures, and benefit soil and water conservation. Windbreaks can be made of varying densities, allowing for more or less penetration. Additionally, windbreaks can be made of taller or shorter trees, involve a single or multiple rows. Windbreaks are often, though not always, made using evergreens or deciduous trees (or a combination). Evergreens are more impenetrable than deciduous trees. More widely spaced deciduous trees would be more suited for breaking up a driving wind and for scattering snow more widely. Windbreaks are often, though not always, linear in structure. Windbreaks interact primarily with wind patterns. Windbreaks can have the following benefits, including but not limited to:
    A. Research suggests vegetable crop yield and quality can be increased through the effects of windbreaks (Baldwin, 1988, Agriculture, Ecosystems & Environment)
        1. They can help to prevent desiccation in field crops.
        2. They can prevent mechanical crop damage from wind-thrash and wind-throw. Here, they can also prevent the sand-blasting of delicate field crops (e.g., eggplants, melons, peppers, and squash).
    B. They can help prevent wind-generated soil erosion (i.e., are a form of wind erosion control).
    C. They can be used to protect buildings from wind-related damage and reduce winter heating costs.
    D. They can create pleasant spots for human recreation.
    E. They can be used to reduce wind-induced stress in livestock.
    F. They can be used to block the line-of-site views, odors, and noise.
    G. They can help to prevent chemical drift (as well as leaf and soil drift) in either direction, either from the site in question and from external sites (i.e., prevent chemical drift coming onto a site from outside). Trees planted as windbreaks for the reason of chemical drift are sometimes called sacrificial trees. Inexpensive, fast-growing, expendable trees like poplars good for this purpose.
    H. They provide a wide diversity of habitats for numerous beneficial organisms from the obvious nesting sites for birds to the not-so-obvious alternative pollen sources and homes for native wild bees.
    I. When planted along roadsides or driveways windbreaks can act as snow fences that reduce the need for snow plowing due to a reduction in snow drift accumulation (i.e., are a form of snow dispersal control). Multiple rows of trees can be used to catch snow in between them.
3. **Riparian buffers (a.k.a., perennial riparian buffers, riparian forest buffers; i.e., woody plants bordering a body of flow of water)** - Riparian buffers resemble windbreaks in that they are used to interact with an energy flow. Riparian buffers interact primarily with water patterns (not water streams, but overland water flow). Riparian buffers are often, though not always, linear in structure. These buffer zones act as mechanical filters and biological sponges. Buffer plants provide wildlife habitat and can attract pollinators. Runoff from the waterway or water body is filtered through the riparian buffer, which keeps nutrients and agricultural chemicals from washing into the water. Additionally, the perennial vegetation in a perennial buffer strip decreases velocity of water, increasing infiltration. Note that as the velocity of the overland water flow decreases, suspended particles often begin to settle out, the riparian buffer captures and accumulating soil. Perennial plants planted in riparian zones can tolerate being under water for weeks or months. With adequate water, nutrients and accumulating topsoil, riparian zones have the potential for higher yields than upland agricultural fields. An example riparian zone strategy may be to plant five or six rows of hazelnuts along the sides of a smaller stream.
    1. Note: Riparian zones are the area of land along the edges of bodies of water. In other words, a riparian zone or riparian area is the interface between land and a river or stream. The width of a riparian zone, immediately adjacent to any body of water, depends to a large extent on the size of the water body. Riparian areas are often flood zones.

2. Riparian buffers have the following benefits, including but not limited to:
   i. They help protect water quality.
   ii. They reduce soil erosion.
   iii. They provide unique plant growing environments.
   iv. They provide habitat for aquatic and semi-aquatic organisms and other terrestrial wildlife.

4. **Alley-cropping (a.k.a., alleycropping, keyline alleycropping, silvoarrable; i.e., rows of woody plants separated by non-woody crops)** - the cultivation of food, forage or specialty crops between rows of woody plants (e.g., trees). In other words, it is the growing of a row of trees or shrubs (or both, and potentially other plants) in between annual or perennial crop fields. Annual crops can still be planted in the alley cropping system. Note here that the row of woody plants will create a windbreak and will add additional shade to the land. It is a larger version of intercropping (planting two or more crops in close proximity) or companion planting conducted over a longer time scale. The alley width should be at least the width of the widest cultivation/harvest machinery (if machines are beings used to harvest crops in the alleys). In the case of annuals planted in the alley, for the most efficient number of passes across a field, alley widths should be in multiples of two times the width of the equipment being used. The tractor travels up the field then back, up then back, however many times it takes to reach a desired width. The trees that seem to do the best in alley-cropping systems are trees with taproots. Such trees do not have a shallow mat of roots to get compacted and damaged by equipment and they don’t "steal" as much water and nutrients from the crop. Another technique to prevent nutrient theft is to drive a subsoiler along the row of trees every year from the very first summer after they are planted. This clips any young roots that attempt to go after the crop nutrients. Subsoilers can cut back roots extending into the pasture that would otherwise take nutrients away from alley crop. It keeps roots within the tree row and encourages them to dive deeper, instead of spread wider. If the tree is not subsoiled when young and is only subsoiled after the tree has grown large and the tree roots are much bigger, then the tree could suffer from all kinds of decay pathogens as well as it will not be as wind-fast (i.e., secure from wind). Root prune the alley cropped trees every year beginning in year one. If automated harvesting machines are to be used in an alleycropping system, then there must be sufficient space between woody plants for the machine to harvest nuts and/or fruits. Significant considerations for alleycropping systems include:
   A. The shade density of the mature trees.
   B. The number of trees planted per row.
   C. The orientation of the trees. In a restoration agriculture system that has first installed a keyline water management system, the rows of trees would parallel the keyline. Instead of straight, rectilinear rows of trees, the trees would sweep along (or, near) contour; thus, revealing the natural shape of the landscape as it relates to water. Including, the location of shrubs and bushes
   D. The potential benefits of alley cropping include, but are not limited to:
   E. Improved microclimate conditions for crop growth.
   F. Increased diversity of cultivation system.
   G. Enhanced nutrient cycling and availability.
   H. Improved soil quality and reduced erosion.
   I. Increased functional biodiversity (e.g., improve pollination services, improve resistance to pests and diseases).
   J. Watershed protection and an improved hydrologic functioning (through action of woody plant roots and a larger canopy).
   K. Enhanced ecosystem services.

5. **Silvopasture (a.k.a., agro-silvo-pastoral; i.e., trees, woody forage plants, and livestock together)** - the intentional combination of trees, forage plants and livestock together as an integrated, intensively-managed system. In its most simple form, silvopasture is the planting of trees in a pasture. Trees reduce heat stress for livestock, increase their well-being, and provide fodder in times of scarcity. There are three general components to a silvopasture:
   A. Trees.
   B. Forage for the livestock.
   C. Livestock.

   Note here that allowing livestock to graze in the woods is not silvopasture and will likely result in inadequate nutrition for the animals and damage to forest regeneration. In general, these trees are cropping trees (i.e., harvest yielding trees, trees that produce crop) perennial woody cropping systems. Because of woody plants land becomes partially shaded by cropping trees. Trees produce food for people and foraging animals. Trees protect the slips from erosion. The general goal of a silvopasture is to have trees evenly spaced across a landscape.

It is relevant to note here that when livestock crowd around one or just a few trees for extended periods of time the tree can suffer from overfertilization, the grass around the tree(s) will likely die, and root damage can occur. The ideal shade cast by the trees over the landscape is between 40-60% of the landscape being shaded. Moderate shading can reduce leaf temperature and transpiration, without reducing net photosynthesis in many plants (Diaz-Perez, HorScience, 2013). Livestock move through the pasture and always have sufficient shade. There is no need for the livestock to bunch up under one or a few trees when the shade is evenly spread. To turn a pre-existing forest into silvopasture requires clearing out the underbrush, removing undesirable and invasive species, opening up the canopy to let more light down, establishing shade-tolerant grasses, and grazing livestock. In silvopastures it is often best to plant deeply rooted trees. Trees with shallow roots can potentially suffer excessive root damage from animal trampling. Also, shallow roots can remove moisture from forage crops. It is relevant to note here that in most commercial silvopasture operations, livestock are the primary cash flow, and thus, high-quality forage production is the primary concern.

6. **Forest farming** - the intentional manipulation of the forest canopy and ground layer in order to improve the forest stand and to create ideal conditions for an intensively grown, shade-tolerant crop. Note that forest farming is slightly different than forest gardening which is generally defined as the cultivation of a diverse, multi-layered system of useful woody plants are vertically integrated one on top of the other. Forest farming takes place in a closed-canopy, or nearly closed-canopy forest. Grasses and livestock forage require at least 40% light in order to thrive; however, typically forest farming takes place in forests with higher density and where the shade is more than 60%. Grasses, generally, do not thrive in this type of environment. Alternatively, other types of plants will thrive in a densely shaded environment, such as ginseng, goldenseal, gooseberries, currents, and fungi.

### 4.3.5 Landscape modification using animals (animal agriculture)

*READ: Livestocked landscape cultivation planning.*

The animal ecological sub-system must be planned.

#### *4.3.5.1 Identify the animals*

*A.k.a., Animal selection planning.*

Animals are matched to land type and stage of succession.

Identify and select the animals:

1. The animal species to include with the local biome, given the environmental conditions and succession of plants.
2. How many animals, and how many of each type, to include.
3. When to include them (e.g., when they have sufficient forage).

There are two important terms in rotational livestock grazing:

1. **Stocking rate** is the overall number of animals on the farm.
2. **Stocking density** is the number of animals in a specific paddock at a specific period of time.

Stocking rates (animal density) - identifying how many animals should optimally be on the pasture. The stocking rate is significant in concern to overgrazing in two ways:

1. Overstocking a pasture with one type of livestock, and not rotating them to new pasture, will lead to overgrazing. Overstocking can degrade pastures by removing more living plant matter than can regenerate before the next round of grazing.
2. Understocking a pasture can also lead to overgrazing. When few animals eat only their preferred forage and leave less palatable forage as well as noxious weed , as the season progresses the undesirable forage goes uneaten and slowly grows stronger and more woody, and sets seeds. This eventually produces a pasture full plants undesirable to the animals. By allowing the animals to eat only their preferred forage and not removing the unpalatable plants, only a few animals can destroy a previously abundant pasture. Understocking can degrade pastures when not followed up by finish mowing or grazing with other animals in order to prevent undesirable plants from proliferating and setting seed.
3. Set-stocking (continuous grazing, extensive grazing) is leaving livestock in the pasture for the whole year.

When the forage quality is high it will support more animals. More animals provide more fertilizer, in the form of manure and urine, to the plants. However, too many animals clustered around one or a few trees for too long can damage the tree and landscape.

The common sources of overgrazing include:

1. Overstocking a pasture - too many animals.
2. Understocking a pasture - too few animals.
3. Not rotating animals - the animals are never rotated to new paddocks/pastures.
4. Placement of water, shade, and supplemental food - placement of a water, shade, or food source in a field may cause the animals to graze close to the source, thus causing overgrazing in that area.

Overgraze of animals causes of land degradation and desertification. Degradation of land from overgrazing is used by proponents of animal confinement operations as a propaganda tool to eliminate the small graze or rancher as competition in the food markets.

#### *4.3.5.2 Identify animal succession*

Identify which animals should be placed on the land first, and the succession of animals (i.e., their introduction) over time.

#### *4.3.5.3 Identify the functions of the livestock*

There are several key functions that livestock can perform on a landscape, these include:

1. Site preparation
2. Tillage
3. Mowing and grazing
4. Insect control
5. Weeding
6. Picking up harvest drops
7. Fertilization (with manure)

#### *4.3.5.4 Identify how many paddocks*

For all methods but continuous grazing, a whole pasture is subdivided in paddocks. A good start may be to subdivide the 1 pasture into 14-15 paddocks. Then, for example, in a mob-stocked, intensive grazing system with cattle, the cattle would only be in each paddock for 1-2 days. Thus, giving 1-3 weeks of rest per paddock.

#### *4.3.5.5 Identify the animals movements (animal rotation planning)*

Identify the daily or cyclical movement of the animals through the pasture or paddocks. The observing intersystem team cultivation member ("farmer") should observe and apply a set of grazing rules dependent upon the observation. A good general grazing rule is: by the time the last livestock species vacates a paddock, there should be no odd patches of ungrazed plants. Pastures recover more evenly and require less finish mowing when they are evenly grazed. In general, the ideal movement of livestock is to have them eat all of their possible first bites, or all of the plants that are intended to be eaten, and then move them to the next paddock.

#### *4.3.5.6 Animal paddock movement*

Movement considerations for animals ought to account for plants and changes in plants over season and year:

1. Changes in the [plant] systems during a single season.
2. Changes in the [plant] systems through the years.

There are many different ways of rotating multiple species of animal [in a leader-follower procedure] around a set of paddocks. In other words, there are many different arranges of leader-follower system.

#### *4.3.5.7 Simplified example of landscape modification using animals*

A simple example may be a to start with cattle. Cattle are the first because they are the pickiest (i.e., fussiest) grazers. Sheep and goats can follow behind grazing on the remaining lush forage, but most importantly cleaning up the re-sprouts and will also eat less desirable and more woody plants, even plants that are toxic to cattle (e.g., larkspur and leafy spurge, are readily consumed by sheep). Pigs can follow behind everyone grazing the "second bites" that the others ignored. When early "fall" fruit drops, hogs are the perfect way for a farmer to take the normally unharvestable wild fruit and nut crops. Also, cattle, sheep, goats and hogs all love to eat the leaves of various woody plants.

A more complete example of a rotational leader-follower grazing system:

1. **Start with cattle.**
   Cattle are grazers, and prefer longer grass; they will tend to not eat grasses too low to the ground if possible. Intentionally plant feed species for cattle foraging. Grass is the top feed species for grass. Grass comes relatively early on in the process of natural plant succession. Also, cattle are almost the fussiest grazers desiring the highest quality forage. Cattle graze by taking a bit from the top of the most nutritious pasture according to their needs. They will then move on to the next first bit, and so on until all of their preferred pasture has been bitten. They will then move back over the pasture and take the next bite down the stem, moving into less and less nutritious forage. In the simplest leader-follower example, young cows (calves) are moved into a paddock first; they have the highest nutrient demand of any cow life stage and will take the best of the best pasture bites. Once the young have grazed their first bit for the whole pasture, and before they begin the second bite stage, they are then moved on to the next pasture where they can continue to graze the most vital and nutritious feed. Lactating cows are then moved into the pasture that the calves have now vacated. This system allows for optimal weight gain in the calves

and will not reduce milk production in the lactating cows. The system can be refined even further. The calves can be grazed first, and the cows can be divided into two classes based on their production. The heaviest milk producers can be moved into the pasture behind the calves, then the lighter producers behind the heavy producers. Dry cows can follow behind. This grazing system matches pasture growth. On a pasture, first bites are the smallest portion of available feed. This matches with the smaller size and high nutrient needs. Older cows require more bulk and dry matter in their diet, which matches what is available after the leaders move through.

Simply put, one or more waves of cattle have grazed through it first, with the calves eating the tips of the most nutritious plants, the best cows taking the second bites, lower-producing cows taking the thirds, and dry cows the fourths.

2. **Hogs (pigs) follow the cattle.**

Pigs eat almost anything (not brush or thorny plants), and with their snouts will turn over the soil in search of roots and grubs. They also have the helpful habit of eating the roots of invasive species, which eliminates the need for herbicides. Intentionally plant feed species for hog foraging. Once the cattle have moved through the system, then the pigs are moved in. Pigs are a broadly omnivorous animal. and use hogs with nose rings to prevent rooting up the pasture. Naturally, when pigs are turned loose in a forest, they will root up the ground and destroy forest seedlings. When left to themselves, they graze green forage, but they prefer to root through the ground to graze plant roots, grubs, and worms. In season, they eat dropped fruits and nuts. Hogs are used for pest control when they graze through the cultivation system to harvest the pest infected "June drop", and after harvest, when they eat the pest riddled fruit that pickers toss on the ground. Pigs will also sometimes eat snakes, rodents, and ground nesting birds. Pigs often disturb the ground more than other animals and this soil disturbing behavior can be used just prior to planting grain/grass seed crops for when the cattle return. Pigs should not be allowed to diminish forage health by rooting it all up. In order to do this, nose rings are recommended. One nose ring across the columella (the fleshy part between the nostrils). And another into the tip of the snout. The procedure is painful when performed (like when a human gets a piercing), but the pigs stop complaining after the procedure is complete and it causes no long term damage to the animal. Note however, when the pigs try to root in the ground the ring will cause discomfort, thus teaching them to graze for food more than rooting. Some breeds of pig learn more quickly than others. Insertion is best done immediately after weaning or as soon as feeder pigs are received on the farm.

Note: With a "pigs following cattle" system a rule of thumb would be to have no more than two mature pigs per adult cow. Fewer than two pigs per cow works just fine. With too many pigs they'll not have enough leftover forage to thrive, they will get hungry and begin to break through electric fences. Pigs are incredibly intelligent animals and once they learn that it only takes one zap to run through an electric fence, they will do exactly that if they are not getting enough to eat in their paddock.

Note: Different breed of pigs root to differing degrees; some pigs root more (or less) than others. Some breeds of pig do almost no rooting.

Note: Plant small grain or preferred crop for when the cows come back on rotation.

3. **Turkeys (and other fowl) follow the pigs.**

Intentionally plant feed species for fowl foraging. Once the cattle have grazed off their first two bites, and after the pigs have cleaned up behind the cattle, turkeys are an excellent choice to follow. Turkeys will nibble grass and forbs and there will be some left for them, but they prefer to eat big seeds and insects. Turkeys will eat the insects attracted to the dung left behind by the larger grazers as well as any seeds that may have passed through the gut of the animals that went before. They will scratch around in the grazed and trampled debris in search of beetles, caterpillars, worms and large seeds. Many pasture "weeds" that don't provide the best forage for cattle and pigs have large seeds. These large seeds will be eaten by the turkeys and ground into manure in the bird's gizzard.

Turkeys (and all fowl) are also a great way to introduce mineral amendments to the pasture in a low-cost manner over a period of time. To have a high-yielding pasture, whatever minerals are low can be placed in a mineral feeding box and dragged from paddock to paddock with the turkeys.

Note: Coarser-grit minerals are often times less expensive than the finer particle sizes of minerals simply because less milling time went into their production.

As the turkeys graze the pasture they are ingesting the spectrum of minerals available in that pasture. They will be internally deficient in whatever minerals are deficient in the pasture soil. All fowl instinctively will pick at the grit that supplies them with the missing ingredients that they need. The grit gets ground to a fine powder in their gizzard, it gets acted upon by the bird's digestive acids and enzymes, and what isn't used by the organism itself gets defecated onto the very pasture that needs that very mineral.

Turkeys, especially the more intelligent, heritage breeds, are quite low maintenance and only one flock need be raised all during the summer grazing season.

The turkeys really aren't that much of an impact on the pasture itself, and so the green growth begins to rebound.

A good rule of thumb is approximately two turkeys per hog is an adequate number.

4. **Sheep can follow the fowl.**
   Sheep are also grazers, but they prefer shorter grass, and tend to clip the grass low to the ground. Sheep, like goats, are especially good for eating more coarse vegetation than cattle and thrive. Sheep are the finish mower of animal polycultures. Intentionally plant species for sheep (as well as use sheep to clear out weeds).
   With little else to eat the sheep happily graze on these broadleaf plants. Over time these weeds will become less and less prevalent in the pasture thereby providing weed control as a side benefit of the grazing system.
   Generally the pasture has the same number of sheep as there are cattle.
5. **Goats can follow the fowl.**
   They are without a doubt the animal that is able to produce high-quality meat and dairy products on the coarsest, most degraded forage. There are loud breeds of goats and there quiet breeds of goats.
   Note: Archaeologists, anthropologists and historians have discovered evidence over and over again that goats are the last seral phase before total desertification. Over time, as pastures degrade, fewer and fewer cattle can be maintained on the pasture and sheep and goats are then kept. If pasture quality is not maintained and the forage is overgrazed or incorrectly grazed, cattle and hogs give way to sheep and goats which give way to a desert. (Restoration Agriculture, 82)
   Goats will jump fences, easily.
6. **Chickens can follow the sheep/goats.**
   Following the sheep come fowl. Chickens scratch apart manure piles in search of grubs and maggots. This behavior not only spreads fertilizer on the fields, but also contributes to the desiccation and death of parasites, as well as providing a natural control of insect pests such as flies, ticks and fleas. As the chickens move through the pasture following the sheep, they scratch up any remaining manure from the "leaders" ahead of them searching for insects and seeds. If no supplemental feed is provided then fewer chickens can be supported. Wherever fowl mobiles are placed there will be a lot of high nitrogen manure deposited. It is good to part these mobiles in different locations on the paddocks through time to really spread out the manure. Intentionally plant species for chickens. Obviously the fowl will put manure throughout the rest of the paddock too, but with an open bottom mobile, a lot of manure will be deposited under the mobile.
   Chickens come in three general types:
   A. Egg layers.
   B. Meat birds.
   C. A combination of the two.
7. **Geese can follow the sheep/goats.**
   Intentionally plant species for geese. Geese have a special role in managing the understory of a food forest. To my knowledge they are the only species of livestock which eat only grasses and clovers, while leaving other crops alone. In the wild, geese are migratory birds. The eating habits of geese are similar to sheep. Geese graze on broad-leaved plants, insects, fruit and nuts, and are good for following turkeys. Fencing that is set up for pigs and turkeys will also contain geese without any adjustment.
   Characteristics about ducks and geese:
   1. Ducks and geese need a pond.
   2. Ducks and geese are best not kept with chickens. This is mostly for cleanliness reasons, unless there is sufficient land and water space.

# 5 Holistic cultivation masterplan

*A.k.a., Restoration agriculture masterplan.*

A holistic cultivation plan for a the creation and operation of a pasture-based rotational of animals with a succession of plants, including terrain modification (e.g., earthworks) and terrain operations (e.g., a pond network and animal rotation). We are looking to create a rotational pasture grazing system with a combination of the following animals: cows and bulls, goats or sheep, pigs and ducks. We are open to other animals. In terms of 3D plant succession, we are looking to have someone help us plan out a 3d plant succession landscape where the animals will also forage and we can collect an abundance of food, fuel, and fiber. The plants consist mostly of perennials that produce food, fuel, and fiber. The plants may need to be protected as they grow in the pastures from the grazing animals. This 3d temporal planning of the plants must include sun shading-specific categories of plants: trees, shrubs, vines, ground covering, and underground. We need to plan out the pasture lot areas, the number of pastures, dimensions of pastures, and types of plants and water features in each pasture. We need to plan the rotation of animals through the pasture, given that pasture conditions may change and thus affect animal rotation (there must be a start, and best practices to follow afterward). We also need to do earthworks and terrain modification to improve water infiltration and retention for the animals. Other earthworks may be required, such as sub soiling, etc. We estimate that 65% percent of the land is on hills of many different degrees. Some are slightly over a 40 degree slope. The initial land area is 78 hectares. There are three reasonable size ponds on the landscape and about 5 streams. There are currently 42 cattle on the land, being rotated around the pasture area of the 78 hectares (not all of which is pasture area).

The phases of the development of the masterplan include:

1. Needs analysis.
2. Site analysis and assessment (biophysical site assessment).
3. Design concept.
4. Detailed design.
    - A. Drawings.
    - B. Lists.
    - C. Procedures.
    - D. Written descriptions and explanations.
    - E. Calculations.
5. Implementation and evaluation.

Simplified version of cultivation system development:

1. Keyline water/hydrological terrain modification.
2. 3D succession planting.
3. Mob animal rotation.

The detailed design deliverables requires in order to implement the holistic cultivation masterplan include:

1. Pasture drawings:
    - A. Pasture landscape drawings and plans:
        1. Rocks plan - soil re-covering plan (i.e., cover the rocks with soil).
        2. Water design plan (keyline design) - spread water from valleys out to ridges.
        3. Pasture perimeter fence - Pasture for aminals as one fence around a perimeter(s).
        4. Paddock fences - Paddocks for animals and rotation (determine paddocks on landscape).
            - i. Paddock fences.
    - B. Livestock pasture support drawings and plans:
        1. Water.
        2. Food.
        3. Shelter.
2. Organism Lists (fill-in Organism Cultivation Lists):
    - A. List of plants.
        1. Plant cultivation list.
            - i. Name of plant:
                1. Perennial and annual.
                2. Genetics.
            - ii. Spatial:
                1. Location of plants (determine placement of plants on landscape).
                2. Location requirements (including but not limited to: light, nutrients, water). Must account for:
                    - a. Soil type.
                    - b. Water availability year round.
                    - c. Heat and cold.
                    - d. Terrain.
                    - e. Human preference.
                3. Quantity (number of).
                4. Polyculture grouping (including, allelopathy accounting).
                5. Plant protection requirements (fencing, fencing type, fencing duration).
            - iii. Temporal:
                1. Success of plants (determine succession of plants on the landscape). Growth of plants over time (producing shade coverage).
                2. Plant production over time (producing fuel, fiber, and food for the livestock and humans).
            - iv. Expected production over time.
    - B. List of animals.
        1. Animal cultivation list.
            - i. Animal type and genetics.
            - ii. Food requirements (including area).

            1. Light requirements.
            2. Temperature requirements.
            3. Terrain requirements.
        iii. Life duration.
        iv. Quantity (stocking rate; number of).
3. Organism drawings:
    A. Drawings of plants.
        1. Draw the location of plants on the landscape when full sized (and how many months/years until it reaches that point). It is also possible to show:
            i. The change in dimensions of the plant as it grows.
            ii. The likely harvesting dates into the future.
        2. If there is succession, draw the succession of plants as 'layers' (i.e., overlays).
    B. Drawings of animals.
        1. Draw the animals and their location(s) over time.
4. Procedures:
    A. Steps in procedures for creating the cultivation system.
    B. Steps in procedures for operating the cultivation system.
5. Written:
    A. Descriptions of primary cultivation systems.
    B. Explanations for selections of:
        1. Plants.
        2. Animals.
        3. Terrain modification.
6. Calculations:
    A. Formulas.
    B. Sources of data.

Design considerations include, but are not limited to:

1. Woodland (forest) thinned to allow light to the under-story for pasture establishment.
2. Young trees fenced from livestock and guarded against other wildlife.
3. Periodically trample grass or mulch around young establishing trees.
4. A 3 meter or more buffer zone from sources of running water.

Determine the rough location of where to place the following objects/structures throughout the landscape:

1. The swale and berm or terrace structures across the sloped landscape.
2. Retention ponds and spillways over the landscape.
3. The paddocks and animal corridors between paddocks (if there are any).
4. Agroforestry silvopasture restorative line polycultures. In other words, determine where to put lines of perennial plants selected to be in that location under account of their height and shade tolerance.
5. Fencing to fence in animals into paddocks and to fence off trees to protect them from animals.
6. Human waste processing pond network.
7. Structures/buildings for animals (including in pastures/paddocks):
    A. Feeding.
    B. Watering.
    C. Sheltering.
    D. Processing (e.g., for milk).

# 6 Plant cultivation specifics

Plant cultivation is the act of caring for, raising, using, and harvesting plants.

The cultivation of plants includes the following human support functions (plant utility):

1. For animal nutrition (food, spices, feedstock)
2. For animal medicine
3. For other plants
4. For human aesthetics
5. For other material resources (timber, fiber, fuel, etc.)
6. For research purposes
7. For decomposition and chemical cycling

Some essential phases needed for successful cultivation of the plants includes:

1. Medium and/or Field Selection - As per requirement of the plants (and farmer), the field and/or medium should be selected. In the case of soil, the selected area should be fertile soil, sufficient water, and light for the specific plant.
2. Plant selection, preparation, and initialization: As per the climactic bio-region and disease presence, the cultivated plant species and genetics should be selected. Plant propagules can be directly sown/ grown or indirectly through nursery preparation. Different plant species and different planting methods will determine the distance between plant to plant and the angles between plants.
3. Coordination of the plant cultivation system includes:
    1. Weeding– Weeds should be removed from the field. This practice should be done in before and after the cultivation of the Plants.
    2. Watering – is necessary in some amount for plant life. A suitable amount of water should be provided and the plants should be protected from water stress as well as water logging.
    3. Fertilizing – Each nutrients that may be micro and/or macro nutrients playing a key role in plant life so, as per need of the plants these should be supplied.
    4. Diseases preventing – In different stage of a plant's life various diseases may appear and should be controlled by suitable measures. Suitable measure may include the culling of the plant in restorative agriculture or the using of a chemical in agro-chemical agriculture. In the latter case, the plants may need to be continually protected from biotic and abiotic factors.
    5. Harvesting – After complete maturation of the plants, they may be harvested (or grazed, even before complete maturation).
    6. Storage – Harvested plant parts should be stored in a manner that protect against microbial infection, fungal infection, viral infection, etc.

## *6.1 Plants life overview*

Plants perform both photosynthesis and respiration. During photosynthesis they absorb carbon dioxide, bind the carbon with water to form glucose, and release the oxygen. During respiration they absorb oxygen and release carbon dioxide. Most plants release 2 to 5 times more oxygen during photosynthesis than they use during respiration. When attempting to improve plant productivity farmers manipulate the plants environment to increase this ratio sometimes aiming as high as 40 times more oxygen produced than consumed.

The photosynthesis equation:

1. Plants use light for energy.
2. Plants take water and CO2 and combine them into sugar and oxygen.
3. Nutrients are not in the photosynthesis equation.

The nutrient component:

- Nutrients are the calories that support exercise. Exercise is the light. Nutrients balance the plant with its environment.

There are three primary types of plants as categorized by their lifespan that may be present in a plant cultivation system:

1. **Perennials** - return every year (keep living), and grow for many growing seasons. Perennials need to be planted once. Perennials are mostly ever growing.
2. **Annuals** - die at the end of a year. Annuals need to be planted annually.
3. **Bi-annuals (biannuals)** - are plants that normally live for two years before dying. However, like self-seeding annuals, biennials are also known for dropping seeds, which bloom two seasons later. If yearly bi-annual flowering is desired then it is often optimal to planting them two years in a row; that way the two crops will alternate blooming.

For all known plants, each year, a percentage of collected solar energy is used to build its body. In the case of annual plants, the plant needs to build its entire body structure every year. This is not true with perennial plants. The plants keep their body structure from the previous year and add to it in every subsequent season, thus expanding (relatively) their surface area exposed to the sun and atmosphere. This confers a three-dimensional advantage not accessible to annual plants. Some perennial plants can live a relatively long time, and continue to produce food for other animals year after year with no human intervention.

### 6.1.1 Plant life cycle

The phases of plant life growth and death include:

1. Seed.
2. Germination.
3. Seedling/sprout.
4. Vegetative.
5. Pre-flowering.
6. Flowering and fertilization.
7. Fruiting and seeding.
8. Death.

## *6.2 Plant cultivation locations*

There are several locations that plants are cultivated in the habitat service system; there are the following locatable mediums:

1. Soil cultivation
   A. In earth soil (including at surface, below, and raised).
   B. Potting (using pots, containers from the small to the large).
2. Soil-less cultivation
   A. Aquatic natural (e.g., natural ponds).
   B. Aquatic-liquid controlled (e.g., hydroponics, also a potting type-of cultivation).
   C. Atmospheric-moisture controlled (e.g., aeroponic, also a potting type-of cultivation).

## *6.3 Plant cultivation methods*

*A.k.a., Plant cultivation techniques.*

Plants can be cultivated by several different primary methods.

### 6.3.1 Ecological cultivation of plants

A wide variety of plants can be cultivated for both humans and livestock animals using a variety of techniques that apply ecological principles to a landscape. This method refers to cultivation on the soil of a landscape These sets of techniques are often given the following common names:

1. Restorative agriculture
2. Permaculture
3. Agroforestry
4. etc.

### 6.3.2 Controlled environmental agriculture

Here, the environmental dynamics of the cultivation system are highly controlled by the cultivator, using specialized technical systems, including:

> **NOTE:** *These controlled system can consume large amounts of electricity, for illumination and water movement.*

#### *6.3.2.1 Aquaponics (water)*

Aquaponics is the practice of fish farming combined with the cultivation of plants in water without soil.

#### *6.3.2.2 Hydroponics (water)*

Hydroponics is the practice of growing plants in specialized, enclosed, water-based systems. Hydroponic systems can take on the form of localized vertical farms. The new systems are designed to produce a sanitary crop, grown without pesticides in hygienic buildings monitored by computers, so there is little risk of contamination from pathogens.

Although the nutritional profile of hydroponic produce continues to improve, no one yet knows what kind of long-term health impact fruits and vegetables grown without soil will have. It is relevant to note here that no matter how many nutrients indoor farmers put into the water, it is extremely challenging, if not impossible for indoor farms to match the taste and nutritional value, or provide the environmental advantages, that come from the marriage of sun, a healthy soil and soil microbiome, and plant biology, found on well-run holistic farms. Trying to enhance water with nutrients to mimic what soil does is virtually impossible, in part, because it is not yet known how the soil microbiome works.

#### *6.3.2.3 Potted cultivation of plants (soil)*

Plant pot material composition types:

1. Cloth-type fabric pots
2. Ceramic and clay pots
3. Concrete vessel pots
4. Plastic pots
5. Etc.

Some of these types of pots have a much higher replacement rate than others. For example, cloth-type pots often need to be replaced in a cycle based upon a set number of weeks or months (due to buildup of organic and inorganic materials and the deterioration of the fabric).

Some pots can have secondary functions, such as:

1. Air pruning pots - root bounding occurs when the roots of a plant contact the side of a solid container

where they have nowhere else to go to find air. The roots then begin to circle around the side of the pot. One solution for root bounding is transplanting the plant in a larger planter (i.e., pot). Some plants, trees in particular, can become so root bound that they essentially "strangle" themselves. When the roots hit the side of an air pruning container, the roots air prune themselves, and begin to branch their root system throughout the container. The aerated area around the outside of the plant is an environmental stimuli to which the plant responds to by branching its root system.

A. Low density air pruning: cloth, fabric, and geo-textile pots
   1. Products: Smart Pot;
B. High density air pruning: multi-hole mesh pots
   1. Products: Air-Pot;
C. Self-watering (sub-irrigation) pots

**NOTE:** *Depending upon the plant type, usage requirements, and desired growing environment, some plants are better pot bound.*

The common growing mediums for pots are:

1. Soil - soil mixed well with 30% perlite to help with drainage and allow more air/oxygen to come into contact with the roots. Without perlite or another coarse medium, water input from the top may not drain to the bottom root, and the dense packed soil may choke off the roots.
2. Compost additive.
3. Manure additive.
4. Coconut coir chips - more renewable. Comes from the husk of coconuts. Drains well.
5. Peat moss - less renewable. Comes from peat bogs, which are not highly renewable. Peat has a cation exchange capacity - it has the ability to absorb nutrients and hold them away from the plants roots as the medium dries out, then when the peat is rehydrated (i.e., watered), the nutrients are released.
6. Water (aerated).
7. Air (humid).

## 6.4 Germination optimization

Using magnetics it is possible to optimize the germination and initial growth of seeds. North pole exposed seeds are desirable, whereas south pole exposed seeds turn bad easily. The best practice is to tape seeds on the north pole edge of a 2" by 2" by 1“ neodymium iron boron magnet. The seeds need only be positioned there for about 30-45 min, but it is possible to leave them there for longer. Even better results are possible if they are germinated over the top of the north pole of a magnet. (Davis, 1996 & 1979)

## 6.5 Harvestability

Someone can't (or at least, shouldn't) harvest a plant like dandelion greens where people are walking dogs (because dogs may have urinated on it). So, there are areas where dogs cannot go; there is separation of objects (e.g., people, animals, etc.) through structure where necessary in order to ensure cultivation plans are successful. That which cultivated foods and other resources need to be separated from may include wild animals, it may include animals within and around humans, and it may include separation from humans (e.g., so as not to contaminate a food or food process).

## 6.6 Locating

Firstly, different plants grow best in different locations. Location factors include, but may not be limited to:

1. Shade tolerance.
2. Nearness to syntropic plants and antagonistic plants.
3. Soil type.
4. Water amount.
5. Topographic slope amount.
6. Human requirements.

For example, olive trees work on slopes in some climates, and citrus trees planted on flattish areas dug into the soil (submerged planter beds) with large seasoned logs buried underneath (Hugel style) to sponge and hold water through the dry seasons.

## 6.7 Soil planting warnings

The following are two warnings for when planting plants in soil:

1. Do not leave the pot or basket or wire basket in place around the roots of a plant when planting in soil. If this is done it will girdle the roots of the plant.
2. Do not fill a hole dug for a plant with gravel as this will collect water and possibly drown the roots, along with preventing the roots from continuing to grow farther downward.

## 6.8 Plant growth parameters

Humans can measure all of these parameters (i.e., all plants need these elements to some degree in order to grow and survive):

1. Above ground
   A. Space
   B. Radiation (light)

1. Photosynthetic radiation
   C. Temperature
   D. Humidity (correct atmospheric water composition)
   E. CO2 (correct atmospheric gas composition)
   F. Wind (relative; appropriate air movement conditions)
2. Below ground
   A. Space
   B. Nutrients
   C. Water
   D. Oxygen
3. Time

## 6.9 *Nutrients for plants*

Plants have the following nutrient requirements:

1. Organics - plant roots are capable of taking up complex organic molecules like amino acids directly; thus, bypassing the mineralization process.
2. Primary [macro] mineral nutrients - used in highest quantity and most essential for plant growth and development. The most common building blocks for the plant.
   A. NPK - nitrogen (N), phosphorus (P), and potassium (K).
3. Secondary [macro] mineral nutrients - similar to primary in importance, but not quite as important as the primary nutrients.
   A. Calcium, magnesium, sulfur, etc.
4. Micro mineral nutrients - all of the mineral nutrients required in smaller quantities by the plants for growth and reproduction. Just because they are an input at low levels does not mean they are critical to plant survival.
   A. Silica, etc.
5. Synthetic nutrients (note: not a nutrient requirement)
   A. Phosphate (P) - Synthetic phosphate made from phosphoric acid.
   B. Potassium (K) - Synthetic potassium made from potassium hydroxide.

Nutrient solutions can be formulated separately for individual plants, or a common formula can be used for an area or region.

Fertilizer (nutrients) include:

1. Bacterial additives
2. Fungal additives
3. Mineral additives
4. Organic waste additives (including compost and manure)
5. Air while mixing a liquid compost solution
6. Worm additives
7. Good quality soil

Fertilizer solution sub-additives include:

1. Solid (dry) matter - often in powdered form applied either dry (atop or mixed into the growing medium) or in water/compost tea solution.
2. Liquid matter - generally, this is a formerly solid (dry) substance that has been solubilized in water. Or, for instance, it could be ocean water which has been processed to remove a large amount of the sodium chloride. Unnecessary shipping of water and
3. Water soluble nutrients - Under certain conditions, these can end up getting washed out and create environmental pollution; water soluble fertilizers leach into the groundwater, runs down the rivers and streams into the ocean and creates dead zones).
   A. Synthetic water soluble nutrients.
   B. Organic.
   C. Hybrid - some synthetic and some organic. transitioning fully to organics over time.
4. Soil amendments - General organics ancient forest - humus soil amendment - made through fungal activity (versus thermal activity) - good to add to a compost tea. Helps create fungal dominated compost as opposed to bacterial dominated compost (made through thermal reactions). Letting wood chips rot and compost down, while inoculating them with some mycelia over several years will create a high fungal dominant compost.
5. Pasteurized soil - for indoor so that there are no insects or possible pathogens inside. Will have to add bacteria and fungus to this.

### 6.9.1 Soil

Soil is made in two primary ways:

1. In a holistic cultivation system, soil is made by a plant (crop) and animal (livestock) cycle, wherein plants grow and feed animals that in turn fertilize the soil to grow more plants, and together, more soil is created.
2. In the sense of environmental decomposition, soil is also made by decomposing organisms (decomposers) that convert otherwise unusable organic matter into something useful [for other organisms]. The primary decomposers are fungi, mold, and bacteria. A compost pile is an example of this type of soil creation. There are two main classes of decomposing organism:
   A. **Recyclers** - Common recyclers found in nature

include, but are not limited to: earthworms to ants, springtails, nematodes, etc. Some recyclers are recognized as food by different human cultures.

B. **Decomposers** - Common decomposers found in nature include, but are not limited to: bacteria, fungi, lichen, etc. Some fungal decomposers are recognized as food (or medicine) by different human cultures.

Soil can be damaged by environmental factors. When soil is incapable of growing useful plants, it is often called, "dirt". The sun, for example, will oxidize exposed soil. The plough, which digs up and overturns soil will expose more soil to the sun and atmosphere, increasing its oxidation. It is recommended to keep the soil covered with plants or some other material to prevent oxidation by the sun and atmosphere. The soil can be covered by mulch or by growing biomass.

Common soil amendments include:

1. Compost
2. Minerals

In concern to minerals, it is important to do a soil test to determine what minerals are missing from, or are in an over-abundance in, the soil:

1. Magnesium - Excessive magnesium in the soil causes the existing calcium to become less and less available to the plants. Magnesium also tends to cause soils to lose their loft (fluffiness) and become stickier and compacted. Note, whereas calcium is easily up-taken by plants and livestock, the magnesium can stay behind and accumulate over time.
2. Lime - Adding lime year after year like this can, over time, actually chemically create clay soils.
3. Many other possibilities.

#### *6.9.1.1 Roots in the soil*

Deeper root systems allow plants to draw more nutrients from the soil. They also help reduce field erosion.

#### *6.9.1.1 Microbes in the soil*

Microbes in the soil break down the solid organics, transforming them into salts which are then absorbed by the roots of plants. In other words, organics are salts by the time they break down to the point that they're absorbable by a plant. A prolific and healthy microbial population is also a necessary component of a soil grow.

High concentrations of inorganic salts tend to kill the microbes in the soil. That's why factory farmers have to let fields lay fallow every few crops - all the inorganic salts they pump into the soil renders it infertile, so they have to add organic material (compost/topsoil) and give the soil time to recover its microbial health and become fertile once again before they can sow it.

#### *6.9.1.2 Decomposing manure*

The decomposition of manure over a landscape will, when deposited sufficiently (and not in excess) will increase the fertility of the area..

#### *6.9.1.3 Decomposing wood*

Ramial wood (brush wood) is shoots and branches that are less than 2.5 inches in diameter (or less) with deciduous or hardwood trees. If soil is to be subjected to a lot of tillage apply about 10 tons over 1 acre as wood chips. Ramial wood can be added to compost piles. Add chips to soil alongside a perennial ground cover crop. Chipping and composting, or dispersing around the environment, planted with legumes, alphalpha. Dispersing chipped trees can change the ground layer and cause problems in the growth of some plants.

#### *6.9.1.4 Decomposing organic matter (compost)*

Compost is biodegraded and degrading organic matter. Composting material is decayed plant or food products mixed together in a [compost] pile and let to decompose before being spread on the landscape to help plants grow. The organic matter breaks down. Decomposition is a natural process occurring everywhere organic matter is present and no longer living. Everything rots. Composting is the procedural organization of organic decomposition. Composting is the intentional returning of organics back to the soil, and facilitating ecological sustainability and the organic fertility of land.

> **NOTE:** *It is important to note that compost piles can turn "bad" and become breeding grounds for insects and harmful bacteria. This may occur when wrong materials (given conditions) are added to a compost pile.*

Organic (food) outputs need to be separated from the rest of the material outputs.

1. Primary nitrogen sources
    - Vegetables and fruits (i.e., kitchen scraps)
2. Primary carbon sources
    - Wood chips; coco coir; leaves (best to shred).
        1. Products: Compressed sawdust for animal bedding.

Hence, an optimal ratio of the two material sources is anywhere from:

- 50% nitrogen - 50% carbon to 90% nitrogen - 10% carbon. Regardless of ratio, mix the compost well.

> *Note: Mixing is preferable to layering. The best bio-chemical reaction comes by mixing the materials and sources.*

Technically, however, a ratio of the two is not required. Compost can be made, and bio-degradation (organic breakdown) will work with primary nitrogen or primary carbon sources.

Composting outputs include (soil, then plant growth, then plants, then compost and manure, then anaerobic digestion to soil and biogas:

1. Soil
2. Fertilizer (nutrient and biological organism source)
3. Biogas

Methods of compost creation include:

1. Bury under soil.
2. Dig a hole in the ground and layer compost on top of it.
3. Form a circle or square with fencing or wood slats (in a manner similar to a raised garden wood slat bed), and fill up the inside space. This method can be combined with the hole method (#2, as in, dig a hole and then at the top form a circle or square with fencing or wood slats).
4. Put material in a compost tumbler bin, which is spun on a regular cycle to mix and aerate the compost.
5. Worm bin (a.k.a., vermiculture or vermicomposting) - worms break down the materials. Note, however, that worms prefer fruit and vegetable matter, and worms will not thrive as greatly on compost composed entirely of any combination of the following: grass clippings, leaves, shredded pruning's, etc. Note that worms don't generally like coffee grounds. If coffee grinds (or the like) are present, then fungi mycelium can be added to decompose the coffee. The coffee grounds are decomposed by the mushroom mycelium. The mycellium pre-digests the coffee grounds and makes it into a form that is easily composted.

Supplements for compost include:

1. Zeolites may be added as a mineral supplement, the zeolites will also absorb some of the amonia if the compost is producing amonia and other odors. They also hold and release water. Zeolites may reduce insect presence.
2. Pre-existing compost to inocculate with pre-existing microbes.
3. Rock dust - adds trace minerals to the compost.
4. Coffee grounds - adds minerals, moisture, and increases the rate of decomposition.
5. Worms. Be careful of mixing worms with zeolites. If the zeolite is in too high a ratio it could cut up and harm the worms.

The two types of liquid solution compost include:

1. **Compost extract** - in the field you add the microbes to the compost solution, then you agitate it, and the spray it quickly.
2. **Compost tea** - put all ingredients in a tank (maybe mix them, maybe not) and aerate it over time.

Compost tea is the creation of a liquid fertilization mixture that is aerated over a period of time before being given to plants. Compost tea (biologially active) involves putting compost (and other additives, or just additives) in water and letting it soak or aerate for a few hours. The process of adding water to a compost mixture and then aerating it is known as "brewing compost tea". Any compost can be turned into a tea (i.e., the addition of water) and brewed (i.e., the addition of air).

> **WARNING:** *Do not use human or other mammal waste (as in, manure) in the composition of the tea.*

Compost tea ingredients generally include:

1. Water
2. Compost (if available)
3. Powder and liquid minerals
4. Bacteria
5. Hummus - is the aged, broken down further version of compost. Wood chip based hummus produces the fungal ecology.
6. Humic and/or fulvic acid
7. Worm castings - contains colony forming units of chitinase (enzyme that digests the exo-skeleton matter of insects, chitin), and colony forming units of cellulase (enzyme that dissolves the ... of powdery mildew spores). What the worms are fed matters. Produces a healthy bacterial ecology.

Additional ingredients include:

1. Organic components, for example:
    A. Worm castings, soluble sea-kelp powder, amino acids, kelp meal, legume meal, grass meal.
2. Mineral component
    A. Ocean minerals
        1. For example, minerals collected from a flood tide region after the area has been dehydrated. (e.g., Sea90 and Ocean Grown)
    B. Land minerals
        1. Mined minerals
        2. Soil minerals
        3. Volcanic ash

#### *6.9.1.5 Overfeeding plants nutrients*

It is difficult to overfeed in soil, but easy to overfeed in aquatic (e.g., hydroponic) environments. Overfeeding leads to:

1. Leaf "burn"
2. Stunted growth
3. Poor finished product

## *6.10 Plant specific characteristics*

Different types of plants have different characteristics, the following are some unique characteristics to some categories of plants.

### 6.10.1 Trees

Most trees take 2 to 5 years to become established, depending on site conditions and plant genetics. Trees take carbon dioxide out of the atmosphere and store it in long lived plant tissues. As plants live and die, and are consumed by animals, the organic matter is deposited (contributed) to the soil. Hence, woody plants can be used for carbon cycling purposes.

Trees can remain unpruned when young. When placed in an orchard a tree should never be pruned. Trees that begin their orchard lives unpruned never need to be pruned.

There are different pruning strategies that can be implemented:

1. **Challenging pruning:** typically involves limbing up tall timber trees or topping them at five meters. This is done either with chainsaws while off of the ground or with specialized machinery. Note that this type of pruning, with chainsaws in trees, is technical and dangerous.
2. **Cultivation under small tree system (STS):** is a tree pruning technique that keeps the height of the tree plants (e.g., a mango plant) at nearly nine feet, which will increase mango production about five times.
3. Many trees are "designed" by nature to be either burned down, blown down, or grazed by animals; because, they will sprout back from the roots. Hence, many trees can be cut off ~0.5m above the ground and the tree will sprout back from the stump.
4. It is sometimes optimal to harvest trees that are growing under a larger canopy, but will likely not survive because they are not shade-tolerant.

#### *6.10.1.1 Mulberries*

Mulberries have an interesting trait in that the pollen-bearing male flowers occur on one plant and the berry producing female flowers occur on another. This feature allows us to create a silvopasture system with both fodder production and berry production. Simply plant a row of mulberries with the plants spaced very close together, 3-5 feet, for example. Protect them from browsing for the first three or four years and by then the ones that produce male flowers and the ones that produce berries will become evident. In the late winter, the male plants at this age can be trimmed severely and the tops thrown to the cattle, sheep or goats. The female berry-producing plants can be left to grow tall and not allowed to be browsed. Cutting the male plants will not bother them but will instead stimulate them to send up numerous shoots, which will be delicious, tender and green for the livestock by mid-summer. With proper management a mulberry plant can be browsed twice each season without killing the plant. Over time the browsed mulberry row will develop a two-storey appearance with berry-producing trees up high (mulberries will grow to 25 feet or so) and forage-producing shrubs down low. (Shepard, 2013, p.132)

### 6.10.2 Grasses

It is relevant to note here that fertilizer may have to be applied (generally, one time) in order to get grass seeds started on soil that is low quality. Mowing and grazing grass stimulates it's growth and makes it a more dense pasture. There are annual grasses as well as perennial grasses.

## *6.11 Plant habitat-ecological uses*

Plants can perform different and useful ecological functions within the material habitat service system. There are a number of plants that efficiently perform chemical synthesis at night when it is dark. The following are some of these plants. These plants clean the air to a small degree and provide oxygen at night (useful in bedrooms where humans are sleeping at night):

1. Money plant - removes formaldehyde. This one does most of the pollutant removal.
2. Areca palm - removes chemicals in the atmosphere.
3. Mother in laws tong - produces oxygen at night. While most plants take in carbon dioxide and release oxygen during the day, mother in law's tongue plant converts carbon dioxide to oxygen at night as well.
4. Cactus - an ideal plant for the bedroom because they produce more oxygen at night than non desert plants. This is because they use a mechanism called crassulacean acid metabolism which allows them to photosynthesize during the day while exchanging the oxygen for carbon dioxide at night.

By planning and using these plants effectively within a building it is possible to can reduce the amount of CO2 in the building. While most plants take away oxygen at night, these types of plants may give off oxygen at night. These plant also filters chemical pollutants, including but not limited to: formaldehyde, trichloroethylene, xylene, toluene, and benzene from the air.

#### *6.11.2.2 Plant bio-chemical defenses*

Plants defend themselves from consumption via the production of a variety of plant-derived compounds. Classification of plant defense compounds includes:

1. Nitrogen Compounds
   A. Alkaloids
   B. Amines
   C. Non protein amino acids
   D. Cyanogenic glycosides and Glucosinolates
2. Terpenes
   A. Monoterpenes
   B. Cartenoids
3. Phenols
   A. Simple phenols
   B. Polyphenols

## *6.12 Plant pest and disease control*

*A.k.a., Pest and disease control for plants.*

There are mechanical and biological methods for dealing with plant pests and diseases. Animals can be extremely useful in this case. Many diseases and insect pests pass a part of their life-cycle in these dropped fruits and leaves, and then in the soil beneath them as they decompose. By rotating hogs, chickens, or turkeys at the right time it is possible to break that link in the life-cycle of the past and give the livestock a tasty protein bonus at the same time. In general, the first fruits and nuts that fall to the ground have some sort of insect larvae in them. Hogs can be introduced when fruit begins to first fall to the ground and they will consume all the fruit with the first hatch of pests that otherwise would have pupated; and instead, they are consumed.

> **NOTE:** *Plants and animals do not (i.e., are not known to) share diseases. Animals, however, can pickup diseases from other animals. Insects can transmit diseases to plants.*

In cases where "plant and preserve" (versus "scatter and cull") strategy is used, it is often better not to wait until the plants have insects (pests); instead, develop a schedule that works to facilitate the plants don't acquire pests and diseases. Often waiting until problems/pests are seen it is too late to do something, or something is done in a panic. Panicking leads to hasty decisions that can lead to crop failure.

## *6.13 Plant cultivation steps*

The cultivation of plants often involves the following steps:

1. Plant species selection.
2. Plant growth location (and medium) selection (a.k.a., field selection).
3. Preparation of medium - Selected area/field should be well prepared for germination and growth. The selected area should be fertile nature soil and better water, light facility.
4. Plant sowing/growing in the prepared field – Selected and prepared plant propagules are now grown in the field by maintaining specified distances. Plant to plant spacing is better for growth of the plants.
   A. Plant sowing - planting seeds or transplanting plants.
   B. Plant growing - giving the plant a conducive medium, nutrients, atmosphere and light to grow.
5. Plant harvesting.

Plant cultivation coordination involves:

1. Avoided plants – Plants that are to be avoided during cultivation should be removed from the field. This practice should be done in before and after the cultivation of the plants.
2. Water – Plant life requires a suitable amount of water.
3. Nutrients – Plant life requires nutrients.
4. Diseases – Diseases should be avoided and control measures enacted when it appears.
5. Protection of the cultivated plants - The plants should be protected from harmful biotic and abiotic factors. And, weak plants (with weak or non-adapted genetics) are let die and removed over time.
6. Harvesting – When to harvest must be determined.
7. Storage – Some harvested plants are stored after harvesting.

### 6.13.1 Plant protection from animals on pasture

Young plants need to be protected from herbivorous animals on pasture. It is a requirement to protect young trees and shrubs as they grow on pasture. Herbivorous animals will likely kill them if they are not protected as they grow (to sufficient size). Trees in particular must be protected on pasture as they grow.

There are different methods to protect trees and other plants:

1. Tree tube (for trees only) - a tube that fits around the growing trunk of a tree. They protect from cattle as long as the cattle are not allowed to eat the tree tubes.
2. Fencing:
   A. Individual fence cage around every single tree.
   B. High tensile electric around a grouping of trees.

C. Note: If the cultivation system has goats and/ or sheep, then it may be preferable to use both individual fenced cages around every single tree and high tensile electric around groupings of these same trees.

## 6.14 *Light for plants*

Light provides photosynthetically active radiation (PAR) for plants. Plants absorb different colors of light during photosynthesis in different amounts in different stages of growth. With sufficient data, photosynthesis and plant growth can be predicted (along with other necessary inputs).

Light intensity is measured with (note: the units is different for plants and humans):

1. For plants: PAR - PAR is measured with a PAR meter in micromol (umol) - an expression of the amount of plant-usable light energy hitting a square meter during a single second. The PAR reading will aid in determining how far or near a grow light should be from the plants. 800-1000 PAR is often optimal. Often, a grow light should be positioned as close as possible to the plants without causing them radiant heat stress.
2. For humans: LUX

Photosynthetically active radiation (PAR) is also known as:

1. Photosynthetic photon flux density (PPFD)
2. Photosynthetic photon flux (PPF)

Here, flux has two definitions:

1. **Per time.** Hence, in the case of photosynthesis it is measured in units of moles/seconds.
    - PPFD; where, D = density.
2. **Per area and tim**e, together. Hence, in the case of photosynthesis it is measured in units of moles/ (m2 x s).
    - PPF (No "D" as in PPFD, because the density is redundant).

*Note: Regardless of the definition, PPF and PPFD equal the same thing.*

Light instrumentation for plants includes, but is not limited to:

1. PAR (PAR measurement instrument) - Sensor options for measuring PAR. PAR sensors measure moles of photons. Note that to effectively determine PAR, the sensor must cover the full 400-700nm range, and not cut in past 400nm with a relative quantum response of 3.0 or cut off before 700nm with a relative quantum response of 3.0. The relative quantum response is the y axis on the graph below.
2. Spectrometer - A spectrometer (or spectroradiometer) is used to break up the light, which is then read by a series of detector arrays for each frequency providing the user with the frequency spectrum of the measured light.

Plants can use ultraviolet or infrared sections of the electromagnetic radiation spectrum for photosynthesis, but they generally do not. In general, photosynthesis occurs in chloroplasts where large protein complexes called photosystems I and II use light to excite electrons, evolve oxygen, pump protons across the thylakoid membrane (ultimately generating ATP), and reducing NADPH. Photosystem I and II absorb light to excite electrons, and do so optimally at 700nm and 680nm (red light). One photon excites one electron, and is the first step in photosynthesis.

To efficiently collect photons, the reaction centers of the photosystems are surrounded by proteins that contain light-absorbing molecules like chlorophyll and carotenoids. These are capable of absorbing higher-energy photons and channelling the energy to the photosystems. Thus, plants are able to use both red and blue light, while largely transmitting green (hence plants look green). Chlorophyll is the mechanism responsible for photosynthesis in plants. Notice that green does not get absorbed, and why is that? Plants are green, so they reflect green light. There are different types of chlorophyll.

The following are the sub-categories of possible light for plants:

1. Ultraviolet (UV) light: Each photon of ultraviolet electromagnetic radiation contains too much radiation for most biological systems. Its high energy drives electrons from molecules and breaks weak bonds. It is absorbed by oxygen in the forms O2 and O3 (ozone). The ozone layer of our atmosphere protects life on the planet from high levels of ultraviolet radiation. ultraviolet will outright kick the electron out of the molecule (which is in fact how it is defined). UV is in general just too destructive to be used to synthesize large molecules. There are a few exceptions.
2. Infrared (IR) light: Each photon of infrared electromagnetic radiation does not contain enough energy to do useful work in a biological system. Cells do absorb this radiation but it contains insufficient energy to excite electrons of molecules and is thus converted to heat. Infrared radiation is absorbed by water and by carbon dioxide in the atmosphere. IR is too weak.
3. Visible light: Each photon of visible light contains

just enough energy to excite the electrons of molecules without causing damage to the cell." Visible light is just enough to move an electron up a few energy levels;
4. Gamma radiation (a form of ionizing radiation): A gamma photon would knock several electrons off of the molecule and likely break bonds while doing it.
5. X-rays: When x-ray research was a very new field, some scientists did test if skin could get immune to x-rays, assuming it could just be like a sunburn but skin could also get a tan against x-rays. Cancerous results.

*Important: The sun peaks in wavelengths around the visible light spectrum. That is why our eyes adapted to see a range of wavelengths that we call visible light: it's the brightest and most useful range of wavelengths that are available to be seen.*

## *6.15 Plant compounds*

Plant chemical communications and defense compounds include:

1. Phenols (e.g., lignan)
2. Lectins (protein type molecules)
3. Alkaloids
4. Terpenes
5. Terpenoids
6. Flavanoids
7. Terpenophenolic compounds

# 7 Animal cultivation specifics

Animal cultivation is the act of caring for, raising, using, and harvesting animals. Pasture animals are essential to optimize soil regeneration and to provide essential food nutrition (and therein, flavor) for humans. The pasture animals are essential to optimize soil regeneration and to provide essential food nutrition for humans. Animals poop, pee and die on the land, feeding it.

The cultivation of animals includes the following human support functions:

1. For human nutrition.
2. For other animal nutrition (e.g., dogs).
3. For soil, and hence, for plants.
4. For human aesthetics.
5. For other material resources.
6. For decomposition and chemical cycling, and chemical repositioning on the landscape.

## *7.1 Pasture grazing of animals*

*A.k.a., Animal pasture grazing. animal semi-wild (semi-domestic) caretaken grazing.*

In a pasture, animals will graze for food, which includes searching for the food and consuming it. Different animals may search for the same or different types of organisms to consume from the environment. Generally, animals consume plants and/or insects for base nutrition. In other words, pasture animals graze (eat) plants and/or insects primarily.

Different animal species have different grazing behaviors. In addition, the animals eat different forage species in different way. (Undersander, 2021, 24)

### 7.1.1 Grazing land types

*A.k.a., Pasture types, grazing lands.*

Technical types of grazing lands include, but are not limited to:

1. Native range.
2. Seeded range (human seeded).
3. Riparian areas (wetlands or situated near the bank of a river).
4. Permanent pasture (irrigated/non-irrigated).
5. Grazed forest or woodlands.
6. Aftermath grazing of cropland or hayland.

Pasture lands classified by common bio-food area type include, but are not necessarily limited to:

1. Grass pastures (and legume pastures).
2. Tuber pastures.
3. Forest [pastures].
4. Orchard pastures (tree pastures, silvo pastures) -

silvo meaning tree, and silvo pasture meaning trees in the pasture. Planting trees in the pasture. Young trees need to be protected because otherwise grazing animals will kill them by eating them or rubbing/scratching on them. The right species will protect the animals and provide shade, as well as food. If it is the right species it increases the productivity of the pasture. There are many types of silvo pasture. In particular, there is the

- Intensive silvo pasture - planting trees every square meter or closer, and interplanted with pasture grasses. Silvo pastures require a hydrated pasture and wont work on land with very little water.
- Aquatic or riparian [pasture].

Note that all pasture types will be caretaken to some degree. For example, grass pastures will be planted with pasture grasses. The animals enter a pasture and graze them down to the found whereupon they are moved into another paddock. The grass repeats and you bring the animals in again. Forests may need to be caretaken to prevent

## 7.1 Rotational animal grazing cultivation

*A.k.a., Rotational grazing coordination, rotational pasture coordination, rotational pasture control, rotational grazing, rotational pasture coordination, rotational pasture control, grazing management, grazing coordination, paddock coordination, grazing management, grazing coordination, paddock coordination, Voisin grazing, Hohenheim grazing, intensive grazing management, management intensive grazing, short duration grazing, Savory systems, strip grazing, controlled grazing, grazing control, and high-intensity, low-frequency grazing, holistic land grazing management (land recovery) - process of soil restoration and terraforming outward, polyphase farming, circular symbiotic farming, syntropy farming. Terraforming land recovery. (note: each prior term implies a slight difference in coordination)*

To produce the quality and quantity of animals and animal forage from pastures, pastures must be coordinated (managed). Under rotational grazing, only one portion of pasture is grazed at a time, while the remainder of the pasture either:

1. has another species of animal grazing on it, or
2. it rests.

To accomplish controlled grazing, a large meadow/pasture is subdivided into smaller areas (referred to as paddocks) and animals are moved from one paddock to another. Rotating different animals can improve the health of animals, the forage for animals, while also improving the soil. Intentionally rotating different animals through series of paddocks must be monitored. Resting grazed paddocks allows forage plants to renew energy reserves, rebuild vigor, deepen their root system, and give long-term protection. (Undersander, 2021, 1)

**NOTE:** "*To graze" means, to eat from a pasture or other natural ecological habitat.*

Rotational grazing is simply moving the animals from one paddock to another to allow the previously grazed paddock to recover. The time for this rest varies greatly, depending on local climatic conditions, time of the year, and forage in question but is often anywhere from three weeks to two months. In concern to regeneration/growth rate is affected by soil productivity and fertility levels, even within a pasture system, rest periods will vary. The best way to manage this situation is to have a flexible rotational scheme, moving animals to those paddocks that have reached their optimum available pasture. Animals should be kept off a particular paddock until it reaches its desired optimum available pasture.

Rotational species grazing is a biomimicry process that mirrors what occurs in nature -- the intent is to mimic nature in a way that provides for an abundance of human food. Here, the “farming” follows natural ecological cycles to the greatest extent possible within a human controlled environment. Grazing area are primarily a combination of pasture and orchard land that different animals are moved through in a particular order to mimic natural cycles, which builds the soil base and provides food. Regenerative and cyclical farming (a.k.a., symbiotic farming, etc.) necessitates the caretaking of other animals and the total ecology.

For rotational grazing to be successful, the timing of rotations must be adjusted to the growth stage of each animals forage. In some cases, rotational grazing involves simple and regular animal shifts from paddock to paddock based on rigid time scheduling. In other cases, rotational grazing involves animals being shifted from paddock to paddock based on a monitoring, analysis, and controlled (Read: collection, analysis, and response) to forage growth rates (and other cofounding factors). Note here that there is more benefit to reducing rigid schedules when there is better information about where to move each animal next given all the paddocks available. With sufficient soil, climate, and human coordination and material resources, most animals on meadows (pastures/paddocks) receive a substantial amount of their feed from the pasture. (Undersander, 2021, 2)

Rotational grazing has aesthetic and human environmental benefits. It is a quieter way of farming than mechanically harvested feed. It provides humans with activity spaces. It provides humans with differing aesthetic views and with food. Animal grazing systems are healthier than animals housed in confinement. Selected animals have their needs sufficiently met in the meadows. However, risks associated with exposure to sever weather and predators may be increased by grazing (depending on region). Animals redistribute minerals in the land through eating and excreting. Every day, the animals are eating, and excreting over the land, leading to a redistribution of minerals.

In a rotational grazing system, animals are moved around from paddock to paddock in order to mimic herds in nature, who moved from place to place away from predators and to areas with more fertile grazing land. This can now be done with fencing and planning.

Well-coordinated perennial pastures have several environmental advantages over tilled land (Undersander, 2021, 3):

1. Dramatic decrease in soil erosion potential.
2. Require fewer pesticides and fertilizer.
3. Decreases the amount of farmyard runoff.

The benefits to rotational grazing systems include:

1. Greater yield potential.
    - This is a human [animal] life-support need from the cultivation system.
2. Higher quality and fertility pasture.
    - This is an human life-support cultivation system need from the cultivation system.
3. Higher quality forage available.
    - This is an animal life-support need from the cultivation system.
4. Higher quality life for farmed animals.
    - This is an animal life-support cultivation system design.
5. Decreased weed and erosion problems.
    - This is an life-support cultivation system issue.
6. More uniform soil fertility.
    - This is an life-support cultivation system issue.

Regular rotation of the animals has several benefits. First of all, it keeps them amused with plenty to eat which reduces their interest in escaping. It's healthy for them, allowing them to rotate out of spots where parasites might build up and boosting their immune system with different vegetation. And of course, it is how you get them to manage a large area of land in manageable chunks.

Pasture coordination is the controlled movement of cultivated animals to accomplish desired results in terms of animal, plant, land, or economic responses. Therein, grazing coordination is the controlled movement of grazing animals to accomplish desired results in terms of animal, plant, land, or economic responses. Note here that a paddock is general term for an enclosed meadow or cultivated grazing area. Each paddock provides food and water for the cultivated animals. Animals may be transferred from one paddock to another, and this process is known as pasture/paddock coordination (a.k.a., pasture management).

## *7.2 Pasture cultivated animal types*

*A.k.a., Paddock cultivated animals.*

There are three primary types of pasture cultivated animals, each with unique needs (Undersander, 2021, 20):

1. **Ruminant animals** - such as cattle, goats, and sheep are "natural grazers" and have a rumen with microbes that break down most plant fibers. Ruminant animals usually obtain most of their nutrient and energy from grasses and other vegetation on the pasture. These animals may also graze the non-fiberous portions of plants, seeds, insects, and fruit. Some high producing animals may need to be fed supplementary feed to fulfill their production ability (e.g., dairy cows).
2. **Pseudo-ruminant animals** - such as horses. These animals do not have a rumen, but do have appropriate microbes in an enlarged cecum, which digests some plant fiber. These animals often graze longer than true ruminants to get adequate nutrition. These animals also get nutrition from non-fibrous portions of plants, seeds, insects, and fruit.
3. **Non-ruminant animals** - such as pigs and poultry. These are non-ruminants with smaller digestive

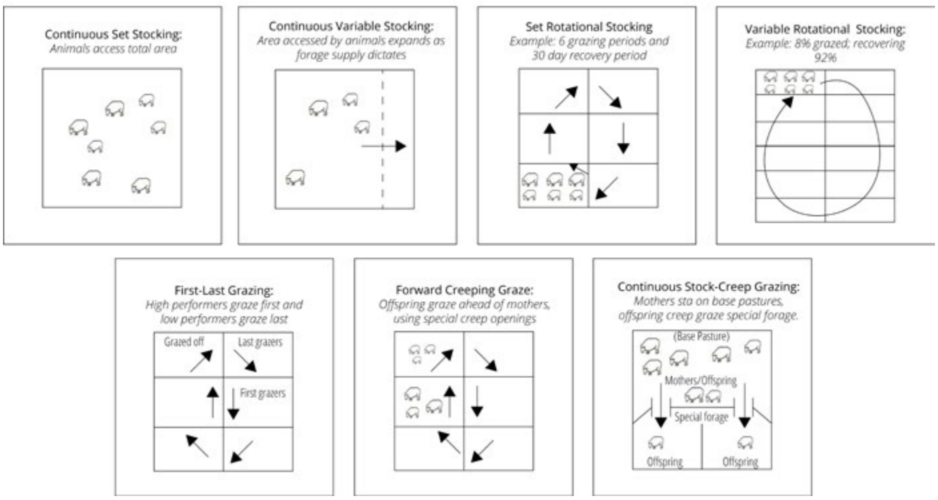



**Figure 15.** *Nutritional optimization stocking methods.*

tracts within which relatively little fiber digestion occurs. These animals get nutrition from non-fibrous portions of plants, seeds, insects, and fruit. In pastures without sufficient additional food sources other than grass, these animals must be fed supplemental food.

Ruminant animals raised properly are part of a natural ecosystem cycle that sequester carbon into the soil, making the soil more fertile, increasing the bicrobiome of the soil, including mycorhyzal networks, that allow plants to grow more robustly, feeding the plants, and in turn, the animals. When the soil is provided with nutrients, animals I  turn are provided with nutrients. The best way to increase soil carbon is by having plants and animals together on land, which requires proper regenerative grazing of ruminants on grassland and other ecosystems. The way to create healthy soil is with regenerative systems that include animals responsively.

**NOTE:** *Ruminants animals are upcycling non-human edible nutrients in their environment. Pasture materials that might otherwise be wasted are upcycled by livestock. Ruminant livestock in particular can make use of grass and other similar plants, where humans cannot. Hence, these animals upcycled non-human [edible] forage into a nutritious source of animal food and materials.*

Ideally forage production (or availability) should correspond with animal (livestock) needs. Animals need forage all year round. Providing an adequate supply from pasture alone requires a specific and flourishing pasture environment.

Supplemental feed can be made from grasses or other plants grown on some pastures during periods of rapid forage growth with little to no grazing. This vegetative matter can then be dried and stored for later supplemental use on grazing pastures.

**INSIGHT:** *Animals are essential for a healthy ecology.*

### 7.2.1 Animal ecological functions

*A.k.a., Ecological niches.*

Different animals will/can perform different ecological functions the support a healthy and flourishing ecology.

The following grazing (pasture and forest) animals have characteristics unique to their species (note: some animal species are combined below because their combination creates additional ecologically useful services):

1. **Goats**
   A. Prefer the leaves and steps of woody plants over grass. Because of this preference, they can be used to clear land. Do not leave them in a pasture so long that they are forced to eat poisonous plants.
   B. Goats will often graze six feet high and eat the light-shading canopy before chewing the undesirable plant (from the cow's perspective) to the ground. This creates an opportunity for grass to fill in.
2. **Sheep**
   A. Will eat more weed-like plants than goats or cattle.
3. **Sheep and goats**
   A. Sheep and goats graze often bite plants close to the ground. This biting behavior combined with trampling can lead to erosion problems in some pastures.
   B. Ensure rocks are available for sheep and goats so that you do not have to trim their hooves. In our case, we have never trimmed animal's hooves, giving them the environment to do it naturally themselves.
4. **Pigs**
   A. Pigs can recycle some of the unused production from the farm/cultivation system. A certain number of the eggs from the hens won't pass inspection, and so feed them to the pigs. Pigs are forest animals, as opposed to pasture animals like cows and sheep. They do a great job of clearing out the scrubb so that it isn't a jungle right beyond the pasture land. Goats can go in the forest with the hogs. Hogs will eat the goat faeces. When they do that, they will pick up some nutrients. Heterosis. The pigs eating the faeces of the goats breaks the lifecycle of an internal parasite called barberpole worm. The eggs are passed through the goat, its faeces, it pupates in the earth, then the goats graze the grass and reinfect themselves. When the pigs eat the faeces they break the lifecycle.
   B. Pigs prefer to root, which makes them perfect choices for woodlands or marginal perimeter land. Most breeds can easily be trained to a solar electric fence charger that's located just a few inches off the ground (snout high). When pigs remain near fences pigs just love to root dirt and debris up to the fence, which could cause it to short out. When their paddock is cleared, simply create a new adjacent paddock for them, move them in, and (if you're so inclined) toss some seeds (turnip, pumpkin, squash) into the soil they just disturbed. Return them several months later; they'll harvest the crop for you, free of charge, and turn your seeds into pork.
   C. Some breeds of pigs can be effectively grazed

along with the cows, sheep, and goats. I'm thinking mainly of the Large Black breed of pigs, and while they are effective grazers, like all pigs, they like (and need) to root. As a result, you'll likely end up with pastures ranging from lightly torn to having large wallows. In our experience, it's best to keep the pigs in the woods.

D. Pigs are natural rooters and are likely to eat the entirety of plants, including leaves, stems, and particularly tubers, which they dig up and pull out of the ground. Note here that snout rings are sometimes applied to deter rooting behavior.

E. Pigs like wooded areas. It is simple to have six pigs per half an acre given an appropriate passage. Pigs can be moved monthly to a new paddock, confined by a solar-charged electric fence and fed by hand. Smaller herds of pigs (e.g., one or two pigs), it is often optimal to locate the paddock adjacent to a garden for ease of growing, feeding human food waste, and monitoring.

5. **Goats, sheep and pigs**
   A. Goats (and, sheep an pigs to a lesser extent) can be "run" through nature surrounding the habitat service system as a fire mitigation strategy. They help eliminate excessive vegetative fuel in the area by eating invasive plant species and more woody material. In some circumstances, goats be used to eliminate noxious weeds. This will mitigate the risk of wildfire by reducing the amount of readily available flash fuel. The alternative to prevent growth is weeding, mowing, or chemical usage. Depending upon the area, goats in particular can clear about 0.8 hectares a day. Pigs, sheep, and goats can be used in border and woodland areas to reduce fuel loads, which, in turn, reduce wildfire risk.
6. **Poultry (fowl, including waterfowl)**
   A. Fowl will eat plants, roots and soil insects. Because of this they can be used to weed, reduce parasites, and fertilize.
   B. Pulling a mobile hen house or moving a flock of ducks or geese a couple of days behind the herbivorous grazers allows hens to scratch through manure piles and harvest grubs (insect larvae). This provides them with much-needed (and free) protein, while drastically reducing the potential fly population.
   C. Turkeys can be grazed with the hens and they can be moved together as a flock. The turkeys tend to roost on top of the portable hen house at night, while the hens sleep inside.
   D. Chickens and turkeys act as the insect sanitation crew, ridding the pasture of grasshoppers, crickets, fire ants, and worms, which can wreak havoc in a pastures.
7. **Cattle (cows and bulls)**
   A. When bulls are a permanent part of the herd, then humans need to be careful of their safety around the bulls.
8. **Insects**
   A. **Bees**
      1. Bees are essential for the pollination of some plants. Insects, such as bees, provide an essential ecosystem service, pollination.
      2. Bees concentrate sugars and produces wax as well as venom.
      3. A bee can fly up to five miles (kilometers) away from their hive.
   B. **Earthworms**
      1. Earthworms increase soil aeration, infiltration, structure, nutrient cycling, water movement, and plant growth. Earthworms are one of the major decomposers of organic matter. They get their nutrition from microorganisms that live on organic matter and in soil material.

## 7.2.2 Nutrient cycling in grazed pastures

Nutrient cycling in grazed pastures involves the following flow cycle:

1. Livestock and land - animals present on land.
2. Nutrient leaching -the downward movement of dissolved nutrients.
3. Livestock grazing - livestock consume resources and produces excreta and plant litter (etc.) as waste into the soil.
4. Nutrient uptake by plants and other organisms.
5. Human mineral addition and/or fertilization.

In this process, animals can upscale nutrients and make them available (or, more available) to humans.

## 7.2.3 Animal nutrition amendments (supplements)

Animals can be fed supplemental minerals and trace elements when they are missing from the landscape. These minerals and elements can also be added to the soil and specific plant genetics selected to uptake those elements and make them available to the animals.

## 7.2.4 Mineral toxicity for animals

Supplemental feeding of minerals and trace elements should be carefully monitored. Soil testing and forage testing is prudent in order to understand what your soil mineral levels actually are doing.

The following risks are present when feeding supplemental minerals.

1. Hogs can overdose on salt, whereas cattle love salt licks and are not likely to overdose.
2. Mineral supplements for cattle and hogs may include copper and be necessary for their health, but can be toxic for sheep.

### 7.2.5 Plant toxicity for animals

Some plants are toxic to some animals and not others. Plants do contain defense chemicals, and even animals that are primarily herbivorous need to take that into account when they are consuming plants.

> **NOTE:** *A toxin is a material in the wrong place, at the wrong dose, and/or at the wrong duration.*

## *7.3 Pasture coordination*

Standards for grazing coordination include:

1. US NRCS Conservation Practice 528: Managing the harvest of vegetation with grazing and/or browsing animals with the intent to achieve specific objectives. (*Prescribed grazing*, 2021)

The purpose of the pasture coordination is the following;

1. Sustain/maintain/improve:
   A. Land
      1. Soil - desired soil composition, structure, and vigor.
      2. Species - desired species composition, structure and vigor.
   B. Food
      1. Human food sources - quantity & quality of food for humans.
      2. Animal food sources - quantity & quality of forage for animals.
   C. Watershed
      1. Watershed - surface and/or subsurface water quality/quantity; riparian/watershed function.
2. Improve range health:
   A. Human health
   B. Plant health and resiliency
   C. Water quality
   D. Soil quality
   E. Wildlife habitat

To succeed, pasture coordination must account for at least the following variables:

1. The land
   A. Pasture area positioning (paddocks) - pastures can be divided into paddocks. Those smaller paddocks can then be sub-divided also.
   B. Soil status - the positioning, quality, and characteristics of the soil.
   C. Water status - the positioning, quality, and characteristics of the available water.
   D. Consider the basic land resources - the types of elements, including water and mineral.
2. The animals
   A. Design and calculate for:
      1. Animal performance (Read: animal fulfillment) - animal inputs and outputs for a fulfilled life.
      2. Plant productivity - plant inputs and outputs for productivity.
      3. Human requirements (Read: human viability) - human requirements for human fulfillment.
   B. Match animal type and nutrient needs to forage availability/quality in a matrix:
      1. Animal types
      2. Nutrient needs (animal requirements)
      3. Nutrient availability (quantity)
      4. Nutrient quality
3. The plants
   A. Consider the basic plant resources - the types of plants (cool season/warm season, grasses, forbs and/or shrubs) and plant growth cycles.
4. Human coordination
   A. Combination of coordination tools and techniques that promote distribution of livestock.

Pastures coordination is designed to meet human and cultivated animal food-associated requirements:

1. The pastures must ensure the appropriate quantity and quality of food for the animals.
2. The pastures must ensure the appropriate quantity and quality of food for the human population.

## *7.4 Grazing methods*

*A.k.a., Grazing systems.*

Grazing methods include, but are not limited to the following high-level categories (some overlap and be combined):

1. **Continuous grazing (i.e., no rotation)** - Animals have unrestricted access to the entire pasture throughout the grazing period (season, year-long); the animals craze continuously on a single pasture.
   A. Advantages
      1. Least capital and coordination required.
      2. Allows greatest selectivity of forage quality.
      3. Generally - greater livestock production per

unit area.

B. Disadvantages
   1. Livestock have preferred areas of grazing.
   2. Non-uniform distribution of livestock and manure.

2. **Rotational deferred (a.k.a., deferred rotation)** - the skipping of pastures at specific times, for any reason.
   A. Multi-pasture, multi-herd systems.
   B. Each pasture receives period deferment (every 2-4 years).
   C. Design to maintain or improve range condition and forage productivity.
   D. Works best where considerable differences exist between palatability of plants and convenience of areas for grazing.
   E. Disadvantages:
      1. Individual animal performance less than continuous.
      2. Added requirements for fencing and fence maintenance.
3. **Rotational rest (a.k.a., rest rotation; rotational stocking)**
   A. Multi-pasture, multi-herd or multi-pasture, single herd.
   B. Uses recurring periods of grazing and rest among two or more pastures.
   C. Plans periodically receive a full growing season of rest for recovery.
   D. Disadvantages:
      1. Individual animal performance less.
      2. Added requirements for fencing and fence maintenance.
4. **Rotational high-intensity low-frequency (a.k.a., rotational management intensive grazing)**
   A. Multi-pasture, single herd.
   B. Stock density is high to extremely high.
   C. Length of grazing period is moderate to short, with a long rest period.
   D. Grazing units are not grazed the same time of year each year.
   E. Disadvantages:
      1. High fencing requirements.
      2. High levels of grazing intensity may reduce livestock performance.
      3. Soil compaction, grazing on wet soils.
5. **Rotational mob grazing (a.k.a., intensive rotational grazing, mob-stocked, mob grazing) -** refers to short-duration, high-intensity grazing of many cattle (or other livestock) on a small area of pasture (i.e., in a smaller paddock), moved several times a day, or every day or so, to new forage. This is short-duration, high-intensity grazing, which can be designed to improve pasture while increasing stocking rate.
   A. Multi-pasture, multi-herd or multi-pasture, single herd.
   B. Length of grazing is short.
      1. When a large number of animals are put in a small paddock for a very brief period of time (hours, or a day or two).
   C. Advantages
      1. More equal manure distribution.
      2. More uniform grazing.
      3. Higher number of animals per paddock.
6. **Leader-follower grazing systems** - one animal type is let into a paddock first. Once it has eaten its preferred foods in the first paddock, it is rotated into the next paddock. Then, the next type of animal is introduced to the first paddock (where the first animal just recently vacated). Leader-follower systems can often out-produce other types of grazing systems (for total animal weight gain), because each animal is allowed to eat its optimal foods first. In turn, each animal eats its preferred forage first. When it is done it is moved the next paddock, and the next livestock is let into the vacated paddock. The pasture is allowed sufficient recovery time before the first (original) grazing animal is returned to the initial paddock.
7. **Silvopasture grazing system** (silvo-pasture, animal and tree systems, trees plus grazing livestock together) - the intentional combining of livestock production and woody plants. It is the intensive and intentional management of both the forage system and the woody crop. Silvo pasture is not the process of turning animals loose in the forest to graze. Instead, it is intensively managing an open canopy tree and forage system. This type of grazing models mirrors the grazing in natural savannah systems and other highly product ecosystems.

In the wild savannah's, herds of grazing animals are food for predators. Pressure from predators causes the grazing prey animals to form tight groupings, to graze fairly quickly on only their preferred foods, then move on to water and greener pastures. To mirror the wild flourishing savannahs, it is possible to implement a combined leader-follower, mob-stocked, silvopasture grazing systems. The concept of restoration agriculture uses this combination of practices to produce stable perennial plant and animal foods, while restoring soil and ecological services to a local area of land. A leader-follower, multi-species mob-stocked silvopasture can designed for growable biome.

In concern to the number of species being rotated for grazing, there are two categories:

1. **Single species rotation** - a single species is rotated around paddocks.
2. **Multi-species rotation** - multiple species are rotated around paddocks.

#### *7.4.5.1 Manure rotation coordination*

Shorter periods of occupation, small paddocks and ensure the correct amount of feed in the pasture for the animal duration. One of the many benefits of moving towards shorter periods of occupation in the paddocks, and getting each paddock correctly sized so there is the right amount of feed in there for the number of days they are there is that it moves toward an improved stocking density. The stocking density is the total number of animals in a specific paddock for a specific period of time. With improved stocking density the animals will more evenly distribute the manure in that paddock. Animals may still deposit more manure near shade and water sources, but overall the manure will be distributed more evenly. Smaller paddocks are easier to coordinate and to observe over time. The better the grazing coordination, the higher the stocking density, and the more likely animal manure deposition will be evenly dispersed across the pasture.

When animals are left for too long in a particular are their excessive deposit of manure is likely to damage the localized soil and plants. For example, when a chicken mobile hut is left too long on a particular ground the excess chicken manure can damage pasture vitality (temporarily) through excess nitrogen. When cattle cluster around the shade of a tree for too long a time, their manure can damage the tree.

"Manure scoring" is a method for monitoring and assessing livestock well-being in the grazing system. By observing the texture of the manure it is possible to get an idea of how effectively the paddocks are meeting their nutritional needs. In a cow, if the manure looks dry and balled up (and with a lot of non-digested fiber in it), then the pasture is probably over mature and has too much non-digestible fiber in them. In this case the animals may need to be supplemented or moved to a different area. In cows that graze very lush pastures, ones that are perhaps too high in protein and too low in fiber, then the manure will start to become soft and loose. And in extreme cases, the animals can get diahrea, cause by having too much protein and not enough fiber and energy.

A common manure coordination strategy is:

1. Drag manure out with a plough, or have it scratched by animals.
2. Mow the area with a mowing machine or other animals.
3. Let the paddock recover.

### 7.4.1 Multi-species rotational grazing (co-grazing)

*A.k.a., Co-grazing, coordinated animal movement, coordinated multi-species movement, coordinated multi-species grazing.*

It is possible to rotate multiple species around paddocks. The following is an example movement of animals. Cattle are the lead animal in the orchard; they mow by down by eating much of the grass. And, as they go the cattle fertilize the tress. They deposit their waste, and then, trample it into the ground to create fertile, carbon rich soil. Trampling from grazing animals incorporates their manure into the soil and crates hoof print pits that acts as miniature seed and water collection pits (basins or pockets). A few days after the cattle, the goats or sheep move through the same paddock. The goats eat the shrubbery that the cattle wouldn't necessarily eat. The goats also climb up and prune the bottom 6 feet of the trees. They also fertilize. Pigs are run through as left-over waste consumers. Then we send through the chickens in a mobile chicken coup. The chickens also fertilize the soil and eat all the bugs that hatch from the manure of the first two ruminants that went through. Chickens come in after the pigs have dug up big clumps of grass. They "cleaning out" the area and fertilize with their high  manure. The chickens will eat some of the parasites from the sheep that are there (if there are any there), which makes the sheep healthier because it cuts down on the parasite load. If animals are kept on the same piece of land all the time, then one sick sheep will inoculate all the sheep, and make for poor soil. By moving them around their parasite load is reduced, and the consequence is healthier soil and healthier animals. The interaction of multiple species together, either in the same or separately rotated paddocks can create a healthier ecology and more productive cultivation system.

It is possible to coordinate the movement of i 4 different animal species through an area, and as a result, acquire multiple cultivations, build up our soil base, and have the opportunity to play a role in the well-being of other symbiotic species, while giving humans a picturesque environment to enjoy in a variety of fashions.

Pastures may be used for herbivores and onmivores. When a herbivore is on a piece of pasture, they are walking around, and their hoofprints make indentations, which helps the land the hold water. The herbivores are chewing on the grass, which stimulates grass growth (including root growth). When grass is cut it grows. The grass and other plants are chewed by the herbivore, digested, and excreted with a host of microbes onto the soil. The herbivore then spread and compact their manure into the ground. Animals also poop on the ground and their manuŕe has microbes and other nutrients that build the bio-ecological network of the soil (i.e., build the soil). When perennials are allowed to continue growing, while being grazed occassionally, their roots grow deeper. Deep roots help with water retention in the soil. The animals improve the pasture through their grazing, rooting and fertilizing.

When grazing more than one species, it is best to graze the most selective ("picky") grazers first, and follow with the less selective grazers (e.g., start with cattle or horses and follow with sheep or goats). (Undersander, 2021, 24)

## 7.5 Grazing groups

It is often optimal to divide animals into different groups based on nutritional requirements for desired performance and condition of the landscape. Animals requiring the highest level of nutrition get the highest quality forage, while saving the lowest quality forage for the animals with lower nutritional requirements.

There are two ways to use forage to meet animal needs together:

1. Graze more than one group on the same paddock sequentially.
   A. All the animals could be introduced together.
   B. Introduction of different species into a pasture can be a staged process where high producers are introduced first (to consume the highest quality forage), animals with lower nutritional needs graze second, followed by the animals with only maintenance requirements.
2. Graze different groups in separate paddocks. Different species are in different paddocks. If there are poor quality pastures, then it is often useful to let the animals with lower nutritional needs graze them.

## 7.6 Cultivating pasture animals

*A.k.a., Animal stewardship.*

Animal stewardship involves the caretaking and use of other animals.

### 7.6.1 Animal life requirements

The seven cardinal parameters for growing animals:

1. Boundary transference environment:
   A. Light
   B. Temperature
   C. Humidity
   D. Wind (air velocity)
   E. Atmospheric composition with at least $O_2$
   F. Water
   G. Nutrients
   H. Land

Non-human animals have a set of [life-support] needs similar to those of humans:

1. Animals need appropriate light.
2. Animals need appropriate climates.
3. Animals need appropriate shelter.
4. Animals need appropriate food.
5. Animals need appropriate water.

### 7.6.2 Animal water needs

Although animals on sufficiently abundant pasture can get the majority of their water from forage (which is 80-90% water), an appropriate supply of clean water is essential in a grazing system, especially on hot sunny days. Some animals need more drinkable water, some need less, and some need ponds of water. Drinkable water can be distributed across a pasture by means of either gravity or pumping. A passive water system can be gravity fed from a pond at a higher elevation. These ponds, and water sources in general, should not have manure in them. For herbivores, it is generally important to have a water infrastructure on each paddock so that the herbivores can drink each day.

In general, clean water should be available to animals at all times, and watering tanks or troughs should be emptied and purged between species. Or, there should be sufficient water bodies or water flows nearby. Water distribution points should be appropriately placed and of appropriate size for the herd of animals.

**Table 47.** *Averaged daily water requirements of grazing animals. Note that animal water needs will be greater on hot, dry, and sunny days, or when grazing forage is dry. Needs will be less on cool, rainy days and/or when grazing on lush forage. Water needs will also be different depending on reproductive phase.*

| Animal | Liters per day |
|---|---|
| Beef cows | 56 - 76 |
| Dairy cows | 76 - 114 |
| Yearling cattle | 37 - 57 |
| Sheep | 7 - 11 |
| Horses | 37 - 57 |
| Goat | 7 - 11 |
| Pigs | 1.8 - 5.6 |
| Chickens | ~.4 |
| Ducks | 1 |
| Geese | 1.6 - 3.9 |

The placement of water in a field is essential. For cattle, ideally, water should be available within about 243 meters of the maxim distance from which animals might have to travel in a grazing system. Missouri research indicates that cattle, for instance, will not graze much further away from water than this. Performance per animal may be reduced when cattle are forced to travel more than 243 meters to access water. For many animal species, consuming water is a social function in that it requires movement of the whole herd. (Undersander, 2021, 22)

When considering watering equipment, determine the proper size of the watering tank based on the grazing system used and animal type. One of the best references here is USA NRCS FOTG Conservation Practice Standard – Watering Facility. (No.) CODE 614. [nrcs.usda.gov].

It is important to locate watering tanks away from waters surface water sources will help reduce contamination. Avoid sloping terrain to prevent erosion and run-off. Select a level and well-drained site to minimize trampling of vegetation and creation of a muddy area. (Hawkins, 2021)

Generally, it is optimal to have water available for animals in all paddocks. In some cases, it is better to siphon water to the animals, rather than brining them to the source of the water. Channelling water reduces disease and parasite problems and preserves water quality. (Undersander, 2021, 22) There are both moveable and stationary solar and battery powered pasture-based water pumps.

Drought is a period of little water (i.e., an excessive climactic incident). During periods of drought it is often necessary to take remedial action to ensure that forage lasts longer (or, as long as possible). Rest between grazing becomes more crucial as drought stress increases. In some cases, it is possible to set land aside to be grazed only during a drought. Such land should be populated by extremely drought tolerange forage (e.g., warm-season grasses). (Undersander, 2021, 30)

## 7.6.3 Animal food needs

Primary animal food-associated life requirements:

1. Nutritional needs at various stages of lifecycle.
2. Forage-animal balance: match forage available with the needs of the [grazing] animals.

How much forage is consumed per animal depends on a variety of factors. Animal feeding species type, quality, and quantity based on the animal characteristics of:

1. The species of animal?
2. The size of the animals?
3. The reproductive stage of the animals?
4. The animal density (density of herd)?
5. The amount of forage available?
6. The quantity of forage available?
7. Calculate: energy required by animal(s)?
8. Calculate: energy intake?
9. Determine: Is there dietary sufficiency?

The amount of forage available influences consumption. If forage is tall, for example, large amounts may be wasted because of trampling. When forage is too short or thin, animal intake will decline and animal performance will suffer.

Animal dietary selection includes three characteristics:

1. **Species** for consumption by animal. What is the specific specie or species that the animal will consume? E.g., grass for ruminant animals, etc.

   Animals consume species either alive or dead:

   A. **Live** [species for consumption by animal]. Will the animal will consume the specie alive, is this preferred (and when), and if so, how much is consumed?
      - Biomass composition.
   B. **Dead** [species for consumption by animal]. Will the animal will consume the specie dead, is this preferred (and when), and if so, how much is consumed?
      - Biomass composition (e.g., dry matter, DM).

Many animal species prefer not to graze during the hottest part of the day. Often, the heaviest grazing periods occur in the morning and after sunrise for two or three hours. During hot days, animals need abundant water and may benefit from being provided with shade. (Undersander, 2021, 23)

Animals that consume plants will often selectively graze certain plants parts over others. Rumanent animals eat from the top down, taking the youngest, most nutritious leaves first, leaving the less nutritious stems for later. Smaller mouthed animals, such as sheep and goats, can graze more selectively than larger ones like cattle.

#### *7.6.3.1 Species-specific diets*

*A.k.a., Species-appropriate diet.*

Animals species consume a species-specific diet:

1. Cattle consume:
   A. Plant matter - pasture grasses (and related plants), along with relatively small amounts of grain when the grass is going to seed.
   B. Other organisms - insects, and small mammals rarely.
2. Sheep consume:
   A. Plant matter - pasture grasses and plants (including woody material).
   B. Other organisms - small mammals and insects.
3. Goats consume:
   A. Plant matter - pasture grasses and plants (including woody material), fruit.
   B. Other organisms - small mammals and insects.
4. Pigs and hogs:
   A. Consume:
      1. Plant matter - particularly tubers and roots, leaves, and fruit.
      2. Small mammals, newborn of larger mammals, eggs and young of ground-nesting birds.

3. Invertebrates - such as worms, insects, and insect larvae, crayfish.
4. Reptiles.
5. Dairy.
6. Human scrapes.

B. Some basic principles of pig grazing include:
1. More pigs on fewer square feet root up the soil over a shorter time.
2. Fewer pigs rotated faster graze rather than root.
3. Soft soil (e.g., spring, rain, etc) will get rooted more.
4. Larger pigs root deeper than smaller pigs.
5. Pigs often require supplemental feed on pasture, unless the pig is:
    i. A breed of pig that is nearly feral and B) lots of land for them to roam. If you do choose to feed them, I recommend hand feeding daily in a trough and not using a metal feeder with a flap lid. Those metal feeders produce a loud and unmistakable noise that will be heard far away as the pigs clank the lid up and down through the day and night, calling attention to your bacon on the hoof.

5. Fowl and waterfowl
    A. Foul
    1. Plant matter - grasses and other plants, and seeds.
    2. Other animals - insects, worms, snails, amphibians, fish, eggs, small mammals and reptiles.

    B. Waterfowl - mostly live on aquatic or near-aquatic organisms:
    1. Plant matter - pond weed, seeds, grasses and other plants.
    2. Other animals - insects, worms, snails, amphibians, and crustaceans, fish and eggs.

How much land and what conditions of the land are required for one animal of a species, and are required for the whole herd:

1. Stage of development
    A. Amount of food (quantity and quality) for health.

When pastures do not provide sufficient food, supplemental food (nutrition) can be provided. Supplements should be formulated to complement the forage growing on the pasture.

### 7.6.4 Animals grazing on plants

Grazing is not "bad" for pasture plants. Pasture plants have special ways to cope with grazing. Some plants are more adapted to continuous grazing, and some are not. Taller growing forages usually die under continuous grazing since most of the leaves can be grazed off. Taller growing forages needs [more] rest between grazings to survive on a pasture. If allowed to grow tall, taller forages will block the sunlight of shorter forages and plants.

There are two types of plants that may be present in a pasture:

1. Perennials - return every year (keep living). Perennials need to be planted once. Perennials are mostly ever growing. Perennial plants photosynthisize earlier in the spring and later in the fall than annual plants.
2. Annuals - die at the end of a year. Annuals need to be planted annually. Annual plants photosynthisize later in the spring and earlier in the fall than perennial plants.

For most perennial grasses, for every foot above ground there are roughly two feet of roots below ground, and those root systems. These root systems do a number line f things. They infiltrate and break up the ground so that when it rains the ground can hold more water, and the capillary action of the root system can sequester water.

There are many plant species and parts of plants that can be grazed on a landscape by pastured animals. Animals may graze on the following types and parts of plants:

1. Grasses and legumes (type) - Grasses are generally herbaceous plants (i.e., lack woody stems). Grass means any plant of the family poaceae, characterized by leaves that arise from nodes in the stem and leaf bases that wrap around the stem, especially those grown as ground cover rather than for grain.
2. Herbs (type) - Herbs are a short-sized plant with soft, green, delicate stem without the woody tissues. They normally complete their life cycle within one or two seasons. Herb means any green, leafy plant, or parts thereof, used to flavour or season food.
3. Shrubs (type) - Shrubs are medium-sized, woody plants taller than herbs and shorter than a tree. These plants generally have a woody stem.
4. Trees (type) - Trees are big and tall plants. They have very thick, woody and hard stems called the trunk.
5. Climbers (type) - Climbers are the plants with long, week and very thin green stem, which use external support to grow and carry their weight. (e.g., beans, cucumber, gourd, jasmine, money plant, etc.)
6. Creepers (type) - Creepers mainly refer to those plants which have a weak stem and are extended

horizontally along with the soil on the ground as they cannot stand upright. (e.g., pumpkin, passionflower, sweet potato, etc.)
7. Leaves (part)
8. Fruit (part)
9. Flowers (part)
10. Root or tuber (part)

### *7.6.4.1 Plant rest periods*

Optimal growing conditions for plant will decrease the rest period required for a pasture. Plants under environmental stress (drought, extreme weather, poor soil fertility, etc.) will require longer rest periods. Rest periods for plants are closely related to seasonal conditions:

1. Legumes generally need rest periods of 3 to 4 weeks throughout the season.
2. Cool-season grasses need as little as 2 weeks of rest during cool weather and 5 to 7 weeks during hot weather.
3. Grass-legume mixes should be grazed when the grass reaches an optimal height (i.e., yield to quality).
4. Warm-season grasses need to rest for 5 to 6 weeks during cool weather and about 3 weeks during hot weather.

Short grazing periods is often best, because livestock graze selectively and will eat the highest quality forage when first accessing a paddock. The animals will be forced to eat lower quality feed each day. Shorter grazing periods are more likely to provide more uniform forage consumption. It is important to note here that some species do not benefit greatly from rapid rotations. Other species can be moved to a new pasture 2 to 6 days (in general). (Undersander, 2021, 27)

Often, the longer a pasture is grazed, the longer the pasture needs to rest. The higher the plant nub, the more quickly the plant will be able to recover after grazing. In principle it is appropriate to leave 4 to inches of nub for cool-season grasses and legumes, and 4 to 8 inches for warm season grasses.

The pasture soil and plants can be collected should occasionally and tested for nitrate levels. Grazing pastures with plants that are known to concentrate nitrates should be avoided, introduced slowly, or have supplemental feed available, especially after a drought (which, would have concentrated nitrates even more). (Undersander, 2021, 38)

### *7.6.4.1 Grass plant grazing*

Grazed grass growth and life requirements include:

1. Appropriate soil and atmospheric conditions.
2. Leaf area
3. Growing points.
4. Moisture for growth/regrowth.
5. Opportunity for regrowth.
6. Frequency and intensity of defoliations (how often and much?).
7. Timing of Grazing (when?).

The effect of defoliation of grass by grazing animals includes:

1. Defoliation above growing points of leaf blade causes the following:
   A. Growth continues provided water, sunlight and proper temperatures are present.
   B. Photosynthesis produces carbohydrates. Some used for new cells and cell enlargement. Some becomes soluble carbohydrate reserves and plant health not affected.
2. Defoliation below terminal growing point causes the following:
   A. Growth stops.
   B. Few carbohydrates produced or stored.
   C. New growth from dormant basal buds.
      1. Uses soluble carbohydrate pools stored in the root crown and/or lower part of stems.
         i. Repeated defoliation below growing points, during the rapid growth phase, across years, reduces and can eliminate stored energy reserves, which kills tillers and plants.

Types of grasses include, but are not limited to:

1. Elongated tillers
2. Unelongated tillers
3. Short grass - more grazing tolerant.
4. Long grass - often less grazing tolerant.
5. Root growth - Grass root growth – 20-50% of roots must be replaced annually (Dietz, 1988)

There are four general grass forage growth patterns include:

1. Cool-season grasses - most productive in the spring and fall, but go through a mid-summer decrease in production.
2. Legumes - growth starts later in the spring than cool-season grasses. Many withstand heat and drought better an cool-season grasses.
3. Warm-season grasses - need warm soils for germination and thrive on mid-summer heat the slows the growth of most other species.
4. Other alternative forages - such as annual grains (oats, winder rye, and winter wheat) and crop residue (e.g., corn stalks) can be grazed in the early spring and/or late fall.

Continuous grazing grass types includes but are not limited to:

1. Kentucky bluegrass
2. White clover
3. Many prostrate "weeds" (where low growing leaves may escape being grazed off)

> **NOTE:** *A tiller is an additional shoot (often forming from buds below the soil surface).*

Grasses that may be grazed more aggressively include grasses that tiller early and produce heads profusely throughout the year. The stems of these grasses do not elongate after initial heading (grazing of the head of the grass). Examples of these grasses include:

1. Tall fescue
2. Perennial ryegrass
3. Kentucky bluegrass

Grasses that should not be grazed until new tillers are visible at the base of the plant usually have stems that elongate after heading, lifting the potential growing points above the soil surface where they may be removed by grazing. These grasses must be coordinated differently. Examples of these grasses include:

1. Bromegrass
2. Timothy grass

#### *7.6.4.2 Grasses and legumes*

Characteristic of forage grasses and legumes can be input into a table where each row is a type of grass or legume and the subsequent columns are A through H:

1. Grass/legume type is either excellent, good, fair, or poor for the following characteristics:
   A. Regrowth potential
   B. Legume compatibility
   C. Winter hardness
   D. Ease of establishment
   E. Drought tolerance
   F. Flooding tolerance
   G. Grazing tolerance
   H. Species persistence.

#### *7.6.4.3 Legume plant grazing*

Unlike grasses, legumes flower in the seeding year and several times annually every year thereafter. Like grasses, grazing or harvesting top growth encourages development of new tillers at the crown. Legumes continue to branch and enlarge, and eventually flower. (Undersander, 2021, 7)

> **NOTE:** *Many pastures use grass and legume mixtures.*

#### *7.6.4.4 Plant species pasture control*

Pastures should be coordinated so that they contain useful plants. A pasture design should avoid the inclusion of plants that the livestock avoid eating, that have low nutritive value or are poisonous. Good rotational grazing systems will tend to keep most avoided plants out of the pasture. Note here that grazing coordination alone will not normally correct pre-existing plant problems. (Undersander, 2021, 8) There are different regional control regulations and recommendations for getting rid of plants.

Common control procedures include, but are not limited to:

1. Animal movement.
2. Cleaning equipment.
3. Mechanical uprooting (dug up).
4. Controlled fire (controlled burn).
5. Herbicide chemical (chemical death).
6. Graze frequently.

> *Note that different procedures will be required for different plant species.*

Avoided plants are generally more of a problem in overgrazed, infertile pastures, rather than, in fertile and well-coordinated pastures). To prevent the spread of avoided plants, avoid spreading manure contaminated with the seeds of these plants. Clean equipment after working in a pasture containing those plants. Repeated grazing, mowing, clippings, and mechanical uprooting can diminish unwanted plant populations. Tillage can also be used to suppress avoided plants by covering them with it. In concern to herbicides, spot spraying is often the appropriate treatment. Herbicide usage must include the correct identification of the plant, and should not be applied until animals have left the paddock. The paddock should not be grazed again until treated areas how followed label restrictions. (Undersander, 2021, 9)

#### *7.6.4.5 Plant life requirements*

The nine cardinal parameters for growing plants:

1. Foliar zone environment parameters:
   A. Light
   B. Temperature
   C. Humidity
   D. Wind (air velocity)
   E. $CO_2$
2. Root zone environment parameters:
   A. Temperature (root-zone)
   B. Water
   C. Oxygen
   D. Nutrients

There are three general categories of plant nutrients:

1. Sunlight (EM radiation)
2. Mineral nutrients
   A. 13 mineral nutrients (at least)
   B. Macro nutrients
      1. Primary
      2. Secondary
   C. Micro nutrients
3. Non-mineral nutrients
   A. Hydrogen, carbon, and oxygen found in the air and water.
   B. Bacterial outputs

#### *7.6.4.6 Plant mono-agriculture*

Growing acres of mono-agriculture will deny that land to the animals that would otherwise have lived, and eaten, and thrived there.

#### *7.6.4.7 Plant seeding methods*

There are a number of different approaches for seeding pastures:

1. No-till or reduced tilage - Seeds are drilled into existing sod.
2. Frost seeding - The seed is spread onto pasture in late winter or early spring (during or just after snowmelt). Moving animals across the seeding area immediately after thaw may help to sow the seed and improve its growing condition.
3. Grazing coordination - using livestock to seed. Using livestock to do the seeding in areas not accessible or not preferable by technical equipment. The animals eat the seed, and some of it is available in manure for generation. For areas that are available for equipment, it is possible to mix seed with manure before spreading. Seed can be mixed directly with manure before its spread on pastures.
4. Tiling based seeding (a.k.a., conventional seeding) - this method exposes most of the soil by digging up soil and forming small trenches.

#### *7.6.4.8 Soil fertility*

To maintain healthy pastures, coordination must ensure that soil nutrients are returned to the soil at the same rate they are removed. Once soil nutrient levels are optimal, nutrient cycles naturally. Grazing animals normally return 60 to 80 % of available pasture nutrients (with extreta). Even in an optimal environment, some additional fertilization will probably be required or would at least provided added benefit. However, in some cases, supplemental feed can provide too many nutrients to a specific animal (e.g., pastures rotationally grazed by dairy cows receiving high levels of supplemental feed can have such high phosphorus and potassium levels that they do not need maintenance fertilization). (Undersander, 2021, 10)

Animals interact with the soil in a variety of possible ways:

1. Tread on soil.
2. Dig up soil.
3. Trample forage.
4. Deposit manure.
5. Disperse manure.

Animal treading on soil can be both harmful and beneficial to the soil. Animal treading can cause erosion, but it can also break up the soil surface allowing better water penetration.

Some grasses improve the treading tolerance of pasture. For example, sod-forming grasses are very tolerant to treading (e.g., bromegrass, reed canarygrass, and kentucky bluegrass). Adding some of these grasses may greatly increase the treading tolerance of a pasture. (Undersander, 2021, 25)

Manure is a significantly important source or recycled nutrients and its deposition can be coordinated to the benefit of the pasture. With continuous grazing, manure is less effective as fertilizer because grazing animals may concentrate manure in areas where they congregate and not where they graze. As a result, some areas receive overload and other areas receive no load. Rotational grazing improves more equal manure distribution. It is also relevant to note that grazing on lush (high water concentration) plants (and plant parts) helps distribute manure more uniformally and accelerates the breakdown and recycling of nutrients because the manure is more liquid. Extreta (e.g., manure) is essential to pastures, providing both nutrients, organic matter, water, and microorganisms. Note that animals will usually avoid eating near manure of their own species but are likely to eat right up to the manure of a different species. This avoidance is in part due to the odor of the manure to the animal that produced it. This aversion can be taken advantage of -- a species manure can be spread in an area of the pasture to keep that animal off of it. It is also relevant to note here that animal density (stocking rate) will decrease the "zone of distaste". High stocking rates will also increase manure distribution and decomposition through trampling ("hoof action"). However, animals should not be forced to eat right up to their own manure. To obtain additional nutrients, some animals will eat the manure of another species. Pigs, for example will often eat the manure of another animal. (Undersander, 2021, 25)

### 7.6.5 Animals grazing on insects

Insects are often abundant in flourishing ecological environments. Animals frequently graze on insects, either intentionally or unintentionally (as they graze on other foods, the attached insects are consumed inkind). Insects can be found in the pasture environment, but they can also be cultivated separately and dispersed into the pasture or they can be fed directly to the livestock animals as feedstock.

## 7.6.6 Animal reproduction stages

Animal reproduction phases and graphing:

1. Calving
2. Breeding
3. Weaning

Food intake can be plotted against reproduction phases:

1. Early gestation
2. Lactation
3. Flushing and breeding
4. Gestation

The phases of reproductive gestation are generally,

1. Mid-gestation
2. Late gestation
3. Calving through breeding
4. Breeding through weaning
5. Mid-gestation

A survey of animal reproduction requires:

1. Pregnancy rates
2. Body condition score

## 7.6.7 Animal medical issues

Grazing animals can succumb to a number of potentially serious medical conditions. The following are some of the most relevant medical health issues to consider with pasture raised animals.

### *7.6.7.9 Animal diseases*

Like most of the parasites, livestock diseases are passed along through mouth and nose contact, and in the feces. It is possible to limit parasite and disease transmission:

1. By separating different animal species (in a "leader-follower" system), for example, keeping cattle separate from pigs, pigs separate from the fowl, and fowl separate from the sheep.
2. Care should be taken that animals are not stressed, as stressed animals are more likely to become sick.
3. Clean water should be available to the animals at all times and watering tanks or troughs should be emptied and purged between species.
4. Pastures should not be grazed until the soil is exposed.

### *7.6.7.1 Animal parasites*

Grazing animals can easily contract and spread parasites. Parasites are a significant and ongoing concern with certain pastured animals, most notably, sheep and goats. Regardless of the livestock species, worm eggs are deposited in the animal's manure, which then incubates the egg until it hatches. If the species that deposited the manure is allowed to graze nearby when it hatches, it will ingest the parasite. Repeated exposure of this kind will result in a build-up of parasites, which can harm the health of the animals and their productive rate.

Rotational grazing is a very effective method of parasite control since animals are moved away from their manure deposits, which incubate their species-specific parasites. Further, when they return to graze, the plant growth will be taller and since parasites tend to stay on the lower parts of the plant, the risk of parasite contraction is further reduced. Some parasites can subsist externally from their host animal in suspended animation as dehydrated cysts.

Some animals and certain breeds of sheep and goat species have greater resistance to parasites (e.g., Katahdin sheep. Sheep and goats share the same internal parasites. Pigs and chickens share the same internal parasites.

One alternative to rotational grazing for parasite control is the leader-follower method. In this model, species are grazed separately in paddocks and follow one another to clean up what the previous species chose to not graze without any fear of parasite contraction.

The best way to limit parasites in a multi-species livestock operation is to understand:

1. The types of potential parasites.
2. What the potentials of the parasite are (i.e., how they affect the animals).
3. The parasite's life cycle.

In order to limit the propagation and continuation of parasites, it is best to:

1. Not to combine livestock with similar parasites in the same or even the following paddock.
2. Always have a species break between one host species and the next susceptible species.
3. Maintain a diverse pasture forage mix, and especially a mix that includes perennial plant species that are known to be parasiticides (anti-parasitic). These can be planted along main fence lines, as well as the occasional members of the walnut and hickory species (leaves and nut husks show parasiticide effects).

Some of the most well-known anti-parasitic plants include: wormwood (Artemisia absinthium), members of the sage family in general, garlic, gentian, fennel and other strong herbs such as lespedeza.

Important considerations in parasite lifecylces involve:

#### 7.6.7.2 *Nitrate poisoning*

Nitrate poisoning acts quickly and is hard to detect before being fatal. When animals consume these high-nitrogen foods at too high a species excess, their body fails and they die. Certain plants have a tendency to concentrate more nitrates than others (e.g., lambs quarters, pig weed, annual grains, etc.). Nitrate accumulation can come after excessive environmental disturbance, including drought, too mush shade, and herbicide application. The application of any manure or fertilizer will also increase the quantity of nitrates in the soil. (Undersander, 2021, 38)

#### 7.6.7.3 *Bloat*

A medical condition where foam producing compounds of immature plants cause continuous foam production in the rumen (of susceptible animals). This foam prevents them from belching rumen gas. This disease can quickly lead to an animals death. We already have the logistics of complicated social economic relations in a manner that allocates goods and services efficiently using non-market based solutions. (Undersander, 2021, 37-38)

Bloat can be significantly avoided and prevented with several principles/practices (Undersander, 2021, 38):

1. Do not graze hungry animals on pure legume pastures. Feed the animals with hay before releasing them on a pasture with the potential of causing bloat. Leave feed on a pasture continuously so the animals do not gorge themselves.
2. Move the animals frequently.
3. Feed poloxalene to the animals as an anti-foaming agent.
4. Avoid grazing legumes and brassicas rain or dew on them.
5. Avoid grazing grass and legume pastures that are in an immature stage.
6. Plant non-foaming plants (e.g., the legume birdsfoot trefoil).

#### 7.6.7.4 *Poisonousness plans*

In many areas of the world, the existing forage mix may be harmful to one species but not another. Some plants are toxic, or mildly toxic to animals. Animals will usually avoid toxic plants, but during times of low abundance they may be driven to consume dangerous dosages of these plants.

Problem plants that are poisonous to many species, such as certain thistles and poison hemlock, pose little danger to goats.

#### 7.6.7.5 *Anti-herbivory (plant bio-chemical defenses)*

*A.k.a., Antiherbivory.*

Classification of anti-herbivory compounds includes:

1. Nitrogen Compounds
   A. Alkaloids
   B. Amines
   C. Non protein amino acids
   D. Cyanogenic glycosides and Glucosinolates
2. Terpenes
   A. Monoterpenes
   B. Cartenoids
3. Phenols
   A. Simple phenols
   B. Polyphenols

## *7.7 Pasture area control [plan]*

It is essential to remember that pastures conditions may vary with season, and the control of pasture areas may need to account for this dynamic environment with flexibility of decisioning.

Computational factors relevant to pasture coordination control include:

1. **Time** - the duration animals remain in a given grazing area.
2. **Number** - the number of animals on the grazing area (stocking density).
3. **Area** - the land available for grazing.

Technical pasture control practices include, but are not limited to:

1. Fencing.
2. Water development.
3. Animal trails and walkways.
4. Herding
5. Behavior modification
6. Salt and supplement placement

The non-fencing approach (which still includes some fencing) involves created a permanent herd with multiple species in the same paddock together (e.g., cows, goats, and donkeys. A mixed species herd may be significantly less prone to seek a way out through the fencing. The animals are rotated into each paddock together, instead of having them follow a leader-follower procedure.

Pasture quality acceleration practices include, but are not limited to:

1. Brush management (e.g., controlled, cutting, clearing).
2. Prescribed/controlled burning.
3. Range or pasture planting.
4. Nutrient management (chemical management).
5. Irrigation water management.

### 7.7.1 Fencing control

Paddocks should always be fenced. The rougher and rockier the terrain, the more difficult the fencing requirements. With fencing it is possible to create a common lane for animals as they move between paddocks (the "lane"). The banks of bodies of water (e.g., ponds and streams) may need to be fenced in order to prevent damage and erosion to the land water interface by grazing and treading of animals.

In concern to gates within fences, gates between paddocks and/or a lane are generally located in or nearby a corner of each paddock.

Fencing consists of at least the following elements:

1. Fencing wire or border material.
2. Fencing posts or fencing support structure.
3. Fences may also include the following additional functions:
   A. Automation
   B. Transportation
   C. Electrification
4. Sharpness appearance (i.e., barbs).

Fencing may be used to separate a general pasture for a specialized pasture:

1. Only for the those of a specific reproductive age (e.g., the young).
2. Only for one species.
3. Only for stockpiling.
4. Only for extreme climactic weather events.

There are different types of fencing and fencing configurations, including but not limited to:

1. **Permanent fencing** - Often the choice for perimeter fencing. Permanent fencing will can be used to create a permanent paddock.
2. **Lightweight movable fencing** (dynamic fencing, temporary fencing) - Moveable electric fencing allows easy moving of a fence line, it is light weight and easy to take down and re-install - it can be done by one person in a matter of an hour. Allows for the changing of paddock size and area. These fences are often made with portable wires and tapes composed of polyethylene embedded in stainless steel strands. Polywire is braided wire and is frequently used as a moveable electric fence material. Lightweight plastic or fiberglass posts can be used to hold up polywire.
3. **Strip grazing wires** - A system that uses two wires that are moved along two permanent fences. Move the front wire according to animal needs and pasture coordination decisions. The back wire follows the front to prevent movement of animals in the reverse direction.

Type of fencing by fence material and function include, but may not be limited to:

1. Wood fence.
2. Stone fence.
3. Wire fence.
4. Barb-wire fence (warning: never electrify barb-wire fencing).
5. Electric fence (note: fencing can be constructed so some or all of a fence is electrified).
   A. An electric fence line must be clear so that the charge does not short out anywhere along the line. A short will render the whole fence useless.
   B. The charger for an electric fence must be well grounded. If there are issues being experienced with the fence, it's likely the grounding of the charger. The depth of a grounding rod can vary depending on the type of charger being used and the soil type. In general, grounding rods should be rooted relatively deep into the earth.

The following are the most common categories of fence:

1. Non-electrified
2. Electrified
3. Barbed
4. Non-barbed
5. Gapped
6. Non-gapped

The most common type of fencing for pastured animals include:

1. Piled stones.
2. Four-strand, high-tensile electric fence around the perimeter of the grazing land, powered by a solar fence charger.
3. Six to eight strands of high tensile cord to confine animals (e.g.,goats and sheep).

The maintenance and monitoring of fences include:

1. Is the fence intact?
2. Do plants near the fence need trimming?
3. Is there debris building up beneath the fence?
4. Is there erosion around the fence?
5. Do parts of the fence need replacing?

6. If electric, is the electricity flowing when required (i.e., is there a short in the fence or has the energizer broken).

The design of some fences can be dangerous to specific animals. For example, goats can easily stick their heads through a fence with gaps, get their horns caught, and either starve or become a predators food. In some cases, goats are de-horned goats to eliminate this risk.

#### *7.7.1.1 Animal specific fencing*

In concern to electric fencing, different animals may require differently charged electric fences:

1. Pigs
    - Pigs can be kept in with two strands of polywire.
    - Pigs can be kept with netting, which is less likely to succumb to the pigs will throw some turf over the fence and shorting it out.
2. Goats
    - Goats need netting and their fencing should be at least 40" tall so they don't jump it.

### 7.7.2 Movement and gating control

Movement of livestock and the opening of gates can occur in the following ways:

1. Manually
    A. Humans open the gates.
    B. Human operation of tumble wheel for fencing.
2. Automatically
    A. Using a batt latch automated computer operated gate opener. No humans have to be there when the gate opens and the livestock move to the next paddock.
    B. Automated electric (or non-electric) tumble wheel for fencing.

Donkey-goats (donkey killers, mata-burros, etc.) are devices that prevent the escape of livestock on farms, even when the gate is open. These devices are platforms that function as bridges, usually made of wood, concrete or steel with gaps in between beams or rods. These devices are installed as a mechanism to discourage animals from crossing the open gate.

### 7.7.3 Animal transportation

There are different possible types of animal transportation in a cultivation system, these include:

1. Mobile animal harvesting machines.
    A. Milking mobiles - a trailer used to milk lactating animals.
    B. Chicken hut trailer - a trailer used to transport animals like hens from one paddock to the next.
2. Animal trailers.
    A. Most often used to transport animals for harvest.

It is important to train the animals to load into a trailer from a young age. Somewhere in the grazing paddock system park a livestock trailer. When animals are not trained to load into a trailer from a young age then loading them can be challenging and unnecessarily stress the animals. When the cattle are in that paddock lead the animals into the trailer where they find a tasty treat of a well-balanced feed. Simultaneous with the livestock discovering the tasty treat the herder should give out a species-specific whistle or call. As this happens periodically through the grazing season, the animals become familiar with the trailer. They see it frequently, they graze near and around it frequently, and they get a morning treat inside of it along with scratches and pats from the human. The animals become comfortable with seeing the trailer arrive and seeing it drive away. Eventually the trailer becomes associated with a positive experience. Once on pasture for sufficient time, animals may needed to be transported for harvest.

It is relevant to note here that mobile coops are crowded, hot, stink, are hard to clean, and hard to move. If used, mobile coops should be on a tractor bed, or on some other easily moved platform. Moving chickens is best done through open-bottomed, portable chicken pens or trailer-mounted, mobile chicken coops. Buying enough square-mesh portable electric fence to set up permanent paddocks for all of the chickens that you can raise is quite expensive. And moving mesh-fence paddocks every day is a lot extraneous and unnecessary work.

### 7.7.4 Predation

Under specific bio-geographic conditions grazing animals may have predators in the local environment. Livestock protection from predators includes, but may not be limited to:

1. Guardian dogs, such as Great Pyrenees or Anatolian Shepherds. These animals will defend the herd when attacked.
2. Goats and sheep often played the role of an early warning system and retreated to the herd when a predator is identified As a result, while the sheep and goats sometimes venture away from the herd, but at the sign of any trouble, they retreat to the herd with the larger cows.
3. Donkeys are very effective guardian animals, instead of dogs. They are part of the herd, just like all the others, and our two donkeys often stand quietly facing opposite directions, ready to stomp any invader. These animals will defend the herd when attacked. Use donkeys to kill predators.
4. Bulls can be a permanent part of the herd (humans must be careful around bulls as they can be very

dangerous). These animals will defend the herd when attacked.
5. Fencing perimeters.

### 7.7.5 Riparian area grazing control

A riparian zone or riparian area is the interface between land and a river or stream. Riparian area grazing coordination involves (Undersander, 2021):

1. Attract livestock away from riparian areas:
   A. Offsite water developments.
   B. Manipulation of upland vegetation.
   C. Supplementation.
2. Excluding use or promoting avoidance of riparian areas:
   A. Fences, barriers, stream access points, low-stress herding.
3. Herd coordination and animal husbandry:
   A. Culling practices - "riparian areas".
   B. Breeds.

## *7.8 Grazing rotation control [plan]*

*A.k.a., Livestock movement control.*

The rotation of grazing animals can be done in an automated, semi-automated, or manual form. Batlatch automated computer operated gate openers allow for the automated opening of gates between pastures. No humans have to be there when the gate opens and the livestock move naturally to the next paddock. Tumble wheels for movable fencing.

## *7.9 Grazing plan development*

A grazing plan requires the following elements:

1. Describe present coordination; identify opportunities, issues, problems.
2. List what resources are available to work with (land, allotments, resources, facilities, animals, soils, plants, water, equipment).
3. Determine objectives.
4. Determine animal needs and timing.
5. Determine plant needs and timing.
6. Determine coordination/management tools and techniques.
7. Design the plan, grazing strategy, contingency plan for disasters.
8. Determine monitoring design.

A grazing plan requires at least two assessments and one calculation:

1. Conduct a pasture resource assessment:
   A. Identify pasture size.
   B. Identify pasture composition.
   C. Identify pasture state/status.
2. Conduct a species resource assessment:
   A. Identify the animal and forage species.
   B. Identify the animal availability (do you have the animal).
   C. Match animal needs with forage production.
3. Calculate an optimal paddock size and rotation schedule (be flexible).
   A. Identify optimal foraging time and schedule, including optimal grazing and rest periods for a pasture.

A grazing plan requires rotational coordination:

1. Determine the number of animal units that will be in the grazing system.
2. Estimate how many hectares will be needed throughout the grazing season.
3. Estimate how large each paddock should be.
4. Estimate the number of paddocks needed.

The plan must account for all relevant resources, including:

1. **Land resources**
   A. Land base (soils, plants, minerals) for a year-round ranch plan
   B. Private lands – irrigated pastures
   C. Public lands – rangelands
   D. Soil resources
   E. Water resources
   F. Mineral resources
2. **Technology resources**
   A. Fences
   B. Facilities
   C. Equipment
   D. Etc.
3. **Animal resources**
   A. Cultivated animals (livestock and animal companions)
   B. Wild animals (wildlife)
   C. Feral animals (i.e., animals that belong to a domesticated species like cats and horses, but live wild)
4. **Plant and other species resources**
   A. Cultivated plants (food and medicine, aesthetics)
   B. Wild plants (wildlife)
   C. Feral plants (i.e., plants that belong to a domesticated species like, but live wild)
5. **Human contribution**

Guidelines for a grazing plan include:

1. Provide as much growing season recovery time as possible (i.e., reduce duration of grazing for each

unit).
2. Consider the rate of plant growth (soil moisture and temperature) in planning duration.
3. Increase the number of pastures (use areas) and stock waters to increase flexibility.
4. Consider combining herds to make more pastures available.
5. Try not to graze the same unit at the same time of the year every year. *Why?*
6. Adjust the intensity to match the season and duration of use.
7. Make the whole plan fit together.
8. Develop a contingency plan.

### 7.9.1 Identify the animal species

It is essential to identify the animal species to be grazed on the pasture (and therein, paddocks). There are a number of factors that go into the selection of specific species of animal:

1. Geographic and climactic location
2. Soil type
3. Plant type
4. Predator type
5. Disease types in area and common to a species
6. Desired noise level

#### *7.9.1.1 Select animals, grazing species and breeds*

Choosing breeds of animal for pasture grazing involves the following significant decision factors:

1. Choose breeds that require little labor. For example, wool sheep require shearing, but hair sheep (such as Katahdin) do not. Choose breeds that fit the environment.
2. Choose parasite-resistant breeds.
3. If you supplement with minerals, take care to choose appropriate minerals and quantities. For example, as sheep are more sensitive to copper than cows.
4. Identify local recommendations for animal species and land access. For example, for every one hectare there could be one cow, one calf, two goats, one sheep, ten chickens in movable hen-houses (no roosters), two turkeys. Maybe for two hectars, there could be three cows, three calves, three sheep, six goats, 30 chickens, six turkeys.

#### *7.9.1.2 Identify desired noise level*

The noise level in a rotationally pastured environment is based on the following factors:

1. There are guardian dogs, and will they make noise.
2. Bulls separated from cows will call the cows.
3. Roosters have loud early morning calls.
4. Equipment will make noise also.
5. There are loud breeds of goats and other livestock, and there are quiet breeds of goats and other livestock.

### 7.9.2 Calculate for optimal paddock size

1. How many animal units are being grazed?
   - Animal unit (AU) - 500 kilograms
2. What is the grazing capacity of the area?
   - Carrying capacity - the number of days it is possible to graze 1 AU on a hectare before moving the animal to another paddock and letting the area rest for the remainder of the year.
3. Calculate the square meters required per paddock for one day:

   Carrying capacity / Animal units = sqr m

### 7.9.3 Calculate for optimal paddock number

To determine the optimal number of paddocks for a rotational grazing system, it is necessary to estimate (identify):

1. The length of the longest rest period (often, occurring during the slowest period of forage growth).
2. The length of the grazing period.
3. The number of species and animal groups that will be grazing sequentially.

Paddock numbers can be calculated from the following formula:

Number of paddocks = (rest period / grazing period) + number of animal groups

- For example, a pasture with 15 day rest periods and 5 day grazing periods that is grazed by 1 animal results in determination of 3 paddocks as appropriate. ((15 / 5) + 1) = 3 paddocks.

### 7.9.4 Calculate for land capacity

The carrying capacity of a set area of land is the number of animals that can be sustainably grazed on the available land over a season or year (an elongated period of time). Carrying capacity is measured over a long period of time, either a season or a year. The critical piece of that definition is sustainably grazed. Sustainably grazed refers to a feed-stocking rate (not animal-stocking density) that allows animals access to their daily feed requirements while maintaining the resource base of the land. If more animals are grazed than the land can support over a season, then the resource base will begin to deteriorate in the form of decreased plant species, erosion, increased weed pressures and decreased productivity. If the land has stopped producing sufficient feed to support the life requirements of the number of animals, then remediation action must be, which may include a reduction in the population of the species.

Calculating for land capacity requires:

1. Calculating the current carrying capacity of the pasture(s).
    A. Identify amount of land available.
    B. Identify amount of feed available on land.
    C. Identify amount of feed available in stock (feedstock).
    D. Calculate optimal animal to feed solution given available conditions.
2. Calculate the future expected carrying capacity of the pastures.
    E. Calculate optimal animal to feed solution given future available conditions.

There are four basic data-points that go into the carrying capacity calculation:

1. **Forage production (in kilograms/hectare)** - Forage production is expressed in kilograms/ hectare. Estimates should be specific to a forage species and the specific climactic- and bio-region. The result should be expressed in: Dry matter (with units, kilograms/hectare). Animal nutrition requirements, expressed as daily dry matter (DM), which are species associated numbers (note: this data is easily found online). Alternatively, it is possible to calculate the actual production value by clipping, drying and weighing your forage in the context of soil nutrient content and plant nutrient type [for a/the species].
    A. Macro-nutrient dry matter available?
    B. Micro-nutrients available?
    C. Species and number of organisms available?
    D. Species life stage requirements?
2. **Utilization rate (in percent usage, e.g., .50; consumption over paddock rotation in a season or duration of time) -** At what rate (usage over time) is feedstock being consumed?
3. **Regeneration rate (in percent regeneration, e.g., .50; regeneration over paddock rotation in a season or duration of time)** - At what rate (regeneration over time) is the feedstock being regenerated?
4. **Animal nutrition requirements (dry matter in kilograms per day; matrix of specific amounts)** - What are the animals nutritional requirements in dry matter?
5. **Length of growing season, grazing season (duration of time, often in days)** - What is the time length of the growing season; what is the time length of the grazing season?

The equation for the carrying capacity of land by selected single species is:

1. How many of animal *A (,B,C,...)* can be put on *X* hectares of pasture?
    • What is the carrying capacity of the land per hectare?

    Hectares Carrying capacity = Forage Production x Utilization Rate x Available Hectares Carrying Capacity ÷ Daily Intake x Growing Season

    For example: Carrying capacity = 12 kg per hectare * .5 utilization * 5 kg of DM per day ÷ 4 kg of DM per day * 12 months = 90 organisms per hectare [can be carried on the pasture land]

2. How many hectares are needed to support *N* number of animals?
    • How many hectares are required for the desired size of the population?

    Hectares Required = Number Of Animal x Daily Intake x Growing Season ÷ Forage Production x Utilization Rate

    For example: 90 organisms per hectare * 4 kg of DM per day per organism * 365 days ÷ 12 kg per hectare * .5 utilization = 180 hectares of land are required for the population size

The same information for a one-species calculation must be added to for a multi-species population. Herein, reference to a specific animal (e.g., cow or sheep) is removed and replaced with the unit label "animal unit" or AU.

To translate our results into various combinations of animal species, an equivalence chart (equivalency chart) is required. There are many different versions of this chart, but most differences are subtle and unimportant.

• The NRCS National Range and Pasture Handbook contains a reputable chart

Calculate the numbers for specific individual species in 1 and 2 above, and then, divide the results (now AUs) by the equivalent number from the chart:

Multi-species carrying capacity = Per hectares carrying capacity ÷ charted equivalence

Carrying Capacity = 90 (cows) ÷ 0.02 = 2,330 (rabbits)

### 7.9.5 Required determinations for a multi-species rotational grazing system

A multi-species rotational grazing system involves the following determinations (Williams, 1996):

1. Determine the number of animal units that will be in the grazing system.
2. Determine the forage requirements of the population of animals using animal units (AU).
3. An animal unit (AU) is equivalent to the daily forage intake of a 453kg cow (~11kg/day).
4. Determine total AU of herd adding up all the AU to get a total for the whole population.
5. Estimate how many hectares will be needed throughout the grazing season. Estimating the number of hectares required to pasture a population depends on both
   A. The feed requirements of the animals.
   B. The available forage produced.
   C. Pasture growth is dependent upon:
      1. Plant species
      2. Soil characteristics
      3. Topography
      4. Fertilization
      5. Temperature
      6. Soil moisture

   *Note: Because of the variability in pasture growth, we can only estimate the number of acres required for grazing animals. Table 2 provides some estimated values of the acres required for grazing animals on various types of pasture.*

6. Estimate how much pasture a population will need, first calculate the total AU of the herd (Step 1). Using a species forage table, estimate how many acres each AU will need during each month of the grazing season.
7. Estimate how large each paddock should be. Use a table that includes paddock sizes based on grazing period and available pasture. Use a table of suggested paddock sizes (hectares per AU) for rotational grazing. Paddock size depends on:
   A. The AU of the herd.
   B. The amount of available pasture at the beginning of grazing.
   C. The desired grazing period.

   *Note: Available pasture is pasture present in a paddock at the start of grazing minus the amount present when the animals are removed from the paddock. Depending on plant density,*

8. Estimate the number of paddocks needed. The number of paddocks needed for a rotational grazing system will depend on the number of days the animals graze in a paddock and the maximum rest period needed. Rest periods should be based on the growth rate (regeneration rate) of the pasture, which will vary with the season and weather conditions.
   A. Identify the maximum days rest and divide by number of days grazing + 1 = paddock number
   B. Example: The herd will graze each paddock for 3 days, and the maximum rest period between grazings will be 35 days.
      - (35 days rest divided by 3 days grazing) + 1 = 13 paddocks

   *Note: Species and class of grazing animal may determine the grazing period.*

Additionally, it is much preferred is so much better to have too much grass and not enough animals at the end of this calculation than the other way around.

#### *7.9.5.3 Animal forage stocking rate*

*A.k.a., Feed restocking rate.*

In concern to the quantity of forage, the resource allocation rate (forage stocking rate) is the number of specific kinds and classes of forage or utilizing a unit of land for a specific period of time. (NRCS-NRPH 1997) The selection of the optimal stocking rate is the most important of all grazing coordination decisions. (Holecheck et al, 1999)

The method of determining initial stocking rates is:

1. Determine land area in squared units.
2. Determine forage area in squared units.
3. Determine individual forage demand (e.g., 3% of BW or 13 kgs/day air-dry).
4. Select harvest coefficient.
5. Adjust for distance from water.
6. Adjust for slope.
7. Compute correct stocking rate.
8. Cross check actual and expected use.

### 7.9.6 Deciding a grazing and resting schedule

Determine a schedule of when to move the animals from one pasture to another. The number of paddocks grazed and the length of the grazing and rest period can (and often, should) vary as pasture growth rates change with the weather and climate; this is a flexible pasture schedule.

### 7.9.7 Optimal grazing time for plants

The goal of a grazing system should be to maximize both forage yield and quality. The best time to graze most grass, for example, is immediately before flowering and seeding. Species develop differently however and the best time to graze one grass species may not be the best for another. For grass, there is a two variable spectral graph with:

1. An *x-axis* as yield (low yield when young to high yield when old).
2. A *y-axis* for feed quality that goes from (high quality when young to low quality when old).

This graph plots the grass (or other feed) in concern to yield from the plant and quality of the plant for animal feed. When including animal requirements, a best time to graze can be determined from the graph plot. The best time to graze is where yield crosses quality (of food for animal).

Summarily, phases of grazing plant maturity includes:

1. Phase 1 (non-optimal grazing)
2. Phase 2 (optimal grazing)
3. Phase 3 (non-optimal grazing)

In general, as plants mature, growth slows since most energy is diverted to flower and seed production. While yield is highest at the start, quality is very low. Quality is high when plants are small and vegetative. Quality declines as plants mature. This occurs because as plants get larger and stemmier, a greater percentage of nutrients and dry matter is bound up in indigestible forms (such as lignin). Greater amounts of indigestible fiber result in lower quality forage with decreased amounts of total digestible nutrients (TDN). (Undersander, 2021, 6)

### 7.9.8 Pasture grass grazing capacity

*A.k.a., Pasture productivity.*

There are two general methods of estimating pasture capacity (pasture productivity). (Undersander, 2021, 19)

The first method is the direct estimate method (note: example weights are given):

1. Clip and collect - collect the forage in 1 square meter of pasture. Clip at the intended grazing height (note, this will vary with species).
2. Weigh and record the forage. Take all measurements in kilograms (e.g., 2.07 kgs/sq meter).
3. Dry a sample.
   A. Record the weight of an empty paper plate (e.g., 1kg).
   B. Take a half pound sample, approximately, of the forage. Place it on the plate and weigh it (e.g., 4 kg).
   C. Place the same in a microwave oven along with a cup of water. Turn on the microwave (on high) for 3 minutes. Weigh the sample. Warning: leave the water in the microwave throughout the drying process. The water reduces the chance of damaging the microwave or starting a fire.
   D. Microwave the same for another minute, then reweigh the sample. Repeat this step until the weight remains the same.
   E. Record the final sample weight (e.g., 2 oz).
4. Calculate the percent forage dry matter (DM):

   % forage dry matter = (final weight of sample - weight of plate) / (original weight of sample - weight of plate)

   Example: (2oz - 1oz) / (4oz - 1oz) = 0.333 (33% forage dry matter)

5. Determine pasture probable yield:

   Pasture yield (kgs/hectare) = [(total weight of forage (step 2)) * (% forage DM (Step 4)) * (10000 sq m/ hectare)] / 1 square meter

   Example: (2.07 kgs/sq m) * .33 * 10000 sq m/ hectare) / 1 square meter = 6,831 kg/hectare

The second method is the pasture plate method:

1. Make a the plate tool.
   A. An 45.72cm square sheet of acrylic (0.55-cm thick), a meter stick, and a 5.08cm bolt.
   B. Drill a 3.81cm hole in the center of the plate. The meter long measuring stick goes through the hold and a bolt is attached to the bottom of the meter stick.
2. Instrument usage.
   A. Place the meter stick on the ground.
   B. Hold the plate on the meter stick about 1 foot above the standing forage and let it drop.
   C. Record the plate's height (in centimeters) off the ground.
   D. Take measurements in 5 to 10 locations in the pasture and use the average height.
   E. Calculate dry matter yield (kgs/hectare) by multiplying the height by 390.
   F. For accurate results the plants must be dry when taking using the instrument.

   Pasture yield (kgs/hectare) = 390 * height (cm)

   Example: 390 * 6 cm = 2340 kgs/hectare

### 7.9.9 Contingency planning

Contingency plans account for potential environmental and coordination problems, including but not limited to:

1. Extreme climactic events
   A. Drought
   B. Excessive rain and/or flooding
   C. Wildfires
2. Predators
   A. Animal predators
3. Insects
   A. Non-biting insects
   B. Biting insects

Contingency plan techniques include, but not limited to:

1. Put additional hay or other food on pasture.
2. Reduce herd size (cull open cows, replacement heifers, broken mouth, older animals).
3. Early weaning.
4. Alternative feeds (corn stalks, alfalfa stubble, human food scraps).
5. Acquire additional grazing land.

#### *7.9.9.1 Backup and supplemental forage (stockpiling forage)*

*A.k.a., Stockpiling food, silage.*

The length of the grazing season need not be restricted to the length of the growing season. Stockpiling means allowing an accumulation of forage for later use. The technique is to defer grazing on a portion of the pasture beginning in fall. This forage is allowed to accumulate and is grazed throughout the fall and winter after pasture growth has stopped. Certain grasses and plants should be avoided in they produce relatively little growth in the fall. If there is little pasture area to set aside stockpiling forage for fall and winter grazing, then it is probably not a good option.

### 7.9.10 Grazing system monitoring

Monitoring of a grazing system must include:

1. It is essential to understanding the effects of coordination decisions and actions on the health and sustainability of land.
2. Document successes and failures.
3. Document annual grazing use.
4. Document climatic conditions.
5. Document long-term trend in vegetation – photo points, transects, utilization cages.

Observations of the animals, pasture, coordination plans and ideas should be recorded as part of a continuous monitoring process:

1. **Animal observations** - try to match animal needs with forage production.
   A. Record animal health problems that might be grazing related.
   B. Keep track of forage stocking rates. Are the rates high enough to prevent spot grazing.
   C. Are the animals camping in specific areas?
   D. Are the animals getting enough forage from the pasture? Why or why not?
   E. Is there significant trampling loss?
   F. Is production at desired levels? Do animals need supplement or does the pasture need renovating?
2. **Pasture observations** - try to match pasture conditions to animal needs.
   A. Keep track of rest and grazing periods. How is the pasture responding to these periods? Does the pasture recover slowly?
   B. Keep track of species movement schedule.
   C. Keep track of the species of the forage.
   D. Keep track of the growth stage of the forage. How long does it take to reach, from seed and/ or regrowth, to reach optimal stage for grazing?
   E. How much stubble is being left by the animals?
   F. Is it possible to extend the growing season?
   G. If forage is being stockpiled, how much forage do you need?

### 7.9.11 Adaptive pasture coordination

Adaptive pasture coordination includes four project phases that represent a whole cycle:

1. Plan (assume that the system can continually be improved)
   A. Evaluate the present land (condition, situation, status).
   B. Identify a 3 to 5 year plan for improvement of the land.
2. Implement
3. Monitor
4. Review and revise.

Pastures may need renovating, or new plot of land may need a pasture created within it. Some important questions to ask in consider to pasture renovation (Read: cultivated terrain modification) include, but are not limited to:

1. What is the current condition of the land?
2. What change in condition should the new state of the land have?
3. What is the species composition of the land?
4. What change in species composition needs to take place (should the new state have)?
5. How long will it take to sufficiently modify the state of the land?
6. Is tillage and an option? Is it possible to tillage good soil, compost, and manure into dry and dead soil, and clay?
7. Is herbicide an option?

# 9 Fungal cultivation specifics

*A.k.a., Mycological cultivation.*

A simple way to dispose of surplus woody material is to convert the inedible wood into the edible, or otherwise useful, fungus. Mushroom logs or wood chip beds can be inoculated with specific fungal species. These fungal decomposing logs can be placed in different locations on-pasture, or nearby structures for human selection.

Branches and logs can be inoculated with fungal spores. Inoculated logs can be placed anywhere in or around a pasture to be inoculated with fungal spore spawn. Often, in agroforestry environments, logs are placed on the ground between the trees in a row or between rows of trees.

It is important to note here that not all fungus is good fungus, some fungus is harmful to plants, and some fungus is harmful to animals.

The following can be inoculated with symbiotic fungal spores:

1. Compost can be inoculated.
2. The soil can be inoculated.
3. The feed and water of livestock can be inoculated.

## 9.1 Fungi and bacteria

To stimulate fungal growth in the soil, it is important to previously (or, simultaneously) stimulate commensurate bacteria. The appropriate bacterial species will provide a substrate and environment in which the fungi can thrive.

# 10 Insect cultivation specifics

Feed food waste to insects. The flavor of an insect to another consuming animal can be changed by changing the feed fed to the insect.

## 10.1 Honeybee pasture-based cultivation

*A.k.a., Pasture-based honeybees.*

It is relevant to note here that in a diverse ecological system the honeybee is not needed for pollination services; there are many other insect pollination services generally available.

Honeybees (from Europe) are only one type of pollinating insect, of the genus Apis and in the Apidae family. Prior to the introduction of the European honeybee, insect pollination of most flowering plants was taken care of by number of species of flies, beetles, wasps, butterflies and moth. Note here that some plants require insects for pollination, others are pollinated by wind (e.g., oaks, chestnuts, beech, hazelnut, butternuts, walnuts, pecans, wild rice, corn, etc.). However, the most effective pollinating insects are bees. European-type honeybees derive their sustenance from flowering plants. (Shepard, 2013)

Pollen, which is analogous to the male reproductive cells of a plant, is high in the protein required by bees to build their bodies. Nectar is a liquid secreted by the analogous female portions of a flower and it has no apparent reason for existing except as a lure to attract pollinating insects. Nectar is high in sugars — fructose, glucose and the like — which are an extremely high-energy drink. All bees eat pollen and drink nectar for their sustenance. When bees crawl around on the anthers of a flower in order to eat pollen, or even when they bypass the pollen en route to the nectar itself, some pollen sticks to tiny bristles that cover the bee's body. As the bee laps up the sweet nectar some of the pollen covering its body may make contact with the stigma (analogous to the vagina in female mammals) of the flower, where it will eventually travel through the style to make contact with an ovum and create a new seed. After a drink of nectar the bee travels up out of the flower and eventually combs itself to remove the stray pollen grains from its hair. Much of the pollen is stored in specialized regions on the legs, inaccurately called pollen sacs, where it is taken back to the nest to later serve as a food source for larval bees.

Many species of plants cannot use their own pollen and have to receive pollen from other individuals of their same plant species in order to produce viable seed. Bees pollinate flowering plants in the process of feeding themselves. The functional relationships is that the flowering plant feeds the bees, the bees pollinate the flowers to make more flowers, which feed the bees.

Bees produce honey. Like cane sugar and maple syrup, honey is a high-sugar, simple-carbohydrate sweetener. One pound of honey is likely to have over

1,382.4 calories in simple carbohydrate form. One hive of honeybees located in the northern United States can easily produce over 50 lbs. of surplus honey per year. If only two hive were kept on one hectare, those two hives would add a possible additional 138,204 calories to the system. (Shepard, 2013, p112)

There are many ways to cultivate bees over time by how their beehives are dealt with. Historically, the stronger hives would be kept and the weaker hives harvested. Historically, the beehives were harvested by drowning them in water or smashing them open. In the case of culling weaker hives, the strongest hives had produced more honey and therefore would have more reserves to feed them through the winter when there are no flowers in the fields and forest. The strongest hives would obviously have stronger queens, which would produce stronger offspring and more offspring providing the beekeeper with more and stronger colonies in the spring. This strategy of division of the strong hives in the spring and killing the weak hives in the fall is a strategy to improve the overall survival qualities (both genetic and behavioral) in bees. In addition to removing bees that may be genetically inferior or behaviorally disadvantaged it is entirely possible that this technique of beekeeping also killed the very pests and diseases. It is possible to interrupt pest and disease cycles with periodic destruction of weaker hives

On pasture, it is important to have locations for wild pollinators to nest and create their hives. Hedgerows are an excellent nesting site for wild pollinators, and can be placed between fields and along the riparian zones of stream and pond sides. It is relevant to note here that a plastic queen cup, artificial insemination by a needle, and a regular regime of chemical powders and liquids selects for stronger pests and diseases and honeybees dependent on artificial insemination and chemicals.

Basic beekeeping equipment for observing and harvesting include:

1. Smoker
2. Capping knife
3. Extractor
4. Personal protective clothing

Direct honey products include:

1. Honey and fermented honey alcohol.
2. Propolis
3. Wax (comb)
4. Royal jelly

## *10.2 Wild pollinator insect cultivation*

By using natural ecological practices, natural ecological species can survive and provide an important function in the environment. In a holistically designed landscape, there will likely be wild populations of pollinator insects, because the environment is conducive to their existence.

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### 7.9.12 Grazing system matrix

A grazing system matrix is a tool for grazing coordination that defines systematically recurring periods of grazing and deferment for two or more pastures (or, grazing control) units. (NRCS-NRPH 1997)

A grazing system matrix must include one or more of three basic elements:

1. Deferment (non-use for less than a year)
2. Rest (non-use for a year or more)
3. Rotation (livestock movement on a schedule basis)

Grazing system land usage:

1. Rangeland
    1. Continuous or season-long.
    2. Deferred rotation.
    3. Rest rotation.
    4. Short duration.
2. Irrigated Pasture
    1. Continuous or season-long.
    2. Rotational or coordinated intensive grazing.

A grazing system matrix must account for the selection of foraging species based on cultivation viability:

1. Climate type and viability - different climates will provide different levels of productivity.
2. Soil type and viability - different soil types will provide different levels of productivity.
3. Moisture level and viability - different moisture levels will provide different levels of productivity.
4. Nutrient level and viability - different nutrient levels will provide different levels of productivity.
5. Grazing intensity and viability - different grazing coordination methods will provide different levels of productivity.
6. Desired length of grazing period - different grazing lengths will provide different levels of productivity.

# 8 Aquatic cultivation specifics

*A.k.a., Restorative aquaculture.*

No content here yet.

# TABLES

**Table 49.** *Examples of grazing systems: Two-Pasture - Switchback System*

| | | | | | | |
|---|---|---|---|---|---|---|
| | | | G | *Graze* | | *Rest* |
| **PASTURE** | M A M J | J A S O | N D J F | M A M J | J A S O | N D J F |
| **1** | G | | G | | G | |
| **2** | | G | | G | | G |

**Table 50.** *Examples of grazing systems: Three-Pasture - One Herd System*

| **PASTURE** | A M J J A S O N D J F M | | | A M J J A S O N D J F M | | | A M J J A S O N D J F M | | |
|---|---|---|---|---|---|---|---|---|---|
| **1** | G | | G | | G | | G | | G |
| **2** | | G | | G | | G | | G | |
| **3** | | | G | | G | | G | | G |

**Table 51.** *Examples of grazing systems: Three-Pasture - Two Herd System*

| **PASTURE** | A M J J A S O N D J F M | | | | A M J J A S O N D J F M | | | | A M J J A S O N D J F M | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **1** | | G | G | | G | G | | G | G | | | |
| **2** | | | G | G | | G | G | | G | G | | |
| **3** | | | | G | G | | G | G | | | G | G |

**Table 52.** *Examples of grazing systems: One Herd - Multi-Pasture System*

| **PASTURE** | A | | M | | J | J | | A | S | | O | | N | D | | J | | F | M | | A |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **1** | G | | | | | | | G | | | | | | | G | | | | | | |
| **2** | | G | | | | | | | G | | | | | | | G | | | | | |
| **3** | | | G | | | | | | | G | | | | | | | G | | | | |
| **4** | | | | G | | | | | | | G | | | | | | | G | | | |
| **5** | | | | | G | | | | | | | G | | | | | | | G | | |
| **6** | | | | | | G | | | | | | | G | | | | | | | G | |
| **7** | | | | | | | G | | | | | | | G | | | | | | | G |

**Table 48.** *Harvest succession timeline. This is a table showing spatial and temporal layout of plants to be used for planting. When planting a landscape the following chart may be used. This chart ensures that a farmer is covering all the possible strata for the 5-100 years. The columns are time durations in growth-stage categories. The rows are the elevation layer location in space for the pants. It is possible to develop a 3D plan (i.e., a 3D planting plan, 3D model) that covers all of the strata for more than 50 years. Plant growth is subsequently observed, human removal of specific woody species may occur, and the chart can be continuously adjusted as needed. Avocado and ginger are given as examples. In concern to avocados, a farmer knows that for the best quality avocados, there can be no other plants that are emergent strata in the 5-to-20-year mark and take up the same 3D space as an avocado tree, or don't do well in its soil (i.e., avocado at years 5-20 will take up a specific location in 3D space, and no other plant can reside there). Its residence there for a long duration of time will likely influence what other plants can be grown in the surrounding area.*

| | Placenta 1 | | Placenta 2 | Secondary 1 | Secondary 2 | Climax | | |
|---|---|---|---|---|---|---|---|---|
| Time till harvest: | 45-90 days | 90-120 days | 120-180 days | 180-365 days | 2-3 years | 3-5 years | 5-20 years | 20-100 years |
| Emergent | | | | | | | Avocado ⟶ | |
| High | | | | | | | | |
| Medium | | | | | | | | |
| Low | Ginger ⟶ | ⟶ | | | | | | |
| Ground cover | | | | | | | | |

# TABLES

**Table 53.** *A single alley-cropping two-dimensional landscape chart showing two rows (in dark gray) and four rows in the alley. The woody crops are primarily planted throughout the first two rows shown in dark gray. However, over time, trees in some rows may be culled and trees may also be planted in alleys. This is a simplified example showing the row an column separation of plants over a 2D landscape with low-quality stratification detail. This table shows 2 woody crop areas and an alley primarily filled with perennial grasses, and scattered with other plants in a manner that works for the animals and humans.*

| STRATIFIED | TREE & GRASS | STRATIFIED | TREE & GRASS | STRATIFIED | TREE & GRASS | STRATIFIED | TREE & GRASS | STRATIFIED | 10 meters in width |
|---|---|---|---|---|---|---|---|---|---|
| Tumeric and cassava every 15cm | | | | | | | | | |
| Raspberry<br>Mulberry<br>Avocado<br>Acacia<br>Banana | Mulberry | Raspberry<br>Mulberry<br>Moringa<br>Acacia | Mulberry | Raspberry<br>Mulberry<br>Coffee<br>REd cedar<br>Acacia<br>Banana | Mulberry | Raspberry<br>Mulberry<br>Moringa<br>Acacia | Mulberry | Raspberry<br>Mulberry<br>Acacia<br>Banana | 1 Meter woody-crop area |
| Ginger every 15cm | | | | | | | | | |
| Perennial grasses | Clover | Radish | Perennial grasses | Perennial grasses | Perennial grasses | Perennial grasses | Perennial grasses | Perennial grasses | 2 meter woody-crop area |
| Perennial grasses | Perennial grasses | Perennial grasses | Perennial grasses | Blackberry | Perennial grasses | Perennial grasses | Perennial grasses | Perennial grasses | 2 meter alley |
| Perennial grasses | Perennial grasses | Clover | Perennial grasses | Perennial grasses | Perennial grasses | Perennial grasses | Blackberry | Perennial grasses | 2 meter alley |
| Perennial grasses | Perennial grasses | Perennial grasses | Tomatoes | Potato | Perennial grasses | Perennial grasses | Perennial grasses | Perennial grasses | 2 meter alley |
| Tumeric and cassava every 15cm | | | | | | | | | |
| Rasberry<br>Mulberry<br>Lemon<br>Red cedar<br>Acacia<br>Banana | Mulberry | Mulberry<br>Maringa<br>Acacia | Mulberry | Line<br>Acacia<br>Mulberry<br>Banana | Mulberry | Mulberry<br>Moringa<br>Acacia | Mulberry | Mulberry<br>Red cedar<br>Acacia<br>Avocado<br>Banana | 1 Meter woody-crop area |
| Ginger every 15cm | | | | | | | | | |
| 8 Meters in distance | | | | | | | | | |

# TABLES

**Table 54.** *The following table shows the set of hazards, compatible planting understory types, and food sources for different animal species. These represent constrictions/limitations in a holistic cultivation environment for different species of livestock.*

| Boundaries and risks of holistic cultivation livestock | | | | | |
|---|---|---|---|---|---|
| Species | Hazards | | Compatible planting understory types | | Food source (simplified) |
| **Livestock species** | **Damage young trees** | **Scratch or dig** (damage roots, plants, or expose bare soil) | **Pasture only** | **Diverse perennial crops** | **Consumes** |
| **Cattle** | Yes | | Yes | | Grasses |
| **Sheep** | Yes | | Yes | | Grasses and woody matter |
| **Goats** | Yes | | Yes | | Grasses and woody matter |
| **Llama (or other)** | | | | | |
| **Hogs** | Yes | Yes | Yes | | Woody plants, tubers, and protein |
| **Chickens** | | Yes | Yes | | Insects, amphibians, grain |
| **Ducks & Muscovies** | | | | Yes | Insects, amphibians, grain |
| **Geese** | | | | Yes | Insects, amphibians, grain |
| **Turkey** | | Yes | Yes | | Insects, amphibians, grain |
| **Guinea fowl** | | | | Yes | Insects, amphibians, grain |

**Table 55.** *Table showing the holistic functions of different species of livestock.*

| Holistic cultivation functions | | | | | | |
|---|---|---|---|---|---|---|
| Species | Functions | | | | | |
| **Livestock species** | **Mow & graze** | **Clear brush** | **Insectivorous** | **Till** | **Weed grass only** | **Clean drops** |
| **Cattle** | Yes | | | | | |
| **Sheep** | Yes | Some breeds | | | | |
| **Goats** | Yes | Yes | | | | |
| **Llama (or other)** | | | | | | |
| **Hogs** | Yes | | | Yes | | Yes |
| **Chickens** | Yes | | Yes | Yes | | Yes |
| **Ducks & Muscovies** | Yes | | Yes | | Yes | |
| **Geese** | Yes | | | | Yes | |
| **Turkey** | Yes | | Yes | | | Yes |
| **Guinea fowl** | | | Yes | | | |

# TABLES

**Table 56.** *Livestock land carrying capacity. (INCOMPLETE)*

| Holistic cultivation functions | | | | | | |
|---|---|---|---|---|---|---|
| **Species** | **Area Types** | | | | **Requirements** | |
| Livestock species | Soil Type | Feed Amount | Feed Quality | Water Amount (liters/day) | Land Area Required | Water Area Required |
| **Cattle** | good | | | 56-76 | 1-1.5 cows per .4 hectare | Supplemental in pasture |
| **Dairy Cows** | good | | | 76-114 | 1-1.5 cows per .4 hectare | Supplemental in pasture |
| **Sheep** | | | | 7-11 | | |
| **Goats** | | | | 7-11 | | |
| **Llama (or other)** | | | | ? | | |
| **Hogs** | | | | 1.8 - 5.6 | | |
| **Chickens** | | | | ~.4 | | |
| **Ducks & Muscovies** | | | | 1 | | |
| **Geese** | | | | 1.6 - 3.9 | | |
| **Turkey** | | | | ? | | |
| **Guinea fowl** | | | | ? | | |

# TABLES

**Table 58.** *Empty table showing the measurements of different animal species (livestock) in terms of their nutrient values. The same table will work for plants and fungi.*

| **Nutrient values of polycultured animals.** | | | | | | | |
|---|---|---|---|---|---|---|---|
| | | Beef (cut specific) | Chicken (specific) | Lamb (cut specific) | Pork (cut specific) | Sheep (cut specific) | Total |
| **Nutrient type:** | **Measurement** | | | | | | |
| **Macro-nutrient** | **Units** | **V/100g** | **V/100g** | **V/100g** | **V/100g** | **V/100g** | **V/100g** |
| Water | *g* | | | | | | |
| Carbohydrate | *g* | | | | | | |
| Protein | *g* | | | | | | |
| Ash | *g* | | | | | | |
| Energy | *kcal* | | | | | | |
| Energy | *kj* | | | | | | |
| Lipids | *g* | | | | | | |
| **Vitamins** | | | | | | | |
| Vitamin A | *mg* | | | | | | |
| Vitamin E | *mg* | | | | | | |
| Vitamin K | *mg* | | | | | | |
| **...** | | | | | | | |
| **Minerals** | | | | | | | |
| Calcium | *mg* | | | | | | |
| Magnesium | *mg* | | | | | | |
| ... | | | | | | | |

**Table 57.** *Empty table showing the measurements of different plant species in terms of their nutrient values.*

| **Nutrient values of polycultured plants.** | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | Grass | Chestnut | Apple | Hazelnut | Raspberry | Currants | Grapes | Total |
| **Nutrient Type:** | **Measurement** | | | | | | | | |
| **Macro-nutrient** | **Units** | **V/100g** | **V/100g** | **V/100g** | **V/100g** | **V/100g** | **V/100g** | **V/100g** | **V/100g** |
| Water | *g* | | | | | | | | |
| Carbohydrate | *g* | | | | | | | | |
| Protein | *g* | | | | | | | | |
| Ash | *g* | | | | | | | | |
| Energy | *kcal* | | | | | | | | |
| Energy | *kj* | | | | | | | | |
| Lipids | *g* | | | | | | | | |
| **Minerals** | | | | | | | | | |
| Iron (not hem iron) | *mg* | | | | | | | | |
| Magnesium | *mg* | | | | | | | | |
| ... | | | | | | | | | |
| **Vitamins** | | | | | | | | | |
| Vitamin A | *mg* | | | | | | | | |
| Vitamin E | *mg* | | | | | | | | |
| ... | | | | | | | | | |

# TABLES

# **Technology Support:** Information Processing Service System

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**Affiliation contacts:** *trvsgrant@gmail.com*

**Version Accepted:** 8 July 2022

**Acceptance Event:** *Project coordinator acceptance*

**Last Working Integration Point:** *Project coordinator integration*

**Keywords:** information processing, information technology, computational servicing, information interfacing, information system production, information system servicing, data processing, computing services

## Abstract

An information-based society relies on information, including data, flows, and processes, in order to reconfigure itself optimally. Information is "stored" in repositories, which take up physical space. Information in the form of signals can be transported between physical spaces. Information can be displayed to a user, it can be monitored for changes, or it can be kept within a closed loop framework. A society can model itself informationally, the most useful representation being a complete simulation. In a real-world information system, there is information that is purely conceptual, there is information about objects, and there is information about distances between objects. And, in an adaptive information system, there is past, present, and possible future, information. All material designs are conceptual information (ideas) prior to their creation in a shapeable [spatial] environment. The configuration of objects in an environment has consequence, the results of which may be accepted as data [feedback] into an organizing information system. Early 21st century information systems are sustained through combined hardware-software packages known as computers. Computers store data in matter, and process data through patterns of electrical powered matter configurations. Calculation upon all societal-level accountable information allows for the unified socio-technical, economic planning of society at a global level without trade or coercion. In a community-type society, working groups develop an information system standard, and the InterSystem/Habitat Information Team engineers the information systems service. Through decisioning processes, information that has been structured through some social ordering becomes integrated into solutions upon which teams take action. Actions have affects in a spatial environment; those effects are fed back as data. In a community-type society, all decisioning is transparent and must be understood prior to action. Information is a conceptual-type of access.

## Graphical Abstract

Image Not Yet Associated

*A.k.a., Information cycling service.*

Information technology refers to information that can be input and calculated by a computer.

No additional content here yet.

# **Technology Support:** Communications Service System

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**Version Accepted:** 8 July 2022

**Acceptance Event:** *Project coordinator acceptance*

**Last Working Integration Point:** *Project coordinator integration*

**Keywords:** communications, communication system, communication service, language interface

## Abstract

When signals are moved coherently, communication occurs and information becomes available as required. Communications refers to signal [electromagnetic object] generation and processing. For communications to occur, the entity receiving the signal must be able to interpret and/or otherwise understand the signal. In order for entities in different locations to understand each other's signals, the subjects (entities) must have a common protocol for sharing and or otherwise generating meaningful signals (Read: object signal creation). To the entity that generates the signal and a receiver of the signal, the signal is a message (i.e., an information packet with meaningful data). Communicating systems use protocols for coherently sharing messages. At the software level, each subject-relevant meaning is encased in a technical level meaning that ensures data (meaning) is received without error (e.g., header and footer metadata). In order for sharing to occur, there must be a protocol used by all subjects and systems. That communications protocol provides pre-determined information flow responses based on provided information. A protocol defines the format of signals (messages), which is a language, though it is not commonly called that. Programming languages are those languages whose semantics describes computations. Protocols in general do not describe computations; though, some specific protocols do, such as, RPC protocols. A protocol uses well-specified signals to express well-specified meanings, but rather few of them (only two different meanings). Thinking languages (e.g., English, Mandarin, Russian, etc.) allow people to think about and to coordinate (or not) their work and service lives. Pilots and traffic controllers use protocols to communicate, some of which are highly complicated. Essentially, a protocol is a language and a language is a protocol, and subjects must share a protocol in order to think and communicate coherently. The communications service system is information oriented.

## Graphical Abstract

Image Not Yet Associated

No content here yet.

# **Technology Support:** Transportation Service System

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**Version Accepted:** 8 July 2022

**Acceptance Event:** *Project coordinator acceptance*

**Last Working Integration Point:** *Project coordinator integration*

**Keywords:** transportation, transportation system, transportation service, distribution, distribution system, distribution service

## Abstract

When objects are moved coherently, transportation occurs and access [to objects] becomes available as required. Transportation refers to object translocation (i.e., the movement of an object from one location to another). For transportation to occur, the entity receiving the object must be able to available to receive and to understand the object. In order for entities in different locations to understand each other's outputs, the subjects (entities) must have a common protocol for sharing and or otherwise generating meaning from objects. An object is a structure (shape) that may or may not have meaning to subjects. Transporting systems use hardware and software for optimizing the safe and effective transportation of objects. At the software level, each object is encased in a material enclosure to some varying degree, which transports the object without loss of the object. In order for the population-scale sharing of objects to occur, there must be a hardware transportation network signaled by environmental sensors upon which a software platform calculates the optimal packaging and logistics for transportation solutions. A transportation package moves through a network of well-specified signals-object processing devices that guide it to an intended destination. Within a habitat service system, these destinations can be integrated with the infrastructural environment. For instance, think of an integrated pneumatic distribution system in an office or at a bank teller, and then imagine such a system (or, its equivalent) at the city level. Transportation can be easily scheduled or requested on demand. Some transportation is of a higher priority than other transportation, for instance, a medical evaluation, or the introduction of medical personnel into an situation. The transportation service system is materially oriented. All transportation is integrated within and between cities. Consider the reduced transportation logistics when everything needed is in a life radius and is in walking distance.

## Graphical Abstract

Image Not Yet Associated

# 1 Introduction

Objects can be transported throughout the local and global habitat [service system] network without the need for excess packaging, which is what creates the majority of the waste/trash in the early 21st century. An integrated [habitat service] object transportation system is required.

# 2 Habitat transportation circulation

*A.k.a., Transportation access.*

Habitat circulation planning involves the planning of access by means of some form of transportation.

The planning of a transportation system within a habitat service system requires the identification and analysis of access, and its various sub-types:

1. Walking access.
2. High, medium, and low speed vehicular access.
3. Cyclist (or like) access.
4. Location access.
5. Service access (InterSystem Team access).

# 3 Transportation systems within the habitat

There are multiple ways of transporting services, resources and products within a habitat and between a habitats. These include, but may not be limited to:

1. **Package/object transportation** (a.k.a., box transportation) - where packaged objects move through.
   A. Transports items in a box. May also transport waste in special boxes.
   B. Transmission tube technology (a.k.a., transmitting tube technology, pneumatic tube, rail tube, etc.)
2. **Liquid transportation** - where liquids move through.
3. **Atmospheric transportation** (a.k.a., air/gas transportation) - where atmosphere moves through.
4. **Electrical power transportation** (a.k.a., power transportation) - where electrical power moves through (e.g., atmosphere in the case of WiFi, and cables in the case of electricity).
5. **Road/path transportation** - where persons and road/path specialized vehicles locomote.
6. **Rail transportation** - where specialized rail vehicles locomote.
7. **Cable transportation** - where specialized cable vehicles locomote.

# 4 Habitat object transportation system

A habitat object transportation system is a mechanical packaging, transportation, and distribution system technology that is used in some integrated city systems. This automated packaging and transportation distribution technology allows almost any object to be appropriately packaged and transported anywhere in the local habitat network. Using this technology, objects can be sent and received safely and with the greatest efficiency almost anywhere in the habitat. Every dwelling, for example, can receive packages from elsewhere in the habitat. This service is like an extremely advanced version of the packaging and delivery services of the early 21st century. There are two main ways to seriously increase efficiency in the world. One of them is computation and mechanization, and the other is linking all the phases of life (education, contribution, liberation) to free access to that which is required to meet human need (i.e., without any form of exchange, except for contribution). It is foreseen that there will always be necessary human work, which can be reduced and also made more liberating (in terms of human choice) through automation. This socio-technical life optimization transport technology multiplies efficiency. This transfer (a.k.a., transport, transmission) technology is seen as the next huge development in freeing user access to all material services. This integrated object transfer network includes a variety of different interoperated sub-transportation technologies, including pneumatics, conveyors, rails, vehicles, access ports, and packaging systems. Most dwellings, and all common and systems access locations have access ports to this habitat transport system. Those dwellings that do not have access to the network do not have access because that is the personal preference of the user. Of note, this system may also interoperate with the human vehicular transport system, and may even transport objects automatically between local habitats in a network of habitats. This type of system is sometimes known as a habitat object storage and transportation system (a.k.a., integrated city resource transportation network technology). It is an integrated and highly automated habitat-wide (sometimes inter-habitat) object locating, storing, and transporting technology. Objects can be sent (or, simulated with high certainty to be sent) from the warehouses to people, from people to people, and from any relative location in the habitat to another, efficiently. Object transport occurs, in part, for continued usage, re-allocation [of resources], and sharing. The storage of objects is done in one or more location centralized and appropriately automated (cold and ambient temperature) storage warehouses located in the habitat. These systems are still monitored by people, and where there is no danger, but still demand for that type of contributed job, then human labor is included. It is automated to the desire of individuals in a habitat to perform absolutely necessary work and/or find the work intrinsically desirable to do. Possibly the first form of this system, earlier in history, was the pneumatic tube transport system for large buildings. Robotics and vehicular technology advanced over time, as well as logistic software technology. There was a synthesis of this technology over time into the engineering of an automated packaging, storing, retrieving, and delivering (transport) that could cover whole cities, as well as transport between cities; like the years earlier postal service did. Access ports for the service are placed within architectural structures. Because of this system, people in community do not need so much storage space in their home and other habitat access spaces; storage can be centrally distributed, as can the mechanization of services. People no longer need to feel trapped to their homes and properties therein, because it is easily distributable around the habitat. This habitat service transportation and locationing sub-system creates greater freedom for our population, reducing the feeling and sense of needing to possess objects. The application of this technology reduced the sense of needing to own objects to sustain happiness. In an integrated city system, this transportation technology is seen as just another conduit for transport into (and out of) architecture, like electricity, water, and gas. Water was once seen as a basic input for any family or household, now too are other needed products, and that principle is conveyed by this service (transportation and delivery of objects, without trade). An automated object delivery service, like the pre-existing water and electricity services, is seen as a basic right. One of the biggest events that amplified the recycling of resources was the global, habitat-centered, object packaging, storage, and transportation network. In other words, one of the biggest advances in the habitat, in concern to the recycling of resources, was this technology, which allowed for such efficient tracking, relocating, and packaging of resources that recycling became an integrated habitat process and an almost intuitive process for all inhabitants. This technology amplifies the recycling of resources.

# 5 Packaging

It is possible to optimally pack and store objects given what is known and available. Packaging is the task of packing something for transportation or storage. Product packing may include, but is not necessarily limited to:

1. Product Information
    - A. Assembly Diagrams
        1. Lists parts
        2. Lists required tools
        3. Describes assembly procedure
    - B. Technical Specifications
        1. Lists relevant parts, materials, or compositions.
        2. Describes relevant specifications of the parts. What is relevant?
            - i. Energy requirements
            - ii. Care / Maintenance Requirements
            - iii. Disposal / Upcycling guidelines
            - iv. Operating Guidelines
2. Product Protection
    - A. From environment
        1. Abrasion
        2. Corrosion
        3. Infection
        4. Deterioration
3. Product Storage
    - A. Each piece has a place
        1. Place is determined by how it is accessed (How it is accessed means by whom and in what order)
4. Product Transportation
    - A. Moving the product from point of manufacture to place of access / use
    - B. Moving product from one point of access to another
    - C. Moving product from a state of access to a state of suspended access (a.k.a. “storage”) Why?
        1. Seasonality of suitable access environment
        2. Reaction to demand for access

# 6 Transportation network drainage

Transportation networks require drainage, mostly from rainwater.

## 6.1 Roadway drainage

The construction of roads affects the natural surface and subsurface drainage patters of an environment. The provision of adequate drainage is important to prevent the accumulation of excess water or moisture on or within road constructions that can adversely affect their material properties, compromise overall stability and user safety.

Drainage must account for water from:

1. Carriageways.
2. Hard shoulders.
3. Foot/cycle paths.
4. Verges.
5. Adjacent catchment areas.

The design of roadway drainage will depend on several factors, including:

1. The intensity of rainfall expected.
2. The size of catchment area.
3. The permeability of the surfaces.

The road camber or cross-fall should be designed to cope with heavy water run-off. Insufficient cross-fall can increase the risk of vehicles skidding or aquaplaning on the surface water. The standard cross-fall for roads is usually taken as 1:40, although the camber will vary depending on the individual requirements of the road.

Drainage on urban and rural roads may be handled differently (Design Buildings: Highway Drainage, 2001):

1. Urban roads - Surface water is generally collected in channels at the road-side and discharged through gullies (drainage gratings at the edges of the road) into storm water sewers or storm water channels. Gullies are typically positioned at intervals of 25-30m, depending on the road width and nature of the cross-fall. Gully covers can be either top opening or side opening. To reduce the number of required drainage points, pavings and verges should be graded towards the channel. Culverts may also be used. A culvert is a closed conduit or tunnel used to convey water from one area to another, normally from one side of a road to the other side.
2. Rural roads - Minor roads usually use simple openings or channels which feed into roadside ditches. Most main roads use a system of gullies and piped sewers. However, soakaways may also be used to discharge water, these are large underground chambers into which water flows from a gully. Water collects and gradually soaks through holes into the surrounding ground or to streams and roadside ditches.

## 6.2 Paved area drainage

Paved areas are provided with some method of surface water drainage, including but not limited to (Designing Buildings: Drainage, 2021):

1. **Permeable pavement** - allows the water to percolate downward into the ground.
2. **Yard gully collection** - wherein, a paved area near a building is laid to falls of 1:60 towards a gully. The type of area being drained and the shape of the paved area will determine the size and number of gullies. The maximum paved area per gully should be 400sq.m. If it is connected to a combined sewer, the yard gully should be trapped with a minimum 50mm water seal.
3. **Channel collection** - The paving, laid to the same falls, drains away from a building to a channel laid to falls of 1:120. The channel is connected to the drainage system. The channel is typically:
   A. Half-round glazed clayware channel: Either open or with a grating cover.
   B. Precast concrete channel blocks: With a continuous slot down the centre of the top.
   C. Precast or in situ concrete box channel: With a cast iron square mesh grating.

# **Technology Support:** Materialization Service System

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**Version Accepted:** 8 July 2022

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**Last Working Integration Point:** *Project coordinator integration*

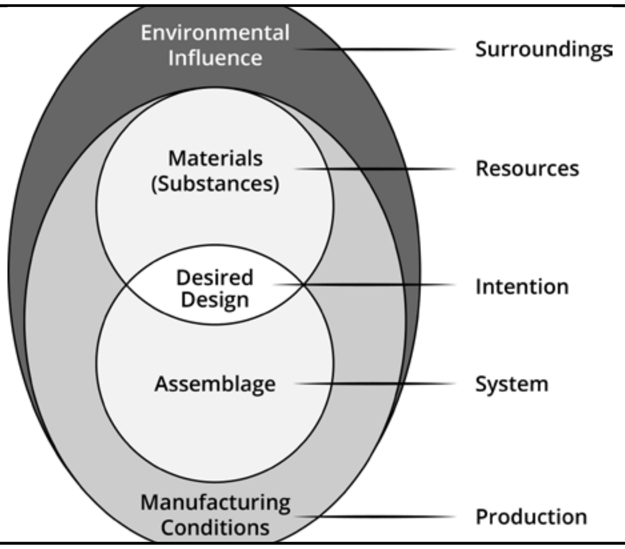
**Keywords:** materialization, material cycling material production, production, manufacturing, assembly, construction specification, material standardization

## Abstract

There are objects that could exist, and there are objects do exist. There are intangible objects, such as the software model of a chair (i.e., the chair displayed on a monitor is an intangible object). When/if the chair is assembled to be a chair, then it will have been materialized [as an event, a new object-resource] in the system. A materialized chair is a tangible object. There is a distinction between objects recognizable on a monitor screen and made up of software, and a physicalized (materialized) chair that a subject can sit in. Any material environment must be composed of any one or combination of: life (subject), land, object, structure (architecture), and energetics (power). The prime objective of the materialization (materials cycling) system is to materialize and de-materialize objects, as compositions of resources. The decision system determines the solution for the next iteration of the societal configuration upon which teams may put effort. The human animal [subject] has evolved to send moral signals about their well-being and the state of its habitat, in three primary way: life, technology, and exploratory. Different types of societies could be looked at as different types of signaling configurations. A decision system allows for coherency in the fulfillment of societal configuration solutions to meet the demands of life, technology, and exploration opportunity. Different signal configurations may have significantly different effects on peoples actions, behaviors, and lives. The moral visions (values) people have for one another really matter from an evolutionary perspective. Humans are an evolved living individuated organism, and hence, have needs for life-support services at that habitat level. Humans explore life together through an exploratory service support system. Humans use technology to support their informational and spatial needs. This service system combines decisioning data with executionable data for InterSystem team tasking, which may combine in a variety of different ways depending upon a given society's configuration.

## Graphical Abstract

**Figure 16.** *The reconfiguration of a material environment through intentional effort.*



# 1 Introduction

*A.k.a., Materials cycling service system, the production and recycling system, the manufacturing system, fabrication, construction, production, generation, manufacturing, assembly, creation, generation, object realization and cycling.*

There are many ways to bring new visualizations into real materialization. Humans have a need to cycle materials through their habitat(s). Some of the realized objects these materials take remain static and/or stationary for a long duration of time, relative to others. Materials cycle in and through habitats and human life systems. Materials become objects. Some objects and their relationships are of a sufficiently coherent nature to be called the materializations of life support, or technology support, or exploratory support. There are materializations that are appearing. There are materializations in memory of that which existed, and that which could exist (or, could be shown to potentially exist). When there is recognition that which comes after can be different than that which came before allows for real-time materialization, then there is potential for adaptation. Engineering InterSysem teams work in the materialization of habitat service sub-systems which are constructed primarily as integrated city systems (a.k.a., total city system). Material flows can be traced to remain accountable for finite resources. To materialize is to be materially realized. In a community-type society, realization is executed (i.e., "is done") through team contribution. Teams contribute to the decided reconfiguration and operation of the habitat environment. Many objects become larger and more functional technological objects, which become useful services of function with object, for which there is a habitat of them.

**INSIGHT:** *Matter, which is the expression of nature that humans receive signals from and interact, is architected and engineered into different configurations for human need fulfillment.*

To "produce" means to combine the materials (i.e., elements) and forces within an environment in coherent manner to change the expression (configuration) of existence. In simple words, it is possible to reconfigure the material environment to produce different objects and different functions. Here, "materialization" means to cause or become real, to become actualized in existence. Materialization also means to be realized or carried out. The materialization of the specifications for community, as a type of society, are partly experienced as a habitat service system and partly experienced as an information environment. Matter can be reconfigured. The intentional reconfiguring of matter can produce greater function (ability) within an environment. City systems allow for the localized coordination of materialized service systems. The idea of materialization carries with it the idea that embodied consciousness exists within an environment that is responsive to thought by some degree, for it is conscious thought that moves capable effectors in the system. Simply, a physical environment can respond more quickly or less quickly to though by embodied consciousness. A lower order dynamic of though responsiveness may be an environment where someone must think of vase (type of object) and then use their body to use a tool to produce the vase. A middle order dynamic may be an environment where someone must think of a vase and then use modeling software and 3d manufacturing hardware to produce a vase-like object. A higher order dynamic may be an environment that can communicated with via thought, such that the user simply thinks of a vase and the environment procedurally develops it and then 3D manufactures it in real-time.

Other words for the term "materialization" include, but are not limited to: production; manufacturing; construction; fabrication & prefabrication; and assembly. All of these terms include in their definitions the meaning that something occurs that changes or reconfigures the materially sensed expression or appearance of existence. For example, when you whittle wood you are materializing a different structure. When you construct a building you are doing similarly. When you assemble a toy you are modifying the position and location, and maybe even composition, of material for a new function. When you code a program you are assembling a new set of functions into the world.

Information takes material form and becomes active in terms of doing things. Nature doesn't separate information and matter. When we understand this we can make objects that integrate with natural cycles. All production comes from an information system. Digital materialization is the term used to describe this, and it means a two way conversion between matter (material information) and information, or at least matter in different forms. One is more information friendly, electrons and photons, the other is static, matter. In order for this to exist we need: symbols; volumetric (3d or 4D space); constructive (modular); continuous (infinite surface, you can scale to any resolution you want); exact.

Fabrication is part of the production process in which an item is made ("fabricated") from raw or semi-finished materials, instead of being "assembled" from already-made (i.e., pre-fabricated) components or parts.

Another less common definition which does not apply here is: "materialization" is the appearance of something out of nowhere, or from an unknown source.

**INSIGHT:** *For anything which is to be of service its formation must be accounted for.*

Every material thing in the universe has a three phase cycle:

1. A birthing or construction period.
2. An optimal running life cycle.

3. A period where it gets broken down and re-purposed.

Materialization has several related meanings:

1. Materialization as an organized physical structure for implementing a technology.
2. Materialization as an organized structure for reifying a concept.
3. Materialization as the science of designing physical objects and structures.

## 1.1 Materialization specifications

> **INSIGHT:** *There are constraints imposed on what we can make by the universe, by our knowledge of the universe, and by our intelligence in the universe. There is a general constraint determined by the physics of the universe, and within that "cone" of constraint there is our knowledge, our intelligence, and our will/intentionality.*

Specifications are written documents that describe the materials, products, work and techniques, and tolerances (and other aspects) that must be adhered to and are required for a specific materialization.

The most common types of specifications used in projects are:

1. **Outline specification** - The first stage in the development of a specification is the preparation of an outline [specification]. An outline specification is a brief description of the main components to be used in materialization.
2. **Performance specifications** - specification to address the operational requirements of an installation, service, or technology. The focus is on the project outcome, indicating how the final project must be able to function. Performance specifications describe the result that is required from particular items.
3. **Prescriptive specifications** - specification that contain detailed descriptions of what specific materials must be used as well as the installation instructions. Prescriptive specifications typically contain detailed descriptions of the following components:
    A. **General requirements (a.k.a., general provisions):** requirements surrounding standards, regulations, and codes.
    B. **Required materials and products**: the type of materials and products required based on performance and structural stipulations.
    C. **Execution procedures:** how to do the install and measure its effectiveness. The execution and installation methods required.
4. **Proprietary specifications -** specification that demand that only one specific product be used for a given installation. It is commonly utilized if the portion of a project requires a certain performance that only one product can achieve.
5. **Service level specification (SLS)** - identifies the standards required of a service system (Read: service provider).

Specifications can also be classified according their allowance of one or more suppliers:

1. **Open specifications** - an open specification when an architect does not name a specific supplier or product and allows for substitutions to be made by the contractor. Open specifications do not limit competition, but rather is dictated by a set of standards that more than one manufacturer can meet, allowing for many alternatives to be submitted for approval. Performance specifications are often considered to be open.
2. **Closed specifications** - a closed specification lists specific products, systems and manufacturers, with no alternatives or mechanisms to apply a substitution. Closed specifications are most often seen when matching a specification to an existing building, or when an exact duplication is important. By default, closed specifications are proprietary. However, they can be made “open” by not referring to a singular brand or providing requirements applicable only to a specific product. This is commonly done by adding “or equal” after the listed brand.

## 1.2 Manufacturing

> *A.k.a., Production, materialization, fabrication, construction, assembly, etc.*

This document uses a variety of terms to refer to the materialization of products (i.e., production, manufacturing, etc.). It is important to note here that "manufacturing" is sometimes defined from a commercial perspective: “Manufacturing is the production of merchandise for use or sale using labour and ...” Considering that there is no commerce in community, this definition does not apply.

> **NOTE:** *Production and construction are essential to consider because they effects so many of the remaining choices (i.e., future probable choices).*

### 1.2.1 Materialization and servicing

Manufacturing is a service, but not all services are of the manufacturing (materialization) type. Manufacturing and services can be seen as two different categories of production:

1. **Service organizations** - produce services as well as intangible products (e.g., music) that cannot be produced ahead of time. Additionally, for example, if there is a million person demand for a song, the one song can be produced as a service, and then, distributed as a service to a million people. Information assemblies, because they are computational networks, will require an initial outlay of resources, but after that initial outlay, the service is continuous. It is important to note here that services produce all objects. Informational operational services refer to knowledge, procedures, and digital content (e.g., songs as .mp3, books as .pdf, or computer games as .exe).
   A. The technological (technical) service organizations that produce and distribute objects throughout the habitat are:
      1. A service to produce objects via objects (materialization).
      2. A service to transport objects via objects.
      3. A service to perform computation via objects.
      4. A service to enable human communication via objects.
2. **Manufacturing (materialization service)** - manufacturing organizations produce physical, tangible goods that can be stored in inventory before they are needed. Additionally, for example, if there is a million person individual demand for personal vehicles, then some production facility may have to produce a million individual vehicles. Here, material resources become material products. Manufacturing operational services refer to the physical production of material objects.

## 1.3 Manufacturing locations

*A.k.a., Manufacturing facility placement.*

Placement of possible manufacturing facilities include:

1. Land
2. Ocean (or, water bodied) positioned manufacturing facilities.
   A. Ships on the ocean as integrated manufacturing platforms producing products as they travel.
3. Space

## 1.4 Manufacturing processes

*A.k.a., Fabrication processes, construction processes, materialization processes, re-materialization processes, production processes.*

The basic manufacturing methods are:

1. **Cutting and joining** - a process of subtracting and then joining.
2. **3D printing** - an additive process whereby layers of material are built up to create a 3D part, and then maybe, joining.
3. **Solid extrusion** - a process used to create objects of a fixed cross-sectional profile by pushing material through a die of the desired cross-section.

The possible fabrication methods include, but may not be limited to:

1. **Additive processes (additive manufacturing):**
   A. 3D printing (3-D printing) - consecutively layering a material or materials, on top of one another, building the structure from the based up (in gravity) or from anywhere (without gravity). 3D printers extrude, deposit, and fuse material one layer at a time. 3D printers rely on software control and multi-axis automated tooling. Their crucial advantage over CNC machines is their ability to create hollow shapes, such as curved tubes and globes, in one single piece.
2. **Subtractive machining processes (subtractive machining manufacturing)** - cuts away material (i.e., cuts away the contrast to the intended object; cuts away the excess material surrounding the intended object). Various controlled machining and material removal processes that start with solid blocks, bars, rods of plastic, metal, or other materials that are shaped by removing material through cutting, boring, drilling, and grinding. Computer numerical control (CNC) machines carve objects out of solid blocks of material (e.g., wood, metal, etc.) with computer-driven lathes and mills. 3D printers extrude, deposit, and fuse material one layer at a time. CNC machines rely on software control and multi-axis automated tooling. Newer types of CNC machines can create simple hollow spaces.
   A. Working piece rotation processes (**turning production**) - This type of tool rotates a workpiece, while the cutting tool moves in a linear motion. Turning forces a workpiece to rotate and stationary or linearly moving cutting tool removes material from a workpiece.
   B. Cutting tool rotation process (**milling production**) - milling forces the cutting tool to rotate. Milling operations involve using multi-point rotary cutters to remove material from a workpiece. Milling systems can use different

numbers of axis, anywhere from 1 axis to 5.
   C. Cutting tool rotation process (**drilling production**) - Drilling creates a round hole in a workpiece by the use of a rotating cutting tool.
   D. **Milling and turning system** - an advanced system that is capable of milling and turning with the same machine (not at the exact same time).
   E. Benefits: Precision is easy.
   F. Disadvantages:
3. **Subtractive light processes**: using light to etch away material.
4. **Subtractive + additive (hybrid manufacturing)** - One after the other.

**NOTE:** *All of these manufacturing process, to one degree or another can be automated in that objects are built automatically bit by bit using pre-existing schematics stored as data.*

Manufacturing methods are considered in relation to their:

1. Method life-cycle analysis.
2. Method characteristics (e.g., method, curing/off-gassing, finish type, etc.).
3. Method reliability analysis.
4. Location analysis:
   A. On-site production.
   B. Factory production (where repetition, predictability, quality control, and economies of scale can more readily be realized).
5. Cost analysis (market only).

### 1.4.1 3D printing for non-building objects

The following are the possible material types for the 3D printing of non-building objects:

1. Ceramic and clay mixtures.
   A. Objects can be printed by extruding layers of a ceramic / clay paste from a nozzle or by glue-bonding powder particles layer-by-layer.
2. Polymers and plastics

## *1.5 Optimization of manufacturing*

Parallelization is the fundamental type of process involved in the material automation processes, such as 3D printing, silicon processors, the printing press. Parallelization in product manufacturing massively increases productivity.

Early types of parallelism in manufacturing include:

1. Printing done in parallel through many printing press.
2. Spinning mill parallelization (spindles can run in parallel meaning one worker could monitor many, versus one worker to one spindle).
3. Liquid molding metal into objects done in parallel. Parallelization of liquid metal molding. Mass production of cast iron (complex iron objects can be made in a single action by pouring molten iron, wherein a mold transmogrifies the iron (or iron complex) into a specify defined object).
4. Metalwork operations such as folding, pressing and rolling are done in parallel. Parallelization of metal dipress molding. Dipresses allowed the forming of complex metallic framework, which allowed for the mass production of cars by forming the bottom framework part (chassis) or upper framework part of the car with a single impression of the dipress.
5. Injection molding plastic done in parallel.
6. Silicon processor production run in parallel. Integrated circuitry manufacturing done by a single photolithographic process (multiple of them).
7. 3D printing done in parallel. Multiple write heads that go back and forth, operating serially.
8. Dexterous robotics done in parallel. Multiple dexterous robots working together.

## *1.6 Manufacturing types*

There are two main types of manufacturing:

1. Production lines:
   A. Automated production line - a fully automated system geared to manufacturing only one type of object.
   B. Hybrid production line - a production type that combines automation with human effort.
2. On demand production (e.g., 3D printing) .

## *1.7 Materialization phases and workflow models*

*A.k.a., Manufacturing phases, production workflow.*

The phases of the production/materialization (i.e., manufacturing and integration) process are:

- Materials conversion > FAIT (Fabrication > Assembly > Integration > Testing)

Example with a simple window frame module:

1. Conversion = raw lumber; molten glass
2. Fabrication = frame wood; window panes
3. Assembly = assembled windows
4. Integration = window placed in building
5. Testing may be a separate phase, but may also be a

process associated with each of the other phases.

## 1.8 Production process methods

*A.k.a., Production order methods, manufacture order methods, business models of assembly industries.*

Production order acronyms include, but are not limited to:

1. **Engineer to order (ETO)** - the items are produced only after receiving a customer order with one key difference—the product specifications are custom for each item. In other words, a type of manufacturing where a product is engineered and produced after an order has been received. Items are produced with low frequency or sporadically in ETO. Since the specifications are custom, every item will also have a different materials list (bill of materials, BOM).
2. **Make to order (MTO, single product orders)** - a pull approach where production begins only after receiving a customer/user order. The materials list (bill of materials, BOM) and specifications remain the same for goods produced in MTO. Since items are made only after receiving a customer order, it's called 'make to order'.
   A. **Configure to Order (CTO)** - CTO is a variant of make-to-order production approach in which configuration starts only after a customer's order is received. Product standards will be pre-defined.
   B. **Assemble to order (ATO), Build to order (BTO)** - assembly starts according to demand. Assembling occurs after the producer receives a user's (customer's) order is ATO (Assemble To Order).
3. **Make to stock (MTS)** - inventory is manufactured and stocked in warehouses. MTS is the most common manufacturing method prevalent in fast moving "consumer" goods (FMCG), garments, and other similar industries. In MTS, the materials list (bill of materials, BOM) remains the same for one type of product. These are the important factors to consider when manufacturing items to stock:
   A. Forecasting
   B. Seasonality
   C. Market demand
   D. Product expiry dates
   E. Available warehouse space

The selection of a different production method will affect the following production factors:

1. Delivery time
2. Change impact
3. Development time and requirements
4. Engineering time and requirements
5. Risk of design error

## 1.9 Classic manufacturing processes

These are the classic manufacturing processes in commercial practice (in order of decreasing volume):

1. Continuous flow - large and continuously required production volume (e.g., oil and utilities).
2. Production line - high-volume production of standard products or "design window".
3. Batch (high volume).
4. Batch (low volume).
5. Job shop - low volume, one-of-a-kind products.
6. Project - one of a kind or too large to be .

## 1.10 Geometric modeling for 3D printing

The "geometric kernel" defines what is possible. It asks, how to capture and represent physical space and objects. It answers the question, "How do we define the world around us and how do we design?" A geometric model generates a modeling framework (describing the systems functionality), upon which exists a graphical and user interface. And, the graphical interface informs what is possible in terms of production and application simulation."

## 1.11 Product standards

**Product standards** are established by research and consensus. Product standards define what products are made of, as well as how they perform. For most products, product standards standardize ("govern") the characteristics, materials, performance and operability, as well as how products need to interact with other system elements. Alternatively, **prescriptive product standards** differ from performance-based product standards in that they attempt to achieve a desired outcome by specifying the characteristics, materials, performance and operability of products. For example, a prescriptive product standard for fittings would specify the maximum amount of alloy material, such as lead, that can come in direct contact with the drinking water.

### 1.11.1 Product codes

**ASSOCIATION:** *This section is associated with an equivalent section in the Decision System > Classification of the Economic Decision System for a Community-Type Society > ... > Product coding.*

Product codes allow for the appropriate categorization, tracking, and coordination of all products (including services) and their used materials.

### 1.11.2 Product safety assurance

NSF International [nsf.org] is a not-for-profit, non-governmental organization that develops standards and product certifications in the area of public health and safety.

# 2 Production via machines

*A.k.a., Production through automation.*

Machines must be produced, including the energy to power machines. Machines (machine labor) improve human life in two ways.

1. They amplify the human ability to produce goods and services (e.g., a crane allows one human to lift very heavy loads).
2. They extend/expands human ability to. It allows us to do thins that no human being could do (e.g., virtual reality or simulation).

If a population wants a world that is more liveable, they might need a world where machines are doing more work for humanity than in the early 21st century (and in the market-State, that requires energy being low cost). All human beings desire the time and freedom to peruse intrinsic interests and life purposes. This pursuit at a global scale is only possible if machines are doing most of the banal, and often laboriously and dangerous physical work. In the market-State, low cost reliable energy allows machines to do a lot of the work for humanity and free up time to facilitate transition to community.

# 3 Standardized specification data (for an architectural object)

The standard outline for writing specification includes the following sections:

1. Integrated discussion section.
   A. Social system data.
2. Product materially realizable as/into an environment.
   A. Product section (knowledge of product) - data to sufficiently complete description of production, product production, and product cycling to safely, efficiently, and effectively [by the decision inquiry process] realize the system in the real world.
3. Execution of construction, operation (and recycling/dissembling if applicable).
   B. Execution section (knowledge of execution) - execution by teams and system to realize, re-realize, or de-realize architectural realizations (i.e., "the built environment")

The **integrated discussion section** generally includes:

1. **Purpose of system (needs):** Quick checklist on products or materials:
   A. Why is it needed?
   B. What is it and what does it do?
   C. Who is it made by?
   D. How is it fabricated (how is it made)?
   E. How can it be made at a specific geo-positional location.
   F. How to apply and/or operate the system?
   G. What does it cost to research, construct, maintain in operation, de-construct?
   H. Warranties for products by businesses and States?
2. **Objectives:** Detailed checklist on evaluating new products, materials, or systems based on a set of objectives related to the re-orientation of the real world, constructed environment (that a population safely and intentionally constructs together):
   A. Structural serviceability - resistance to natural forces such as wind and earthquake; structural adequacy and physical properties such as strength, compression, tension, shear, and behavior against impact and indentation.
   B. Fire safety - resistance against the effects of fire such as flame propagation, burn through, smoke, toxic gases, etc..
   C. Habitability - livability relative to thermal efficiency, acoustic properties, water permeability, optical properties, hygiene, comfort, light, and ventilation, etc.
   D. Durability - ability to withstand wear, weather resistance such as ozone and ultraviolet, dimensional stability, etc.
   E. Practicability - ability to surmount field conditions such as transportation, storage, handling, tolerances, connections, site hazards, etc.)
   F. Compatibility - ability to withstand reaction with adjacent materials in terms of chemical interaction, galvanic action, ability to be coated, etc.)
   G. Maintainability - ease of cleaning; repairability of punctures, gouges, and tears; recoating, etc.
   H. Code acceptability - review of code and manufacturer's claims as to code compliance.
   I. Market economics - financial, currency costs associated with acquisition, installation and maintenance of everything from the market.
   J. Governmental (jurisdictional) legality - reviewing and paying the government to meet codes and permit requirements as set by different governmental jurisdictions.
3. **Values:** Detailed decision inquiry process that evaluates new products, materials, and systems based on a set of qualitative and quantitative data acquisition and analysis processes (a.k.a., inquiry processes). Products and systems are informed and checked for optimization to human goals, objectives, and requirements. These inquiry process determine solution state configurations of the real world. Some state reconfigurations include local population-wide consensus solutions (as ~90% or other; for example, landscape semi-permanent redesign), and other state configurations only involve InsterSystem team members as those responsible and accountable for the reconfiguration of the habitat.
4. **Titling and numbering requirements:** title and number checklist of everything that makes or goes into the architectural system, their contents and surroundings.

The **product specification** as represented in the socio-decisioning system as a set of requirements and associated specifications (inquires for knowledge or knowledge inquiries), which generally include:

1. Material [knowledge] requirements and specifications
2. Quantity-related [knowledge] requirements and specifications
3. Quality-related [knowledge] requirements and specifications
4. Construction [knowledge] requirements and

specifications
5. Operation [knowledge] requirements and specifications
6. Personnel [knowledge] requirements and specifications

# 4 Materialization specification standards

Material standards ensure the safe, efficient, and effective construction of objects and architecture in society.

A summary of the required steps in the development process:

1. There is a demand (need) from society.
2. A working group prepares the draft standard.
3. The draft standard is submitted for public enquiry.
4. The standard is approved and put forth to society.

## *4.1 Global organization of standards*

Global standards are hierarchically organized in the following ways:

1. International (e.g., ISO, IEC, ITU)
2. Regional/sub-regional
3. National
4. Associations
5. Companies

In general, going up the hierarchy the standards are more restrictive and less generic, and going down the hierarchy, the standards are less restrictive and less generic.

## *4.1 Cradle-to-cradle product standard*

> **NOTE:** *In the market all constructions are products.*

The Cradle-to-Cradle Certified Product Standard guides designers and manufacturers through a continual improvement process that looks at a product through five quality categories — material health, material re-utilization, renewable energy and carbon management, water stewardship, and social fairness. A product receives an achievement level in each category — Basic, Bronze, Silver, Gold, or Platinum — with the lowest achievement level representing the product's overall mark. Necessarily, Cradle to Cradle involves a labeling system and the declaration of ingredients.

Product assessments lead to the earning of a "certificate" indicating that the business standards body known as "Cradle to Cradle" has assessed and qualified the product to meet one of multiple achievements. Assessments are performed by a qualified independent organization trained by the Institute. The training and accompanying accreditation provided by Cradle to Cradle Products Innovation Institute comes at a financial cost (i.e., it is sold). The assessment provided by the "independent organizations" that purchased training from Cradle to Cradle comes at a financial cost to the product producer.

The idea that waste is actually food [as input for some other life process]. The essence of Cradle to Cradle is the importance of a closed loop, that only materials and processes that can be reused endlessly should be included in product design. And that if these guidelines are followed, humans can live in a world of abundance.

The cradle-to-cradle process accounts for the following:

- **Material health** - Knowing the chemical ingredients of every material in a product, and optimizing towards safer materials.
  - Identify materials as either biological or technical nutrients
  - Understand how chemical hazards combine with likely exposures to determine potential threats to human health and the environment certified
- **Material re-utilization** - Designing products made with materials that come from and can safely return to nature or industry.
  - Maximize the percentage of rapidly renewable materials or recycled content used in a product
  - Maximize the percentage of materials that can be safely reused, recycled, or composted at the product's end of use
  - Designate your product as technical (can safely return to industry) and/or biological (can safely return to nature)
- **Renewable energy & carbon management** - Envisioning a future in which all manufacturing is powered by 100% clean renewable energy.
  - Source renewable electricity and offset carbon emissions for the product's final manufacturing stage
- **Water stewardship** - Manage clean water as a precious resource and an essential human right.
  - Address local geographic and industry water impacts at each manufacturing facility
  - Identify, assess, and optimize any industrial chemicals in a facility's effluent
- **Social fairness** - Design operations to honor all people and natural systems affected by the creation, use, disposal or reuse of a product.
  - Use globally recognized resources to conduct self-assessments to identify local and supply chain issues and third party audits to assure optimal conditions
  - Make a positive difference in the lives of employees, and the local community

Cradle to Cradle certification launched in 2005 and rates products using five criteria:

1. Their use of environmentally safe and healthy materials
2. Materials are designed for recycling or composting at end of life
3. Manufacturing must make use of renewable energy and carbon management
4. Water stewardship
5. Social fairness

## *4.2 The cradle-to-cradle red list*

In the cradle-to-cradle decisioning process, the "Red List" contains ingredients that inhibit all further forward movement. Or, it can move forward, but the company producing the Red Listed ingredient must be notified that the ingredient will be changed as soon as a suitable alternative becomes available. If a construction list has any of these ingredients, and production can't move forward without 1 of them, then the producer must send a letter to the provider of the Red Listed product stating that as soon as there is another option available "we wont use your product".

## *4.3 Connectivity (interconnectivity) of objects*

Materials are connected in various ways, including but not limited to the type and degree of [being fully] integrated:

1. Clips (e.g., metal clips).
2. Corks (e.g., wood stopper).
3. Velcro (e.g., hook and loop fastening).
4. Zips (e.g.,, crimped fastening).
5. Laces (e.g. cordage fastening).
6. Screws and nails (e.g., twist or stretch insert fasting)
7. Adhesion.
8. Solder.

# 5 Materials recycling

Most habitat service system recycle the following types of materials from user consumption:

1. Compost recyclable (biodegradable).
   A. Carbohydrates - biodegradable (may use compostable trash bag).
   B. Protein - biodegradable (may use compostable trash bag).
   C. Lipids - biodegradable (may use compostable trash bag).
2. Recyclables (no trash bag required)
   A. Plastic
   B. Glass
   C. Paper
   D. Metal
3. Not recyclable (no trash bag required).
   A. Waste to be buried.
   B. Waste to be burnt.
   C. Waste to be upcycled.

Within buildings and along transportation networks it is optimal to place (position and orientation) appropriate disposal tanks (i.e., trash receptacles, trash cans, material cycling bins, recycling bins, waste collectors). A habitat service system that maintains a local automated object transportation network will be able to automate the transportation of trash receptacles from filling location to centralized areas for processing.

# 6 Product packaging

Products need that need to be transported need to be properly prepared, labeled, and packaged. This is so they can be received accurately and in functioning order (i.e., in the best possible condition).

## *6.1 Instructions and warning labels*

Packaging should have appropriate instructions and warning labels. Depending on the products, some additional labeling may be required.

Common warning labels include, but are not limited to:

1. Suffocation.
2. Heavy objects.
3. Dangerous materials (e.g., lithium batteries).
4. Handle with care (Read: Fragile).
5. Loose products.
6. Expiration dates.

There are also labels for phase of preparation prior to shipping:

1. Not ready to ship.
2. Ready to ship.

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# TABLES

**Table 59.** **Technology Support > Materialization**: *Material cycling solutions.*

| Material Cycling Solutions | | | | | | |
|---|---|---|---|---|---|---|
| Repair & Maintenance | Reuse & Distribution | Refurbishment & Re-manufacturing | Recycling | Cascading & Re-purposing | Organic Feedstock | Market |
| Repair | Reuse, refurbish, maintain, redistribute | Re-manufacturing | Closed-loop production | Co-product generation from waste | Co-product generation from waste | Sell waste and/or product |
| Product life extension | Reuse | Upgrading | Re-materialization | | Circular supplies | Waste exchange |
| Classic long-term model | Product life extension | Product life extension | Recycling and waste management | | Resource recovery | Product lease |

# TABLES

# **Exploratory Support:** Scientific Discovery System

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**Last Working Integration Point:** *Project coordinator integration*

**Keywords:** scientific discovery, scientific experimentation, laboratories,

## Abstract

Humans are, at least, adaptive and self-integrating systems who express evolved exploratory signaling ability. Young humans express exploratory behaviors oriented at learning (understanding) and controlling (testing). Every society is, in many ways, an experiment. Science involves environments appropriate for thinking and testing, for learning and demonstrating, for practicing and experimenting. It is favorable for humans to have the opportunity to select a scientific discovery system as one of its exploratory subsystems, because allows for safe navigation and technical validation. Some scientific discoveries may be operated at the community access scale and others may be operated through intersystem teams and working groups. Science enables reproducibility, and it is reproducibility that enables technology. Technology, then, enables societal-level services, and highly automated and coordinated fulfillment therefrom. New scientific discoveries may advance understanding and/or technological development. Safely coordinated discovery is possible at the societal level, when local individuals may choose to participate in scientific endeavours, particular as a life-learning experience. Some of these endeavours may be objectives at the societal level (e.g., the launching of a spaceship), and others may be localized, such as a youth running a common experiment in a lab in a city somewhere. The scientific discovery system is primarily run as a working group, but some cities and regions do have InterSystem habitat scientific discovery teams; those on other planets, for example. Some scientific discoveries are new and others are simply required for self-verification, since a community-type society is composed of self-directing individuals with life experience to be explored.

## Graphical Abstract

Image Not Yet Associated

Here, research may be more accurately known as scientific research. In the early 21st century, research is primarily an academician's category and development is an industrial category. Community organization, however, is not concerned with labor roles, but with where the actual information being worked on fits into a unified information model, and therein, a habitat service model. Scientific research and engineering development representing two distinct states of knowledge. Science is used to explore what happens and why in the natural world, while engineering uses the discoveries of science to create (and operate) technical constructions. Essentially, technical information about the operation of nature can be discovered [through science] and applied toward technical fulfillment [through engineering]. Science discovers what already is, and engineering creates that which isn't. Together, research and engineering/ technology development (R&D) is composed of those activities which rely on science and engineering, and which are devoted to developing and operating socio-technical systems and services. Science informs, technology bridges. Technology is applied science. Scientists work with things that are testable, falsifiable, and reproducible. Then, systems engineers work through scientific discoveries to develop technologies.

The outputs of research feed into engineering development, and the output of engineering development are technical service modules (i.e., technologies) which are in use and operational as part of the habitat service system.

Science is about explaining and technology is about developing technical systems through trial and error.

# **Exploratory Support:** Technology Development System

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**Last Working Integration Point:** *Project coordinator integration*

**Keywords:** technological development, technological engineering, laboratories

## Abstract

Technology is the engineered interface of a commonly interrelated world. Technology enables function, as well as destruction of all function. Technological advancement continues over time to look like a more thought responsive environment. Humans can build and understand technical systems together. When humans are building technical systems together, they may rely on a pre-developed standard for building the new system. Working groups develop technological systems and their standards. Teams construct and operate the standards of a habitat service system. Technological development is an exploratory behavior, naturally enjoyable to humankind. Engineered technology is synonymous with high certainty deliverables, given the data and what is known. Technologies are operated. Some technologies are enjoyable by humans to operate. Technologies, or the use of technologies, that detract from human life or harm human operation should be reduced and monitored where necessary. An InterSystem Team herein is responsible for containing, sustaining, and restoring technological disasters (e.g., Chernobyl, Four Mile Island, etc.). This team would operate in conjunction with other InterSystem teams. In many ways, a technology is a control package influential at the information and/or spatial level. Technologies can be shared, communicated, transported, and materialized together, or not. Technologies enable the extension of function throughout an environment. Technologies and their applications can improve and degrade the quality of a life. Technological development is an exploratory working group and InterSystem team that develops technologies.

## Graphical Abstract

Image Not Yet Associated

No content here yet.

*See also:*
The Material System Standard > Technology Accounting System.

# **Exploratory Support:** Learning System

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**Acceptance Event:** *Project coordinator acceptance*

**Last Working Integration Point:** *Project coordinator integration*

**Keywords:** Education system, learning service, education service, certification service

## Abstract

A learning system isn't so much an infrastructural integration, but an arrangement of services, some of which are informational and others of which are material that facilitate individual learning. Given that which is available, learning necessitates access to creative and collaborative technologies assistance (facilitation) in developing new skills, and mentorship in developing new established team member positions. Learning is a lifelong process that originates from within the individual. In a community-type society, learning about the society progresses best through participation in the society. Technologies and the flow state enable learning. More formalized learning is that which involves mentorship and possibly certification (e.g., like being certified to fly an airplane or conduct a surgical procedure). Learning requires materials that would otherwise be superfluous to a stable state society. The application of resources to learning structures facilitates societal adaptation and safety overall. The very nature of facilitation, is allowing another to determine what interests him (or her) to create or select their own "roadmap" for learning. There is structure, if desired. But, there is no such thing as a set curriculum, which must be completed within a certain period of time. Sharing one's own interests engages the interests of others. With proficiency come responsibility to encourage others who are less proficient and to use systems safely; not impress others, but express what is possible. Bringing out the best in others is how we find the best in ourselves. It is necessary to give to one another the tools to structure information in meaningful ways so that anyone can do something fulfilling with it. Failure is never a problem when there is play, the response may be. Knowing and experiencing are necessary. An event "happens" only when it is "experienced", and consciousness has been verified of its existence.  A event is "experienced" only when it is "known", and consciousness only knows of its possible existence. All events are visualizable.

## Graphical Abstract

Image Not Yet
Associated

No content here yet.

*See also:*
The Lifestyle System Standard > The Education Phase

# **Exploratory Support:** Recreation System

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**Last Working Integration Point:** *Project coordinator integration*

**Keywords:** leisure, rest and recreation, playful and restorative activities

## Abstract

A recreation system is composed of many different components, the combination of which provide facilities and landscapes for indoor and outdoor recreation. Many entities are involved in the development and coordination of recreational areas and facilities within a habitat service system and its local network. There may be a recreational belt in any given city, and there may be recreational centers out in nature. In many market-State societies, a recreation system is a governmental function and a necessary State expense. In the market-State, recreation is largely considered to be unpaid/unpayable actions.

In community, habitats have recreational areas (zones) for recreational activities, which are highly customized to the local habitat population, and may change over time. All habitats have recreational activities that everyone in the habitat can enjoy. Recreation refers to all those activities that people choose to do to refresh their bodies and minds and make their leisure time most interesting, restorative, playful, and/or enjoyable. It is important to note here that 'leisure' is a life phase in community, and 'recreation' is a habitat service sub-system. In common parlance, the two words are often used synonymously.

## Graphical Abstract

Image Not Yet Associated

No content here yet.

# **Exploratory Support:** Art and Music System

Travis A. Grant

**Affiliation contacts:** *trvsgrant@gmail.com*

**Version Accepted:** 8 July 2022

**Acceptance Event:** *Project coordinator acceptance*

**Last Working Integration Point:** *Project coordinator integration*

**Keywords:** art, music

## Abstract

An art and music system is composed of many different components, the combination of which provide facilities and tools for art and sound production. Many entities are involved in the development and coordination of art and music components within a habitat service system and local network. In general, locations with music require sound protection barriers to reduce disturbances in the surrounding environment. Art and music are forms of human expression. This sub-system could be considered the human expression service, allowing.

## Graphical Abstract

Image Not Yet Associated

No content here yet.

# **Exploratory Support:** Consciousness System

Travis A. Grant

**Affiliation contacts:** *trvsgrant@gmail.com*

**Version Accepted:** 8 July 2022

**Acceptance Event:** *Project coordinator acceptance*

**Last Working Integration Point:** *Project coordinator integration*

**Keywords:** consciousness exploration system, spiritual service system

## Abstract

A consciousness exploration system is composed of many different components, the combination of which provide facilities and tools for consciousness exploration, healing, and spiritual connection/growth. Many entities are involved in the development and coordination of a consciousness service system for a habitat's population.

## Graphical Abstract

Image Not Yet Associated

No content here yet.

The Auravana Project exists to co-create the emergence of a community-type society through the openly shared development and operation of a information standard, from which is expressed a network of integrated city systems, within which purposefully driven individuals are fulfilled in their development toward a higher potential life experience for themselves and all others. Significant project deliverables include: a societal specification standard and a highly automated, tradeless habitat service operation, which together orient humanity toward fulfillment, wellbeing, and sustainability. The Auravana Project societal standard provides the full specification and explanation for a community-type of society.

This publication is the Habitat System for a community-type society. A habitat system describes the organized structuring of a service environment; the habitat service structuring of community. This habitat system standard identifies the services, technologies, and other processes constructed and operated in a material environment. A habitat service system encodes and expresses our resolved services. When a decision resolves into service, that service is specified to exist in the habitat system. Different configurations of the habitat lead to different levels and qualities of fulfillment. The coherent integration and open visualization of the habitat systems is important if societal requirements are to be met by a master plan. This standard represents the encoding of decisions into a habitat service system that acts as a fulfillment platform for the community population. The visualization and simulation of humanity's connected habitat integrations is essential for maintaining a set of complex, fulfillment-oriented constructions and operations. As such, the habitat system details what has been, what is, and what could be constructed [from our information model] into our environment. This specification depicts, through language and symbols, visualization, and simulation, a habitat service environment consisting of life support, technology support, and exploratory support. For anything that is to be constructed in the material system, there is a written part, a drawing part, and a simulation part, which is also how the material system is [in part] sub-divided.

Fundamentally, this standard facilitates individual humans in becoming more aware of who they really are.

All volumes in the societal standard:

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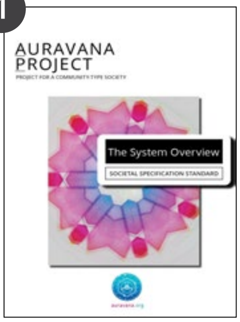


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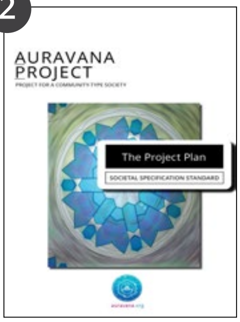


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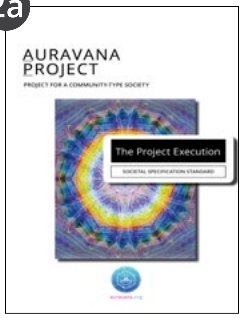


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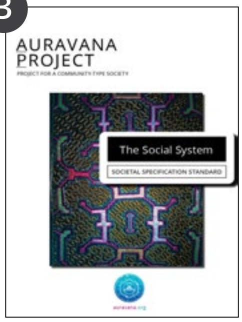


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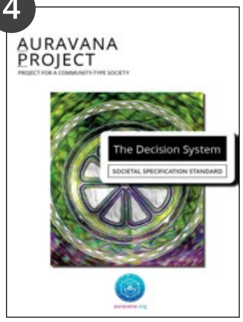


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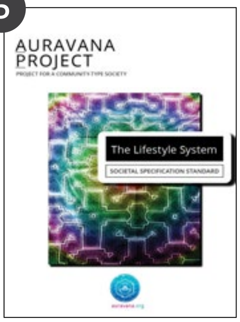


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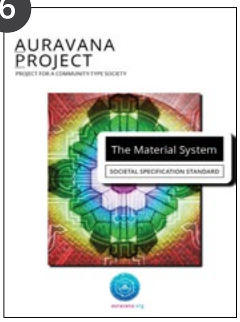


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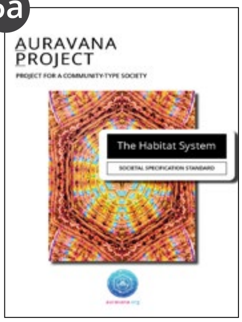


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