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.

9.3.1 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**

9.3.2 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.

9.3.3 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.

9.3.4 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

9.3.5 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):

- $P = (\Delta p Q) / \eta$
- 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.).

- $\Delta P = ((v^2{}_2 - v^2{}_1) / 2) + \Delta zg + (\Delta P\text{static} / p)$

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.

9.3.6 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	-

Data Category	Specifics
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.

10 Water system failure modes

The common water failure modes are:

1. **Penetration** - where water gets into areas and materials it was expected it would remain separated from.
   A. Leaking (i.e., penetration of water into a surface it was not supposed to have penetrated).
2. **Flooding** - the rapid and unexpected rushing of some volume of water.
3. **Standing water** (a.k.a., sitting water, pooling water) - is water on the landscape or surfaces that has not infiltrated rapidly. For example, this can be caused by improper grading of the landscape, thus causing pooling of water near a buildings foundation.
4. **Discharge polluting** - where water that is contaminated with pollutants from production or usage is discharged into an exterior area it was not intended to be discharged into.
5. **Contaminating (contamination)** - where water is contaminated from some outside source.
6. **Eroding (erosion)** - where water moving over the landscape removes some essential part of the surface as it moves, over time.

10.1 Erosion

A.k.a., Eroding.

Erosion is the process of landscape decomposition over time. Wherever there is water and drainage, there is the potential for erosion. Physical erosion is the geological process in which earth materials are transported from one place to another naturally; the displacement of solids over a landscape because of planetary geo-physical conditions.

Generally, however, there are two ways erosion occurs (i.e., two ways earth decomposition and natural gravity transportation occurs):

1. **Weathering** - refers to the decomposition of soils and minerals and rocks through direct contact with the earth's atmosphere.
   A. Wind erosion - damages uncovered soil by drying out and physically removing the most fertile part, lowering water-holding capacity, degrading soil structure, and increasing soil variability across a field, resulting in reduced crop production. It tends to remove silts and clays making the soils sandier. This is also a large contributor to air and water pollution.
   B. Rain erosion - damages uncovered soil by compaction.
2. **Physical erosion** - refers to earth changing

physical properties and location without their basic chemical composition changing. Here, weathered rocks and soils are moved from one place to another. Here, weathering causes rocks to break down, and erosive physical gravity-driven transports moves the sediment downhill to another place.
3. **Chemical erosion** - causes the breakdown and decay of rocks and living soil through a chemical process. The most significant of this is oxidation.

Without deep-rooted prairie grasses covering non-plant shaded ground, to hold the soil in place and provide some covering, it will begin to decompose, become weathered and erode. Rain falls at an average speed of 22.5km/h (14mph) depending on wind and drop size. When landing on bare soil, rain compacts the ground. When landing on grass, it bounces and the motion dissipates before impaction. For soil creation, it is desirable to have rainfall land on ground cover (e.g., grass, trees, etc.) that breaks the impact and allows for more optimal infiltration. Without impact by rain, the soil remains more habitable for essential soil biology, while slowing the speed of infiltration. Runoff from bare soil will tend to evaporate before it can be absorbed by the soil. Grasses reduce evaporation by keeping moisture under cover of shade.

10.2 Standing water

Standing water is surface water that rests on the landscaping in the form of puddles. Note, some puddles on the landscape are normal, but not all. Puddles can create problems. They can kill plants, attract and spread biting insects, spread bad odors, and cause foundational damage to architecture. Standing water can even reduces the quality of soil overall. Drainage systems are installed to collect and channel water that might otherwise pool in low-lying areas or hardscapes, keeping water away from foundations, reducing water damage, and enhancing water seepage (ground infiltration).

10.3 Water discharge

Many habitat architectural systems discharge waste-water. There is building and habitat code for the discharge of wastewater from any given habitat fixture (including light production, heavy production, recreation, personal dwelling, etc.). Waste-water coming from production generally needs to be treated before discharge.

In community, there is waste water discharge from production systems, and waste-water discharge from common and personal habitat access centers of service. Production system waste-water must generally go through a more processes intensive treatment prior to discharge to ensure a safer water ecology.

Generally, waste-water that is sufficiently clean or cleaned from the a habitat infrastructure system may be discharged to one of the three:

1. To surface water (e.g., lakes, wetlands, etc.).
2. To bodies of moving water (e.g., river, stream).
3. To swales or pits.
4. To aquifers (i.e., deep pit).

10.4 Loss of water quality standards

There are several additional failure modes of water system (drinking water in particular), stated as objectives:

1. 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.
2. Drinking-water is unmodified. Water that has elements or compounds with additive pharmacological effects (e.g., sodium fluoride/fluoridation) is not pure drinking water.
3. Any 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.

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TABLES

Table 18. *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 19. *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.

TABLES

Table 20. *Sanitation water system and technologies.*

Input	User Interface	Input/ Output Products	Collection & Storage / Treatment	Input/ Output Products	Conveyance	(Semi-) Centralized Treatment	Input/ Output Products	Use and/or Disposal
Stormwater	Infrastructural drainage architecture	Stormwater	Soil drainage & Conduit to retention	Stormwater	Stormwater drains	Ponds	Stormwater effluent	Disposal/ Recharge
Bluewater	Landscape	Rainwater	Soil drainage & Conduit to retention	Rainwater	Landscape channels	Ponds	Rainwater on landscape	Disposal/ Rechanrge
Greywater	Architectural fixtures	Greywater	Reactor retention	Greywater	Greywater drains	Bio-reactor	Greywater effluent	Irrigation, soak pit, disposal/ recharge
Organics to liquids	Waste can collection	Organic waste	Biogas reactor	Sludge, biogas	Deposition port	Bio-reactor	Biogas, sludge	Soil, fuel, gas chemicals
Organics to solids	Waste can collection	Organic waste	Composter	Compost	Container of compost	Bio-reactor	Compost	Soil
Faeces to liquids	Flush toilet	Blackwater	Biogas reactor	Sludge, biogas	Blackwater conduit	Bio-reactor	Biogas, sludge	Soil, fuel, gas chemicals
Faeces to solids	Waste can collection	Organic waste	Composter	Compost	Container of compost	Bio-reactor	Compost	Soil
Urine to bioreactor	Urinal, Urine Diverting Toilet	Brownwater (yellow water)	Biogas reactor	Sludge, biogas	Brownwater conduit	Bio-reactor	Biogas, sludge	Soil, fuel, gas chemicals
Urine to nitrogen application	Urinal, Urine Diverting Toilet	Yellow water (brown water)	Storage tank	Stored urine	Tank with motorized emptying & transport	Tank	Urine chemical (fertilizer)	Application, soak in pit
Dry cleaning material	Synthetic chemical solvents and textile cleaning machines	Solvent and textiles	Dry cleaning machine	Hazardous solvent effluent	Solvent drains	Blackwater integration	Dry and clean textiles, blackwater	More hazardous chemicals necessitate special conditions
Wet cleaning material	Synthetic chemical solvents and textile cleaning machines	Solvent, water, textiles	Wet cleaning machine	Hazardous solvent effluent	Soap water	Blackwater drain	Dry and clean textiles, blackwater	Less hazardous chemicals reduce special conditions

Life Support: Power Service System

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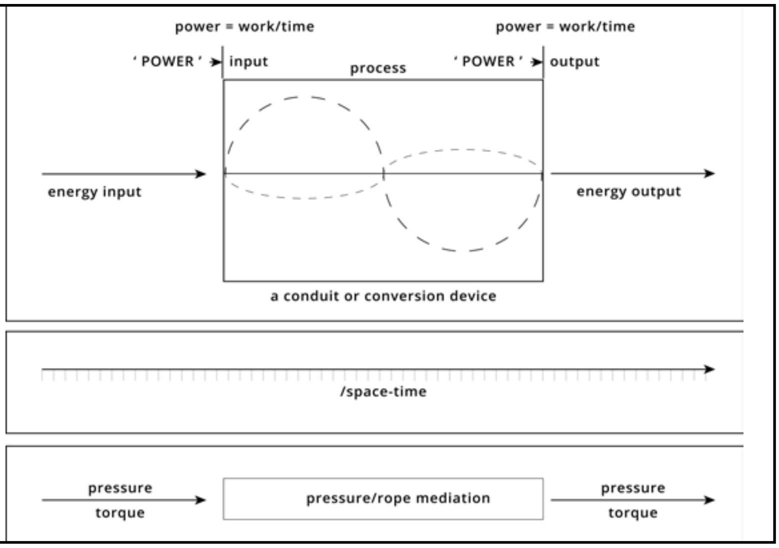
Abstract

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 2. *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 Overview of the power/energy system

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:** the capacity, the ability ...
2. **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. 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, chemical energy, gravitational energy, nuclear energy, etc.). Energy can exist in numerous carriers ("forms").
    A. **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. Energy is the capacity to do work; it is a dynamic concept, a calculation.
        1. Energy maintains its identity after being "transferred". Because, energy remains just a calculation of capacity, a dynamic concept. The total quantity of energy may or may not be conserved in a system.

Power-type functional systems and activities include, but may not be limited to:

1. Power production centers (i.e., plants, arrays).
2. Power transformation centers.
3. Power transfer pathways.
4. Power technology production and cycling centers.
5. Computational, architectural, and power systems are required.

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. Objects can be destroyed, energy is a calculation. 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.

> **NOTE:** *Every system in the physical environment needs energy to support its initial setup and sustained 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.

> **NOTE:** *In the early 21st century, the power/ energy sector [of the economy] is the biggest industrial user of fresh water, accounting for 40% of all freshwater withdrawals in the United States. (EIA, 2018)*

In any habitat, power/energy goes to all the following sub-systems:

1. Power goes toward moving atoms around.
2. Power goes toward computation
3. Power goes toward production and cycling.
4. Power goes toward usage.

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.).

A power system can contain and produce power. In other words, there is [a maximum] amount that a power system:

1. **Can contain (storage capacity, static capacity)**. For example,
   A. A drawn limbs of a crossbow can contain 150lbs of "potential energy".
   B. A battery with sufficient electrolyte can contain 10 watt-hours (Whr) of "potential energy".
2. C**an produce (output capacity, dynamic capacity)**. For example,
   A. A crossbow with the above "potential energy" can physically move an arrow at 210 meters-per-second for a distance of 110 meters.
   B. A circuit with the above "potential energy" in a battery can power a 10 Watt circuit for 1 hour (10W * 1hr = 10 Whr).

'Power' is a process set (i.e., 'power' is multiple different dynamic concepts representing actionability - the ability to take action):

1. Motion by gravity:
   A. Power = force multiplied by speed (velocity).
2. Motion by time:
   A. Power = work over elapsed time (delta *t*).
3. Electricity in motion (note: technically, electricity is something in motion - electron shells spinning in situe):
   A. Electrical power = voltage times intensity.
   B. Electrical power = voltage squared over resistance.
   C. Electrical power - intensity squared times resistance.

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.*

1.1 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.

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.*

1.2 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.

> **CLARIFICATION:** *Energy is a construct meaning the motive force to do work.*

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.*

1.3 Technical power units

A.k.a., Power technical units.

The technical units in a power system in a habitat are:

1. Technical power production units (motors and electrical turbine machines).
2. Technical power transfer units (mechanical and electrical conduits).
3. Technical power storage units (fuels/batteries chemicals).

1.3.1 Technical power production units

Electricity [power] network habitat technical production unit classes:

1. Flow harnessing electricity turbine generators:
   A. Photovoltaic solar - a photovoltaic electric production with battery system.
   B. A turbine electric production with battery

storage system.
   1. Water turbine.
   2. Wind turbine.
2. Nuclear fuel production and reaction ecosystem:
   A. Nuclear fission leads to turbine produced electricity.
3. Electrolysis hydrogen fuel production ecosystem:
   A. Hydrogen fuel cell technology - an electric chemical fuel-battery system (e.g., hydrogen gas). Hydrogen electrolysis using hydrogen fuel gas transformed in a "fuel cell" into electricity.
4. Battery storage (e.g., lithium) ecosystem:
   A. Batteries are electricity on demand storage devices. Where electricity from an outside source is spent bringing the "battery cell" up to a high chemically charged state, so that electricity power can be drawn from it on demand.
5. Combustion of hydrocarbon fuel production ecosystem (a hydrocarbon combustion system):
   A. Hydrocarbons are combusted in furnaces to produce heat, internal combustion motion, and turbine electricity.

Tasks are contextual to unit class and include, but are not limited to:

1. Produce electricity.
2. Produce electric batteries.
3. Charge electric batteries.
4. Produce hydrogen for hydrogen cells.

1.4 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).

1.5 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.

1.5.1 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:

1. An inherent inertia hence an inherent buffer storage capacity.
2. 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.

1.5.2 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:

1. No inherent inertia, hence no inherent buffer storage capacity.
2. To be powered exclusively by electricity or [other] pressurized substances.

2 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.

2.1 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.

2.2 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 gas or electrolysis). This conversion comes always with energy losses.

2.2.1 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.

2.3 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'.*

2.3.1 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).

2.3.2 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; pull.

NOTE: *Flows are renewable more quickly than fuels. Solar radiation varies over the year and on a day to day basis. Wind typically varies over a week to week and month to month period.*

NOTE: *There needs to be at least 4 weeks buffer storage for industry to be operating reliably.*

It is further relevant to note here that renewable is not a technically precise term when it comes to describing the renewable energy harnessing technologies themselves. Instead, re-buildable is a better term for the technology; solar and wind harnessing machines are re-buildable (given sufficient material). They are re-buildable machines that can harness the renewable flows of the sun and wind.

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.*

2.4 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.

2.5 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.

2.6 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. When generating power, 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. When transmitting power, energy is carried by the transmitting system at a specific rate.
3. When utilising power, 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:
   A. Mechanical > fluidal (e.g, power steering pump).
   B. Mechanical > electrical (e.g., alternator).
   C. Mechanical > fluidal (e.g., fan, propeller).
   D. Mechanical > thermal (e.g., thermal welding).
2. Fluidal power conversion transfers energy carried by a fluidal system to:
   A. Fluidal > mechanical as linear/rotational motion (e.g., turbine)
3. Electrical power conversion transfers energy carried by an electric system to:
   A. Electrical > mechanical (e.g., electric motor, actuator).
   B. Electrical > thermal (e.g., heater, light bulb).
   C. Electrical > electromagnetic (e.g., antenna transmitter).
   D. Electrical > magnetic (e.g., electromagnetic induction, electrical transformer).
4. Magnetic power conversion transfers energy carried by a magnetic system to:
   A. Magnetic > electrical (e.g., electrical generator).
   B. Magnetic > mechanical (e.g., magnets).
5. Electromagnetic power conversion transfers energy carried by a electromagnetic system to:
   A. Electromagnetic > electrical (e.g., antenna receiver, solar panel).
   B. Electromagnetic > mechanical (e.g., electromagnet).
6. Thermal power conversion transfers energy carried by a thermal system to:
   A. Thermal > fluidal (e.g., steam plant boilers generate electricity).
   B. Thermal > mechanical (e.g., combustion engine)
   C. Thermal > electric (e.g., thermopile, thermoelectric generator).
7. Chemical power conversion transfers energy carried by a chemical system to:
   A. Chemical > mechanical (e.g., chemical motor, internal combustion engine).
   B. Chemical > electrical (e.g., chemical battery).
   C. 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.

2.7 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 η = (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.

3 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

3.1 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].

3.2 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.

3.2.1 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.

3.2.2 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).
   A. 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.

A. 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.
   A. The study of motion and its relation to forces.
   B. In engineering, **dynamics** is sometimes referred to as the combination of <u>kinematics</u> and <u>kinetics</u> 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:

1. Continuum mechanics is the study of the physics of continuous materials, and can be subdivided into <u>solid mechanics</u> and <u>fluid mechanics</u>. 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.
   A. **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.
   B. **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.
   C. **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.
   D. **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).*

3.3 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.*

3.4 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 = ∫F • x
- W = F x d x cosΘ
- 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) • 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.*

3.4.1 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.

3.5 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:

5. Levers and linkages, which interface translational mechanical subsystems.
6. Gear sets, which interface rotational mechanical subsystems.
7. Belt drives, which interface rotational mechanical subsystems.
8. 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 produce mechanical power 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 absorb mechanical power 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 transmit mechanical power 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.*

3.6 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.

3.6.1 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.*

3.6.2 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.

3.6.3 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.
   A. 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.

A. 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.
B. 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.

3.6.4 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.
   A. 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.

3.6.5 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.

3.7 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
   A. Physical space requirement

3.8 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:
   A. The imbalanced system (spin alignment system)
   B. The induction expulsion system (catch and release)
   C. 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.
   A. 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.

4 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.
   A. Work occurs in a fluid system when a fixed volume of fluid V moves through a pressure difference (ΔP). If the pressure increases, ΔP 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, ΔP 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.
   A. Work occurs in a fluid system when fluid pressure p causes a given volume (ΔV) of liquids or gases to move. Here, ΔV can be positive or negative, but P is always positive. If the fluid volume increases, ΔV 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, ΔV 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.

4.1 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.

4.2 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

4.2.1 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.

4.3 Hydraulic non-electricity water-driven pump

The hydraulic ram is a mechanical pump uses gravity flowing water pressure to pump water. One of the most invaluable advantages of the hydraulic ram is that it can work reliably for decades and barely needs any maintenance. The hydraulic ram does not use electricity to pump water, and must be started with some amount pressure. The pump pumps water using only the pressure created by the falling water. The downsides of this system are that it can't pump large amounts of water and that the mechanism creates significant noise which must be attenuated with distance or shielding.

4.4 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.*

4.5 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:

1. 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.
2. 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).*

4.6 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).

4.7 Pneumatic energy "storage"

Pneumatic power (energy) may be "stored" in the following ways:

1. Storage Tanks
2. Tubing, Fittings & Valves
3. Compressor

5 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.

'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:

- $P(t) = I(t) \cdot V(t)$
- $P(t)$ 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:

- $P^{avg} = VI \cos\varphi$ = 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 = $P = |V|\ |I|\ \cos\varphi$
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 = $Q = |V|\ |I|\ \sin\varphi$
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.*

5.1 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:

1. Voltage is a measure of how much energy is delivered to charge.
2. Voltage isn't a property of electrons. However, in electronics, charge is generally carried by electrons.
3. Voltage unit is potential energy per change: V = potential energy / charge
4. 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.
5. 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.
6. 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.
7. 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.

8. 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 = ΔW / ΔQ
- 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).*

5.2 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.*

5.3 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).

5.3.1 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.

5.3.2 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 <u>purely resistive</u>, 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 <u>purely reactive</u>, 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. <u>Practical loads</u> 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.*

5.4 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 1.6×10^{-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: $V = \Delta W / \Delta Q$. 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").

5.5 *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.

5.5.1 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.

5.6 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.
   A. 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).
   A. 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.
   B. **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. A chemical reaction in a system directly create an electric potential and current.
   B. 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.
   A. Light (electromagnetic energy) contacting a system directly creates an electric potential and current.
   B. 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.
   A. Heat (thermal energy transfer) into a system directly creates electric potential and current.
   B. 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.
   A. Mechanical stress in a system directly creates electric potential and current.
   B. 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).
   A. 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?

5.6.1 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.

5.6.2 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. Gas can be turned on and off at will. Wind and solar are intermittent and require stationary battery storage facilities.

> **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.

5.6.3 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.

5.6.4 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.

5.6.5 Operating principles of electrical machines

The operation of electrical machines is explained by four general principles:

1. The electromagnetic action principle: An electrical current creates a surrounding magnetic field that is strengthened by passing through an iron core.
2. The motor action 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 generator action 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 transformer action 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).

5.6.6 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.
   A. Strator electrical element variations include:
      1. **Strator armature winding/coil** - generated current to load.
      2. **Strator field windings** (forming an electromagnetic electro motor) - AC or DC supplied.
      3. **Strator permanent magnets** (strator-PM motor) - magnets mounted to strator.
      4. 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:
      1. **Rotor armature winding/coil** - generated current to load.
      2. **Rotor field windings** (forming an electromagnetic electro motor) - AC or DC supplied.
      3. **Rotor winding as cage** (rotor cage) - windings are shorted.
      4. **Rotor permanent magnets** (rotor-PM motor) - magnets mounted to rotor.
      5. **Rotor-fed commutator.**
      6. **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).
2. The armature can be on either the rotor or the stator.
3. 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.
4. In a generator, the windings from which current is generated are called armature windings. All other windings therein are field windings.
5. The armature always carries current; hence, it is always a conductor or a conductive coil.
6. **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).
   A. 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.
   B. 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.

C. 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).

5.6.7 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.

A. *Rectifier AC -> DC*
B. 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).
C. **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*

A. To convert from AC to DC. An AC powered motor connected to a DC generator.
B. To modify DC voltage - DC at a fixed voltage to DC at a different voltage.
C. 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).*

5.6.8 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.

A. *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.

5.6.9 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:

1. **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.
   A. Single-ended single-phase system: 1 phase, 2 wire - one of the wires is for the power, and one wire is for neutral.
   B. 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.
2. **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.
   A. 2 phase, 4 wire - two separate pairs of current carrying conductor, and no neutral.
   B. 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.
   C. Note: Two-phase power can be derived from a three-phase source using two transformers in a Scott connection.
3. **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.

A. 3 phase, 4 wire - three wires for the power and one for neutral.
B. 3 phase, 4 wire Delta - three for the power and one for neutral.

5.6.10 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)

5.6.11 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.*

5.6.12 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.

5.7 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.

5.8 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.

5.8.1 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

5.8.2 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).

5.8.3 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).

5.8.4 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.

5.9 Localization of electrical power generation

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.
   A. 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).
   B. Batteries are not required for off grid systems, but their presence has [at least] three benefits:
   C. Storing energy for use when energy from the primary source is unavailable.
   D. As a buffer between an intermittent supply and varying/peak demand (a form of load demand management).
   E. 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.

A. 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.*

5.10 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.*

5.10.1 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.

5.10.2 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.

5.10.2.1 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.

5.10.2.2 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.

5.10.2.3 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.

5.10.2.4 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.

5.10.3 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.

6 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.

6.1 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).*

6.2 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.*

6.3 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:

6.3.1 Unintentional combustion

1. **Spontaneous combustion** - Combustion in which substances suddenly burst into flames, without the application of any apparent or intentional cause.

6.3.2 A type of combustion, but also, part of the definition of combustion

1. **Rapid combustion** - Combustion in which substances burn rapidly to produce heat and light. Combustion, itself, is generally defined as a rapid redox reaction.

6.3.3 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.

6.3.3.1 A combustion-related process, but technically not a type of combustion

Some combustion processes and combusting substances produce a flame (a.k.a., glowing). 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.

6.4 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.

6.5 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.*

6.5.1 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. Biomass can be combusted.
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 decompose 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.

6.5.2 Fuel storage and fuel transport

Fuel must be stored and transported for usage:

1. Solids will be stored in appropriate storage containers, ready for transport.
2. Gas and oils/liquids will be stored in appropriate storage containers. Liquids, oils, and gas can be transported as solid objects via vehicles in sealed containers, or they can be transported as fluids via pipes at different rates. Of note, oil can go through pipelines at room temperature a lot faster, because it is fluid, than coal can go through railroads.

6.5.3 Physical phases of fuel for combustion

Fuel can take any of three (more or less) phases of matter.

6.5.3.1 Gaseous fuel

A.k.a., Gaseous hydrocarbons.

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 (gaseous hydrocarbons) include:

1. **Natural gas** 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.

6.5.3.2 Liquid (and oil) fuels

A.k.a., Liquid hydrocarbons.

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 (liquid hydrocarbons) include:

1. **Crude oil** - 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.*

6.5.3.3 Solid fuel

A.k.a., Solid hydrocarbons.

Solid fuels (solid hydrocarbons) 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. **Preheating phase** - 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. **Distillation phase or gaseous phase** - 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.
   A. **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 anthracite 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)**: A carbonaceous solid delivered from oil refinery coker units or other cracking processes.

6.5.4 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_2O_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:

1. **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.
   A. **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.

6.5.5 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.

6.5.6 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.

6.6 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.

7 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'.*

7.1 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:

1. Land.
2. Ocean/marine.

In general, ocean energy can be sub-classified into six types of different origin and characteristics:

1. Ocean wave (wave).
2. Tidal range (tidal).
3. Tidal current (current).
4. Ocean current (current).
5. Ocean thermal energy (thermal).
6. 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.

7.1.1 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.

7.1.2 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.

7.1.3 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.

7.1.4 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. Sub-surface float - a float can be connected to the sea bed and move up and down with waves (generally the float rests below the water surface. The float moves up and down, which moves a turbine at the foot of the cable connected to the float.
   B. Surface float - a float can rest on the surface of the water and move up and down as waves move by. Hinged float movement is used to generate electricity.
   C. 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.
   D. Pneumatic systems in which the air displaced in the cylinder is used to power an air turbine which drives the generator.
   E. 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 power air compression power generation** - waves enter a conduit that becomes pressurized forcing air in and out, which moves a turbine.
7. **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.

8. **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.
9. **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.
10. **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.
11. **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.

7.1.5 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.

7.1.6 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.

7.2 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 (2020) 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.

8 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.

It is relevant to note here that wind energy is typically sub-classified into:

1. Off-shore wind - where there is generally more wind, but also the necessity for more materials.
2. On-shore wind - where there is generally less wind and less materials required.

8.1 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:

- $E = ½mv^2 = ½(Avtρ)v^2 = ½Atρv^3$
  - 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:
- $P = E/t = ½Atρv^3$
  - 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.

8.1 *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)

8.2 *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.
      1. 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.
      1. 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.
      2. 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.

8.2.1 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.

8.3 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.

8.3.1 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.

8.3.2 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.

8.3.2.1 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.

8.3.2.2 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