characteristics of a new wind farm is required to ensure predictable stable behaviour during system faults.

In concern to power generation per rotation speed (i.e., speed architecture), wind turbines can operate at either fixed or variable speeds:

1. **Fixed-speed turbine/generator** (FS architecture; FSG) - turbine speed is not adjustable as a function of wind speed; a fixed-rpm machine. These turbines have synchronous electric generators and operate on the grid's frequency. These machines are not the best solution for the wind turbines, because the wind always changes its speed. For fixed-rpm wind turbines, there is only one wind velocity on the turbine's power curve (power versus wind speed) at which the tip-speed ratio is optimum. Those turbines designed to operate at fixed speed (an FS architecture) generally have a gearbox in between the turbine's rotor and the shaft of the electric generator, and are connected directly to the grid as long as the wind speed is within operation limits. Constant speed using a synchronous generator (out-dated design). In other words, the generator expects a constant shaft speed. Fixed speed induction generators (FSIG) operate within a few percent of constant speed. When connected to an AC grid, fixed speed (FS) turbines use synchronous machines, and operate at an FS that depends on the grid's frequency. Early versions of the wind turbine were fixed speed turbines; that is, the rotor speed was a constant for all wind speeds.
2. **Variable-speed turbine/generator** (VS architecture; adjustable speed generator; ASG) - turbine speed is adjusted as a function of wind speed. These turbines can operate over a wide-range of speeds and usually have asynchronous generators. When the input power changes/ fluctuates (randomly), then the output voltage and frequency is variable. In variable-speed turbines have greater output efficiency over fixed-speed turbines. A wind turbine that can produce power over a continuous range of rotor speeds (varying wind supply) can be controlled to operate constantly at or near its optimum tip-speed ratio. All variable-speed turbines require power electronics to change varying AC power to a constant voltage and frequency. Electrical distribution grids (to which a wind turbine may be connected) must maintain steady frequency and voltage levels to avoid damaging demand-side equipment of other users on the same network. Electrical harmonics are also a critical issue for any variable-speed design. Harmonics distort the normally smooth sinusoidal variation of a grid's voltage.
3. Since the input voltage and input frequency are variable, this variable AC magnitude and frequency must be converted to constant frequency AC.
    A. A variable-speed system may base its variability on generator speed variability and/ or mechanical speed variability. Variable-speed generator methods/architectures are based on allowing the speed of the generator to vary as the supplied [wind] energy varies. Variable-speed mechanical methods are based on the use of continuously variable-speed mechanical or hydraulic drives, which allow the rotor rpm to vary while maintaining a constant generator speed. By using power electronics and controllers, AC can be converted to DC and then back to AC (AC>DC>AC) to produce a reliable and steady frequency, instead of a just outputting varying AC voltages and frequencies ("wild AC"). In other words, the "wild" AC is rectified into a steady direct current, which is then inverted to grid-grade alternating current of constant voltage and frequency. Variable-speed operation was accomplished with a current source-load commutated inverter, also known as a DC current link frequency converter. This provided AC-DC-AC conversion These power control elements can be located within the turbine itself, or located at some distance away from the turbine where its output connects to an electrical circuit/grid.
    B. Synchronous generator with in-line frequency control - the rotor and turbine can be run at a variable speed corresponding to the prevailing wind conditions. This will produce a varying frequency output from the generator synchronised with the drive shaft rotation speed. This output can then be rectified in the generator side of an AC-DC-AC converter and the converted back to AC in an inverter in grid side of the converter which is synchronised with the grid frequency.
    C. Doubly fed induction generator (DFIG) - the DFIG system consists of a 3 phase wound rotor generator with its stator windings fed from the grid and its rotor windings fed via a back to back converter system in a bidirectional feedback loop taking power either from the grid to the generator or from the generator to the grid. The doubly fed induction generator design means that the electronic control circuits and frequency converter do not have to be dimensioned to carry the full generator power.

D. Variable speed turbines use DC machines, brushless DC (BLDC) machines, and induction machines. DC machines are not commonly used due to the maintenance problems with the brushes.
E. AC regulation by the control system: The control system regulates the speed of the blades, and hence torque of the shaft, in an effort to match the electrical networks required parameters. This may be done by changing the pitch of the blade tips.
F. Generator operating principle: The feedback control system monitors the stator output voltage and frequency and provides error signals if these are different from the grid standards. The frequency error is equal to the generator slip frequency and is equivalent to the difference between the synchronous speed and the actual shaft speed of the machine.
G. Grid Side Converter (GSC): Carries current at the grid frequency.
H. Machine Side Converter (MSC): Carries current at slip frequency. It is a DC to AC inverter used to provide variable AC voltage and frequency to the rotor to control torque and speed.

NOTE: *The output of a variable-speed turbine with no frequency/voltage output controls is known as "***wild AC***", because it varies with the variability of the "wild" primary energy source.*

A typical fixed speed system employs a rotor with three variable pitch blades (generally), which are controlled automatically to maintain a fixed rotation speed for any wind speed. The rotor drives a synchronous generator through a gear box, and the whole assembly is housed in a nacelle on top of a substantial tower with massive foundations requiring hundreds of cubic metres of reinforced concrete. Fixed speed systems may suffer excessive mechanical stresses, because they are required to maintain a fixed speed regardless of the wind speed. There is no "give" in the mechanism to absorb gusty wind forces, resulting in high torque, high stresses and excessive wear on the gear box, increasing maintenance requirements and reducing service life.

Variable speed wind turbines can capture more of the wind's energy than constant speed machines; they can speed up and slow down per wind conditions, and the electronic control systems will keep the generator's output frequency constant during fluctuating wind conditions. For variable speed wind turbines, one of two types of generators can be used: a DFIG (doubly fed induction generator) or an FRC (fully rated converter). For variable speed wind turbines, one of two types of generators can be used: a DFIG (doubly fed induction generator) or an FRC (fully rated converter).

A DFIG generator draws reactive power from the electrical network; this can increase the vulnerability of a transmission system in the event of a failure. A DFIG configuration will require the generator to be a wound rotor; squirrel cage rotors cannot be used for such a configuration.

Consider a variable speed wind turbine with a permanent magnet synchronous generator. The generator produces AC electricity. The frequency of the AC voltage generated by the wind turbine is a function of the speed of the rotor within the generator:

- N = 120f/P
- where, N is the rotor speed, P is the number of poles in the generator, and f is the frequency of the output Voltage. That is, as the wind speed varies, the rotor speed varies, and so the frequency of the Voltage varies. This form of electricity cannot be directly connected to an AC balanced transmission system. Instead, its AC electrical output must be corrected such that its frequency is constant. For this, power converters are employed, which results in the de-coupling of the wind turbine from the transmission system. As more wind turbines are included in a national power system, the "inertia" of the transmission system is decreased. This means that the frequency of the transmission system is more strongly affected by the loss of a single generating unit.

The voltage generated by a variable speed wind turbine is non-grid compliant (AC grid). In order to supply the transmission network with power from these turbines, the signal must be passed through a power converter, which ensures that the frequency of the voltage of the electricity being generated by the wind turbine is the frequency of the transmission system when it is transferred onto the transmission system. Power converters first convert the signal to DC, and then convert the DC signal to an AC signal.

NOTE: *All wind turbines that generated electricity were variable speed before 1939. All grid-connected wind turbines, from the first one in 1939 until the development of variable-speed grid-connected wind turbines in the 1970s, were fixed-speed wind turbines. As of 2003, nearly all grid-connected wind turbines operate at exactly constant speed (synchronous generators) or within a few percent of constant speed (induction generators). (Bassyouni, 2013)*

8.3.2.3 Wind turbine aerodynamics

Wind powered devices are designed [in part] for their aerodynamic characteristics. Aerodynamics the study of the properties of moving air, and the movement of substances and system moving through air -- the interaction between the air and solid bodies moving through it. As the wind blows, an aerodynamic force produces a torque that is transmitted through the drive-train to the generator.

The aerodynamic efficiency of a wind turbine depends on the wind's characteristics and the design of the wind turbine itself:

1. Design of the airfoils (blades) - The aerodynamics of the blades/airfoils (wing-shaped) include: chord length; blade shape; blade mount position/angle - angle of attack; blade dimensions; and revolutions per minute (rpm). Note that aerodynamic torque [from wind] is "captured" by the blades. The design of the airfoil and its angle of attack are critical to the power-producing capacity of the rotor. Each airfoil/blade has an optimum angle of attack to produce an optimum lift-to-drag ratio (the point at which the airfoil will have its optimum performance).
2. Design of the system's other structural components: rotor hub (if there is one), nacelle, tower structure, and foundation.

In addition to aerodynamic design of the blades, the design of a complete wind power system must also address the design of the hub, controls, generator, supporting structure and foundation. Further design questions arise when integrating wind turbines into electrical power grids.

> **NOTE:** *It is generally understood that noise increases with higher blade tip speeds.*

8.3.2.4 Wind turbine blades/airfoils

The number of blades in the turbine's rotor, their aerodynamic design, and the rotor's rotational speed must be optimised to extract the maximum amount of power (energy) from the available wind. While using rotors with multiple blades may capture more wind energy, there is a practical limit to the number of blades that can be used, because each blade of a spinning rotor leaves turbulence in its wake and reduces the amount of power the following [rotational] blade can extract from the wind. This same turbulence effect also limits the possible rotor speed, because a high speed rotor does not provide enough time for the air flow to settle after the passage of a blade before the next blade comes along.

There is a lower limit to both the number of blades and the rotor speed for the turbine to function. With too few rotor blades, or a slow turning rotor, most of the wind will pass undisturbed through the gap between the blades reducing the potential for capturing the wind energy. The fewer the number of blades, the faster the wind turbine rotor needs to turn to extract maximum power from the wind.

The ratio between the speed of the blade tips and the speed of the wind is called **tip-speed ratio (TSR)**. In part, tip-speed ratio is a concept used by wind turbine designers to optimise a blade set to the shaft speed required by a particular electricity generator to generate maximum energy output from the available wind. It is also one way of comparing performance between variable- and constant-speed turbine operation.

Tip-speed-ratio is generally plotted on a two dimensional graph with wind speed (m/s) as the x axis, and rotor speed (rpm) as the y axis.

Operating closer to their optimal tip speed ratio during energetic gusts of wind allows wind turbines to improve energy capture from sudden gusts (typical in urban settings).

The tip-speed-ratio for a wind turbine is given by the following formula (λ, lambda = TSR):

- $\lambda = \omega R/v$ (sometimes written as $TSR=\Omega R/V$)
    - Where, ω is the rotor speed (i.e., the angular velocity of the rotor; in radians per second), R is the length of a blade (the distance between the axis of rotation and the tip of the blade), and v is the wind speed.
- For a fixed-speed wind turbine, the value of the tip-speed ratio is only changed by wind speed variations. In reference to a C_p-λ graph (the power coefficient versus tip-speed ratio C_p vs λ curve), illustrates the relationship between tip-speed ratio and efficiency, it is evident that only one value of λ yields the highest efficiency. C_p is the power co-efficient. That is, the fixed speed wind turbine is not operating at peak efficiency across a range of wind speeds.

The tangential velocity S of any blade section at a distance r from the centre of rotation (the root of the blade) is given by:

1. $S = r\,\Omega$
2. Where, Ω is the angular velocity of rotation in radians.

Larger rotor blades are useful for maximizing air stream conversion to mechanical energy. Unfortunately, larger blades (in high wind conditions) lead to very high tip speeds. And, higher tip speeds equate to higher (possibly unacceptable) noise levels. Hence, depending upon the surrounding environment smaller blades/turbines may be necessary to reduce noise levels to a sufficiently safe (and non-polluting/non-disturbing) level.

Additionally, system reliability is affected by blade count and weight through the dynamic loading of the rotor within the drive train and tower systems. While aligning the wind turbine to changes in wind direction (yawing), each blade experiences a cyclic load at its root end depending on blade position. This is true of one, two, three blades or more. When these loads are symmetrical, the turbine with yaw more smoothly during operation. Turbines with one or two blades can use a pivoting teetered hub to also nearly eliminate the cyclic loads into the drive shaft and system during yawing.

> **NOTE:** *High capacity wind turbines, such as those used by the electricity utilities in the electricity grid, typically have blades with a cross section similar to the aerofoils used to provide the lift in aircraft wings.*

In general, ideal materials for blades should meet the following criteria:

1. Low weight or density to reduce gravitational forces.
2. High [tensile] strength to withstand strong loading of wind and gravitational force of the blade itself.
3. High fatigue resistance to withstand cyclic loading.
4. High stiffness to ensure stability of the optimal shape and orientation of the blade and clearance with the tower.
5. High fracture toughness.
6. The ability to withstand environmental impacts such as lightning strikes, humidity, and temperature.

Today, wind turbine blades are mainly made of composite, materials including: polyester resin, vinyl resin, epoxy thermosetting matrix resin, E-glass fibers, S-glass fibers, and carbon fiber reinforced materials. Construction may use manual layup techniques or composite resin injection molding. The majority of current commercialized wind turbine blades are made from fiber-reinforced polymers (FRP's), which are composites consisting of a polymer matrix and fibers. The long fibers provide longitudinal stiffness and strength, and the matrix provides fracture toughness, delamination strength, out-of-plane strength, and stiffness. Material indices based on maximizing power efficiency, and having high fracture toughness, fatigue resistance, and thermal stability, have been shown to be highest for glass and carbon fiber reinforced plastics (GFRP's and CFRPs). (Griffin, 2003)

Use of aluminum and composite materials in their blades has contributed to low rotational inertia, which means that newer wind turbines can accelerate quickly if the winds pick up, keeping the tip speed ratio more nearly constant.

Manufacturing blades in the 40 to 50 metre range involves fibreglass composite fabrication techniques. There are a variety of applied variations on this technique, some including carbon and wood with fibreglass in an epoxy matrix. Other options include pre-impregnated ("prepreg") fibreglass and vacuum-assisted resin transfer molding. Each of these options use a glass-fibre reinforced polymer composite constructed with differing complexity. Perhaps the largest issue with more simplistic, open-mould, wet systems are the emissions associated with the volatile organics released. Pre-impregnated materials and resin infusion techniques avoid the release of volatiles by containing all VOC's. However, these contained processes have their own challenges, namely the production of thick laminates necessary for structural components becomes more difficult. As the preform resin permeability dictates the maximum laminate thickness, bleeding is required to eliminate voids and ensure proper resin distribution.

> **NOTE:** *The transportation of long blades and towers to their final placement may require unconventional transportation methods due to their significant length.*

8.3.2.5 Wind turbine control systems

The control system of a wind turbine allows for programmed adjustment of the system (mechanically and/or electrically) for maximum, or less than maximum, power output. Wind turbines designed for maximum power output (i.e., maximum power point tracking) attempt to pull the maximum possible electrical power from a given turbine under the current wind conditions. However, wind turbines control systems can also be designed to deliberately pull less electrical power than they possibly could in most circumstances, in order to provide other benefits, which include:

1. Spinning reserves to quickly produce more power when needed—such as when some other generator suddenly drops from the grid—up to the max power supported by the current wind conditions.
2. Variable-speed wind turbines can (very briefly) produce more power than the current wind conditions can support, by storing some wind energy as kinetic energy (accelerating during brief gusts of faster wind) and later converting that kinetic energy to electric energy (decelerating, either when more power is needed elsewhere, or during short lulls in the wind, or both).
3. Damping (electrical) subsynchronous resonances in the grid.
4. Damping (mechanical) resonances in the tower.

In wind turbines with a nacelle, the nacelle houses the gearbox and generator connecting the tower and rotor. Sensors detect the wind speed and direction, and motors turn the nacelle into the wind to maximize output. In conventional wind turbines, the blades spin a shaft that is connected through a gearbox to the generator. When present, a gearbox is inserted between the rotor hub and the generator. The gearbox increases the generator's incoming shaft rotations per minute. The presence of a gearbox may allow a reduction in the generators weight. In gearless wind turbines (also called 'direct drive turbines') the rotor shaft is attached directly to the generator, which spins at the same speed as the blades.

Wind turbines without gearboxes are called direct-drive wind turbines. An advantage of a gearbox is that generators are typically designed to have the rotor rotating at a high speed within the stator. Direct drive wind turbines do not exhibit this feature.

> **NOTE:** *Older style wind turbines rotated at a constant speed, to match power line frequency, which allowed the use of less costly induction generators[citation needed]. Newer wind turbines often turn at whatever speed generates electricity most efficiently. The varying output frequency and voltage can be matched to the fixed values of a power network (the "grid") using multiple technologies (e.g., doubly fed induction generators or full-effect converters) where the variable frequency current produced is converted to DC and then back to AC.*

The speed at which a wind turbine rotates must be controlled for efficient power generation and to keep the turbine components within designed speed and torque limits. The centrifugal force on the spinning blades increases as the square of the rotation speed, which makes this structure sensitive to overspeed. If the rated wind speed is exceeded the power has to be limited via a control system. A control system involves three basic elements: sensors to measure process variables, actuators to manipulate energy capture and component loading, and control algorithms to coordinate the actuators based on information gathered by the sensors.

> **NOTE:** *Wind powered devices often include an anemometer for measuring wind speed and direction (a common weather station instrument).*

Methods of control for dumping power include (because of a rapid increase in the velocity of the wind):

1. Change aerodynamic efficiency.
   A. Variable pitch, feather or stall.
   B. Operate at constant rpm.
   C. Spoilers.
2. Change intercept area.
   A. Yaw rotor out of wind.
   B. Change rotor geometry.
3. Brake.
   A. Mechanical, hydraulic.
   B. Air brake.
   C. Electrical (resistance, magnetic).

8.3.2.6 Wind turbine pitch control

Active pitch control, where the blades are twisted from the hub. The pitch angle of turbine blades can be changed to control for speed (blade control):

1. Stalling works by increasing the angle at which the relative wind strikes the blades (angle of attack), and it reduces the induced drag (drag associated with lift). Stalling is simple because it can be made to happen passively (it increases automatically when the winds speed up), but it increases the cross-section of the blade face-on to the wind, and thus the ordinary drag. A fully stalled turbine blade, when stopped, has the flat side of the blade facing directly into the wind.
2. Furling works by decreasing the angle of attack, which reduces the induced drag from the lift of the rotor, as well as the cross-section. One major problem in designing wind turbines is getting the blades to stall or furl quickly enough should a gust of wind cause sudden acceleration. A fully furled turbine blade, when stopped, has the edge of the blade facing into the wind. Since furling requires acting against the torque on the blade, it requires some form of pitch angle control, which is achieved with a slewing drive.
3. Some blades are designed to automatically increase their angle of attack at higher wind speed, as the blades speed up.

Modern large wind turbines are variable-speed machines. When the wind speed is below rated, generator torque is used to control the rotor speed in order to capture as much power as possible. Applied generator torque controls the rotor speed.

> **NOTE:** *All turbines are equipped with protective features to avoid damage at high wind speeds, by feathering the blades into the wind which ceases their rotation, supplemented by brakes.*

There are three ways of braking (slowing) the rotation of a turbine: aerodynamic stalling or furling, electrical breaking (electromagnetic breaking), and/or mechanical breaking. In concern to electrical breaking, the braking of a small wind turbine can be done by dumping energy from the generator into a resistor bank, converting the kinetic energy of the turbine rotation into heat. This method is useful if the kinetic load on the generator is suddenly reduced or is too small to keep the turbine speed within its allowed limit. Doing this process cyclically (i.e., cyclically braking) causes the blades to slow down, which increases the stalling effect, reducing the efficiency of the blades. This way, the turbine's rotation can be kept at a safe speed in faster winds while maintaining (nominal) power output. In concern to mechanical breaking, a mechanical drum brake or disk brake is used to stop turbine in emergency situation such as extreme gust events or over speed. This brake is a secondary means to hold the turbine at rest for maintenance, with a rotor lock system as primary means. Such brakes are usually applied only after blade furling and electromagnetic braking have reduced the turbine speed generally 1 or 2 rotor RPM, as the mechanical brakes can create a fire inside the nacelle if used to stop the turbine from full speed. The load on the turbine increases if the brake is applied at rated RPM. Mechanical brakes are driven by hydraulic systems and are connected to main control box.

8.3.2.7 Wind turbine yaw control

Wind devices that operate with their blades or sales pointing into the wind require a control systems for reorienting their blades/sales into the wind as the wind direction changes (typically, horizontal axis wind turbines). In general, only the yaw axis is used for this type of reorientation (although, the blades themselves may also have secondary re-orientational capabilities). Hence, the 'yaw system' of wind turbines is the component responsible for the orientation of the wind turbine rotor into the wind.

By minimizing the yaw angle (the misalignment between wind and turbine pointing direction), the power output is maximized and non-symmetrical loads minimized. However, since the wind direction varies quickly the turbine will not strictly follow the direction and will have a small yaw angle on average. The power output losses can simply be approximated to fall with $(\cos(\text{yaw angle}))^3$. Particularly at low-to-medium wind speeds, yawing can make a significant reduction in turbine output, with wind direction variations of ±30° being quite common and long response times of the turbines to changes in wind direction. At high wind speeds, the wind direction is less variable.

There are two types of yaw system:

1. Passive yaw (self-orientation)
2. Active yaw (automatic mechanical orientation)

Both passive and active systems require a yaw bearing, which allows for a horizontal rotation of the turbine element itself. In active systems, in order to stabilize the yaw bearing against rotation a means of braking is necessary. Active systems involve yaw drives (consisting of an electric motor and gearbox), and passive systems involve a yaw vane.

Passive yaw systems utilize the wind's force itself in order to adjust the orientation of the wind turbine rotor into the wind. In their simplest form these system comprise a roller bearing connection between the tower and the nacelle and a tail fin (yaw vane) mounted on the nacelle, designed in such a way that it turns the wind turbine rotor into the wind by exerting a "corrective" torque to the nacelle. Therefore, the power of the wind is responsible for the rotor rotation and the nacelle orientation. The tail fin (or yaw vane) is commonly used for small wind turbines since it offers a low cost and reliable solution. It is however unable to cope with the high moments required to yaw the nacelle of a large wind turbine.

Alternatively in case of downwind turbines, the tail fin is not necessary since the rotor itself is able to yaw the nacelle into the wind.

Passive yaw systems have to be designed in a way that the nacelle does not follow the sudden changes in wind direction with too fast a yaw movement, in order to avoid high gyroscopic loads. Additionally the passive yaw systems with low yaw-friction are subjected to strong dynamic loads due to the periodic low amplitude yawing caused by the variation of the inertia moment during the rotor rotation. This effect becomes more severe with the reduction of the number of blades.

Active yaw systems use a torque producing device for rotating the nacelle of the wind turbine against the stationary tower, based on automatic signals from wind direction sensors or manual actuation (control system override). The design of an active yaw system varies depending on the design characteristics of the wind device; however, all active yaw systems include: a rotatable connection between nacelle and tower (yaw bearing); an active variation of the rotor orientation (i.e. yaw drive); a means of restricting the rotation of the nacelle (yaw brake) and a control system which processes the signals from wind direction sensors (e.g. wind vanes) and gives the proper commands to the actuating mechanisms.

Modern large wind turbines are typically actively controlled to face the wind direction measured by a wind vane situated on the back of the nacelle. This process is known as yawing.

8.3.2.8 Wind turbine design limits

For safety and efficiency reasons wind turbines are subject to operating limits depending on the wind conditions and the system design.

1. **Cut-in Wind Speed:** This is the minimum wind velocity below which no useful power output can be produced from wind turbine, typically between 3 and 4 m/s (10 and 14 km/h, 7 and 9 mph).
2. **Rated Wind Speed** (also associated with the Nameplate Capacity): This is the lowest wind velocity at which the turbine develops its full power. This corresponds to the maximum, safe electrical generating capacity which the associated electrical generator can handle, in other words the generator's rated electrical power output. The rated wind speed is typically about 15 m/s (54 km/h, 34 mph) which is about double the expected average speed of the wind. To keep the turbine operating with wind speeds above the rated wind speed, control systems may be used to vary the pitch of the turbine blades, reducing the rotation speed of the rotor and thus limiting the mechanical power applied to the generator so that the electrical output remains constant. Though the turbine works with winds speeds right up to the cut-out wind speed, its efficiency is automatically reduced at speeds above the rated speed so that it captures less of the available wind energy in order to protect the generator. While it would be possible to use larger generators to extract full power from the

wind at speeds over the rated wind speed, this would not normally be economical because of the lower frequency of occurrence of wind speeds above the rated wind speed.

3. **Cut-out Wind Speed:** This is the maximum safe working wind speed and the speed at which the wind turbine is designed to be shut down by applying brakes to prevent damage to the system. In addition to electrical or mechanical brakes, the turbine may be slowed down by stalling or furling.
   A. Stalling: This is a self correcting or passive strategy which can be used with fixed speed wind turbines. As the wind speed increases so does the wind angle of attack until it reaches its stalling angle at which point the "lift" force turning the blade is destroyed. However increasing the angle of attack also increases the effective cross section of the blade face-on to the wind, and thus the direct wind force and the associated stress on the blades. A fully stalled turbine blade, when stopped, has the flat side of the blade facing directly into the wind.
   B. **Furling or Feathering:** This is a technique derived from sailing in which the pitch control of the blades is used to decrease the angle of attack which in turn reduces the "lift" on the blades as well as the effective cross section of the aerofoil facing into the wind. A fully furled turbine blade, when stopped, has the edge of the blade facing into the wind reducing the wind force and stresses on the blade.
   The cut-out speed is specified to be as high possible consistent with safety requirements and practicality in order to capture as much as possible of the available wind energy over the full spectrum of expected wind speeds (See diagram of Wind Speed Distribution below). A cut-out speed of 25 m/s (90 km/h, 56 mph) is typical for very large turbines.
4. **Survival Wind Speed:** This is the maximum wind speed that a given wind turbine is designed to withstand above which it can not survive. The survival speed of commercial wind turbines is in the range of 50 m/s (180 km/h, 112 mph) to 72 m/s (259 km/h, 161 mph). The most common survival speed is 60 m/s (216 km/h, 134 mph). The safe survival speed depends on local wind conditions is usually regulated by national safety standards.

8.3.2.9 Wind turbine monitoring

Wind turbines must be monitored for their structural health/safety and performance, which requires data transmission. Structural monitoring is usually done through accelerometers and strain gages attached to the nacelle to monitor the gearbox and other equipment. Digital image correlation and stereophotogrammetry are used to measure dynamics of wind turbine blades. These methods usually measure displacement and strain to identify locations of defects. Dynamic characteristics of non-rotating wind turbines have been measured using digital image correlation and photogrammetry. Three dimensional point tracking has also been used to measure rotating dynamics of wind turbines

Wind turbines require regular maintenance to stay operable (operability - reliable and available). Modern turbines usually have a small onboard crane for hoisting maintenance tools and minor components. However, large heavy components like generator, gearbox, blades and so on are rarely replaced and a heavy lift external crane is needed in those cases. If the turbine has a difficult access road, a containerized crane can be lifted up by the internal crane to provide heavier lifting. Wind turbines can be "repowered", meaning that instead of installing new turbines, an existing turbine is replaced with a larger and more powerful one.

A major cause of wind turbine failure is the accumulation of fatigue damage from turbine rotor fatigue loads (i.e., rapid changes in rotor torque due to wind gusts producing load spikes).

8.3.3 Wind power type: Sail power

A sail is means for redirecting the power of the wind to propel a craft on water, ice, or land. Hence, sails provide mechanical propulsion power to a traveling craft/platform. In doing so, sails behave aerodynamically like wings, generating high and low pressure on either side of the sail, and hence, craft. Therein, the sails mobilize lift aerodynamics (as air passes along the surfaces), and they mobilize drag aerodynamics to the degree that air is directed at the surface. When both lift and drag are present, a sail will function similarly to a wing in a vertical orientation. Lift aerodynamics refers to the air moving faster and having a longer way to travel along the outside curve of the sail, and a slower, shorter travel along the inner curve.

In most cases sails are supported by a mast rigidly attached to the sailing craft, however some craft employ a flexible mount for a mast. Sails also employ spars and battens to determine shape in the axis perpendicular to the mast. As a result, sails come in a variety of shapes that include both triangular and quadrilateral configurations, usually with curved edges that promote curvature of the sail.

Sails propel the craft in one of two ways. When the craft is going in the direction of the wind (i.e., downwind), the sails may be set merely to trap the air as it flows by. Sails acting in this way are aerodynamically stalled. Drag, which is always parallel to the wind, contributes the predominant driving force. The other way sails propel the craft occurs when the craft is traveling across or into the wind. The sails acting as airfoils propel the craft by redirecting the wind coming in from the side towards the rear. By the law of conservation of momentum, the wind moves the sail as the sail redirects downwash air backwards. Air pressure differences across the sail area result in forces on sails including drag and lift. A component of the lift is the main driving force.

8.3.4 Wind power type: Airborne wind power

Airborne wind power (i.e., kite power; also known as airborne wind energy, AWE; tethered aircraft wind power) involves the use of kites and wind to generate mechanical and/or electrical power. The kites themselves may or may not be inflatable, and if inflated, they may be inflated with air, or a gas lighter than air. Often the kites are similar to those used in recreational kite surfing and parasailing. They are lightweight structures that can dynamically change with wind direction and altitude.

Airborne wind power systems have several advantages over conventional ground-based wind systems. The first advantage is that airborne wind power density steadily increases with altitude. This is important because not only does it mean that more power can be generated, than would be generated with a conventional ground-level turbine, but that increase in power will not require an increase in size of the airborne structure. Often, geographic locations that are not suitable for conventional wind farms at surface level have ample wind speeds at higher altitudes. Secondly, airborne wind power systems are often less complex and require fewer materials. Most ground-based wind turbines require massive structural foundations in order to support the large blades, while also requiring significant transportation tasks to move the systems into place (i.e.,, each blade must be transported separately, and typically requires unconventional transportation methods due to its size). Further, ground-based wind turbines take-up land area and output polluting acoustics. When airborne, these systems take-up minimal land area, and their acoustic pollution has little affect on the ground. Some airborne are highly portable.

> **NOTE:** *Airborne power generation platforms can double as platforms for instrumentation and/or communication.*

There are two primary types of airborne wind power system:

1. **Kite propulsion systems** - Kites propulsion systems are similar to sails in that they capture the wind with a concave surface, except they are airborne.
2. **Airborne wind power (non-propulsion) systems** (airborne aerofoil-powered system) - kites/aircraft that produce mechanical and/or electrical power.
   A. **Ground-gen** - Systems that generate the electric power on the ground.
   B. **Fly-gen** - Systems that generate the electric power in the airborne/flying part.

Due to their significant elevation above ground level (and ground-based wind power systems) airborne machines come into contact with the more consistent and stronger wind resource at altitude. At 2,000 feet wind speeds above 8 m/s are blowing more than 40 percent of the time at most locations in the northern hemisphere. Furthermore, power densities (kW/m2) are on par with the world's most favorable sites for ground-based wind. Although boundary layer winds provide reasonable power densities, the jet stream winds of the troposphere at ~10km, where average power densities soar beyond 20 kW/m2 and the total available resource is measured in thousands of terawatts (TW), hundreds of times higher than world energy demand.

Every airborne wind power system has three parts:

1. A grounded part
2. An airborne/flying part
3. A connection between the two primary parts - a tethering cable. The tether allows the airborne structure's altitude to be adjusted and periodically brought back to the ground. In addition, depending on the design of the system, the tethering cable can also serve a conduit or conductive wire that connects the system's electrical components to surface electrical components and/or the electrical power grid. In order to counteract the kite moving sporadically, sometimes two tethers are placed on opposite ends of the kite/aircraft, which work to control the kite's position and keep it positioned correctly.

There are three surfaces that the airborne wind power system may be tethered (i.e., connected) to:

1. Land
2. Stationary structure (e.g., building)
3. Moving structure (e.g., boat)

8.3.4.1 Kite propulsion systems

Kite propulsion systems use wind power (energy) to propel (or aid in propelling) a transportation platform (e.g., ship). These wind power systems use large foil kites, similar to those used in kitesurfing. Kite propulsion systems are similar to sails, except the sail is airborne. These kites are supported and controlled by lines that lead from the kite to the transportation platform.

8.3.4.2 Airborne wind power (non-propulsion) systems

In ground-gen systems, the electrical power of the system is produced by a generator on the ground. The generator on the ground is powered by the mechanical power generated by the wind moving the airborne aircraft/kite. The aircraft's mechanical motion is transferred by the tether to the ground. Generally, this system consists of a turbine positioned within a kite/aircraft, placed in the atmosphere, with the turbine therein is spinning horizontally (instead of vertically). Although the ground-gen systems can stand alone, it is possible to connect multiple aircraft and tethers to a single ground-based generator to maximize output.

In fly-gen systems, the electrical generator is located in the airborne/flying part of the system. In fly-gen systems, the tether contains the conductive, insulated cables that run from the generator in the atmosphere to the ground. Unlike ground-gen systems, fly-gen systems do not use the wind to move the aircraft and generate mechanical power that is transferred to the ground. Instead, airfoils (e.g., propellers) are mounted onto the aircraft/kite and generate electrical power by the wind moving past their position. Fly-gen systems can be designed to use their rotors as propellers to thrust the aircraft into the sky, using the generators onboard in "reverse", as engines. Once at the proper altitude, the rotors stop propelling, and allow the aircraft to flow with the wind like a kite, relying on the aircrafts aerodynamics and the wind (i.e., air lift) to keep it afloat. Once at a sufficient altitude, air flow forces the rotors, causing them to spin in the opposite direction, and generate electricity. The electricity is conducted down the tether and into an electrical network. The rotor's controls can be operated from the ground either manually or with an automated system that can adjust the aircraft's flight path according to wind conditions. When it is time to land the aircraft, the rotors can take over as propellers once again and guide the gliding aircraft to the ground with power (i.e., "under control with engine power").

8.3.4.3 Issues with airborne wind power

There are limitations and/or other issues and concerns with airbone wind power systems. Firstly, areas where these airborne wind power platforms are flying are considered no-fly zones, in order to avoid accidents (i.e., air traffic must be re-routed around them). Secondly, weather conditions can be an issue. Depending the operational weather parameters for the system, inclement weather may preclude its airborne functioning, and require its retraction from the atmosphere. During lightning, hail storms, or tornado-strength winds, airborne wind systems must be landed. Icing on the wings will also affect the aircraft performance. Further, without proper monitoring and adhering to safe operation parameters, these systems could break free from their tethering cable, causing them to crash land or cause air accidents, and/or additional air traffic re-routing.

8.3.5 Wind power type: Magnus power effect

The Magnus effect is the commonly observed effect in which a spinning ball (or cylinder) curves away from its principal flight path. The effect involves a force acting on a spinning body in a moving airstream, which acts perpendicularly to the direction of the airstream. The effect can be used to generate propulsion. A "rotor ship", or Flettner ship, is a type of ship designed to use the Magnus effect for propulsion. Rotor ships typically use rotor sails powered by a motor to take advantage of the effect.

8.4 Environmental impact of wind power

The environmental impact of wind power, when compared to the environmental impact of fossil fuels (and other energy sources), is relatively minor. Environmental issues include, but are not limited to:

1. Ecological disturbances - primarily, bird strikes.
2. Noise emission - Some turbines emit low frequency acoustics, which distress complex organisms. Noise emissions are affected by the systems aerodynamics, the location of the blades upwind or downwind of the tower, and the speed of the rotor. Given that the noise emissions from the blades' trailing edges and tips vary by the 5th power of blade speed, a small increase in tip speed can make a large difference in the noise produced.
3. Fires - are particularly dangerous due to the material composition of the blades, and their rotation.
4. Electromagnetic interference - the design of the rotating element can interfere with radar and other electromagnetic transmitting and receiving systems.

9 Solar power

A.k.a., Sun power, solar electromagnetic power.

The sun's energy is the primary source of energy for all surface phenomena and life on Earth. Electromagnetic power (energy) from the sun comes to Earth in the form of radiation. The term 'radiation' denotes the fact that the energy travels as rays, that is, in relatively straight lines. In general, the terms 'solar power/energy' and 'solar radiation' refer to energy from a star (i.e., a sun). The Sun radiates electromagnetic power (energy) "equally" in all directions, and the Earth receives part of this energy. However, because the earth revolves around itself (and the sun), any point on the earth will only receive sunlight periodically (cyclically as a day/night cycle); thus, solar power is directly effective during sunlight (daylight) hours only (although residual heating effects exist). Atmospheric conditions also affect the amount and quality of light reaching the Earth's surface at any given sunlight time.

NOTE: *Solar power is only available during sufficient sunlight conditions.*

The range of electromagnetic power (energy) emitted by the sun is known as the 'solar spectrum', and lies mainly in three regions: ultraviolet, visible, and infrared (of which there are multiple bands of infrared). Therein, the solar spectrum extends from about 0.29 μm (or 290 nm) in the shorter wavelengths of the ultraviolet region, to over 3.2 μm (3,200 nm) in the far infrared. Small amounts of radio waves are also given off by the sun and other stars.

Electromagnetic energy can be discussed in terms of its 'energy distribution' - the spread of energy over a range of wavelengths. This distribution of energy is also known as the 'spectral distribution'. Therein, the measure of radiation may be quantified in terms of the amount of energy falling per second (measured in Watts) per unit area (in square meters, m^2) in each band of 1 μm (1000nm) wavelength.

It is often said that the sun radiates electromagnetic and thermal energy. However, this is not technically correct, because that which is called "thermal radiation" is in fact 'electromagnetic radiation'. Take note here that 'thermal radiation' is 'electromagnetic radiation' generated by the thermal motion of charged particles in matter (i.e., due to the temperature of matter), and when that electromagnetic radiation from those charged particles comes into contact with matter, it will transfer energy (through heating), and raise its internal temperature. Hence, the term 'thermal radiation' describes the source of the radiation and implies that when that radiation contacts matter after its release/generation, that it will likely heat the matter. All matter with a temperature greater than absolute zero emits thermal [electromagnetic] radiation. When the temperature of a body is greater than absolute zero, inter-atomic collisions cause the kinetic energy of the atoms or molecules to change. This results in charge-acceleration and/or dipole oscillation, which produces electromagnetic radiation (i.e., thermal radiation"). The spectrum distribution of EM radiation will reflect the spectrum of accelerations and oscillations that occurred to release that radiation. Herein, the "emissivity" of the surface of a material is its effectiveness in emitting energy as thermal radiation.

Solar [electromagnetic/thermal] radiation heats the earth during the day, while at night the earth re-radiates some energy via heat back into space. In other words, the sun generates solar power (energy), which transfers energy to the earth, heating it and raising its atmospheric and surface temperatures. Whereupon the earth emits electromagnetic/thermal radiation back into space due to its earlier temperature rise and the internal accelerations and oscillations that occurred therefrom.

NOTE: *When light falls on a surface, it can either be reflected, transmitted, absorbed, or varying degrees of all three.*

There are four ways in which solar power (as electromagnetic effects and thermal effects) can be utilized as an energy source. Three of the ways produce electric power, and the fourth produces heating ("thermal power"):

1. Photoelectric effect/power - Solar **electromagnetic power** can be converted into electrical power through the **photoelectric effect**, of which there are a variety of sub-types of this effect. This is an active form of solar power.
2. Non-photoelectric effect - Solar **electromagnetic power** can be directly converted into electrical power through processes **other than the photoelectric effect**. This is an active form of solar power.
3. Solar **heating** can be **indirectly converted into electrical power** (indirect solar-thermal electric). This is an active form of solar power.
4. Solar heating can be used for its **direct heating effect** (e.g., direct heating, drying, distillation). Whereas this is a form of passive solar power, the other three are active forms of solar power.

These effects/technologies can be combined to increase the overall effectiveness and/or efficiency of useful power generation.

These uses of solar power (energy) can be divided into two categories representing two different types of solar power conversion (energy transfer):

1. Active - conversion of the sun's radiated power (energy) to other useful carriers (e.g., electric power and hotter water).
2. Passive (passive solar) - the direct use of the sun's

thermal [electromagnetic] power for [passive] heating (of architecture and liquids).

9.1 The solar radiation supply

NOTE: *The available solar energy increases with altitude due to lower atmospheric absorption.*

Irradiance is a measurement of solar power and is defined as the rate at which solar power is falling onto a given surface. In other words, solar irradiance is a measure of how much solar power is contacting a specific location. The unit of power is the Watt (W). Solar irradiance is usually measured as power per unit area, so irradiance is typically expressed as W/m², or for larger amounts, kW/m^2. The irradiance falling on a surface can and does vary from moment to moment, which is why it is important to remember that irradiance is a measure of power - the rate that energy is transferring, not the total amount of energy.

"Total solar irradiance" is defined as the amount of radiant energy emitted by the Sun over all wavelengths, not just visible light, "falling" each second on a 1 square metre perpendicular plane outside Earth's atmosphere at a given distance from the Sun. It is roughly constant, fluctuating by only a few parts per thousand from day to day. On the outer surface of the Earth's atmosphere the irradiance is known as the 'solar constant', and it is equal to ~1367 Watts per square meter. Solar irradiance at sea level on the equator at noon on a sunny day is ~1000 W/m².

The solar irradiance integrated over time is called solar irradiation, solar exposure, or insolation. However, insolation is often used interchangeably with irradiance in practice. **Solar irradiation** is a measure of the total amount of solar energy accumulated on an area over a period of time. Solar irradiation is expressed as a number of watt-hours per square metre (Wh/m^2), and for larger amounts, kWh/m^2.

CLARIFICATION: *The terms 'irradiance', 'irradiation', and 'insolation' are often used interchangeably to mean the same thing.*

Insolation is another term used to refer to the amount of solar irradiance received over time. The amount of solar energy that strikes a given area over a specific period of time varies with latitude and with the seasons, as well as the weather, and is known as the insolation (incident solar radiation). In other words, the total amount of solar energy that falls over a given time in a given location is called insolation. Whereas, insolation is a measure of solar energy, irradiance is a measure of solar power. Insolation is the power of the sun added up over some time period. For example, if the sun shines at a constant power of 1000 W/m² for one hour, then it has delivered 1 kWh/m² of energy. The amount of power is the product of the power (1000 W/m²) times the length of time (1 hour) and the unit of energy is the kWh. Insolation (measured in kWh) is not the same as power (measured in kW) in the same way that kilometers per hour is not the same as kilometers.

Hence, the power and energy measurements for solar electromagnetic radiation are:

1. Solar irradiance (power) - solar radiation every second is expressed as W/m² or kW/m^2.
2. Solar irradiation - solar irradiance over time greater than a second is expressed as Wh/m^2 or kWh/m^2.
3. Solar insolation - same meaning as solar irradiation.

When the Sun is directly overhead the irradiance (insolation), that is the incident energy arriving on a surface on the ground perpendicular to the Sun's rays, is typically 1000 Watts per square metre. This is due to the absorption of the Sun's energy by the Earth's atmosphere, which dissipates about 25% to 30% of the radiant energy. Irradiance increases with altitude since the radiation passes through less air mass, hence the energy absorption by the atmosphere is less. The amount of solar irradiation received at any particular location on or above the earth's surface varies due in part to atmospheric attenuation ("loss"). This loss of light is caused by contact with air molecules, water vapor, and dust absorbing and otherwise scattering the light. Some of the light is absorbed by atmospheric composition, including but not limited to ozone, water vapor, and carbon dioxide. The amount of light absorbed and scattered depends on atmospheric composition and thickness. The minimum amount of atmosphere the sun's rays have to go through is the condition in which the sun is directly above a given point on or above the earth. This is referred to as the sun's zenith.

Astronomical data is required to calculate how solar insolation varies with time and with the position of the solar device on the Earth's surface. Atmospheric an meteorological conditions impact how much solar radiation will contact a solar powered device. And, the configuration and operation of the solar system itself affect will also impact the ability to interface with the available solar irradiance.

NOTE: *The term* **peak sun hours***, refers to the energy received during total sunlight hours as defined by the equivalent number of hours it would take to reach that total energy value had solar irradiance averaged 1000 W/m2. In other words, peak sun hours are the number of hours per day that solar insolation equals 1000 W/m^2. This term is interchangeable with kWh/m^2 /day.*

Solar power systems operate within a set of three types of parameters: astronomical parameters; atmospheric and meteorological parameters; and [solar power] device parameters. The maximum transfer of energy between the sun and a solar power system occurs when parameters within these three sets are optimized. The set parameters under which a solar power system can produce the maximum power is called 'maximum power' and/or 'optimum power transfer'. For instance, the voltage at which photovoltaic module can produce maximum power is called 'maximum power point' (or peak power voltage). Maximum power varies with solar radiation, ambient temperature, and solar cell temperature.

9.2 Astronomical parameters

The sun changes its position relative to any point on the earth from morning to night, and from one season to another. The following are astronomical parameters relevant to the positioning and orientation of the contact interface of a solar powered device.

1. **Relative solar positioning** - The position of the Sun in the "sky" relative to a point on earth is defined by its:
   A. Altitude angle 'α' (solar elevation angle).
   B. Azimuth angle 'Ψ'.
2. **The Earth's orbit** - The Earth orbits the Sun with one revolution per year in an elliptical orbit with the Sun at one of the foci of the ellipse. The orbit's two foci are sufficiently close together such that the orbit is approximately circular (slightly elliptical) -- the distance to the sun from the perihelion (the point in its orbit closest to the sun, ~ January 2) is approximately 3% less than its distance from the aphelion (its furthest distance, ~July 3). The sun moves faster across the horizon at perihelion, than at aphelion. Because the orbit is approximately circular, the effect of the orbit on solar irradiance remains essentially constant throughout the year as the earth orbits the Sun. The actual energy received at any distance from the Sun is determined by the inverse square law. Thus a 3% change in distance gives rise to a 6% change in the irradiance.
3. **The Earth's rotation** - The earth rotates about its inertial plane, which passes through the north and south "poles" of the planet. The earth rotates about this axis once each "day" (approximately 24 hours). The earth's rotation of once per day defines this planet's day and night cycle. As the Earth rotates the insolation at any point on its surface rises to a maximum at mid day and falls to zero during the night as the earth presents a different region ("face") toward the sun. For maximum efficiency the orientation of a solar should follow the Sun as it passes through the "sky".
4. **Latitude** - A solar device placed on the ground will only receive the maximum insolation when the sun is directly overhead. Because the Earth is roughly spherical, the angle between the plane of the earth's surface and the incident solar radiation will gradually increase from 90° as the device is repositioned away from the equator toward the upper and lower latitudes by an angle 'Θ', equal to the latitude of the device's location on earth. At this point the altitude angle 'α' of the Sun will be (90 - Θ) degrees. Because of the increased inclination of the earth's surface the insolation received by a device placed on the surface will gradually decrease. This shift in the position of the sun relative to a point on earth can be overcome by inclining the interface plane of the device so that it is perpendicular to the incoming solar rays'. The amount of elevation from the horizontal, the tilt angle, should be equal to the latitude angle 'Θ' of the location of the device. For maximum interface, the axis of inclination should be relatively perpendicular to the polar axis.
   A. Note that the polar axis ("true north" and "true south") is not the same as the compass bearing of north and south, because the magnetic poles do not necessarily line up exactly with the geometric poles. In other words, true north/south is not the same as magnetic north/south. The angle between the magnetic and geographical meridians at any place is called the magnetic declination or variation, which can be as much as 20 degrees or more in deviation. It is expressed in degrees east or west to indicate the direction of magnetic north/south from true north/south. If a compass is being used to orient a solar device, then the difference must be corrected for, which varies from place to place.
5. **The Earth's tilt** - The earth's rotational axis is tilted ~23.45 degrees from the plane of its orbit. This tilt is essentially constant, maintained in that direction due to the gyroscopic action of the earth's rotation, and always points in the same direction relative to the stars, so that the north pole points towards the star polaris, the north star. Over very long time periods however, measured in thousands of years, the direction of earth's axis slowly changes due to gyroscopic precession. The fixed orientation in space of the earth's axis as it orbits the Sun determines the length of the day and creates the world's seasons. As a result of the Earth's tilt, the intensity of the insolation varies during the year giving rise to the seasons. This is not because tilt causes a point on the earth's surface to move closer to or further from the sun. The change in distance is negligible. It is because of three factors, which together reduce both the intensity and daily duration of the insolation during "winter" months:
   A. The earth's tilt changes the angle of incidence of the solar radiation, changing its insolation per unit area. The intensity of solar radiation is largely a function of the angle of incidence, the

angle at which the Sun's rays strike the Earth's surface.

B. The tilt also changes the path length of the radiation through the atmosphere, which in turn changes the amount of the Sun's energy absorbed by the atmosphere.

C. The tilt changes the number of sunlight hours.

D. The declination in the elevation of the Sun varies during the course of the year between minus 23.45° in the summer and plus 23.45° in the winter. The angular position of the Sun at its highest point in the sky with respect to an observation point on the plane of the equator and is called the solar declination 'δ' (not to be confused with magnetic variation, also called the declination). Accounting for the solar declination, the altitude angle α of the sun is (90 - Θ ± δ) degrees. Hence, the inclination angle of a solar interface from the horizontal (for maximum efficiency) should therefore be (Θ ± δ) degrees, and the device should be able to follow this variation in declination throughout the year.

6. **Timing (daylight)** - Sunlight is only available during sunlit (daylight) hours.

9.2.1 Atmospheric and meteorological parameters

During sunlight hours the magnitude and quality of solar radiation contacting the earth's surface is dependent upon atmospheric/meteorological conditions. These conditions affect not only solar radiation, but may affect the performance of the solar power system itself.

1. **Meteorological presence (weather)** - will significantly determine the amount of solar radiation available to a solar device. Cloud cover, dust, precipitation, and air pollution, as meteorological conditions, will impact air composition/density and interface clarity, and hence, the effective power output of a solar device.
2. **Air density (atmospheric density)** - the mass per unit volume of atmosphere. The greater the mass, the more likely absorption and scattering become.
3. **Air pressure (atmospheric/barometric pressure)** - the pressure exerted by the weight of air in the atmosphere of Earth as a meteorological condition.
4. **Temperature (atmospheric temperature)** - thermal quality of atmosphere.
5. **Humidity (atmospheric humidity)** - the amount of water vapor in the air.

NOTE: *In general, solar systems, particularly thermal, work in relatively cold weather, because the device interfaces with the Sun's radiation. However, ambient air temperature, and the design of the solar device, will impact functioning.*

9.2.2 Solar power system parameters

These are parameters specific to the solar powered system itself. The orientation of the interface of the solar device/collector/array with respect to the position of the Sun is a major determinant in the efficiency of a solar power system. The amount of energy transferred to/through (i.e., "captured by") a solar system can be maximised if the collector can follow the ecliptic path of the sun so that the plane of the collector or array is always perpendicular to the direction of the sun. In order to get the most power output from a solar device, it needs to point in the direction that captures the largest quantity of solar rays. In other words, the amount of irradiance contacting a collector or array is directly proportional to the area of the radiation wave-front it intercepts. For optimum energy capture the collector must be perpendicular to the Sun's rays (i.e., when the angle of incidence is 90°). For a flat plate on horizontal ground this occurs only when the Sun is directly overhead. Unless the solar device is located within the equatorial region of the Earth, a 90° angle of incidence is not possible due to the position of the sun relative to the system's position on Earth.

When the incident energy is not perpendicular to the collector, the angle of incidence is (90° - Θ) and the effective area of the collector is AcosΘ, where A is the area of the collector, and Θ is the deviation from perpendicular of the radiation.

If the Sun's radiation is not perpendicular to the Earth, the transit path through the Earth's atmosphere will be longer, and hence, the energy absorbed on the way to the collector or array will be greater, because it will encounter more air (as in, air mass).

NOTE: *The 'air mass' is a dimensionless quantity defined as the ratio between the actual path length of the solar radiation through the atmosphere and the vertical path length through the atmosphere at sea level.*

The effect of a longer route through the atmosphere is to increase the energy absorption (or lost energy) by a factor of 1/cosΦ, where Φ is the deviation from perpendicular of the radiation, also called the zenith angle. Thus, in the polar regions as Φ approaches 90 degrees (cosΦ>0), the insolation is very low, even if the collector is pointed directly at the sun, due to the longer path through the atmosphere.

In concern to a solar device's mounting orientation toward the sun, there are two types of orientation:

1. Fixed [static] mount (fixed tilt) - do not track the sun.
2. Automatic tracking [passive and active] - tracks the sun.

Note that a fixed tilt design can be adjusted (re-mounted) at least twice a year to give a meaningful increase in power output. There are two types of automatic tracking: passive and active (both are mechanical). Automatic mechanical tracking systems make it possible to track both the azimuth and the elevation of the sun's position to maximise energy capture.

Automatic tracking systems include:

1. **Azimuth tracking:** Azimuth tracking keeps the device's interface pointing at the sun as the earth rotates.
   A. **Passive systems** provide the simplest form of azimuth tracking. They have no motors, controllers or gears, and they don't use up any of the energy captured by the collector. They depend on the differential heating of two interconnected tubes of gaseous refrigerants, one on either side of the collector. If the collector is not pointing towards the sun, one side heats up more than the other and vaporises its refrigerant. The resulting change in weight is used in a mechanical drive mechanism to turn the collector towards the Sun where it will remain when the temperature and weight of the two tubes will be balanced.
   B. **Active tracking** is also possible by employing temperature sensors and a control system with linear actuating motors taking their drive power from the system.
2. **Altitude/elevation tracking:** Elevation tracking enables the interface to follow the seasonal variations in the sun's altitude, but alignment is less accurate than for azimuth tracking. Compared with the daily variations in insolation, the seasonal variations are slow and the range of the variation, due to the solar declination is much more restricted. Because of this, reasonable efficiency gains can be obtained simply by manually adjusting the elevation of a static mount every two months.
3. **Dual axis tracking:** Combining azimuth and elevation tracking enables the interface to capture the maximum energy using the smallest possible collectors.

9.2.2.1 Maximum power point tracking (MPPT)

Maximum Power Point Tracking (MPPT) is algorithm that included in charge controllers used for extracting maximum available power from power conversion module under certain conditions. Jacobi's Law states that a power source will deliver its maximum power to a load when the load has the same impedance as the internal impedance of the power source. Note that batteries are not generally designed for interconnection with power conversion systems, and the mismatch results in efficiency losses. Thus, a power point tracker is a form of voltage regulator that is placed between the power system and a battery. It presents an ideal load to the power system allowing it to operate at its optimum voltage to maintain its full power (wattage), regardless of the battery voltage. The voltage at which power module can produce maximum power is called 'maximum power point' (or peak power voltage).A variable DC/DC converter in the module automatically adjusts the DC output from the module to match the battery voltage. It is not enough however to match the voltage at the specified maximum power point (MPP) of the PV array to the varying battery voltage as the battery charges up. Due to changes in the intensity of the radiation falling on the array during the day as well as to changes in the ambient temperature, the operating characteristic of the PV array is constantly changing and with it the MPP of the PV also changes. For optimum power transfer, the system needs to track the MPP as the solar intensity and ambient temperature changes in order to provide a dynamic reference point to the voltage regulator.

9.2.3 Solar power interface types

The type of solar device will determine the type of interface. In general, either:

1. The material composition of the solar device itself acts as the interface (e.g., photovoltaic cells/panels or direct solar collector), or
2. A mirror-receiver system is used. In a mirror-receiver system, the mirrors concentrate/reflect the solar radiation onto a receiver that absorbs the radiation; e.g., solar concentrator).

A solar collector is a heat collecting surface that intercepts the sun's radiated energy and heats up a thermal working fluid. In practical thermal systems it is usually more convenient to focus the suns thermal energy onto a small receiver in order to obtain a higher temperature rise of the working fluid. Such collectors are called concentrators. Typically, concentrators are constructed from parabolic mirrors, which reflect the sun's parallel rays on to a single spot at the focus of the mirror.

> **UNITS NOTATION:** *Note that the units used to express the degree of concentration of the mirror system are similar to the magnification factor of a lens, and are called* **suns** *(this unit is not a precisely defined quantity).*

There are several types of concentrators:

1. **Parabolic dish** - a shaped mirror that redirects solar energy onto a suitable heat absorber/receiver located at the focus.
2. **Parabolic trough** - a shaped mirrors that redirects

solar energy onto a pipe-like heat absorber located running through the focus. Generally, this setup forms a type of "solar furnace" used to raise steam to drive a turbine generator.

3. **Power tower** - uses a large array of parabolic mirrors focused on a solar furnace mounted on the top of a tower. Because of the long focal length, the mirrors are almost flat. Generally, this setup forms a type of "solar furnace" used to raise steam to drive a turbine generator.
4. **Heliostats** - sun tracking mirrors used to reflect solar radiation in a fixed direction (such as toward a solar panel or thermal receiver).

NOTE: *For most of these systems, the amount of energy captured, and hence, the temperature rise of the absorber will be proportional to the area of the dish-like mirror.*

9.2.4 Solar power system monitoring

Solar devices require a "clear" (i.e., unobstructed) interface with the solar electromagnetic radiation to function optimally. If the device is covered with a material (e.g., dust, snow, debris), then the device will produce less power relative to the obstructing material type, and amount of material, covering the device. Hence, solar devices require periodic cleaning to ensure the device's interface surface is free of extraneous material.

Note that the solar interface itself may degrade with exposure to sunlight, and may require periodic replacement.

9.3 Photoelectric power: Direct transfer of solar electromagnetic energy to electric power

NOTE: *These systems are sometimes referred to as* **photoelectric transducers***, wherein a transducer is a device that transfers ("converts") energy from one carrier ("form") to another carrier ("form"). The majority of these systems transfer electromagnetic power (energy) to mechanical displacement of charges, which produces electrical power. The other systems transfer a non-electrical physical quantity, such as temperature or sound, to an electrical signal.*

At the top level, the photoelectric and photovoltaic effect refers to the direct production of electric power (as direct current (DC) voltage) through the contact of electromagnetic radiation (energy) with a semiconducting material. Note here that the term 'photo' means 'light', which is another term for electromagnetic radiation. The photo-electric/-voltaic effect (or photoemission) refers to the observed movement of free charge carriers (or electrons) when light (electromagnetic radiation) contacts a material. Electrons "emitted" in this manner may be called "photoelectrons". The photoelectric effect is an electromagnetic, physical and chemical phenomenon.

The photoelectric and photovoltaic effects are closely related, and the terms are sometimes used interchangeably. In either case, light is absorbed, causing excitation of an electron or other charge carrier to a higher-energy state. In other words, "photons" (dielectric perturbations) carry the potential of moving electrons out of materials. Or, said another way, it is the direct conversion of light into electrical power (voltage and direct current) at the atomic level. In either case, an electric potential (or voltage) is produced by the separation of charges, and the light has to have a sufficient energy to overcome the potential barrier for excitation.

CLARIFICATION: *In general, the 'photoelectric effect' is the physical phenomenon responsible for the creation of an electrical potential difference (voltage) in a material when exposed to light. However, when speaking about specific occurrences of the photoelectric effect, the terms photoelectric and photovoltaic mean something different. In specific, the ways in which the electrons are emitted in the photoelectric effect and photovoltaic effect create the difference between them. They differ in definition as the steps of progression are different in each case. The main scientific difference between the two processes is that in the photoelectric effect, the electrons are emitted into a vacuum space (usually via ballistic conduction), whereas in the photovoltaic effect, the emitted electrons directly enter a new material (usually separation is via diffusion).*

There are several basic types of photoelectric device (i.e., photoelectric cell), corresponding to the different forms of the photoelectric effect that they employ. A **photoelectric cell** is defined as a device whose electrical characteristics, such as current, voltage, or resistance, vary when exposed to light.

Modules (a number of connected cells), are connected/arranged into arrays (connected modules/cells). The power production module/cell has no moving parts. All forms of the effect utilize semiconductor material in order to generate the effect. Solar electromagnetic energy may be directly converted to electric potential energy via the following effects/methods. Note that any devices employing these effects/methods could be referred to as a solar cell, although photovoltaic cells are most commonly referred to as solar cells:

1. **Photoconductive effect (photoconductive cell/ photoresistor)** - light "frees" electrons from their valence bonds in a semiconductor material, while reducing the materials resistance (increasing electrical conductivity). The photoconductive cell is a two terminal semiconductor device whose terminal resistance will vary (linearly) with the

intensity of the incident light. For obvious reasons, it is frequently called a photoresistive device.

2. **Photoemissive effect (photoemissive cell, photocell, electric eye)** - light knocks electrons from a cathode to an anode, making a current flow through an external circuit.
3. **Photoelectric effect (photoelectric cell) -** light makes electrons move out of semi-conducting material and into a vacuum space.
4. **Photovoltaic effect (PV cell, photovoltaic cell, or solar cell)** - light makes electrons move between layers of semiconducting material, producing a voltage and a current in an external circuit. A photovoltaic cell may also be used as a photodetector (e.g., infrared detectors), detecting light or other electromagnetic radiation near the visible range, or measuring light intensity. A solid state electrical device that converts the energy of light directly into electricity by the photovoltaic/ photoelectric effect. Photovoltaic cells (PV cells) are the building blocks of photovoltaic modules, otherwise known as solar panels. The operation of a photovoltaic (PV) cell requires 3 attributes:
   A. The absorption of light, generating either electron-hole pairs or excitons.
   B. The separation of charge carriers of opposite types.
   C. The separate extraction of those carriers to an external circuit.
5. A **photo-electrochemical cell (photo-electrolysis cell)** - may either be a type of photovoltaic cell (like that developed by Edmond Becquerel and modern dye-sensitized solar cells), or a type of cell that splits water directly into hydrogen and oxygen using only solar illumination. Photo-electrochemical cells or PECs are solar cells that produce electrical energy or hydrogen in a process similar to the electrolysis of water. Photoelectrolysis is the process of using sunlight directly to decompose water into hydrogen and oxygen through the use of semiconductor material similar to that used in photovoltaics. In other words, by passing light (electromagnetic radiation) through water it is possible to split the water into its component parts.
6. **Photogalvanic effect (photogalvanic cell)** - a special case of the so-called Becquerel effect, in which the influence of light on the electrode potential is due to a photochemical process in the body of the electrolyte (as distinct from photochemical or photoelectric processes in the surface layer of the electrode, which are the basis of the original Becquerel effect).
7. **Photomagnetic effect (photomagnetic cell)** - a material acquires (and in some cases loses) its ferromagnetic properties in response to light. The current model for this phenomenon is a light induced electron transfer, accompanied by the reversal of the spin direction of an electron. This leads to an increase in spin concentration, causing the magnetic transition. (Mahmoud, 2015)

9.3.1 Photovoltaic cells

The most common effect used to create solar panels is the photovoltaic effect. Here, solar power converts sunlight into DC voltage electrical power using photovoltaics. Solar cells, also called photovoltaic (PV) cells get their name from the process of converting light (photons) to electric current (voltage), via a mechanistic effect known as the PV effect. Photovoltaic (PV) technologies may be divided into three generational categories:

1. **Wafer-based PV** (also called 1st generation PV, crystalline silicon, and bulk PV) - This first generation PV cell technology monocrystalline silicone (monosilicon) cells and polycrystalline silicone (polysilicone) cells.
2. **Thin-film cell PV** (also called 2nd generation PV or thin film solar cell, TFSC) - This second generation PV cell technology includes amorphous, protocrystalline, and nanocrystalline cells.
3. **Organic photovoltaic cell** (OPVC) - This third generation PV cell technology uses organic, electronic conductive polymers or small molecules for light absorption and electrical charge transport.

All photovoltaic cells utilize a semiconductor P-N junction. Photovoltaic cells contain p-type materials flush with n-type materials. Sunlight provides the energy to make the current flow from the n-type to the p-type.

In general, the photovoltaic process occurs as follows:

1. "Photons" in rays of sunlight contact a solar panel and are absorbed by semiconducting material.
2. Electrons in the semiconducting material are excited from their current molecular/atomic orbital.
3. Once excited an electron can either dissipate the energy as heat and return to its orbital, or travel through the cell until it reaches an electrode. Once an excited electron reaches an electrode a current is created. The chemical bonds of the material are vital for this process to work.
4. An array of solar cells converts solar energy into a usable amount of direct current (DC) electricity.
5. An inverter can convert the power to alternating current (AC).

Photovoltaic diodes (a.k.a., photodiodes, PV cells, or solar cells) generate an electric current when light of sufficient magnitude impinges on a semiconductor lattice connected to a P-N junction. If the photon energy in the light energy is less than the band gap (energy range in a solid where no electron states can exist), the energy is simply dissipated as heat, and no electrons are released into the conduction band and no current flows. However, if the energy level of the photons is equal to, or higher than, the band gap of the semiconductor material, it will cause the covalent bonds in the semiconductor to be "broken" as electrons jump the band gap into the conduction band. Both the electron and the vacant site left behind by the electron in the valence band (the hole) then act as free charge carriers and contribute to the possible current. Once a photon has caused the release of an electron, any photon energy it had in excess of the band gap energy will be dissipated in the form of heat. Photons pass through the crystal lattice until they are absorbed as heat or until they give up their energy by causing the generation of electron hole pairs and the release of an electron across the band gap.

Photovoltaic cells can be stand-alone systems, or incorporated into other useful materials. Hence, the structural design of photovoltaic cell/panel can take several forms:

- Flexible panels - a flexible stand-alone PV cell.
- Rigid panels - a rigid stand-alone PV cell.
- Shingle and tile panels - a tile (e.g., roof tile) could be a PV cell.
- Window panels - a window could be a PV cell.

9.3.2 Device specifics

Specific devices will be accompanied by the following referential data:

1. Manufacturer - Organization/company name; brand
2. ID - Specific solar module identification code; module name
3. Rating - standard testing conditions; nameplate rating under laboratory conditions
4. Efficiency (%) - Output per input light irradiance using STC; energy conversion efficiency; module efficiency
5. Tier - Solar panel efficiency Trier 1 is highest, 5 is lowest.

9.4 Solar non-photoelectric power: Direct transfer of solar electromagnetic energy to electric energy

Solar radiation can be directly converted into electrical power without the use of the photoelectric effect, via five methods:

1. **Thermoelectric or thermophotovoltaic effect**- The conversion of temperature differences to electric voltage and vice versa. Thermophotovoltaic (TPV) cells involve a direct energy transfer through heat [mode] to electricity via photons (as in, generating electricity from infra-red radiation). A thermoelectric device creates voltage when there is a different temperature on each side. Conversely, when a voltage is applied to it, it creates a temperature difference.
2. **Thermionic emission effect** - The process by which free electrons are emitted from the surface of a metal when external heat energy is applied. Heat energy transfer induces the flow of charge carriers from a surface or over a potential-energy barrier. This occurs because the thermal energy given to the carrier overcomes the work function of the material. Thermionic emission occurs in metals that are heated to a very high temperature. In other words, thermionic emission occurs, when a large amount of external energy transferred via heat is supplied to the free electrons in the metals (i.e., raises the internal energy of the substance and causing the valence electrons to gain enough energy to break their bonding with the parent atom, whereupon they become "free" (i.e., acquire kinetic energy).
3. **Ferroelectric effect (ferroelectricity)** - Ferroelectricity is a property of certain materials that have a spontaneous electric polarization that can be reversed by the application of an external electric field. Certain solids exhibit spontaneous electric polarisation when exposed to light (Read: light has an electric field, as in electromagnetic field). The nonlinear nature of ferroelectric materials can be used to make capacitors with tunable capacitance.
4. **Magnetohydrodynamic effect** (MHD; also magneto fluid dynamics or hydromagnetics) - The study of the magnetic properties of electrically conducting fluids. Examples of such magneto-fluids include plasmas, liquid metals, and salt water or electrolytes.
5. **Electro-gas-dynamic effect** - The process of creating electrical power by converting the kinetic energy contained in a flowing, high-pressure, ionized combustion gas.

9.5 Solar heating electric power: Indirect transfer of solar energy to electric energy

The production of electric power by solar heating (energy transfer via heat) requires two stages. First, solar radiation (thermal energy) heats a working fluid, which is then used in a second energy transfer stage to generate the electric power. A solar "thermal" power system usually involves an array of mirrors to concentrate the sunlight on to an absorber. The absorbed energy is then used to power a heat engine (and turbine), which in turn drives a rotary generator. In large scale systems, the heat engine includes a turbine driven by steam or other vaporous working fluid. The steam (or other vapor) is produced by the concentrated heating effect in the heat engine, which transforms the working fluid therein.

In other words, electric power via solar heating uses concentrated light from the sun to heat a working fluid in a heat engine (and turbine), which turns a generator to make electricity (AC voltage internally). The working fluid that is heated by the concentrated sunlight can be a liquid or a gas. Different working fluids include water, oil, salts, air, nitrogen, helium, etc. In small scale systems the heat engine may be a Stirling engine. Other engine types include steam engines, gas turbines, etc.

Hence, solar power can be indirectly/secondarily converted into electrical power through the thermodynamic process. The thermodynamic process occurs when energy in solar radiation is transferred via heat into shaft work/power through a heat engine (via the Rankine cycle, Stirling cycle, or Brayton cycle), and then, shaft work (mechanical power) is converted into electrical power through a generator (e.g., alternator).

Herein, devices can be constructed to reflect and absorb/collect solar energy. For instance, a **solar thermal collector** supplies heat by absorbing sunlight for the purpose of either direct heating or indirect electrical power generation from heat. Similarly, a **concentrating solar power (CSP) system**, concentrates the sun's radiated energy using reflective devices such as troughs or mirror panels to produce a focused super heated thermal power source that is then used to generate electricity.

Summarily, a solar "thermal" power system mainly consists of a: solar energy collector field, a fluid flow distribution system, a suitable working fluid, a heat engine (and turbine), an electric generator, and a control system. Amongst the many available systems, the two most generic and common are: the central receiver thermal electric power system and the distributed solar thermal electric power system. These two systems have a comparatively high efficiency. In the central receiver concept large arrays of sun-tracking mirrors known as heliostats reflect the solar flux on to the central receiver boiler at the top of the tower. Here concentration ratios power a turbine (steam type) that in turn powers a generator.

9.6 Solar heating (passive): Direct thermal heating

Solar radiation can be used and concentrated for its heating ("thermal") properties. Uses of direct solar "thermal" energy include, but are not limited to:

1. **Solar water heating** - Solar water heating systems, which contain a black solar collector that faces the sun, and either heats water directly or heats a "working fluid" that, in turn, is used to heat water.
2. **Solar walls** - Transpired solar collectors, or "solar walls," which use solar energy to preheat ventilation air for a building.
3. **Solar evaporation** - Solar desalination and solar distillation has been in practice for a long time as a means for evaporating water.
4. **Solar drying** - Solar drying, dehydrating, evaporation, desiccating, and cooking has been in practice for a long time (e.g., food dehydration; salt evaporation ponds; clothes drying; solar oven/cooker).
5. **Solar ponds** - Solar ponds are used for the collection and storage of thermal energy (as internal energy). The energy can be transferred from the solar ponds for any suitable heating ("thermal") application. Therein, solar pond systems may be used for thermal energy storage, desalination, and electricity generation. A solar pond is a large scale solar collector with an integrated arrangement for storage of heated water. A solar pond is a pool of water (generally, salt water) that collects and stores solar thermal energy (as internal energy). The saltwater naturally forms a vertical salinity gradient also known as a "halocline", in which low-salinity water floats on top of high-salinity water. The layers of salt solutions increase in concentration (and therefore density) with depth. Below a certain depth, the solution has a uniformly high salt concentration. When the sun's rays contact the bottom of a shallow pool, they heat the water adjacent to the bottom. When water at the bottom of the pool is heated, it becomes less dense than the cooler water above it, and convection begins. Solar ponds heat water by impeding this convection. Salt is added to the water until the lower layers of water become completely saturated. High-salinity water at the bottom of the pond does not mix readily with the low-salinity water above it, so when the bottom layer of water is heated, convection occurs separately in the bottom and top layers, with only mild mixing between the two. This hot, salty water can then be pumped away for use in electricity generation, through a turbine or as a source of thermal energy. There are ad-/dis-vantages with solar ponds:
   A. The accumulating salt crystals have to be removed and can be both a valuable by-product and a maintenance requirement.
   B. No need for a separate collector for this thermal storage system.
   C. The extremely large thermal mass means power is generated night and day.

D. Due to evaporation non-saline water is constantly required to maintain salinity gradients.

10 Geothermal power

TERMINOLOGY:

- **Geothermal heat pump:** Devices that utilize the relatively constant temperature of the Earth's interior as a source and sink of heat for both heating and cooling. When cooling, heat is extracted from the space and dissipated into the Earth; when heating, heat is extracted from the Earth and pumped into the space.
- **Geothermal plant/facility:** A combination of devices (forming a facility, or "plant") in which the prime mover is a steam turbine. The turbine is driven either by steam produced from hot water or by natural steam that derives its energy from heat found in rocks or fluids at various depths beneath the surface of the Earth. The energy is extracted by drilling and/or pumping.

Geothermal energy is defined as thermal energy (heat) from the earth. Geo means "earth," and thermal means "heat" in Greek. Heat flows outward from the earth's interior. The earth's heat content is about 10^{31} joules. This heat naturally flows to the surface by conduction at a rate of 44.2 terawatts (TW) and is replenished by radioactive decay at a rate of 30 TW. The earth has been emitting heat for approximately 4.5 billion years, and will continue to emit heat for billions of years into the future.

> **NOTE:** *According to archaeological evidence, geothermal resources have been used by humanity in the form of naturally occurring hot springs for more than 10,000 years.*

Heat emanating from the earth's interior generates magma (a molten and semi-molten rock mixture). This mixture is usually made up of four parts: a hot liquid base, called the melt; minerals crystallized by the melt; solid rocks incorporated into the melt from the surrounding confines; and dissolved gases. Magma exists in the mantle and lower crust, and sometimes bubbles to the surface as lava. However, the crust of the earth traps most of the mantle (and its heat) beneath it. The earth's crust effectively acts as an insulator, which must be pierced by fluid conduits (of magma, water or other) to release the heat underneath. Because magma is less dense than surrounding rock, it rises within the mantle and through conduits within the crust. As the magma rises, it heats the surrounding rock, as well as water contained in rock pores and rock fractures under the earth's crust. Heat is carried to the surface by fluid circulation, either through magma conduits, hydrothermal circulation, hydrocarbon wells, drilled water wells, or a combination of these.

> **NOTE:** *There are many natural geothermal features on the surface of the earth, including but not limited to: geysers; hot*

springs; volcanoes; steam vents; underwater hydrothermal vents; and mud pots. When a volcano erupts, the mantle of the earth flows up through the crust to the surface as lava.

Geothermal energy exists in different carriers ("forms") all over the Earth (by steam vents, lava, geysers, or simply dry heat). Magma, heated rock, and heated water are all sources of geothermal energy. In order for a geothermal power system to operate, the heat must be carried to the surface by fluid circulation, either through magma conduits, hot springs, hydrothermal circulation, oil wells, drilled water wells, or a combination of these. This circulation sometimes exists naturally where the crust is thin: magma conduits bring heat close to the surface, and hot springs bring the heat to the surface. Once at the surface or the system's location, the thermal energy can be captured and used directly for heating, or it can be used as (or converted to) steam, and directed through a turbine-generator to produce electrical power.

NOTE: *Geothermal steam and hot water can reach the surface in two ways: through naturally occurring surface features such as geysers and fumaroles, or through man-made wells that are drilled down into the reservoir to harvest the energy.*

Natural heat from within the Earth may be transferred through a geothermal power system for the production of electric power, space heating, or industrial steam. Geothermal power uses heat from geothermal fuel (i.e., the inner earth) to heat water or another working fluid. The working fluid is then used as space heating, as industrial steam, or to turn a generator, thereby producing electricity.

Unlike other renewable energy sources, geothermal systems are considered "baseload". This means they can continue to operate throughout all seasonal changes on the earth's surface, and are not dependent on changing surface factors, such as the presence of wind or sun. Geothermal electrical power systems are capable of producing energy continuously (i.e., 24/365 - 24 hours a day and 365 days a year, any time and every day).

NOTE: *Rock is considered a reasonably good conductor of heat. Conversely, air is considered a reasonably poor conductor of heat.*

In order to obtain enough energy to generate electricity, geothermal power plants rely on heat that exists a few kilometers below the surface of the Earth. In some areas, the heat can naturally exist underground as pockets steam or hot water. However, most areas need to be "enhanced" with injected water to create steam. The heat energy transferred from the mantle to the waters in the earth's crust can be harnessed to create electricity.

Geothermal power stations are similar to other steam turbine thermal power stations – heat from a fuel source (in the case of geothermal, the earth's core) is used to heat water or another working fluid. The working fluid is then used to turn a turbine connected to a generator, thereby producing electrical current. The fluid is then cooled and returned to the heat source.

10.1 Geothermal sources

NOTE: *Water boils underground and generates steam at temps of 165˚C and pressure of about 100 psi.*

The type of geothermal field/reservoir will determine the type of geothermal power system (plant or station) that can be built on the geothermal site. There are two primary carriers of geothermal energy, and hence two primary geothermal field types:

1. **Water-based fields** - including steam and hot water.
2. **Hot and molten rock-based fields** - including hot and molten rocks, but no water.

Therein, there are four common types of geothermal fields/reservoirs; three of which are water-based and the fourth is rock-based:

1. **Hot water fields/reservoirs** are geothermal aquifers that contain reservoirs of water between ~60°-100° C. In general, these fields are used for direct thermal heating or as part of a binary power plant.
2. **Wet steam fields/reservoirs** are geothermal reservoirs that contain pressurized water that is above boiling point (100° C), so that when the water is pumped to the surface it becomes steam.
3. **Dry steam fields/reservoirs** are geothermal reservoirs that contain pressurized and "superheated" water that is significantly above boiling point. The "superheated" water/steam is pumped to the surface for use. Dry steam fields are rarer than wet steam fields.
4. **Hot and molten rock fields** are geothermal locations with hot rocks.

Electricity production from each type depends on field temperatures, and when water is present, pressures also.

NOTE: *Most geothermal reservoirs are found deeper underground than groundwater reservoirs.*

10.2 Geothermal power types

Geothermal power can be harvested in a number of different ways. Firstly, water can be used via steam to power a turbine and produce electrical power, or the hot water itself can be used for heating purposes. Secondarily, heated rocks can be used to power a closed-loop heat pump with an internal turbine system to produce electricity, or the temperature difference between an underground area and the surface can be used as part of a heating and cooling system.

There are five water-based geothermal power systems include:

1. **Dry steam power (plant/station)** - The direct use of natural underground sources of steam of 150°C or greater to power turbines. In this case, the underground source of steam (water) is from a dry-steam reservoir. The steam is piped directly into the turbine, which is connected to a generator that generates electrical power. Steam directly from the geothermal reservoir runs the turbines that power the generator, and no separation ("flashing") is necessary, because the geothermal wells only produce steam. Dry steam systems use water in the earth's crust, which is heated by the mantle and released through vents in the form of steam. Dry steam geothermal systems have pipes that are drilled into the site and used to trap and redirect the steam. The steam is then used to turn turbines connected to a generator to produce electricity. The underground water reservoirs that feed such a system is refilled when rain falls on the land. The rainwater eventually soaks back into the crust of the earth. Sometimes, however, dry steam reservoirs do not refill themselves in a very consistent manner.
2. **Wet steam power (a.k.a., flash steam plant/ station)** - This system is similar to a dry-steam power system, but water is recycled back into the thermal well. In this case, the underground source of steam (water) is a wet-steam reservoir. This systems use a well that is drilled into the geothermal site to release the steam. After the steam is piped up, and passes through the geothermal power system, it is sent into a condenser, which cools it. This cooled water is then pumped back into the well (i.e., recycled). The water is heated again by the geothermal source, and released as steam, and the process repeats. This process can happen over and over with a minimal loss of water. Wet steam power system use naturally occurring sources of underground hot water and steam, which is "flashed" into steam, used to power a turbine-generator, and then condensed and recycled. Hot water and steam are pumped into a low-pressure area on the surface known as a flash tank. The water evaporates rapidly (i.e., "flashes") into steam, which is funnelled through a turbine connected to a generator to produce electrical power. Any remaining water can be flashed in a separate tank to extract more energy. The water is then condensed and recycled back into the earth. Flash steam systems pull deep, high-pressure hot water into lower-pressure tanks and use the resulting flashed steam to drive turbines. They require fluid temperatures of at least 180°C (usually higher). This is the most common type of geothermal station in operation today. The hot water flows up through wells in the ground under its own pressure. As it flows upward, the pressure decreases and some of the hot water boils into steam.

   NOTE: *A 'condenser' is a heat exchanger, which condenses a substance from its gaseous to its liquid state.*

3. **Binary cycle power (plant/station)** - Water heated underground (at ~107°-182° C) is piped to the surface where it is passed through a heat exchanger, containing a pipe with a secondary working fluids (a fluid with a lower boiling point). After being heated by the water piped up from underground, the working fluid is flash steamed to power a turbine, which is connected to a generator, and produces electrical energy. The geothermal water is never exposed to the air, and is injected back into the periphery of the reservoir. The hot water from underground heats working fluid (e.g., a liquid organic compound) that has a lower boiling point than water (e.g., isobutane). The two liquids are kept completely separate through the use of a heat exchanger used to transfer the energy via heat from the geothermal water to the working fluid. The secondary fluid vaporizes into gaseous vapor and (like steam) the force of the expanding vapor turns the turbines that power the generators. In other words, the organic working liquid creates steam, which flows through a turbine and powers a generator to create electrical power. The water in the pipe is recycled back to the ground, to be re-heated by the Earth and provide future heat for the organic compound again. If the power system uses air cooling the geothermal fluids never make contact with the atmosphere before they are pumped back underground. These systems are the most recent development, and can accept fluid temperatures as low as 57 °C. The moderately hot geothermal water is passed by a secondary fluid with a much lower boiling point than water. This causes the secondary fluid to flash vaporize, which then drives the turbines. This is the most common type of geothermal electricity station being constructed today. Both Organic Rankine and Kalina cycles are used. The thermal efficiency of this type station is typically about 10–13%. In

binary systems, water is only used as a heating agent, and is not exposed or evaporated. It can be recycled, used for other purposes, or released into the atmosphere as non-toxic steam. In general, however, binary systems generally emit no visible steam or water vapor plumes. If the geothermal fluid is not contained and recycled in a pipe, it can absorb biologically toxic substances in the earth, such as arsenic, boron, selenium, mercury, and fluoride. These toxic substances can be carried to the surface and released when the water evaporates. In addition, if the fluid leaks to other underground water systems, it can contaminate clean sources of drinking water and aquatic habitats.

4. **Enhanced geothermal systems (EGS)** - EGS uses drilling, fracturing, and injection to provide fluid and permeability in areas that have hot, but dry, underground rock. To develop an EGS, an 'injection well' is drilled into the ground. Depending on the type of rock, this can be as shallow as 1 kilometer to as deep as 4.5 kilometers. High-pressure cold water is injected into the drilled space, which forces new fractures in the rock, expands existing fractures, and dissolves areas. This creates a reservoir for/of underground fluid. Water is pumped through the injection well, and absorbs the rocks' heat as it flows. This hot water, called 'brine', is then piped back up to earth's surface through a 'production well'. The heated brine is contained in a pipe. It warms a secondary [working] fluid that has a low boiling point, which evaporates to steam and powers a turbine. The brine cools off, and cycles back down through the injection well to absorb underground heat again. There are no gaseous emissions besides the water vapor from the evaporated liquid. Pumping water into the ground for EGSs can cause seismic activity.

   NOTE: *In 2009 an EGS Geothermal project in Basel, Switzerland, was cancelled after the injection process caused hundreds of tiny earthquakes that grew to more significant seismic activity even after the water injection was halted.*

5. **Hot water system (plant/station)** - This system uses a hot water reservoir that does not reach high enough temperatures to become steam, but is still a viable source of direct heating. The water is not used to produce electrical power, but is piped and exchanged to heat desired areas. The heat from the pipes (and venting systems) radiate heat into a surface and/or area. Pipes return the water to the hot water reservoir to be reheated and introduced back into the system. Applications include, but are not limited to: space heating and cooling; food preparation; hot spring bathing and spas (balneology); agriculture; aquaculture; greenhouses; snow melting; and production processes.

There are two rock-based geothermal power systems; one of which is designed specifically as a heating and cooling system, and the other is designed to produce electrical power:

1. **Geoexchange system (geothermal heat pump, GHP) for heating and cooling** - This is a type of heating and cooling system. Technically, this kind of system is not geothermal since it uses a combination of the ground's low relative heat and indirect solar energy, not the earth's geothermal energy. Geoexchange systems involve the drilling of a well 3 to 90 meters deep (shallower than most oil and natural gas wells). The system does not require the fracturing of bedrock. A pipe connected to a system is arranged in a continuous loop ("slinky loop") that generally circles underground and above ground. However, the loop can also be contained entirely underground, for instance, to heat a parking lot or landscaped area. In this system, a working fluid (such as water or glycerol, similar to a car's antifreeze) moves through the pipe (and accompanying heat exchanger and ductwork, if present). This system is mostly used for heating and cooling on a seasonal basis. During the cold season, the liquid absorbs underground thermal heat (from a geothermal and/or solar source). It carries the heat to its desired location. The pipe can be connected to the infrastructure of a building to give off heat into the building through a duct/heat exchange system. These heated pipes can also run through hot water tanks. During the warm season, the geoexchange system works the opposite way: the liquid in the pipes is warmed from the heat in the building (or ground heat source), and carries the heat to be cooled underground.

   NOTE: *Some animals burrow underground for warmth in the winter and to escape the heat of the summer.*

2. **Geoexchange system (geothermal heat pump, GHP) for electrical power** - Unlike geoexchange for heating and cooling, this system does use geothermal energy to do work, and must be placed in a location with a sufficiently high underground temperature. Geoexchange systems for electrical power are typically self-contained tubular units with two principal sections: the process section and the heat absorption section. The heat absorption

section is otherwise called the 'geothermal riser'. The riser has its own pump with an oil compound (biodegradable and non-toxic). The oil is sent downward through a coaxial system to where the geothermal heat exists. As the oil gets hot at the location of the thermal riser, it comes back up through the center tube. The hot oil is transferred to a heat exchange, which contains two chemicals (isopentane and isobutane). These chemicals are pressurized and in liquid form when they absorb thermal energy from the heat exchanger. Once they are heated from the exchange, they turn into a gas, which drives a turbine connected through a shaft to a generator, and produces electrical power. After the gas moves through the turbine it enters a condensing system, and becomes liquid again, which is then pumped back down to the heat exchanger. These systems typically require an operating temperature of at least 148˚C. The power generating system operates at ~10,000rpm and needs only 108˚C. Both sections of the device are closed cycles. One of the most well-known geoexchange electrical power systems is the Power Tube, which is available with the following specifications.

- 10 megawatt system = 55m in length, 142cm diameter (with a 30.48cm diameter riser).
- 5 megawatt system = 47m in length, 112cm diameter (with a 22.86cm diameter riser).
- 1 megawatt system = 43m in length, 92cm diameter (with a 12.7cm diameter riser).

There are also co-produced geothermal systems:

1. **Co-produced geothermal power** - These systems use heat obtained from the steam and hot water produced as a by-product of petroleum and natural gas wells to power an electrical generator.

10.2.1 The Cooling subsystem

Most geothermal electrical power generating system include a cooling subsystem. Cooling can occur through air cooling (e.g., fans) and/or water/wet cooling (e.g., cooling towers and evaporative cooling). A cooling system is designed to prevent turbines from overheating and prolong system life.

> **NOTE:** *A 'cooling tower' is a heat rejection/ dissipation device that ejects waste heat to the atmosphere through the cooling of a water stream to a lower temperature.*

Wet/evaporative cooling used in water cooled systems requires a continuous supply of cooling water and creates vapour plumes (i.e., air emissions as water vapor emissions). Usually, some of the spent steam from the turbine (for flash- and steam-type plants) can be condensed for this purpose. Vapor plumes are unaesthetic and air cooled systems are preferred in areas where the viewshed is sensitive to the effects of vapor plumes. Vapor plumes can also introduce contaminants into the atmosphere, depending upon the purification of the water source.

Air cooled systems, in contrast to the relative stability of water cooled systems, can be extremely efficient in the winter months, but are less efficient in hotter seasons when the contrast between air and water temperature is reduced, so that air does not effectively cool the organic fluid. Air cooled systems emit no water vapor, and thus blend easily into the environment. Air cooled systems are beneficial in areas where extremely low emissions are desired, or in arid regions where water resources are limited, since no fluid needs to be evaporated for the cooling process.

10.2.2 Geothermal resource assessment

Different types of geothermal energy are available on different parts of the planet. Satellites are used to determine geothermal hotspots. Thermal satellite imagery usually provides a 10km x 10km view of the ground. With this information you can determine how large and/or how many geothermal systems can potentially be installed without extracting too much energy (i.e., without cooling the area down).

Geothermal plants are designed for a specific resource. In other words, after satellite imagery is analyzed, wells are drilled, and then, the thermal characteristics and material output (e.g., steam and/or water) of the well are measured. And then, a geothermal system is selected and designed for that specific resource.

The part of the planet known as "Iceland", for example, has abundant sources of hot, easily accessible underground water. Europe has a significant volume of hot dry rock as a source of geothermal energy.

10.2.3 Environmental impact

Before construction of a geothermal power generation system, an environmental assessment must be completed to determine potential social system and ecosystem effects.

10.2.3.1 Environmental contamination and disruption

1. Drilling into the earth's crust produces 'sludge', which is often rich in zinc and sulfur (and other potential pollutants). If the sludge is directly released into the environment it can harm ecosystems.
2. Water that flows through underground reservoirs can pick up trace amounts of toxic elements. These harmful substances can be leaked to water sources or the atmosphere if the geothermal system is

not properly insulated. Hence, the steam used at geothermal plants can become a source of air pollution if it is released into the atmosphere. Frequently it is heavily laced with salts and sulfur compounds that are leached from the earth's crust. If the steam is simply condensed and released into the natural waterways, the high levels of salts and sulfurs can be toxic to aquatic wildlife. If released into the air, the toxins, in the form of acid rain, can still find their way into surface water systems and kill aquatic animals. Geothermal plant operators often cool and condense the steam produced at their plants and recycle it into their wells for these reasons.

3. Some geothermal reservoir fluids contain varying amounts of certain gases, including carbon dioxide, which may be emitted as steam into the environment (with any accompanying particulate matter). In concern to particulate matter, mercury for example, is not present in every geothermal resource. However, if mercury is present in a geothermal resource, using that resource for power production could result in mercury emissions, depending upon the technology used. Because binary plants pass geothermal fluid through a heat exchanger and then return all of it to the reservoir, binary plants do not emit any mercury.
4. Natural geothermal fluids contain varying concentrations of potentially toxic minerals and other elements, and are extremely hot when they reach the surface of the Earth. For these reasons, geothermal fluids can be dangerous to humans and surrounding ecosystems. Hence, fluids from geothermal reservoirs are injected back into the earth and are not allowed to be released into surface waterways. However, geothermal effluents can sometimes (depending upon composition) be stored in evaporative ponds, rather than be injected back into the system. Again, depending upon composition, these ponds may be safe for bathing/swimming.
5. During operation, there is the possibility of aquifer/groundwater contamination.
6. Wells must often be dug, which may disrupt the natural flow of groundwater.
7. Total non-condensable gas emissions (e.g., sulfur dioxide, methane, CO_2 etc.) from geothermal resources are calculated as a percentage of the total steam emitted (generally, less than 5%). Conversely, air emission from combustion (e.g., coal fired electrical plant) contain are a much higher percentage of emissions.

10.2.3.2 Subsidence

1. Subsidence is the slow, downward sinking of a land surface. Other types of ground deformation include upward motion (inflation) and horizontal movements. In some cases, subsidence can damage infrastructure, such as roads, buildings and irrigation systems, or even cause tracts of land to become submerged by nearby bodies of water. Although it can occur naturally, subsidence can also occur as a result of the extraction of subsurface fluids, including groundwater, hydrocarbons, and geothermal fluids. In these cases, a reduction in reservoir pore pressure reduces the support for the reservoir rock itself and for the rock overlying the reservoir, potentially leading to a slow, downward deformation of the land surface. While subsidence can be induced by thermal contraction of the reservoir due to extraction and natural recharge, properly placed injection (see injection sections) reduces the potential for subsidence by maintaining reservoir pressures.
2. Geothermal sights can experience subsidence (setting or sinking of land). Geothermal plants have been linked to subsidence, or the slow sinking of land. This happens as the underground fractures collapse upon themselves. In some areas of New Zealand, the ground under a geothermal power plant subsides at a rate of almost a half a meter every year. This can lead to damaged pipelines, roadways, buildings, and natural drainage systems.

10.2.3.3 Water Depletion

1. Water-based geothermal system can/will deplete the naturally existing underground water (over time). In general, geothermal systems need additional replenishing sources of water, because the steam released exceeds the amount of water that naturally flows into the systems. To restore some of the former capacity, 'water injection' is used. Re-injecting water can sometimes help a cooling geothermal site last longer. However, this process can cause earthquakes. The process of injecting high-pressure streams of water into the Earth can result in minor seismic activity, or small earthquakes.
2. In some geothermal power systems, when electrical power is generated [some amount of] steam is lost to evaporation.
3. Depending upon how it is used and controlled, wastewater (from human or other animal waste) can be used as an alternative replenishing source of water. In other words, wastewater can be used for 'water injection'. Waste water injection projects serve the dual purpose of eliminating wastewater,

which would otherwise be dumped into local waterways, and rejuvenating geothermal reservoirs with new water sources.

10.2.3.4 Heat depletion

1. Geothermal power is considered to be sustainable, because the heat extraction is small compared to the Earth's heat content. Extraction, however, must still be monitored to avoid local depletion. Although geothermal sites are capable of providing heat for many decades, individual wells may cool down or run out of water. Most wells that extract heat from the Earth will eventually cool, especially if heat is extracted more quickly than it is given time to replenish. Hence geothermal system require appropriate control/management over the amount of energy extracted.

10.2.3.5 Aesthetics

1. Geothermal power plants can be designed to blend-in to their surrounding more so than other power generation methods, and they can be located on multiple-use land.

10.2.3.6 Travel

1. The land around geothermal vents is often unstable, and unfit for human habitation. Hence, teams who work at geothermal stations may have to travel some distance from their place of habitation.

10.2.3.7 Seismicity

1. Earthquake activity (seismicity) is generally caused by displacement across active faults in tectonically active zones. An earthquake occurs when a body of rock is ruptured and radiates seismic waves that shake the ground. Although it typically occurs naturally, seismicity has at times been induced by human activity, including the development of geothermal fields, through both production and injection operations.

11 Nuclear power

Nuclear power uses refined nuclear material, which has been turned into a fuel rod. The fuel rod is placed in water where the to heat created by fission turns the water into steam. The steam turns the blades of a steam turbine to produce electricity. Nuclear power is the process of capturing nuclear energy within a machine called a "nuclear reactors" to produce electricity by means of a turning a magnetic-electricity generator. Nuclear power typically enables electricity generation by creating massive amounts of heat. The heat is applied to water to produce steam, and the steam turns a turbine(s) to create electricity. Nuclear power is carbon emission free, but not steam emission free.

> **NOTE:** *Nuclear is not technically renewable because the process degrades atomic material. Modern nuclear reactors also are a very low environmental impact technology.*

There are several possible elements that can be used as the fuel inside nuclear reactors, which generate enough heat to move turbines and generate electricity:

1. Thorium.
2. Uranium.
3. Caesium.
4. Plutonium.

A nuclear power generation system achieves its function by two possible processes:

1. **Boiling water reactor (BWR)** - A boiling water reactor uses nuclear fuel (often in the form of rods of easily fissionable material) to boil water. This water turns to steam, which powers massive turbines that generate the electricity. A BWR nuclear power plant typically uses uranium ore in its fuel rods. The uranium fuel rods generate heat via the radioactive decay of uranium isotopes (types of uranium atoms). This is called nuclear fission. The "reactor's" core generates more heat than is needed to produce steam, so boiling water reactor designs feature massive cooling towers to expel the excess heat and steam.
2. **Pressurized water reactor (PWR):** Water needs to be pressured to stay in liquid form and effectively cool this type of reactor. A pressurized water reactor is a "light" water reactor that uses uranium fuel rods to heat water under high pressure. The water circulates from the reactor core to a steam generator, where it heats a separate supply of water that forms steam to turn turbines that generate electricity. Unlike a boiling water reactor, a pressurized water reactor design keeps boiling water away from nuclear fuel, thus reducing the

risk of a nuclear accident.

3. **Molten salt reactors** *(are in an experimental prototype phase of development)* - use molten salt as the medium. These reactors need no pressurization. The molten salt passively cools itself and will quickly solidify when exposed to air (thus, reducing the likelihood of contamination). Molten salt reactors can be powered by a variety of nuclear materials, including formerly existing nuclear waste.
   A. A molten salt reactor requires highly specialized materials and equipment, including but not limited to:
      1. Highly resistant to corrosion materials.
      2. High-temperature salt pumps.
   B. A thorium-powered molten salt reactor consists of two principal elements:
      1. The thorium fuel source - thorium is not fissile, and hence, cannot sustain a nuclear fission reaction. Instead, it is classified as fertile, and hence, can "capture" a neutron, and eventually decay into uranium-233. The Uranium-233 is fissile, and hence, can sustain a nuclear reaction.
      2. The molten salt. Molten salt is salt that has been heated to the point that it turns molten (liquid). A molten salt reactor uses molten salt for two functions:
         i. As a coolant.
         ii. As the medium into which fissionable and fissile material is dissolved.
      3. Starter nuclear chemical to start the chain reaction, such as uranium-235, because it emits high-energy gamma radiation (continuously).
   C. The benefits of thorium include, but may not be limited to:
      1. Its abundance over other nuclear materials.
      2. It is a waste product of rare earth mineral mining.

Nuclear power has multiple advantages compared to other electrical power generation sources:

1. Minimal carbon emissions: Nuclear power does not emit greenhouse gases like carbon dioxide (CO2) or methane (CH4) during electricity generation. Nuclear power does not emit combustion by-particles (e.g., ash). These characteristics sets it apart from the combustion of fossil fuels like coal, oil, and natural gas.
2. Abundant supply: The planet has many deposits of uranium that can easily accommodate existing nuclear energy systems.
3. High capacity factor: Nuclear power plants provide a strong return on the energy expenditure that goes toward building and operating them. Compared to fossil fuels like coal and natural gas and renewables like solar and wind, nuclear comes closest to exploiting the maximum possible energy generation for a plant at a given time.

There are four principal disadvantages to nuclear power:

1. Economics: The cost of extracting and transporting uranium, mixed with the cost of building and safely operating a plant, makes nuclear power less cost-effective than coal or natural gas. The cost of operating a nuclear power plant is high, both in terms of materials, labor, as well as safety and [planetary] security.
2. Nuclear waste: Nuclear power plants create electricity via nuclear fission, and the "spent" fuel from fission are radioactive waste. Nuclear waste must be stored on-site or transported to a secure location via railroad. This is an expensive and potentially dangerous process, and the nuclear waste storage tanks where the waste ends up may leak radioactive liquid into the soil.
3. Meltdowns: Nuclear power works via a set of interoperable conditions and processes (Read: chain reactions). Without proper cooling, these chain reactions can spiral out of control, overwhelming safety systems and leading to the melting of the nuclear reactor core in an event called a “core meltdown.”

11.1 Nuclear waste

Spent nuclear fuel is still radioactive and must be stored appropriately for biological safety. Generally, spent fuel is placed in underground bunker-type environments made of concrete and lead, with "no dig" signs and symbols written there so that future generations do not accidentally dig it up.

11.2 Radiation risks

Ionizing radiation can cause immediate damage to a person's body, including, at very high doses, radiation sickness and death. At lower doses, ionizing radiation can cause health effects such as cardiovascular disease and cataracts, as well as cancer. Because of the serious risk of ionizing radiation, nuclear power plants are costly and humans working in them require special, expensive equipment.

12 Hydrogen power

A.k.a., Hydrogen energy or hydrogen fuel.

Hydrogen power refers to the utilization of hydrogen gas (H2) as a source of energy. Hydrogen power can be harnessed through various technologies and applications, such as fuel cells and combustion engines. Hydrogen can be combusted or put in a hydrogen fuel cell to produce electricity by combining hydrogen and oxygen atoms. In the early 21st century, hydrogen is not easily available and cost of production is high. Unlike other gases, hydrogen is not readily available in the atmosphere. There are two primary ways to produce hydrogen:

1. Gaseous - hydrogen production via electrolysis involves using an electric current to split water molecules (H2O) into hydrogen gas (H2) and oxygen gas (O2). This process requires the use of an electrolyzer, which typically consists of two electrodes submerged in water and connected to a power source, such as renewable energy, to facilitate the chemical reaction.
2. Electrolysis - hydrogen production via the gaseous method involves the conversion of fossil fuels, such as natural gas or coal, into hydrogen gas through a process called steam methane reforming or coal gasification. This method releases carbon dioxide (CO2) as a byproduct, which needs to be captured and managed to minimize environmental impacts.

To make hydrogen useful as a fuel, a process is required:

1. Acquire material and machines to produce concentrated hydrogen.
2. Compress hydrogen into a tank.
3. Use hydrogen in a machine:
   A. Combustion machine.
   B. Electrolysis machine.

Significant amounts of hydrogen are made two ways and have the foliowing color-labeled names:

1. Black hydrogen - hydrogen made from coal. In the early 21st century, 1/3rd of all hydrogen is made from coal.
2. Gray hydrogen - hydrogen made from the combustion of natural gas.
3. Blue hydrogen - is gray hydrogen with the extra step of burring some of the CO_2 from the combustion of the natural gas and burring it in the ground, which itself creates CO_2. It is gray hydrogen with the extra step of burring some of the CO_2.

12.1 Hydrogen combustion power

Hydrogen can be used in combustion engines, similar to traditional internal combustion engines fueled by gasoline or diesel. However, instead of burning hydrocarbon fuels, these engines burn hydrogen gas, which produces only water vapor as a byproduct.

12.2 Hydrogen fuel cell electrical power production

Hydrogen fuel cells are devices that generate electricity by combining hydrogen with oxygen from the air, producing water vapor as a byproduct. The electrochemical reaction within the fuel cell provides a clean and efficient method of converting hydrogen's chemical energy directly into electrical energy.

The process to make hydrogen useful as a source of electrical power, requires electrical power itself. For example, to produce 1kg of hydrogen, in the early 21st century, ~50kwh of electrical power are required. Then, ~2.5kwh are required to compress the hydrogen gas into a 700bar tank. Then, the hydrogen put it through a proton exchange membrane electrolysis (PEM) system to get 15kwh of electricity as output.

13 Energy from biomass and hydrocarbon

A.k.a., Biomass energy.

Hydrocarbons are different than carbohydrates. Hydrocarbons, per se, only contain hydrogen and carbon. The word "carbohydrate" means: carbo - carbon; hydr - hydrogen; ate - oxygen. Lipids (fats) are organic compounds that contain the same elements as carbohydrates: carbon, hydrogen, and oxygen. However, the hydrogen-to-oxygen ratio is always greater than 2:1. Proteins also contain carbon, hydrogen, and oxygen like carbohydrates and lipids, but they also contain nitrogen, and often, sulfur and phosphorus. All biomass is composed of some combination of carbohydrates, lipids, and/or proteins.

13.1 Biomass

Biomass is the term for organic matter derived from living organism, recently living organisms, and their waste that can be used as a source of energy. Biomass is "organic", meaning it is made of material that comes from living organisms and contains carbon atoms. Biomass may also be defined as biologically-produced matter based in carbon, hydrogen, and oxygen also. Biomass contains potential energy originating from the sun. Energy obtained from any biomass source is often called "bioenergy". Biomass can be combusted to turn a turbine and produce electrical power. Biomass can be composted to produce natural gas and soil.

As an energy carrier ("source"), biomass can either be used directly via combustion to produce heat and light, or indirectly after converting (concentrating and purifying) it to various forms of biofuel. Biomass can be used to produce heat (thermal energy), light (as visible EM radiation), mechanical power, electrical power, and fuel (as well as compost). Biomass can be transformed into usable carriers of energy through direct and indirect means. Biomass can be burned/combusted to produce heat and light (direct), converted into electrical and mechanical power (directly through heat), or processed into biofuel (indirect). In other words, as an energy source, biomass can either be used directly to produce heat and light, or indirectly after converting it to various forms of biofuel (i.e., an energy storage medium).

> **NOTE:** *Biomass is thought to our oldest source of energy after the sun. Combustion (as fire) is understood to be the first controlled chemical reaction discovered by humans, in the form of campfires and bonfires. The ability to control fire (as a technology) led to dramatic changes in the habits (and potentially, the physiology) of early hominids. The combustion of biomass (plant material and animal waste) is the oldest known source of power production.*

Biomass generation is an integral part of Earth's carbon cycle. The carbon cycle is the process by which carbon is exchanged between all layers of the Earth: atmosphere, hydrosphere, biosphere, and lithosphere. Between periods of exchange, carbon is sequestered (stored as terrestrial/biologic or geologic). The carbon in fossil fuels has been sequestered for millions of years. Unlike plants, when hydrocarbons present in fossil fuels are extracted and burned for energy, their sequestered carbon is released into the atmosphere at a volume that cannot be immediately re-sequestered by the earth's natural carbon cycle. Fossil fuels take thousand years to form naturally. They cannot be replaced and sequestered as fast as they can be consumed.

In contrast to fossil fuels, biomass comes from recently living organisms. The carbon in biomass can continue to be exchanged by the carbon cycle. This is because biomass has a lower 'energy density' than fossil fuels. In order to ensure that the carbon cycle continues as trending and desired, biomass materials/resources must be sustainably farmed.

> **NOTE:** *Biomass can be combusted or converted to biofuel.*

13.2 Biomass sources

> **NOTE:** *Biomass is the same energy that makes fossil fuels. Fossil fuels are made through the concentration of biomass over time by heat and pressure within the earth.*

Technically, any plant or animal matter could be used as a source of biomass, because it will contain hydrogen, carbon, and oxygen. A wide variety of biomass forms are available on the planet, and biomass can be produced anywhere that plants or animals can live.

Well-known and highly effective sources of plant matter biomass include, but are not limited to: hemp, bamboo, corn, miscanthus, poplar, switchgrass, sorghum, sugarcane, and a variety of tree species, ranging from willow and eucalyptus, to oil palm (palm oil). Animal waste is another common form biomass.

Biomass resources can be classified as follows:

1. Biologically cultivated materials and residues (e.g., agricultural, aquaculture, permaculture, algae-culture etc.).
2. Forestry materials and residues.
3. Food residues and by-products.
4. Animal by-products (tallow, fish oil).
5. Animal/human solid waste.
6. Landfill gases.
7. Cellulose products (e.g., paper and cardboard).

13.2.1 Biofuel

Plant and animal matter, as an originating source of biomass, can be converted into biofuel. A **biofuel** is a fuel that is produced through natural biological processes, such as anaerobic digestion, rather than a fuel produced by geological processes, such as those involved in the formation of fossil fuels from prehistoric biological matter. Biofuels are classified into two primary categories:

1. First-generation biofuels - First-generation biofuels are derived from food-based biomass sources, which are fermented via sugars (carbohydrates/starch) present in the biomass to produce bioethanol. Bioethanol is an alcohol fuel that can be used directly in a fuel cell to produce electricity, or serve as an additive to gasoline.
2. Second-generation biofuels - Second-generation biofuels utilize non-food-based biomass sources. These biofuels mostly consist of lignocellulosic biomass, which is not edible. Lignocellulosic is a chemically inert and structural rigid form of biomass. Advanced second-generation biofuels are generally made from non-food feedstocks (feedstock that could not also be used as food), such as municipal waste, algae, perennial grasses, and wood chips. These fuels include cellulosic ethanol, bio-butanol, methane gas (biogas), methanol and a number of synthetic gasoline/diesel equivalents.

13.3 Biomass creation

> **NOTE:** *The faster a plant grows, the more efficient it is as a source of biomass energy.*

Technically, all biomass (energy) is derived from plant- or algae-based material, which derives a significant portion of its energetic existence from solar electromagnetic radiation. Plants and other living organisms absorb the sun's energy, and use it to create the organic matter of their body. When biomass is burned, this stored energy is released as electromagnetic (and thermal) energy.

Through the use of solar electromagnetic radiation (energy), green plants convert carbon dioxide and water into carbohydrates and oxygen in a process called photosynthesis. It could be said that these plants "breath in" carbon dioxide and "breathing out" oxygen; however, in plants respiration is a different process. In green plants both photosynthesis and respiration occur as separate processes. During photosynthesis, water is broken down to form oxygen, and during cellular respiration, oxygen is combined with hydrogen to form water. Hence, plants, unlike other living things, produce oxygen. Essentially, photosynthesis is the opposite of [cellular] respiration.

> DEFINITION: **Photosynthetically active radiation (PAR)** *designates the spectral range (wave band) of solar radiation from 400 to 700 nanometers that photosynthetic organisms are able to use in the process of photosynthesis. This spectral region corresponds more or less with the range of light visible to the human eye. Other living organisms, such as Cyanobacteria, purple bacteria and Heliobacteria, can exploit solar light in slightly extended spectral regions, such as the near-infrared. These bacteria live in environments such as the bottom of stagnant ponds, sediment, and ocean depths. Because of their pigments, they form colorful mats of green, red and purple.*

In relatively bright light, photosynthesis is the dominant process. During photosynthesis, chlorophyll, the pigment that makes plants green, absorbs electromagnetic radiation (energy) from the sun and uses it along with carbon dioxide and water to make carbohydrate molecules (sugars). Carbohydrates are complex compounds composed of carbon, hydrogen, and oxygen. At night, or in the absence of light, photosynthesis essentially ceases (in most plants), and respiration is the dominant process. However, plants respire continuously, day and night -- respiration does not depend on light. Whereas photosynthesis absorbs energy (from sunlight), aerobic respiration yields energy (as a result of the oxidation of glucose (a carbohydrate molecule, $C_6H_{12}0_6$).

1. Photosynthesis:
   - $6CO_2$ + $6H_20$ + energy/energy in > $C_6H_{12}0_6$ + $6O_2$
2. Aerobic respiration:
   - $C_6H_{12}0_6$ + $6O_2$ > $6CO_2$ + $6H_20$ + energy/energy out

Biomass generation requires carbon dioxide; hence cultivated and combusted biomass in the appropriate ratio is carbon dioxide neutral. When the carbohydrates that plants have made are burned, they turn back into carbon dioxide and water, and release the energy they captured from the sun.

> **NOTE:** *Some plants absorb carbon dioxide at during the day, and release oxygen at night. Typically, desert plants, such as cactus and other succulents, and epiphytic bromeliads and orchids from the jungle absorb CO_2 during the day and release oxygen at night. These plants include, but are not limited to snake plants, Easter and Christmas cactus, aloe vera plants (a species of succulent plant), mother-in-laws tongue, areca palm, a variety of bromeliads, and orchids such as the moth and the dendrobium.*

Plant-based biomass is often specifically called 'lignocellulosic biomass'. Lignocellulose is composed of carbohydrate polymers (cellulose, hemicellulose), and an aromatic polymer (lignin).

> **NOTE:** *The efficiency of photosynthesis is low, about 5% maximum (solar energy to energy in sugar).*

In general, good biomass material is a combination of cellulose (~60%), lignin (~30%), and other organic materials (~10%). Cellulose and lignin start with simple sugars (glucose) made through photosynthesis. Cellulose is a fiberous organic compound used as structural material in plants (fibers). Cellulose is the most abundant organic polymer on Earth. Lignin is a class of complex organic polymers that form important structural materials in the support tissues of vascular plants and some algae.

Algae is a source of biomass energy. Some algaes produce energy through photosynthesis at a much higher rate than any other biomass source. Further, algae contains oils that can be converted into biofuels (and/or food). Algae can be fermented to produce biofuels such as ethanol, butanol, and methane, as well as biodiesel and hydrogen. Algae can be grown in salt and fresh water; it does not require soil. Algae takes up much less space to produce than other biomass/ biofuel crops; particularly because algae can be grown in bioreactors.

13.4 Biomass to biofuel conversion technologies

Biomass can be converted into a more concentrated energy carrier/source known as biofuel (also known as 'direct energy' or a 'concentrated energy resource'). Biofuels are easier to transport and are more energy dense than their original biomass resource. Also, their combustion characteristics are more convenient and predictable than raw biomass. The conversion of biomass to biofuel can be achieved by different methods, which are broadly classified into: thermo-chemical, biochemical, and chemical. The conversion process leads to biofuel that can take any of the following three forms of matter: biofuel solid; biofuel liquid; or biofuel gas.

1. **Thermo-chemical conversion** is the application of heat and chemical processes in the production of concentrated energy products from biomass (i.e., biofuel).
2. **Biochemical conversion** involves use of enzymes, bacteria, or other microorganisms to break down biomass into liquid fuels. The primary processes are anaerobic digestion/decomposition, fermentation, and composting.
3. **Chemical conversion** involves use of chemical agents to convert biomass into liquid fuels.

Note that hydrocarbons (as hydrocarbon fuels) can be derived from some biomass. There are a variety of ways of producing hydrocarbons from biomass since biomass is a mixture of carbon, hydrogen, and oxygen, and a pure hydrocarbon consists entirely of hydrogen and carbon. For instance, gasification converts whole biomass into a mixture of carbon monoxide and hydrogen gases, which can then be used to synthesize hydrocarbons.

13.4.1 Thermo-chemical conversion

Thermo-chemical conversion involves the use of heat as a significant mechanism for the chemical conversion of biomass into biofuel. Pyrolysis, torrefaction, and gasification are the basic thermochemical conversion technologies.

1. **Torrefaction -** Before biomass can be combusted, it must be dried. Torrefaction, like pyrolysis, is the conversion of biomass to a drier and refined form with the application of heat in the absence of oxygen, but at lower temperatures than those typically used in pyrolysis. During torrefaction, biomass is heated to about 200°C - 320°C. The biomass dries out so completely that it loses the ability to absorb moisture, or rot. It loses ~20% of its original mass, but retains 90% of its energy. The lost energy and mass can be used to fuel the torrefaction process. Torrefaction produces a solid biofuel. During torrefaction, biomass becomes a dry (generally, black) material. It is then compressed into briquettes. Biomass briquettes are hydrophobic, meaning they repel water. This makes it possible to store them in moist areas. The briquettes have a high energy density and are easy to burn.
2. **Pyrolysis** - Heating biomass to 200°C - 320°C in a pressurized environment without the presence (or with a very low presence) of oxygen. The absence of oxygen prevents combustion, causing a different chemical alteration to the substance. Pyrolysis produces a dark liquid called pyrolysis oil, a synthesis gas called syngas, and a solid residue called biochar.
   A. **Pyrolysis oil (bio-oil or biocrude)** - a type of tar (a mixture of hydrocarbons and free carbons). It can be combusted, used as a component in other fuels, and used as a compound in plastic.
   B. **Syngas (synthesis gas)** - a fuel gas mixture consisting primarily of hydrogen, carbon monoxide, and often, carbon dioxide. It can be converted into fuel, such as, synthetic natural gas. And, it can be converted into methane (used as a replacement for natural gas).
   C. **Biochar** - a type of charcoal, which consists of carbon and any remaining ash, obtained by removing water and other volatile constituents from animal and vegetation substances. Biochar is high in carbon. It is used as a soil amendment/conditioner. Biochar enriches soil and prevents it from leaching pesticides and other nutrients into runoff. Biochar is also an excellent carbon sink. Carbon sinks are reservoirs for carbon-containing chemicals,

including greenhouse gases.

D. **Gasification** - A process that converts organic or fossil fuel based carbonaceous materials into carbon monoxide, hydrogen, and carbon dioxide, producing syngas and slag. During the gasification process, a biomass feedstock is heated to more than 700° C with a controlled amount of oxygen. During gasification, syngas is purified of sulfur, mercury, and other polluting particulates. Slag, a by-product of the process, forms as a glassy, molten liquid, which can be used to make shingles, cement, or asphalt.

13.4.2 Biochemical conversion

Many highly efficient biochemical processes have developed in nature to break down the molecules of which biomass is composed. Biochemical conversion processes use the enzymes of bacteria and other microorganisms (e.g., fungi) to convert biomass to gas and liquid fuels.

The primary processes are anaerobic digestion/decomposition, fermentation, and composting:

1. **Anaerobic decomposition/digestion to methane** - the process by which microorganisms break down organic material in an oxygen-free (or low oxygen) environment. Anaerobic digestion is widely used for the production of methane- and carbon-rich biogas from biomass (e.g., crop residues, food scraps, and human and animal waste). Anaerobic digestion is frequently used in the treatment of wastewater, and to reduce emissions from landfills. Controlled anaerobic digestion is usually a multi-stage process. First, the carbohydrates are broken down. The resulting sugars and amino acids are then converted into carbon dioxide, hydrogen, ammonia, and organic acids. Finally, these products are converted into methane and carbon dioxide. Microorganisms are used in each stage of the process. These mixed cultures allow digesters to be operated over a wide temperature range, for example, above 0° C and up to 60° C. Solid remnants of the original biomass input are left over after the digestion process. This by-product, or digestate, has many potential uses. Potential uses include fertilizer (although it should be chemically assessed for toxicity and growth-inhibiting factors first), animal bedding and low-grade building products like fiberboard. Methane production is most useful with animal and human wastes, as well as landfill wastes, where it happens naturally.
2. **Fermentation to biofuel** - a biological/metabolic process by microorganisms that converts carbohydrate (sugar) to acids, gases, or alcohol (e.g., ethanol). Fermentation generally involves multiple stages. The science of fermentation is known as zymology. Biomass is the only short-term renewable energy source that can be converted into liquid biofuels, such as ethanol and biodiesel. Ethanol is made by fermenting biomass that is high in carbohydrates, such as hemp, sugar cane, wheat, or corn through ethanol/alcoholic fermentation. Biodiesel is made from combining ethanol with animal fat, recycled cooking fat, or vegetable oil. Biofuels do not combust as efficiently as petrol. They can, however, be blended with petrol.
   A. **Ethanol fermentation** (alcoholic fermentation) - converts sugars such as glucose, fructose, and sucrose into cellular energy, producing ethanol and carbon dioxide as a by-product. Note that as a material resource, ethanol can be used as a consumable, as a disinfectant, and as a fuel.
3. **Composting** - the process by which organic matter is decomposed and recycled as a fertilizer and soil amendment. Bacteria requiring oxygen to function (aerobic bacteria) and fungi manage the chemical process by converting the inputs into heat, carbon dioxide and ammonium. Note that the composting process naturally produces heat (thermal energy).

13.4.2.1 Biogas

Biogas is the common name for the mixture of gases released from anaerobic digestion. Biogas is comprised of methane (50 to 75%), carbon dioxide (25 to 50%) and varying quantities of nitrogen, hydrogen sulphide, water vapour and other components. Biogas can be collected and burned for fuel (like propane).

13.4.3 Chemical conversion

The utilization of chemical processes to convert biomass into biofuel.

1. **Transesterification** - Transesterification is a chemical reaction through which fatty acids from oils, fats, and greases are bonded to alcohol. This process reduces the viscosity of the fatty acids and makes them combustible. It is an organic chemistry process wherein the organic group R" of an ester is exchanged with the organic group R' of an alcohol. The process refers to a reaction between an ester of one alcohol and a second alcohol to form an ester of the second alcohol and an alcohol from the original ester. It is the most common form of chemical-based conversion. Biodiesel is a common end-product of transesterification, as are glycerin and soaps. For instance, mixing methanol with sodium hydroxide will create sodium methoxide. This liquid can then be mixed into vegetable oil.

When the mixture settles, glycerin is left on the bottom and methyl esters, or biodiesel, is left on top. The glycerin can be used to make soap (or many other products), and the methyl esters are washed and filtered. Almost any bio-oil (e.g., soybean oil), animal fat or tallow, or tree oil can be converted to biodiesel. Transesterification of algal oil is frequently accomplished with ethanol and sodium ethanolate serving as the catalyst.
2. **Black liquor production** - The kraft process (also known as kraft pulping or sulfate process) is a mechanical-chemical process that converts wood into the main component of paper using a hot mixture of water, sodium hydroxide, and sodium sulfide, known as white liquor, that breaks the bonds that link lignin, hemicellulose, and cellulose. One of the by-products of the process is known as "black liquor", which retains more than 50% of the wood's biomass energy. Black liquor can be used as a biofuel feedstock.
3. **Hydrogen production** - Biomass has a high concentration of hydrogen, which can be chemically extracted and used as an energy source (e.g., hydrogen fuel cells).

13.5 Hydrocarbons

CLARIFICATION: *Hydrocarbons are always named based on the longest carbon chain. When a hydrocarbon has a double bond we replace the -ane ending with -ene. When the hydrocarbon has more than three carbon the position of the double bond must be specified with a number. Hydrocarbons with triple bonds are named basically the same, we replace the -ane ending with -yne. Cyclic hydrocarbons with delocalized bonds are called aromatic hydrocarbons the most common of these is benzene.*

Hydrocarbon molecules have a high energy density relative to other molecules, and are "easy" to store and transport. Hydrocarbons are the simplest form of organic [lipid] compound, and contain only carbon and hydrogen (i.e., hydrogen + carbon only).

1. Biomass hydrocarbons.
2. Fossil hydrocarbons.

Hydrocarbons can be found in the forms of matter:

1. Gases (e.g. methane and propane).
2. Liquids (e.g. hexane and benzene).
3. Waxes or low melting solids (e.g. paraffin wax and naphthalene).
4. Polymers (e.g. polyethylene, polypropylene and polystyrene).

Hydrocarbons can be classified at a top-level as either open chain or closed chain:

1. **Aliphatic hydrocarbons (open chain)** - - formed by successive bonds between carbon atoms and may be branched or unbranched (linear or "normal"). Herein, the overall geometry of the molecule is altered by the different geometries of single, double, and triple covalent bonds. A normal/linear/unbranched hydrocarbon has one chain of consecutively bonded carbon atoms. A branched hydrocarbon has at least one carbon atom not bonded to the end carbon of a chain of consecutively bonded carbon atoms. Instead, at least one carbon atom forms a bond to an inner carbon atom in the chain of consecutively bonded carbon atoms. Aliphatic hydrocarbons (open chain) can be either saturated or unsaturated hydrocarbons, neither of which contain a benzene ring. Aliphatic hydrocarbons are classified based on the structure and bonding of the carbon skeleton into one of three groups: alkanes (saturated); alkenes (unsaturated double bond), and alkynes (unsaturated triple bond). Saturated hydrocarbons consist entirely of single bonds, wherein each carbon atom is connected to four other atoms. Unsaturated hydrocarbons have one or more double or triple bonds between carbon atoms. Aliphatic hydrocarbons tend to be flammable; they combust (undergo transformation) through which old bonds are broken, and new bonds are formed.
   A. **Alkanes (a.k.a., saturated hydrocarbons; paraffins)** - Alkane molecules are those chemical structures that are based on carbon atoms having only single bonds, and that are completely saturated with hydrogen atoms. Each carbon atom is connected to four other atoms; either another carbon within the skeletal structure, or a hydrogen atom. Saturated hydrocarbons are the basis of petroleum fuels and are found as either linear or branched species. Alkanes can be described by the formula: C_nH_{2n+2}, where 'n' is the number of carbon atoms present. An example includes, methane, where n=1, described by: CH_4
   B. **Alkenes (a.k.a., olefins; unsaturated form of hydrocarbon)** - Alkene molecules contain at least one carbon-carbon double bond. Alkenes can be described by the one double bond formula: C_nH_{2n} (assuming non-cyclic structures). Alkene hydrocarbons are present in most organic and biological molecules. Alkene compounds do not occur naturally in crude oil, but are produced by reaction during the refining process. Example alkenes include: ethylene;

propylene; or butylene.

C. **β-Carotene carotenoids** (a.k.a., tetraterpenoids and terpenoids) - Carotenoids are organic pigments that are found in the chloroplasts and chromoplasts of plants and some other photosynthetic organisms, including some bacteria and some fungi. Carotenoids can be produced from fats and other basic organic metabolic building blocks by all these organisms. There are over 600 known carotenoids, which are classified into two classes: xanthophylls (which contain oxygen) and carotenes (which are purely hydrocarbons, and contain no oxygen). Carotenes typically contain only carbon and hydrogen (i.e., are hydrocarbons), and are in the subclass of unsaturated hydrocarbons. The term, carotenoid, is a misnomer and originates from a scientist (1831) who proposed the term "carotene" for the hydrocarbon pigment he had crystallized from carrot roots.

D. **Alkynes (unsaturated form of hydrocarbon)** - Alkyne molecules contain at least one carbon-carbon triple bond. Alkynes can be described by the one triple bond formula: C_nH_{2n-2}. Alkyne hydrocarbons rarely occur in biological molecules or pathways.

2. **Cyclic hydrocarbons (closed chain)** - formed by successive rings of carbon. Whenever the ends of a carbon chain are joined together, that molecule is said to be cyclic.

A. **Cycloalkanes** (cycloparaffins or naphthenes, distinct from naphthalene) - are the cyclic analog of an alkane. Cycloalkanes are alkanes that consist entirely of single bonds with at least three carbon atoms linked together to form a structural ring (hence, the prefix 'cyclo-'). In other words, cycloalkanes are alkanes in which all or some of the carbon atoms are arranged in a ring. Cycloalkanes are monocyclic <u>saturated</u> hydrocarbons, and hence, are arranged in a structure containing a single ring (monocyclic, possibly with side chains), and all of the carbon-carbon bonds are single. Note here that there are also polycyclic alkanes, which are molecules that contain two or more monocyclic cycloalkanes that are joined, forming multiple rings. If the carbon chain that forms the backbone of a straight-chain hydrocarbon is long enough, we can envision the two ends coming together to form a cycloalkane. One hydrogen atom has to be removed from each end of the hydrocarbon chain to form the CC bond that closes the ring. Cycloalkanes therefore have two less hydrogen atoms than the parent alkane. When a cycloalkane contains only one ring, the general formula is C_nH_{2n}. However, the complete chemical formula for cycloalkanes is $C_nH_{2(n+1-r)}$, where n is the number of carbon atoms and r is the number of rings. Cycloalkanes are named analogously to their normal alkane parent counterpart of the same carbon count: cyclobutane; cyclopropan; cyclobutane; cyclopentane; cyclohexane; etc. The larger cycloalkanes, with more than 20 carbon atoms are typically called cycloparaffins.

B. **Cycloalkenes** - are the cyclic analog of an alkene. Cycloalkenes are alkenes that consist of three or more carbon atoms linked together with at least one carbon-carbon double bond to form a structural ring (hence the prefix 'cyclo-'). They have no aromatic character.

C. **Cycloalkynes** - are the cyclic analog of an alkyne. A cycloalkyne consists of a closed ring of carbon atoms containing one or more triple bonds. Cycloalkynes have a general formula C_nH_{2n-4}.

D. **Aromatic hydrocarbons (arenes or aryl hydrocarbon)** - have at least one benzene-like ring (i.e., aromatic ring) of alternate single and double bonds with delocalized pi electrons between carbon atoms forming the ring(s). A benzene ring is a ring of six carbons with alternating double and single bonds. As a result, the benzene has six hydrogens and the formula for a benzene molecule is C_6H_6. Aromatic hydrocarbons can be monocyclic (MAH) or polycyclic (PAH). These compounds possess unique properties due to the delocalized electron density in benzene, including additional stabilization. Note that the term 'aromatic', and was assigned before the physical mechanism determining aromaticity was discovered; the term was coined because many of the compounds have a sweet or pleasant odour.

Some sources of biomass contain hydrocarbon substances known as terpenoids, which are similar to petroleum. These plants and algaes are known as "hydrocarbon plants" (or "petro-plants") and "hydrocarbon algaes". Hydrocarbon plants use unique metabolic pathways to produce hydrocarbon products. For instance, some of these plants produce a type of natural rubber (e.g., latex) that contains liquid hydrocarbon terpenoids of a high molecular weight, which can be converted into fuel and other products. Natural rubber is a hydrocarbon that contains long chains of alternating C=C double bonds and C-C single bonds. Terpenoid hydrocarbons may be extracted from the bulk matter of such plants through the use of organic solvents.

Well known families of hydrocarbon plants include, but are not limited to: Apocynaceae, Asclepiadaceae, Dipterocarpaceae, Euphorbiaceae, Hardwickia Pinnata (family Leguminosae), Moraceae, Sapotaceae, and sunflower (family Composiae). The latex of Euphorbia Lathyrus contains a fairly high percentage of terpenoids. And, the carbohydrate (hexose) from such plants can be used for ethanol formation.

13.6 Power from biomass, fossil fuels, and other hydrocarbons

Combustion is the primary way by which power is produced from biomass, biofuel, fossil fuel, and other hydrocarbons. Biomass (and its refined products) can be ignited and combusted for heat, light, and fluid [gas] pressure. Take note that when gases are combusted they generally expand irreversibly, and the fluid pressure which has been generated may be used to power a turbine or an engine.

1. **Combustion as direct firing/burning** - the direct burning of biomass or biofuel in the presence of oxygen. Fire can be used for heat, light, and/or fluid [gas] pressure.
   A. In a furnace, biomass burns in a combustion chamber converting the biomass into heat. The heat may be distributed in the form of hot air or water. A common type of furnace for area heating is known as a wood-pellet stove. A pellet stove is a stove that burns compressed wood or biomass pellets to create a source of heat. Wood pellets are the most common type of pellet fuel and are generally made from compacted sawdust and related industrial wastes from the milling of lumber, manufacture of wood products and furniture, and construction. The biomass (possibly in the form of pellets) are placed in a hopper, which feeds the mass into a furnace, where it is burned. The heat may used to boil water in a boiler. In a boiler, the heat of combustion is converted into steam. Steam can be used to produce mechanical energy through a turbine, electrical energy through a turbine-generator, or heating.
   B. In an engine, combustion occurs as a flame that propagates in a cylinder.
2. **Combustion as co-firing/co-generation** - Biomass is combusted with a fossil fuel, often in pre-existing fossil fuel (coal) plants. Biomass can also be used in co-generation (a.k.a., combined heat and power, CHP), which is the simultaneous production of heat and electricity.

Some biofuel technologies can be directly converted into electrical power via electrochemical oxidation of the material. This electrochemical process can occur in carbon fuel cells, ethanol fuel cells, and microbial fuel cells. The fuel can also be consumed indirectly via a fuel cell system containing a reformer which converts the bio-mass into a mixture of CO and H_2 before it is consumed in the fuel cell.

14 Energy storage (secondary energy carriers)

CLARIFICATION: *Primary energy carriers include all of the natural resources like natural gas, crude oil, coal, uranium, solar radiation, wind power, hydropower, and geothermal energy. Secondary energy carriers are those carriers of for which the production of other energy was needed (i.e., they required charging/ producing by another power source).*

Energy can be stored in a variety of different carriers. There are many different types of energy stored in materials, and it takes a particular type of reaction to release each type of energy. In order of the typical magnitude of the energy released, these types of reactions are: nuclear, chemical, electrochemical, and electrical.

NOTE: *Stored energy can be converted to power through the use of appropriate conversion/ release technology.*

Energy storage refers to the storage of useful energy that may either be used directly or transmitted is input in an end-use application.

Energy can be stored only as potential energy. Storing energy requires mass. Today, the most common way of storing energy is in [a mass of] batteries. Energy storage usually means batteries, but there are other ways, like pumped hydro and molten salt. But whatever the technology, there are two primary performance parameters in concern to energy storage. And, the usefulness of an energy storage system depends on both of these quantities. The two quantitative parameters are:

1. How much total energy can the system store? (Think watt-hours)
2. How much power can it deliver at any moment? (Think watts)

Storage systems have to be able to store enough energy to last through the "blackout" periods, and they have to be able to deliver that energy fast enough to meet the electrical load.

Once you know both the energy storage capacity (say, in megawatt-hours) and the output power (say, megawatts), you can simply divide these numbers to find how long the backup power will last. For example, a 20 megawatt-hour storage facility delivering power at the rate of 2 megawatts will last for 20 ÷ 2, or 10 hours on a full charge.

- Fuel - Matter that stores energy is called a '**fuel**'. Materials that store energy for work are called fuels. The amount of energy a fuel or other energy carrying source contains is called 'energy density'. To acquire energy, you must use energy.

The system uses all available energy from locally generated sources (such as photovoltaic cells) first, then 'fills in' with power from the grid or, when the grid is not available, from batteries. Batteries are used to provide electricity power when solar radiation (including, wind and water) is not available, which means for solar, every nights and on cloudy days when the PV array is not producing enough energy to serve the connected loads.

NOTE: *The external energy of a collection of matter, or system, is related to the relative condition of the matter with respect to its environment.*

14.1 Measurement for energy storage

In general, energy storage is measured in Joules. The formula for energy storage is as follows:

- $J = \frac{1}{2}CE^2$ = 1 watt/second
- where, J = joules, C = farads and E = voltage of the charge.

14.2 Energy storage performance parameters

Energy is a quantity that can be calculated for a given static carrier. Therein, **capacity** is the measure of a system's potential to generate power (or in the case of batteries, both generate power and store energy).

All energy storage devices have:

1. A power rating
2. An energy capacity rating
   There are two main things to consider with the choice of energy storage. Directly,
3. Can it produce enough current to the application (e.g., a motor)?
4. Does it have enough stored energy to last a required amount of time (e.g., 1 hour)?

Batteries have:

- Capacity = amp-hours

Energy storage usually means batteries, but there are other ways, like pumped hydro and molten salt. But whatever the technology, there are two performance parameters of interest:

1. How much total energy can the system store? (Think watt-hours)
2. How much power can it deliver at any moment? (Think watts)
3. How much recover efficiency can the system restore

Once you know both the energy storage capacity (say, in megawatt-hours) and the output power (say, megawatts), you can simply divide these numbers to find how long the backup power will last.

There are two performance parameters of interest in energy storage:

1. How much total energy can the system store? (Think watt-hours)
2. How much power can it deliver at any moment? (Think watts)

The usefulness of a storage system depends on both of these quantities. A system that stored an enormous amount of energy wouldn't be very useful if it could only return that energy a few watts at a time. And a system powerful enough to light up a whole city wouldn't be good for much if its batteries died after a few minutes.

14.3 Carriers/sources/modes of energy storage (energy storage systems)

A widely-used approach for classifying EES systems is the determination according to the source/carrier/form of energy used. EES systems are classified into mechanical, electrochemical, chemical, electrical and thermal energy storage systems:

Take note that these energy storage systems are sometimes as [secondary] energy carriers.

14.3.1 Mechanical storage systems

Energy may be "stored" in a mechanical system. There are many different types of mechanical systems utilized for the storage of [mechanical] energy.

1. **Pumped hydro storage** - the storage of water at elevation, which is released when power is required.
2. **Compressed/pressurized air storage** - the storage of compressed gas, which is released when power is required.
3. **Flywheel energy storage** - the storage of rotational mechanical/kinetic energy in an accelerated rotor, which is released when power is required.
4. **Gravitational potential energy** - the storage of mass at elevation, which is released when power is required.
5. **Tension** - the storage of energy in a device that holds tension, which is released when power is required.

14.3.2 Pumped hydro storage (PHS)

NOTE: *Technically, PHS and hydroelectric dam systems store gravitational potential energy - fluids stored at elevation.*

Pumped hydro storage is a method of keeping water in reserve at elevation. The water is pumped to a storage pool above the power generation mechanism at a time when power demand is low, such as during the middle of the night. The water is then allowed to flow back through the turbine-generators at times when demand is high and a heavy load is place on the system.

The reservoir acts much like a battery, storing power in the form of water at elevation when demands are low, and producing maximum power during daily and seasonal peak periods. An advantage of pumped storage is that hydroelectric generating units are able to start up quickly and make rapid adjustments in output.

Conventional pumped hydro storage systems use two water reservoirs at different elevations to pump water during off-peak hours from the lower to the upper reservoir (charging). When required, the water flows back from the upper to the lower reservoir, powering a turbine with a generator to produce electricity (discharging). There are different options for the upper and lower reservoirs. For example, higher elevation dams and ponds can be used as pumped hydro storage plants. For the lower reservoir, flooded mine shafts, underground cavities, and even the open sea are also technically possible. PHS has existed for a long time – the first pumped hydro storage plants were used in Italy and Switzerland in the 1890s. Advantages are the very long lifetime and practically unlimited cycle stability of the installation. Main drawbacks are the dependence on topographical conditions and large land use. The main applications are for energy management via time shift, namely non-spinning reserve and supply reserve.

14.3.3 Compressed air (compressed gas) energy storage (CAES), also pressurized air storage

This is an electro-mechanical storage solution where air (or gas) is compressed with electrical power, and can then be released again to drive a power generator. Electricity is used to compress air (or other gas) and store it in either an underground structure or an above-ground system of vessels or pipes. When needed the compressed air may be used for fluid power, or it may be mixed with natural gas, burned and expanded in a modified gas turbine to produce mechanical and electrical power. Typical underground storage options are caverns, aquifers or abandoned mines. If the heat released during compression is dissipated by cooling and not stored, the air must be reheated prior to expansion in the turbine. This process is called diabatic CAES and results in low round-trip efficiencies of less than 50%. Diabatic technology is well-proven; the plants have a high reliability and are capable of starting without extraneous power. The advantage of CAES is its large capacity; disadvantages are low round-trip efficiency and geographic limitation of locations.

Compression of air creates heat; the air is warmer after compression. Expansion requires heat. If no extra heat is added, the air will be much colder after expansion. If the heat generated during compression can be stored and used during expansion, the efficiency of the storage improves considerably. There are three ways in which a CAES system can deal with the heat. Air storage can be adiabatic, diabatic, or isothermal.

1. **Adiabatic compressed air energy storage (ACAES)** - Adiabatic storage continues to keep the heat produced by compression and returns it to the air when the air is expanded to generate power.
2. **Diabatic compressed air energy storage (DCAES)** - Diabatic storage dissipates much of the heat of compression with intercoolers (thus approaching isothermal compression) into the atmosphere as waste; essentially wasting, thereby, the renewable energy used to perform the work of compression. Upon removal from storage, the temperature of this compressed air is the one indicator of the amount of stored energy that remains in this air. Consequently, if the air temperature is low for the energy recovery process, the air must be substantially re-heated prior to expansion in the turbine to power a generator.
3. **Isothermal compressed air energy storage (ICAES)** - Isothermal compression and expansion approaches attempt to maintain operating temperature by constant heat exchange to the environment.

14.3.4 Flywheel energy storage (FES)

In flywheel energy storage, rotational energy is stored in an accelerated rotor, a massive rotating cylinder.
This type of energy storage system is also sometimes known as a mechanical battery. The main components of a flywheel are the rotating body/cylinder (comprised of a rim attached to a shaft) in a compartment, the bearings and the transmission device (motor/generator mounted onto the stator). The energy is maintained in the flywheel by keeping the rotating body at a constant speed. An increase in the speed results in a higher amount of energy stored. To accelerate the flywheel electricity is supplied by a transmission device. If the flywheel's rotational speed is reduced electricity may be extracted from the system by the same transmission device. Advanced FES systems have rotors made of high-strength carbon filaments, suspended by magnetic bearings, and spinning at speeds from 20000 to over 50000 rpm in a vacuum enclosure. The main features of flywheels are the excellent cycle stability and a long life, little maintenance, high power density and the use of environmentally inert material. However, flywheels have a high level of self-discharge due to air resistance and bearing losses and suffer from low current efficiency.

14.3.5 Gravitational potential energy storage with solid mass

Changing the altitude of solid masses can store via an elevating system driven by an electric motor/generator. When power (energy) is required, the mass is released and pulled ("falls") toward the center of gravity.

14.3.6 Spring-Tension energy storage

Energy can be stored in a tension device, such as the winding of a spring in an pocket watch. Potential energy is stored in the spring's tension. When the tension on the spring is released, mechanical/kinetic energy (power) is released.

14.3.7 Chemical energy storage systems (secondary energy carriers)

The energy is stored in a static chemical medium (i.e., chemical fuel), such as petroleum fuel (e.g., coal, gasoline, diesel fuel, natural gas) or biofuel (e.g., biogas, char).

14.3.8 Solid fuel energy storage

Any solid fuel is a chemical energy storage medium.

14.3.9 Liquid fuel energy storage (a.k.a., power to liquid)

Any liquid fuel is a chemical energy storage medium.

14.3.10 Gaseous fuel energy storage (a.k.a., power to gas)

Power to gas refers to technology that converts electricity into a gaseous fuel such as hydrogen or methane. The main purpose of the following chemical energy storage systems is to use "excess" electricity (i.e., electricity when available) to produce hydrogen via water electrolysis. Once hydrogen is produced different ways are available for using it as an energy source/carrier, either as pure hydrogen or as SNG.

These chemical energy storage systems allow for the storage of large amounts of energy, up to the TWh range, and for greater periods of time – even as seasonal storage. Another advantage of hydrogen and SNG is that these universal energy carriers can be used in different habitat service sub-systems.

14.3.10.1 Hydrogen (H_2)

Hydrogen is the lightest of all chemical elements. It is odourless, colourless, and non-toxic. It has a high diffusibility, and boiling point of approximately -259.2°C, with ignition limits in air 4.0-75.0 Vol.%. Hydrogen can be stored as either compressed hydrogen (CH_2) in tanks at 200 bar and up to 700 bar in the near future, or as liquid hydrogen in cryogenic tanks, or as metal hydride. In order to increase storage density, hydrogen can be liquified. It is then called LH_2 (Liquid/Liquefied Hydrogen) and has to be stored and transported at -253°C (-423°F) in cryogenic tanks. Liquefaction is highly energy-consuming, and requires about one third of the energy content of the liquid hydrogen. Different approaches exist to storing the hydrogen, either as a gas under high pressure, a liquid at very low temperature, adsorbed on metal hydrides or chemically bonded in complex hydrides. However, for stationary applications gaseous storage under high pressure is the most popular choice. Smaller amounts of hydrogen can be stored in above-ground tanks or bottles under pressures up to 900 bar. For larger amounts of hydrogen, underground piping systems or even salt caverns with several 100 000 m³ volumes under pressures up to 200 bar can be used.

Hydrogen can be produced via water-electrolysis. Electrolysis itself is the separation of bonded chemical elements. Therein, water-electrolysis involves running an electric current through water to split the bonded chemical elements into its compounds hydrogen and oxygen, both of which may then be stored.

Hydrogen may be used in fuel cells for local electricity generation. Therein, a typical hydrogen storage system consists of an electrolyzer, a hydrogen storage tank, and a fuel cell. An electrolyzer is an electrochemical converter which splits water with the help of electricity into hydrogen and oxygen. It is an endothermal process (i.e. heat is required during the reaction). Hydrogen is stored under pressure in gas bottles or tanks, and this can be done practically for an unlimited time. To generate electricity, both gases flow into the fuel cell where an electrochemical reaction, which is the reverse of water splitting (i.e., reverse of electrolysis) takes place: hydrogen and oxygen react and produce water, heat is released, and electricity is generated. For hydrogen storage systems specifically, the oxygen is generally vented to the atmosphere on electrolysis, and oxygen is taken from the air for the power generation.

> **NOTE:** *In fuel cells electricity is generated by oxidizing hydrogen or methane. This combined electrolysis-fuel cell process is an electrochemical energy storage system. However, both gases are multi-purpose energy carriers. Electricity can be generated in a gas or steam turbine.*

14.3.10.2 Oxygen (O_2)

Oxygen can be produced via water-electrolysis. Electrolysis itself is the separation of bonded chemical elements. Therein, water-electrolysis involves running an electric current through water to split the bonded chemical elements into its compounds hydrogen and oxygen, both of which may then be stored.

The oxygen can be compressed and stored in a storage tank. It can then be combusted to produce heat or its combustion can be used to power a turbine generator to produce mechanical and electrical power.

14.3.10.3 Methane and synthetic natural gas (SNG)

Methane is the simplest hydrocarbon with the molecular formula CH_4. Methane is more easily stored than hydrogen and the transportation.

Synthesis of methane (also called synthetic natural gas, SNG or syngas) is the second option to store electricity as chemical energy. Synthetic natural gas (syngas or SNG) can be created in a multi-step process, starting with hydrogen and oxygen. Hydrogen is then reacted with carbon dioxide in a Sabatier process, producing methane and water. Here a second step is required beyond the water splitting process in an electrolyzer, a step in which hydrogen and carbon dioxide react to methane in a methanation reactor. As is the case for hydrogen, the SNG produced can be stored in pressure tanks, underground, or fed directly into a gas grid. Several CO_2 sources are conceivable for the methanation process, such as fossil-fuelled power stations, manufacturing/production installations, or biogas plants.

14.3.11 Biological energy storage

Technically, energy can be stored in biological systems via glycogen, starch, and lipid production. Mammals, for example, store energy in the form of fat (i.e., lipids) and liver glycogen. Many plants store energy in the form of starch.

14.3.12 Electrochemical storage systems

Energy may be stored within an electrochemical system.

> **NOTE:** *An* **uninterruptible power supply (UPS)** *is a device that allows an electrical (or other) system to keep running for at least a short time when the primary power source is lost. It also provides protection from power surges.*

Technically, a battery is a chemical potential energy storage system, however, they are classified herein under electrochemical storage because when the energy in a battery is released it is released into an electrical system. In thermodynamics, 'chemical potential' is defined as the time rate of change of internal energy of a system through changes in the number of particles in the system (or in the limiting case, the derivative of internal energy through the number of particles).

Chemical potential is characterized by the following abilities to do work in a chemical system:

1. To react with other substances (chemical reaction).
2. To move to another state (phase transition).
3. To reallocate the space (diffusion).

There are two types of non-flow batteries: primary batteries (disposable batteries), which are designed to be used once and discarded, and secondary batteries (rechargeable batteries), which are designed to be recharged and used multiple times.

Batteries come in many sizes, voltages, and amperes.

14.3.13 Primary batteries (non-rechargeable)

A primary battery is a portable voltaic cell that is not rechargeable. These batteries must be re-cycled after a single use. In general, the electrochemical reaction occurring in the cell is not reversible, rendering the cell non-rechargeable. As a primary cell is used, chemical reactions in the battery use up the chemicals that generate the power; when they are gone, the battery stops producing electricity and is useless. Primary batteries are used when charging is impractical or impossible (e.g., pacemaker). Primary batteries are designed for high specific energy, long storage times, instant readiness and/or long usage times.

The most common types of primary battery are listed below, but note that secondary batteries, such as lithium ion batteries, can be designed to function as a primary, and not secondary, battery.

14.3.13.1 Zinc Manganese oxide (alkaline battery)

Alkaline batteries are dependent upon a chemical reaction between zinc and manganese (IV) oxide (Zn/MnO_2). The alkaline battery gets its name because it has the alkaline electrolyte, potassium hydroxide, instead of the acidic ammonium chloride or zinc chloride electrolyte of the zinc-carbon batteries. Other battery systems also use alkaline electrolytes, but they use different active materials for the electrodes.

14.3.13.2 Zinc-carbon (Leclanche)

A zinc–carbon battery is a dry cell battery that delivers a potential of 1.5 volts between a zinc metal electrode and a carbon rod from an electrochemical reaction between zinc and manganese dioxide mediated by a suitable electrolyte.

14.3.14 Secondary batteries (rechargeable)

A rechargeable battery, storage battery, secondary cell, or accumulator is a type of electrical battery that can be charged, discharged into a load, and recharged many times, while a non-rechargeable or primary battery is supplied fully charged, and discarded once discharged. In a secondary cell, the reaction can be reversed by running a current into the cell with a battery charger to recharge it, regenerating the chemical reactants.

In conventional secondary batteries, the energy is charged and discharged in the active masses of the electrodes.

The most common types of secondary battery are listed as follows:

14.3.14.1 Lead acid (LA)

Lead acid batteries are the world's most widely used battery type. Typical service life is 6 to 15 years with a cycle life of 1500 cycles at 80% depth of discharge, and they achieve cycle efficiency levels of around 80% to 90%. There are many sub-types of lead acid batteries. One disadvantage of lead acid batteries is usable capacity decrease when high power is discharged. For example, if a battery is discharged in one hour, only about 50% to 70% of the rated capacity is available. Other drawbacks are lower energy density and the use of lead, a hazardous material. LA systems are easy to recycle and the charging technology is simple.

14.3.14.2 Nickel cadmium and nickel metal hydride (NiCd, NiMh)

Compared to lead acid batteries, nickel-based batteries have a higher power density, a slightly greater energy density and the number of cycles is higher; many sealed construction types are available. From a technical point of view, NiCd batteries are a very successful battery product; in particular, these are the only batteries capable of performing well even at low temperatures in the range from -20°C to -40 °C. Large battery systems using vented NiCd batteries operate on a scale similar to lead acid batteries. Like lead, cadmium is a hazardous material. NiMH batteries have much higher energy densities (weight for weight). NiMH batteries are far safer than lithium ion batteries.

14.3.14.3 Lithium ion (Li-ion, LiPoly)

High cell voltage levels of up to 3.7 nominal volts mean that the number of cells in series with the associated connections and electronics can be reduced to obtain the target voltage. Another advantage of Li-ion batteries is their high gravimetric energy density, and the prospect of large cost reductions through mass production. Lithium ion batteries generally have a very high efficiency, typically in the range of 95% - 98%. Nearly any discharge time from seconds to weeks can be realized, which makes them a very flexible and universal storage technology. Standard cells with 5000 full cycles can be obtained on the market at short notice, but even higher cycle rates are possible after further development, mainly depending on the materials used for the electrodes.

Safety is a serious issue in lithium ion battery technology. Most of the metal oxide electrodes are thermally unstable and can decompose at elevated temperatures, releasing oxygen which can lead to a thermal runaway. To minimize this risk, lithium ion batteries are equipped with a monitoring unit to avoid over-charging and over discharging. Usually a voltage balance circuit is also installed to monitor the voltage level of each individual cell and prevent voltage deviations among them.

14.3.14.4 Metal air (Me-air)

A metal air electrochemical cell consists of the anode made from pure metal and the cathode connected to an inexhaustible supply of air. For the electrochemical reaction only the oxygen in the air is used.

14.3.14.5 Sodium sulphur (NaS)

Sodium sulphur batteries consist of liquid (molten) sulphur at the positive electrode and liquid (molten) sodium at the negative electrode; the active materials are separated by a solid beta alumina ceramic electrolyte. The battery temperature is kept between 300 °C and 350 °C to keep the electrodes molten. NaS batteries reach typical life cycles of around 4500 cycles and have a discharge time of 6.0 hours to 7.2 hours. They are efficient (AC-based round-trip efficiency is about 75%) and have fast response.

14.3.14.6 Sodium nickel chloride (NaNiCl)

The sodium nickel chloride (NaNiCl) battery, better known as the ZEBRA (Zero Emission Battery Research) battery, is – like the NaS battery – a high-temperature (HT) battery. Its operating temperature is around 270°C, and it uses nickel chloride instead of sulphur for the positive electrode. NaNiCl batteries can withstand limited overcharge and discharge and have potentially better safety characteristics and a higher cell voltage than NaS batteries. They tend to develop low resistance when faults occur and this is why cell faults in serial connections only result in the loss of the voltage from one cell, instead of premature failure of the complete system.

14.3.15 Flow batteries

A flow battery is also a rechargeable battery, but the energy is stored in one or more electroactive species which are dissolved in liquid electrolytes. The electrolytes are stored externally in tanks and pumped through the electrochemical cell that converts chemical energy directly to electricity and vice versa. The power of a flow battery is defined by the size and design of the electrochemical cell, whereas the energy depends on the size of the electrolyte storage tank(s). Flow batteries can be fitted to a wide range of stationary applications. Flow batteries are classified into redox flow batteries and hybrid flow batteries.

14.3.15.1 Redox flow

In redox flow batteries (RFB) two liquid electrolyte dissolutions containing dissolved metal ions as active masses are pumped to the opposite sides of the electrochemical cell. The electrolytes at the negative electrode are called ‘analytes’, and the electrolytes at the positive electrodes ‘catholytes’. During charging and discharging the metal ions stay dissolved in the fluid electrolyte as liquid; no phase change of these active masses takes place. The anolyte and catholyte flow through porous electrodes, separated by a membrane which allows protons to pass through it for the electron transfer process. During the exchange of charge a current flows over the electrodes, which can be used by a battery powered device. During discharge the electrodes are continually supplied with the dissolved active masses from the tanks; once they are converted the resulting product is removed to the tank. Theoretically, a RFB can be “recharged” within a few minutes by pumping out the discharged electrolyte and replacing it with recharged electrolyte.

14.3.15.2 Hybrid flow

In a hybrid flow battery (HFB) one of the active masses is internally stored within the electrochemical cell, whereas the other remains in the liquid electrolyte and is stored externally in a tank. Therefore hybrid flow cells combine features of conventional secondary batteries and redox flow batteries: the capacity of the battery depends on the size of the electrochemical cell. Typical examples of a HFB are the Zn-Ce and the Zn-Br systems. In both cases the anolyte consists of an acid solution of Zn^{2+} ions. During charging Zn is deposited at the electrode and at discharging Zn^{2+} goes back into solution. As membrane a microporous polyolefin material is used; most of the electrodes are carbon-plastic composites.

14.3.16 Electrical storage systems

> **NOTE: Capacitance** *is a measure of ability to store electric charge.*

Electrical storage refers to the ability to store electric charge. Capacitance is the property that describes the storage of energy electrostatically (i.e., in an electric field). In other words, **capacitance** is a measure of ability to store electric charge. There are two closely related notions of capacitance, both of which are usually designated by the same term capacitance, and have the same SI unit of capacitance, the farad (F).

1. **Self capacitance** - Any object that can be electrically charged exhibits self capacitance. In a circuit, self capacitance is defined as the capacitive load, relative to circuit ground, that an electrode presents to the measurement system.
2. **Mutual capacitance** - the capacitive coupling between objects. The notion of mutual capacitance is particularly important for understanding the operations of the capacitor, one of the three fundamental electronic components (along with resistors and inductors).

A material with a large self capacitance holds more electric charge at a given voltage, than one with low capacitance.

- A 1 farad capacitor, when charged with 1 coulomb of electrical charge, has a potential difference of 1 volt between its plates.

In a mutual capacitance system, capacitance is a function only of the geometry of the design (e.g. area of the plates and the distance between them) and the permittivity of the dielectric material between the plates of the capacitor. For many dielectric materials, the permittivity and thus the capacitance, is independent of the potential difference between the conductors and the total charge on them.

14.3.16.1 Mutual capacitance

In a capacitor, the ratio of magnitude of charge on either conductor relates to the potential difference (voltage) between the conductors. Therein, for any given voltage (supplied by some power source), the amount of Q (charge that can be stored) increases with the amount of capacitance (which is the measure of the capacitor):

- Capacitance in farads = charge on either conductor / potential difference
- $C = Q / \Delta V$

The energy stored in a capacitor is found by integrating the value of work (W):

- $W = .5CV^2$

14.3.17 Capacitors

A capacitor (originally known as a 'condenser', and prior to that known as a permittor) is a passive two-terminal electrical component used to store energy electrostatically (i.e., in an electric field). Practical capacitors vary widely, but all contain at least two electrical conductors (plates) separated by a dielectric (i.e., insulator). In other words, a capacitor is (generally) two metal plates separated by an insulated material (i.e., non-conductive material). A capacitor can store electric energy when disconnected from its charging circuit, so it can be used like a temporary battery, or like other types of rechargeable energy storage systems. Conventional capacitors are commonly used in electronic devices, and the more recent supercapacitor technology has some ability to replace batteries.

Capacitor operation may be understood via the following referenced analogies:

1. Beaty, W.J. (1996). *Capacitor complaints*. Amasci. http://amasci.com/emotor/cap1.html
2. Moffitt, B. (2014). *Capacitor pipe water flow analogy : DC*. Brandon Moffitt Channel. https://youtu.be/lo86naSn3HE

Capacitors store energy in an electrostatic field between their plates. Given a potential difference across the conductors (e.g., when a capacitor is attached across a battery), an electric field develops across the dielectric, causing positive charge (+Q) to collect on one plate and negative charge (-Q) to collect on the other plate, until the capacitor is fully "charged". The charges want to re-combine with one another, but they cannot because the insulator is preventing them from reaching each other. If a battery is attached to a capacitor, then no current will flow through the capacitor.

When capacitors are connected across a direct current DC supply voltage they become charged to the value of the applied voltage, acting like temporary storage devices and maintain or hold this charge indefinitely as long as the supply voltage is present. When a capacitor is connected to a circuit with a direct current (DC) voltage source, two processes, which are called "charging" and "discharging" the capacitor, will happen in specific conditions. By connecting the capacitor to the power supply, the charging phase occurs. Once the charging phase has finished, no more current flows through it. When the capacitor is disconnected from the power supply and connected to a load, then discharging occurs until the voltage between the capacitor's plates drops to zero, $V_c=0$.

When an alternating current is supplied to a capacitor, it will alternately charge and discharge at a rate determined by the frequency of the supply. Therein, the capacitance in AC circuits varies with frequency as the capacitor is being constantly charged and discharged, and a 'displacement current' will appear across the capacitor.

The greater the collection of charge on one surface of the capacitor, due to various parameters, such as surface area, the greater the energy capacitance of the capacitor.

14.3.17.1 Electrolytic capacitors

An electrolytic capacitor is a capacitor that uses an electrolyte (an ionic conducting liquid) as one of its plates to achieve a larger capacitance per unit volume than other types, but with performance disadvantages.

Electrolytic capacitor is the generic term for three different capacitor family members:

1. Aluminum electrolytic capacitors
2. Tantalum electrolytic capacitors
3. Niobium electrolytic capacitors

All electrolytic capacitors (e-caps) are polarized capacitors whose anode (+) is made of a particular metal on which an insulating oxide layer forms by anodization, acting as the dielectric of the electrolytic capacitor. A non-solid or solid electrolyte which covers the surface of the oxide layer in principle serves as the second electrode (cathode) (-) of the capacitor.

Like other conventional capacitors, electrolytic capacitors store the electric energy statically by charge separation in an electric field in the dielectric oxide layer between two electrodes. The non-solid or solid electrolyte in principle is the cathode, which thus forms the second electrode of the capacitor. This and the storage principle distinguish them from electrochemical capacitors or supercapacitors, in which the electrolyte generally is the ionic conductive connection between two electrodes and the storage occurs with statically double-layer capacitance and electrochemical pseudocapacitance.

14.3.17.2 Double-layer capacitors (DLC; supercapacitors)

NOTE: *Electrochemical capacitors go by a variety of names, including but not limited to: supercapacitor, super condenser, pseudocapacitor, electrochemical double layer capacitor, electric double layer capacitor, and ultracapacitor.*

Electrochemical double-layer capacitors (DLC) exist between classical capacitors used in electronics and general batteries. Electrochemical capacitors consist of two electrodes, a separator, electrolyte, two current collectors, and packaging. Within the electrochemical capacitor, charge is stored electrostatically, not chemically as in a battery. It has, as a dielectric, an electrolyte solvent, typically potassium hydroxide or sulfuric acid, and is actually two capacitors connected in series via the electrolyte. It is called a dual layer capacitor because of the dual layers within the structure, one at each electrode. The surface area is directly related to the amount of capacitance. The higher the surface area, the higher the capacitance of the capacitor.

There are two types of electrochemical capacitor technology, symmetric and asymmetric designs:

1. Symmetric designs are designs where both positive and negative electrodes are made of the same material with approximately the same mass, and which are available with aqueous or organic electrolytes.
2. Asymmetric designs uses a different material for the two electrodes, with one of the electrodes having much higher capacity than the other. Currently, asymmetric designs can use aqueous or organic electrolytes.

There are significant differences in the characteristics and performance of the four types which leads to a wide variety of products with many different possible applications. The fourth type is not included in this table since the type has active research programs directed toward its development, but it is currently not available as a commercial product.

The two main features are the extremely high capacitance values, of the order of many thousand farads, and the possibility of very fast charges and discharges due to extraordinarily low inner resistance which are features not available with conventional batteries.

Still other advantages are durability, high reliability, no maintenance, long lifetime and operation over a wide temperature range and in diverse environments (hot, cold and moist). The lifetime reaches one million cycles (or ten years of operation) without any degradation, except for the solvent used in the capacitors whose disadvantage is that it deteriorates in 5 or 6 years irrespective of the number of cycles. They are environmentally friendly and easily recycled or neutralized. The efficiency is typically around 90 % and discharge times are in the range of seconds to hours.

They can reach a specific power density which is about ten times higher than that of conventional batteries (only very-high-power lithium batteries can reach nearly the same specific power density), but their specific energy density is about ten times lower. Because of their properties, DLCs are suited especially to applications with a large number of short charge/discharge cycles, where their high performance characteristics can be used. DLCs are not suitable for the storage of energy over longer periods of time, because of their high self-discharge rate, their low energy density.

14.3.18 Superconducting magnetic energy storage (SMES)

Superconducting magnetic energy storage (SMES) systems work according to an electrodynamic principle. The energy is stored in the magnetic field created by the flow of direct current in a superconducting coil, which is kept below its superconducting critical temperature. 100 years ago at the discovery of superconductivity a temperature of about 4°K was needed. Much research and some luck has now produced superconducting materials with higher critical temperatures. Today materials are available which can function at around 100°K. The main component of this storage system is a coil made of superconducting material. Additional components include power conditioning equipment and a cryogenically cooled refrigeration system.

The main advantage of SMES is the very quick response time: the requested power is available almost instantaneously. Moreover the system is characterized by its high overall round-trip efficiency (85 - 90%) and the very high power output which can be provided for a short period of time. There are no moving parts in the main portion of SMES, but the overall reliability depends crucially on the refrigeration system. In principle the energy can be stored indefinitely as long as the cooling system is operational, but longer storage times are limited by the energy demand of the refrigeration system.

14.3.19 Thermal storage systems

Thermal (energy) storage (TES) systems store available heat by different means in an insulated repository for later use, including space heating or cooling, hot water production, and electricity generation. Thermal storage systems are deployed to overcome the mismatch between demand and supply of thermal energy, and thus, they are important for the integration of renewable energy sources. Second, utilization of waste heat in production processes by thermal energy storage reduces the final energy consumption (i.e., increases energy efficiency if the thermal energy is used or has the possibility of being used).

NOTE: *Thermal energy is challenging to store, due to the ease of heat dissipation in physical systems.*

TES is applied in the field of power generation, production process heat, space heating and cooling, as well as the management of thermal energy processes in vehicles. These classifications of storage characteristics and applications result in specific operation parameters and designs of TES systems.

Thermal energy storage is achieved by different techniques, and can be subdivided into different technologies:

1. Storage of sensible heat - sensible
2. Storage of latent heat - phase change material
3. Thermo-chemical ad- and absorption storage - chemical sorption reaction

14.3.20 Sensible heat storage

The term 'sensible heat' indicates that the storage process can be *sensed* by a change of the temperature. The relation of the change in temperature and the stored heat is given by the heat capacity C_p. The storage of sensible heat is one of the best-known and most widespread technologies, with the domestic hot water tank as an example. The storage medium may be a liquid, such as water and solar ponds, thermo-oil, or a solid such as concrete or the ground. Thermal energy is stored solely through a change of temperature of the storage medium. Herein, the capacity of a sensible heat storage system is defined by:

1. The specific heat capacity, C_p.
2. The mass of the medium used.

Sensible heat can be stored in either solids and/or liquids:

1. *Solids:* metals, stones, salts, ceramics.
2. *Liquid:* water, thermal oil, molten salt.
3. *Liquid with solid filler material:* water with stones/ pebbles, oil with cast iron, molten salt with stone.

14.3.20.1 Solar Ponds

Water-based ponds may be used to capture the sun's radiative energy. A solar pond is a pool of salt water that serves as a form of solar energy collection and sensible heat storage. A solar pond uses the principle of energy transfer by convection to heat saline water. This heated water solution may then be used for various purposes.

In general, a solar pond is a mass of shallow water about 1 or 2 metres deep with a large collection area, which acts as a heat trap. The pond contains dissolved salts to generate a stable density gradient. They are generally filled with saline water made with NaCl, $MgCl_2$, sodium carbonate, or sodium sulfate. Part of the incident solar radiation entering the pond surface is absorbed throughout the depth, and the remainder is absorbed at the very dark, black bottom. If the pond were initially filled with fresh water, the lower layers would heat up, expand and rise to the surface. Because of the relatively low conductivity, the water acts as an insulator and permits high working temperature (over 90 °C) to develop in the bottom layers. Hence, a gradient is maintained at varying densities. The bottom is the most dense and is used as a storage zone. Above the bottom layer is a non-convective zone, or insulation zone, with a density gradient which facilitates a temperature gradient as well. This layer functions as insulation. There is no convection in the gradient layer because even though the warm water would normally rise, the high salt concentration at lower levels does not allow the water to be light enough to float up as it warms. This prevents heat in the bottom from reaching the top of the pond. The top layer, or surface zone, is convective due to wind-induced mixing and daily heating and cooling. The hot brine, or salt water, on the bottom may be extracted and used for direct heating and low-temperature production uses like drying crops and agricultural shelter heating.

The problem with solar ponds is that it is essential to have a controlled saline density gradient, which is quite difficult to maintain. Additionally, the pond must be kept free of dirt and other light-absorbing materials. Thus, for large scale operations, the difficulties are too great to rely upon solar ponds for efficient heat production.

Here is one possible system for converting the heat energy from the salt water in the pond to electricity. The hot brine is pumped from the bottom of the solar pond through an evaporator (where it transfers heat to an organic 'working fluid,), and then, returned to the pond. The organic working fluid is heated in the evaporator, turns into a vapor, thereby producing sufficient pressure to spin a turbine connected to a generator. Therein, the vapor transfers some of its kinetic energy to the turbine. The cooler vapor is pumped to the condenser where it is condensed to a liquid as it transfers energy to the cold water being pumped through the tubes of the condenser. The organic liquid is now pumped to the evaporator to continue the process. As the gradient layer diffuses as time passes, new freshwater and salt water can be pumped into the pond to maintain a sufficient gradient layer.

14.3.20.2 Inter-seasonal thermal storage

Seasonal thermal energy storage (STES) allows heat or cold to be used months after it was collected from waste energy or natural sources. The material can be stored in contained aquifers, clusters of boreholes in geological substrates such as sand or crystalline bedrock, in lined pits filled with gravel and water, or water-filled mines. STES systems can be divided into:

1. Underground systems.
2. Surface and above ground systems.

14.3.21 Latent heat storage

In contrast to the storage of sensible heat, latent thermal energy storage (LHTES) cannot be sensed: The energy which is absorbed or released is stored by a *phase transition*, which takes place at a constant temperature, and therefore, appears to be latent. Materials used for latent heat storage are called PCMs (phase change materials), because the heat storage is achieved by a phase change of the storage medium. In other words, 'latent heat' is the energy exchanged during a phase change, such as the melting of ice. It is also called "hidden" heat, because there is no change of temperature during energy transfer.

Latent heat storage is accomplished by using phase change materials (PCMs) as storage media. PCMs include, but are not limited to the following, which are divided by in-/organic, and then, solid-solid or solid-liquid:

1. Organic phase change materials (organic PCMs)
   A. *Solid-liquid:* paraffins.
2. Inorganic phase change materials (inorganic PCMs)
   A. *Solid-solid:* salt.
   B. *Solid-liquid:* water/ice, salt hydrates, salt/molten salt.

The best known latent heat – or cold – storage method is the ice cooler (ice box), which uses ice (an inorganic PCM) in an insulated box or room to keep food cool during hot days.

Currently, most PCMs use the solid-liquid phase change, such as molten salts as a thermal storage medium or concentrated solar power (CSP) plants. The advantage of latent heat storage is its capacity to store large amounts of energy in a small volume and with a minimal temperature change, which allows efficient heat transfer.

14.3.21.1 Solar molten salt system

Molten salt is salt which is solid at standard temperature and pressure (STP) but enters the liquid phase due to elevated temperature. In this system, salt becomes molten once heated by a concentrated solar radiation system. It is then transported to a hot salt storage tank. To produce electricity, the hot salt passes through a steam generator that powers a steam turbine. Subsequently, the cold salt (still molten) is stored in a second tank before it is pumped to the solar tower again. The main disadvantages are the risk of liquid salt freezing at low temperatures, and the risk of salt decomposition at higher temperatures. In solar trough plants a dual-medium storage system with an intermediate oil/salt heat exchanger is preferred. Typical salt mixtures, such as $NaK\text{-}NO_3$, have freezing temperatures >200°C, and storage materials and containment require a higher volume than storage systems for solar tower plants.

14.3.22 Thermo-chemical heat storage

A thermochemical heat storage (TCS) system uses the enthalpy of a reaction ΔH. In reactions featuring a positive change of ΔH (endothermic reaction) heat can be stored. The energy can be released by a backward reaction ($\Delta H < 0$) afterwards. This chemical reaction always involves gas phase reaction:

1. *Solid - gas reaction:* dissociation reactions and adsorption processes.
2. *Liquid - gas reaction:* absorption in alkaline or acid solution.
3. *Gas - gas reaction:* methane reforming and ammonia dissociation .

Sorption (adsorption, absorption) storage systems work as thermo-chemical heat pumps under vacuum conditions and have a more complex design than sensible or latent heat systems. Herein, heat from a high-temperature source heats up an adsorbent (e.g. silica gel or zeolite), and vapour (working fluid; e.g., water) is desorbed from this adsorbent and condensed in a condenser at low temperatures. The heat of condensation is then withdrawn from the system. The dried adsorbent and the separated working fluid can be stored as long as desired. During the discharging process the working fluid takes up low-temperature heat in an evaporator. Subsequently, the vapour of the working fluid adsorbs on the adsorbent and heat of adsorption is released at high temperatures. Depending on the adsorbent/working fluid pair the temperature level of the released heat can be up to 200°C and the energy density is up to three times higher than that of sensible heat storage with water.

Because of the possibility of storing the sorption compounds separately without the loss of energy, thermochemical storage is appropriate for thermal energy storage over large period of times.

14.4 Grid/network connectivity and power quality

Energy storage systems can be on-grid (network connected) or off-grid (network dis-connected).

14.5 Battery technology as energy storage

> **NOTE:** *If electric current is like water, then in application, a battery is like a water pump. A pump takes in water at low pressure and does work on it, ejecting it at high pressure. A battery takes in charge at low voltage, does work on it and ejects it at high voltage. Batteries, however, do not store electric charges, and hence, they are not analogous to a water balloon shooting out water.*

A battery is a device that converts chemical power (energy) into electrical power (energy), and vice versa. Batteries supply electricity by producing voltage and delivering direct current (DC). Batteries do not produce AC voltage. Also, batteries do not store electricity, but rather store a series of chemicals, and through a chemical process electricity is produced. Hence, it is inaccurate to say that batteries store DC or DC voltage. Although a current can be described as moving electrical charges, it is not true that these charges are "stored in a battery". Batteries store chemical potential energy, which is released as DC voltage when connected to an electrical circuit. Batteries are an electrochemical storage carrier. The energy is stored chemically, but released as electricity. Through a chemical reaction process the battery creates and releases electricity as needed by the electrical system or devices. Batteries are sometimes considered electron pumps.

CLARIFICATION: *Electrical current is the movement of charged particles, such as electrons or ions, through a conductor.*

In composition, a battery is a technological device consisting of one or more electrochemical cells (voltaic cells). A voltaic cell is an electrochemical cell that uses a chemical reaction to produce electrical power (electrical energy). Simplistically, batteries contains atoms and molecules separated into ions that generate a voltage drop across their terminals.

CLARIFICATION: *A* **cell** *is the smallest, packaged form a battery can take and is generally on the order of one to six volts. A* **module** *consists of several cells generally connected in either series or parallel. A battery* **pack** *(battery bank) is then assembled by connecting modules together, again either in series or parallel. The term 'battery' and 'cell' are often used interchangeably; technically, however, a battery is made up from a group of cells.*

A battery releases energy at a more or less constant or flat voltage until depleted. A battery is used where a constant potential difference has to be maintained.

14.5.1 Battery components

All batteries have at least the following components, including two terminals (i.e., electrodes):

1. **The anode (terminal)** - an electrode where oxidation occurs (in a voltaic cell). This is generally a metal material.
2. **The cathode (terminal)** - an electrode where reduction occurs (in a voltaic cell). This is generally a different metal material than the anode material.
3. **The electrolyte (the ionic conductor)** - provides the medium for transfer of charge as ions inside the cell between the anode and cathode. The electrolyte is typically a solvent containing dissolved chemicals providing ionic conductivity. It should be a non-conductor of electrons to avoid self discharge of the cell.
4. **The separator** - electrically isolates the positive and negative electrodes. It is a permeable membrane placed between a battery's anode and cathode. The main function of a separator is to keep the two electrodes apart to prevent electrical short circuits while also allowing the transport of ionic charge carriers that are needed to close the circuit during the passage of current in an electrochemical cell.

CLARIFICATION: *In a galvanic (voltaic) cell, the anode is considered negative (-ve) and the cathode is considered positive (+ve). This seems reasonable as the anode is the source of electrons, and the electrons flow to the cathode. However, in an electrolytic cell, the anode is positive (+ve), while the cathode is negative (-ve).*

14.5.1.1 Anodic index-galvanic corrosion (anodic index

The anodic index is a table showing the compatibility of different metals. This parameter is a measure of the electrochemical voltage that will be developed between two different metals. To find the relative voltage of a pair of metals it is only required to subtract their anodic indices. (Wheeler, 1972)

For example,

1. The potential difference between iron and copper is approximately 0.4v.
2. The potential difference between zinc and carbon is approximately 1.5v.

14.5.2 Battery operation

Batteries use a chemical reaction to do work on charge and produce a voltage between their output terminals. This voltage can be connected to an electrically conductive circuit (a load) to produce direct current (DC) electrical power. When a load completes the circuit between the two terminals, the battery produces electricity through a series of electromagnetic reactions between the anode, cathode, and electrolyte. Batteries operate based on the separation of [electric] charge in a chemical solution (i.e., an energy gradient), which produces an electromotive force (voltage) between their terminals. When the terminals are connected by means of an appropriate electrical conductor, then direct current will flow between the terminals powered by the pressure of the voltage (and, electrochemical discharge will occur).

Charging and discharging refer to the direction of current through a battery cell, and the type of chemical reaction that follows the current. Batteries are discharged or charged due to oxidation and reduction reactions therein.

1. **Charging** - the process of separating charge within a battery by providing DC electrical power to the battery.
2. **Discharging** - the process of releasing DC electrical power and reuniting charges via a conductive circuit.

Some batteries, due to their system's composition, cannot be recharged. Rechargeable batteries pump the charges back to their separate sides during charging, strengthening the electric field all over again. By reversing electrical current flow in a rechargeable battery, the chemical process is reversed, thus charging the battery. The cycle of discharging and charging is repeated continuously and is called **battery cycling**. All rechargeable batteries have a cycling lifespan (i.e., they can be cycled, discharged and recharged, a certain number of times before they need will no longer function without maintenance). Further, energy density decreases as a battery wears out.

> **NOTE:** *A battery charger, or recharger, is a device used to put energy into a secondary cell (or rechargeable battery) by forcing an electric current through it.*

During discharge operation, the anode (terminal) experiences an oxidation reaction in which two or more ions (electrically charged atoms or molecules) from the electrolyte combine with the anode, producing a compound and releasing one or more electrons. In other words, the internal chemical reaction within the battery between the electrolyte and the negative metal electrode produces a build up of free electrons, each with a negative charge, at the battery's negative (-) terminal - the anode. At the same time, the cathode goes through a reduction reaction in which the cathode substance, ions and free electrons also combine to form compounds. In other words, the chemical reaction between the electrolyte and the positive (+) electrode inside the battery produces an excess of positive (+) ions (atoms that are missing electrons, thus with a net positive charge) at the positive (+) terminal - the cathode of the battery. The reaction in the anode produces a direct flow of electrons, and the reaction in the cathode absorbs them. The net product is electricity. The electrical (pump) pressure or potential difference between the + and - terminals is called voltage or electromotive force (EMF).The battery will continue to produce electricity until one or both of the electrodes run out of the substance necessary for the reactions to occur.

Batteries create electron flow in a circuit by exchanging electrons in ionic chemical reactions, and there is a limited number of molecules in any charged battery available to react, hence there is a limited amount of total electrons that any battery can propel through a circuit before its energy reserves are exhausted.

> **CLARIFICATION:** *Reactants in a battery are separated internally by an electrolyte that provides for ion transfer, and externally by an electrical conductor (between the terminals), which provides for electron transfer. When a load is connected to the battery via the external conductive circuit, excess charges present in the negative ions of electrolytes on negative terminal (deposited during charging process) flow through the conductor, until they reach the positive terminal where they combine with positive ions, neutralizing the charge (the equilibrium condition). Under normal equilibrium conditions the electrical potential inside the battery exactly equals the chemical potential, and hence, there is no voltage and no electron flow. Normally, a battery which is not shorted out or connected to a load is under equilibrium conditions, meaning the chemical potential inside the battery exactly equals the electrical potential. Under these conditions, no charge carriers flow. If the positive terminal of the battery is connected to the negative terminal through some load, then the charge carrying electrons at the negative terminal of the battery will flow through the conductive load to the positive terminal.*

A battery is a chemical reactor where red-ox reaction happens. In the battery there is some medium, called an electrolyte, which can conduct only ions, but not electrons. Each voltaic cell consists of two half-cells connected in series by a conductive electrolyte containing anions and cations. One half-cell includes electrolyte and the negative electrode, the electrode to which anions (negatively charged ions) migrate; the other half-cell includes electrolyte and the positive electrode to which cations (positively charged ions) migrate. Redox reactions power the battery. Cations are reduced (electrons are added) at the cathode during charging, while anions are oxidized (electrons are removed) at the anode during charging. During discharge, the process is reversed. The electrodes do not touch each other, but are electrically connected by the electrolyte. Some cells use different electrolytes for each half-cell. A separator allows ions to flow between half-cells, but prevents mixing of the electrolytes. The reaction is driven forward by the chemical potential, an energy gradient. If the battery is not at 0 charge ("flat"), there will be a voltage between the electrodes.

> **INSIGHT:** *When a battery is connected to a circuit, charges moves in the direction which diminishes the chemical potential energy in the battery.*

Because a battery is a system of separated charge, it has a static electric field. When a battery is powering an electrical load (i.e., discharging), over time, the separated charges get reunited via the conductive circuit, and the electric field between the positive and negative electrodes becomes weaker. Hence, as a battery is discharging (i.e., providing electrical power), its voltage (EMF) will drop over time. In a discharing battery, the chemical process is a decoupled redox reaction. As charges move around the circuit, the electrical potential inside the battery is reduced until equilibrium between the chemical potential and electrical potential is once again achieved.

Different metals have different affinities for electrons. When two dissimilar metals (or metal compounds) are put in contact or connected through a conducting medium there is a tendency for electrons to pass from the metal with the smaller affinity for electrons, which becomes positively charged, to the metal with the greater affinity which becomes negatively charged. A potential difference between the metals will therefore build up until it just balances the tendency of the electron transfer between the metals. At this point the 'equilibrium potential' is that which balances the difference between the propensity of the two metals to gain or lose electrons.

> **INSIGHT:** *If you have two different metals in your body, particularly in your mouth, there will likely exist an electrical [galvanic] current between them. Such currents can and will interfere with the body's natural processes, potentially leading to states of dis-ease.*

14.5.3 Electrochemical cell types

Many types of electrochemical cells have been produced, with varying chemical processes and designs, including galvanic cells, electrolytic cells, fuel cells, flow cells and voltaic piles.

1. **Wet cell** - A wet cell battery has a liquid electrolyte. Other names are flooded cell, since the liquid covers all internal parts, or vented cell, since gases produced during operation can escape to the air.
2. **Dry cell** - A dry cell uses a paste electrolyte, with only enough moisture to allow current to flow. Unlike a wet cell, a dry cell can operate in any orientation without spilling, as it contains no free liquid, making it suitable for portable equipment. The common zinc–carbon battery (dry Leclanché cell) and zinc-manganese dioxide (alkaline cell) are both dry cell batteries.
3. **Molten salt** - Molten salt batteries are primary or secondary batteries that use a molten salt as electrolyte. They operate at high temperatures and must be well insulated to retain heat.
4. **Reserve battery** - A reserve battery can be stored unassembled (unactivated and supplying no power) for a long period (perhaps years). When the battery is needed, then it is assembled (e.g., by adding electrolyte); once assembled, the battery is charged and ready to work.

14.5.4 Battery condition parameters

This section describes some of the variables used to describe the present condition of a battery.

1. **State of Charge (SOC in %)** – An expression of the present battery capacity as a percentage of maximum capacity. SOC is generally calculated using current integration to determine the change in battery capacity over time.
2. **Depth of Discharge (DOD in %)** – The percentage of battery capacity that has been discharged expressed as a percentage of maximum capacity. A discharge to at least 80% DOD is referred to as a deep discharge.
3. **Terminal Voltage (V)** – The voltage between the battery terminals with load applied. Terminal voltage varies with SOC and discharge/charge current.
4. **Open-circuit voltage (V)** – The voltage between the battery terminals with no load applied. The open-circuit voltage depends on the battery state of charge, increasing with state of charge.
5. **Internal Resistance** – The resistance within the battery, generally different for charging and discharging, also dependent on the battery state of charge. As internal resistance increases, the battery efficiency decreases and thermal stability is reduced as more of the charging energy is converted into heat.

14.5.5 Battery energy and power units

Average power determines how long a battery lasts. Batteries have a limited amount of energy they can supply before they need to be replaced or recharged. The energy is typically measured in units of Joules. Batter capacity may be specified in Joules, or in amp-hours. If a 12 volt battery is rated at 100 amp-hours, then it means that - at least theoretically - it can supply 100 amps of current at 12 volts for one hour. Or, again theoretically, it can supply 1 amp of current at 12 volts for 100 hours. Either way, the total energy stored in the battery is S=3600VA Joules, where V is voltage in volts and A is the amp-hour rating, and 3600 is the number of seconds in an hour, and S is the number of Joules of energy the battery can supply. Power is measured in Watts, which is Joules/second. If a battery has S Joules of energy, and the average power you are drawing from it is P Watts, then the battery will be discharged in S/P seconds.

14.5.6 Battery technical specifications

This section explains the specifications you may see on battery technical specification sheets used to describe battery cells, modules, and packs.

> **CLARIFICATION:** *In describing batteries, discharge current is often expressed as a C-rate in order to normalize against battery capacity, which is often very different between batteries. A* **C-rate** *is a measure of the rate at which a battery is discharged relative to its maximum*

capacity. A 1C rate means that the discharge current will discharge the entire battery in 1 hour. For a battery with a capacity of 100 Amp-hrs, this equates to a discharge current of 100 Amps. A 5C rate for this battery would be 500 Amps, and a C/2 rate would be 50 Amps. Similarly, an ***E-rate*** *describes the discharge power. A 1E rate is the discharge power to discharge the entire battery in 1 hour.*

1. **Nominal Voltage (V)** – The reported or reference voltage of the battery, also sometimes thought of as the "normal" voltage of the battery. All batteries will be damaged (if not explode and catch fire) if they are charged significantly above their nominal voltage.
2. **Cut-off Voltage** – The minimum allowable voltage. It is this voltage that generally defines the "empty" state of the battery. Some batteries will be damaged if they drop significantly below their cut-off voltage (e.g., lithium polymer batteries).
3. **Capacity or Nominal Capacity (Ah for a specific C-rate)** – A battery's [electric current] capacity is the amount of electric charge it can deliver at the rated voltage. The coulometric capacity, the total Amp-hours available when the battery is discharged at a certain discharge current (specified as a C-rate) from 100 percent state-of-charge to the cut-off voltage. The amp-hour is a unit of battery energy capacity, equal to the amount of continuous current multiplied by the discharge time, that a battery can supply before exhausting its internal store of chemical energy. Therein, capacity is calculated by multiplying the discharge current (in Amps) by the discharge time (in hours), which decreases with increasing C-rate. For example, a battery rated at 100 A·h can deliver 5 A over a 20-hour period at room temperature. An amp-hour battery rating is only an approximation of the battery's charge capacity, and should be trusted only at the current level, temperature and time specified by its technical specification.
   A. Continuous current (amps) = amp-hour rating/ charge to discharge time (in hours)
   B. Charge to discharge time (in hours) = amp-hour rating / continuous current (in amps)
4. **Energy or Nominal Energy (Wh - for a specific C-rate)** – The "energy capacity" of the battery, the total Watt-hours available when the battery is discharged at a certain discharge current (specified as a C-rate) from 100 percent state-of-charge to the cut-off voltage. Energy is calculated by multiplying the discharge power (in Watts) by the discharge time (in hours). Like capacity, energy decreases with increasing C-rate. A 12 volt battery rated for/ producing 100 amps of current has a 1200 watt-hour supply (12V · 100amp = 1200 W-h).
5. **Cycle Life (number for a specific DOD)** – The number of discharge-charge cycles the battery can experience before it fails to meet specific performance criteria. Cycle life is estimated for specific charge and discharge conditions. The actual operating life of the battery is affected by the rate and depth of cycles and by other conditions such as temperature and humidity. The higher the DOD, the lower the cycle life.
6. **Specific Energy (Wh/kg)** – The nominal battery energy per unit mass, sometimes referred to as the gravimetric energy density. Specific energy is a characteristic of the battery chemistry and packaging. Along with the energy consumption of the vehicle, it determines the battery weight required to achieve a given electric range.
7. **Specific Power (W/kg)** – The maximum available power per unit mass. Specific power is a characteristic of the battery chemistry and packaging. It determines the battery weight required to achieve a given performance target.
8. **Energy Density (Wh/L)** – The nominal battery energy per unit volume, sometimes referred to as the volumetric energy density. Specific energy is a characteristic of the battery chemistry and packaging. Along with the energy consumption of the vehicle, it determines the battery size required to achieve a given electric range.
9. **Power Density (W/L)** – The maximum available power per unit volume. Specific power is a characteristic of the battery chemistry and packaging. It determines the battery size required to achieve a given performance target.
10. **Maximum Continuous Discharge Current** – The maximum current at which the battery can be discharged continuously. This limit is usually defined by the battery manufacturer in order to prevent excessive discharge rates that would damage the battery or reduce its capacity. Along with the maximum continuous power of the motor, this defines the top sustainable speed and acceleration of the vehicle.
11. **Maximum 30-sec Discharge Pulse Current** –The maximum current at which the battery can be discharged for pulses of up to 30 seconds. This limit is usually defined by the battery manufacturer in order to prevent excessive discharge rates that would damage the battery or reduce its capacity. Along with the peak power of the electric motor, this defines the acceleration performance (0-60 mph time) of the vehicle.
12. **Charge Voltage** – The voltage that the battery is

charged to when charged to full capacity. Charging schemes generally consist of a constant current charging until the battery voltage reaching the charge voltage, then constant voltage charging, allowing the charge current to taper until it is very small. If a charger cannot detect when the battery is fully charged, then overcharging is likely. Overcharging will damage the battery, possibly causing it to catch fire and/or explode.

13. **Float Voltage** – The voltage at which the battery is maintained after being charge to 100 percent SOC to maintain that capacity by compensating for self-discharge of the battery.
14. **(Recommended) Charge Current** – The ideal current at which the battery is initially charged (to roughly 70 percent SOC) under constant charging scheme before transitioning into constant voltage charging.
15. **(Maximum) Internal Resistance** – The resistance within the battery, generally different for charging and discharging.

15 Energy demand requirements and usage monitoring

> **INSIGHT:** *After electrification, sleep became a disadvantage to feeding your family...because you could still be working for money.*

15.1 Reserve to production

The **reserves-to-production ratio** (**RPR** or **R/P**) is the remaining amount of a material resource, expressed in time. The reserve portion (numerator) of the ratio is the amount of a resource known to exist in an area and to be recoverable (proved reserves). The production portion (denominator) of the ratio is the amount of resource produced in one period (year) at the current rate.

1. RPR = (amount of known resource) / (amount used per year)
2. Units are time = amount / (amount/time)

This ratio is used to forecast the future availability of a resource to determine project life, and to determine whether more cultivation, harvesting, and/or exploration must be undertaken to ensure continued supply of the resource. Annual production of a resource can usually be calculated to quite an accurate number. However, reserve quantities can only be estimated to varying degrees of accuracy, depending on the availability of information and on the methods used to evaluate them.

Note that reserve and production rates are dynamic (constantly changing), and hence, this isn't a static calculation/analysis, but a dynamically recorded calculation. Also, reserves and production rates are not independent.

> **Renewable energy sources:** *energy sources that are capable of being renewed (in a sufficient timeframe), and for which the demand rate (or use rate) is less than or equal to the production rate.*

15.2 Gross and process energy requirements

> *Note: The* **embodied energy** *of a material refers to the amount of energy consumed in providing/producing that material. It is the energy consumed up to the end of the manufacturing process (cradle to gate). However, it may include delivery to the manufacturing site (cradle to site) or even the manufacturing processes into the completed product. This measurement can be used in comparing different materials.*

Technically, all energy inputs and energy outputs can be entered into a matrix, and have analyses run for any type of energy inquiry (i.e., the data can be parsed and analysed). Two of the most common analyses are known as 'gross energy requirement' and 'process energy requirement'.

The energy used in productive systems is measured based upon:

1. Gross energy requirement (GER) - the total amount of energy required for a system, project, object, service, or material. A measure of all the energy inputs that went into its creation and/or sustainment. The total energy consumed.
2. Process energy requirement (PER) - the energy consumed in the process directly undergone by building/creating a specified product (object, service, or material). A measure of the energy directly consumed in the process of producing the product, but not that of the second and higher generation consumption of the facility, transportation, etc.

15.3 Electrical energy demand

QUESTION: *How do we know how much electric charge flow (i.e., electricity) to produce?*

Electrical generation and distribution equipment are designed and deployed to meet the maximum demand that all users/loads may require at one time. Hence, peak demand measurements are used to properly size the electric service ensure that there is sufficient generating capacity available (at all times).

1. The term kilowatt-hour (kWh) refers to the quantity of energy used; energy is signified by kWh. The kWh is a 'unit of energy'. Electrical energy actually used.
2. The term kilowatt (kW) refers to the electric power or rate (a.k.a., pace) at which this energy is used; demand is signified by kW. The kW is a 'unit of power'. The rate at which a load transforms electrical energy. Electrical energy moment by moment demand by a device.

The kilowatt hour (kWh, kW. h, kW-h) is how most home energy usage costs are calculated. The kWh measures [electrical] energy usage - equivalent to one kilowatt (1 kW) of power sustained for one hour. How much "energy" is in something or how much energy is used over a certain period of time.

- Watts * Time Used (in hours) = Wh
- Watts * Time Used / 1000 = kWh

Generator (if, then)

- If a device is rated to generate 1 kW of power (and it operates for one hour at that level), then it sustains 1 kWh of energy.

Load (if, then)

- If a device uses 100 watts over 10 hours, then it would utilize 1kWh of energy (100x10=1,000=1kW).
- For example, if a 40-watt bulb is used for 25 hours (40x25=1,000 watts = 1 kW), then it would use 1 kWh (at the 25 hour mark).

15.3.1 Load and supply

The balancing of load and supply on an electric power system is usually centrally controlled by a system operator or "Dispatch Centre". The dispatch centre continually how much generation is needed at each instant of time and issues orders (dispatch) to individual generating stations in merit order to supply the demand. The dispatch centre has a pretty good idea from forecasts of what will be required but they monitor frequency on an ongoing basis to ensure the balance is maintained.

Very rapid changes are dealt with automatically by stations which have some local frequency control. These stations respond very rapidly to changes in frequency by increasing power generated if frequency begins to drop. Those stations will need to keep some of their generating capacity in reserve for emergencies and the often receive payment just for being available to provide such a reserve.

Power generated must exactly equal power consumed. You have a few seconds to balance it, but frequency will start to rise or fall if there is any imbalance. However, voltage is not dependent on active power generated or consumed, frequency is.

A mentioned above the frequency (electrical cycles per second) is tied to the rotational speed of the generators (mechanical revolutions per second). In the USA the frequency is nominally 60 Hz but it varies slightly around this perhaps (59.97Hz to 60.03Hz). When extra power is drawn from the grid the generators feel the strain and slow down a bit - so the frequency slows down by a fraction of a Hz. This is the signal to put in more gas or steam and increase the power to your generators.

In the past control rooms that actually had big charts on the walls and dials that people turned. Nowadays the whole system is computerised. The longer term decisions still have human oversight but short term decision have to be made automatically because there isn't enough time for human intervention. In fact the fastest responding element is a speed controller on some of the generators (called a governor) which acts like cruise control on your car. When demand for electricity exceeds generation the generators start to slow down and the governors kick in and increase the gas.

To control the spin rate of the generators the system/technicials will, for example: apply more coal; turn on another turbine; in hydroelectric dams, open another gate and start another dynamo; in nuclear plants, pull out a couple of rods.

Some generators could alter their MW output, and some couldn't.

The frequency must stay the same as well. The frequency of the generator(revolutions per minute) goes up, as a result, the energy frequency at the generator output (Hz) goes up. Then it goes through a regulation circuit to synchronize it with the grid, to match the 50Hz(or 60Hz, if that's your thing).

15.3.2 Demand in a DC system

Since the polarity of a DC voltage does not change with time, the DC voltage has no (zero) frequency through time. Alternating current-voltage varies with time while direct current-voltage is constant.

15.3.3 Demand in an AC system

In an AC system, voltage doesn't vary with demand - frequency does.

1. If generation equals demand, then frequency will stay constant.
2. If generation is less than demand, then frequency goes down.
3. If generation exceeds demand frequency goes up.

15.4 Manufactured product energy usage label

The wattage listed is the maximum power drawn by the appliance. Every device, whether it is printed on the device itself or the transformer that powers the device, should have a label indicating the power consumption in Watts. The Watt number on the device may represent the device's maximum power rating, and not be representative of the amount of energy it is actually using when running. For instance, a computer's power supply may have a maximum rating of 400 watts, but someone uses the device at lower than 400 watts 100% of the time.

Take note, that in general, it is not possible to accurately calculate real world energy usage based on a manufacturer's label.

15.5 Market-based billing

> *Note: In general, electric meters record consumption (kWh).*

Typically, consumers in the market are charged for their electricity in terms of energy: the more energy used, the more they pay. A high-power appliance uses energy more rapidly than a low-power one, and therefore, costs more to operate (i.e., "run").

Your energy charges are based only on the total amount of energy you consume. Your demand charges are based on the highest level of electricity supplied at one time during the billing period and at the time of day it's needed by your business. In the market, electrical power companies use an electrical meter connected to a building to determine the power used, from which the total cost is calculated among a number of additional variables;

1. Time of day - peak hours (more cost); off-peak (lower cost)
2. Seasonal differentiated - e.g., more people using AC because of heat, more energy usage (more cost)

16 Energy density and power density

IMPORTANT: *Modern physics is still confused over the concepts herein as is visible in the circularity of their definitions: (1) Energy is possessed by mass due to its motion and/or potential motion; (2) and, mass is a form of energy ($E=mc^2$).*

Energy density refers to the energy content/quantity of an energy carrier based on a mass or volumetric unit. Any material or energy resource (as a region of space) can be measured for its ability to release energy and do work. Similarly, any energy conversion system can be measured for its rate of transferring energy. These measures may be used as metrics for evaluating and comparing the performance of different energy technologies, materials and systems; or, they may be used as parameters for these design [specifications] for a new energy supply system.

CLARIFICATION: *"Energy density" is sometimes known as "work density".*

If a system has a high 'potential energy density' or 'potential energy specificity', then it is able to contain ("store") a lot of energy in relatively little spatial area or mass. If a system has a 'high power density' or 'specific power', then per a given amount of time, it can output/transfer relatively large amounts of energy based on its spatial area or mass. An energy resource with a lower 'energy density' or 'specific energy' means it takes more volume or mass to produce the same amount of work as a higher 'energy density' resource. Similarly, an energy system with a lower 'power density' or 'specific power' means it takes more time per volume or mass to transfer the same amount of energy as a higher 'power density' system.

The quantified presence of 'energy density' does not give information on how quickly this energy can be used/transferred. This knowledge is contained in the term 'power density', which describes the rate at which energy can be put in and/ or transferred out. A high 'energy density' or 'energy specificity' does not necessarily mean a high 'power density' or 'power specificity'. Typically, having a high energy density means the presence of a low power density. In fact, in practical applications, a high energy density often equates to a low power density.

To better understand 'energy density' and 'power density' the case of a campfire could be used. To start the fire, kindling is used, because its high surface area-to volume ratio means that it burns quickly - a high 'power density'. However, once the fire is stable, kindling is no longer an optimal fuel source, because it burns too quickly. Hence, the fuel source is switched to logs, because they have a high 'energy density' and will burn for a longer period of time.

Metaphors are a useful way of understanding power density. For instance, dumping water out of a mug has a high power density, because it is capable of emptying all its contents almost instantaneously. Comparatively, if a jug with a 2cm spout is upended, it would take awhile to release its contents, giving it a low power density. For example, a tiny capacitor may have the same power output as a large battery, but because the capacitor is smaller, it has a higher power density.

NOTE: *Magnetic energy density is the density of energy conveyed to the part of space occupied by the magnetic field.*

Just as energy can be separated at a top-level into potential energy and kinetic energy, energy density can be separated into potential energy density and kinetic energy density. Potential and kinetic energy can be released and transferred in the following ways:

1. **Potential energy** can be *released* from a **system by a reaction** (as "energy density" or "specific energy"), and *transferred* **at a specific rate** (as "power density" or "specific power").
2. **Kinetic energy** can be *extracted and/or released* from a **moving material by a device/system** (as "energy density" or "specific energy"), and *transferred* **at a specific rate** (as "power density" or "specific power").

16.1 Energy [release] in relation to spatial region

Energy in a given region of space may be classified as potential or kinetic. Whether potential or kinetic, there is a maximum available energy per unit of space (volume or mass) that can be released or extracted. Therein, there are two calculated classifications for the amount of *available* energy within said region of space (measured as volume or mass), which create a total of four classifications:

1. [Potential or kinetic] 'energy density' - volume is the unit-region of space.
   A. Potential energy density
   B. Kinetic energy density
2. [Potential or kinetic] 'specific energy' - mass is the unit-region of space.
   A. Potential specific energy
   B. Kinetic specific energy

'Potential energy density' and 'potential specific energy' are applicable to a material potential energy resource, such as fuel or an energy storage medium (i.e., battery). 'Kinetic energy density' and 'kinetic specific energy' are applicable to a material kinetic energy resource, such as wind or flowing water.

'Energy density' is the amount of energy per unit weight (gravimetric energy density) or per unit volume (volumetric energy density). Note that the volume of a three dimensional space (i.e., spatial area) can be given in either metric cubic units (e.g., m^3) or liters (L). And, weight is otherwise known as mass. Energy density and specific energy are measures of the direct use/release of an energy source per spatial area unit as volume or mass. Energy density and specific energy answer the question: How much energy can be (or is being) stored in a volume/mass of space?

1. **Energy density (volumetric energy density)** - the amount of energy stored or contained within a given volume or mass of a substance or system. Energy density refers to how much energy a system contains in relation to its volume. Energy density describes the amount of energy that can be stored or obtained from a specific amount of material or system. Energy density is crucial in assessing the storage capacity or energy content of batteries, fuels, or energy storage systems. Higher energy density implies more energy stored within a given mass or volume, which is advantageous for portable devices, electric vehicles, or energy storage solutions. In other words, 'energy density' refers to how much work a given region of space (as a volumetric spatial unit) is capable of releasing (or exerting). It is typically expressed in watt-hours/volume or joules/volume: watt-hours per kilogram (Wh/kg), watt-hours per liter (Wh/L), joules per cubic centimeter (J/cm^3), joules per cubic meter (J/m^3), gigajoules per cubic meter (GJ/m^3), or megajoules per liter (MJ/L).
   - Potential energy density = energy output per volume of space derived as a result of a reaction (as chemical, thermal, nuclear fission or decay, electrochemical, or electrical).
   - Kinetic energy density = energy output per volume of space as a result of motion (as mechanical).
   - Energy density (Ed) is energy per volumetric spatial unit.
   - $E_d = E / V$
   - where, E is the energy released during utilization (e.g., combustion or energized circuit), and V is the volume of the fuel (as m^3 or liter).
2. **Power density** - the rate of power production or the amount of power generated per unit of area or volume. Power density refers to how much energy (calculated) acquired from a unit of land, or a machine, in operation. Power density is used to assess the concentration or intensity of power generation within a given space or volume. In energy systems, it describes how much power can be produced or transmitted in a specific area or volume. Power density is typically measured in watts per square meter (W/m^2) for area-based measurements or watts per cubic meter (W/m^3) for volume-based measurements.
3. **Gravimetric energy density (specific energy)** - how much energy a system contains in relation to its mass. In other words, 'specific energy' refers to how much work a given region of space (as mass unit) is capable of releasing (or exerting). It is typically expressed in watt-hours/mass or joules/mass: watt-hours per kilogram (Wh/kg), joules per gram (J/g), megajoules per kilogram (MJ/kg), gigajoules per ton (GJ/t).
   - Potential energy density = energy output per mass of space derived as the result of a reaction (as chemical, thermal, nuclear fission or decay, electrochemical, or electrical).
   - Kinetic energy density = energy output per mass of space as the result of motion (as mechanical).
   - Specific energy (Es) is energy per unit mass:
   - $E_s = E / m$
   - where, E is the energy released during utilization (e.g., combustion or energized circuit), and m is the mass of the fuel (as kg).

Energy density in an electric field is given by:

- Energy density = potential energy / volume = $1/2\epsilon_0 E^2$

Electric and magnetic fields "store" potential energy. In a vacuum, the (volumetric) energy density (in SI units) is given by:

- $U = (\varepsilon_0/2)E^2 + (1/2\mu_0)B^2$
- where, E is the electric field and B is the magnetic field. And, U is expressed in Joules per cubic meter (J/m^3).

In normal (linear and nondispersive) substances, the energy density (in SI units) is:

- $U = 1/2\ (E \cdot D + H \cdot B)$
- where, D is the electric displacement field and H is the magnetizing field.

There are many different types of potential energy contained ("stored") in materials, and it takes a particular type of reaction to release each type of energy. A material (substance or system) can release [potential] energy in four types of reactions: nuclear; chemical; electrochemical; and electrical. In other words, these types of reactions are capable of releasing [potential] energy from a material.

Generally, only the useful (or releasable/extractable energy) is measured/quantified. For instance, in concern to chemical energy, chemically inaccessible energy is not applicable when accounting and calculating for energy density.

> **NOTE:** '*Energy density' (how much energy a region of space carries) does not provide sufficient information about 'energy conversion efficiency' (net output per input), or about 'embodied energy' (what the energy output requires in terms of harvesting, refining, distributing, and dealing with pollution, which all use energy themselves). However, the 'energy density' of a system can be calculated relative the inclusion or exclusion of [external] components required to express that energy (e.g., oxidisers, heat sink, temperature, and/or the energy output interface).*

Chemical reactions take in energy to break bonds and give off energy when they make bonds. Relatively large organic molecules like those of hydrocarbons have lots of weak carbon-carbon and carbon-hydrogen bonds which don't take a lot of energy to break. But when these molecules redox ("burn"), then the combustion products make lots of strong carbon-oxygen and hydrogen-oxygen bonds that give out a lot of energy when they form. However, a liquid fuel, for example, is only on chemical combination with Oxygen, that energy is released (converted) to heat. The output energy is more dependent on the bonds that form to make the products, than the bonds in the initial fuel.

> **CLARIFICATION:** *The amount of thermal energy released in a chemical reaction can be calculated through thermodynamic equations. The 'heat of combustion' is the total energy released as thermal energy (heat) when a substance undergoes complete combustion with oxygen under standard conditions (this information is often presented in units of kj/mol). Therein, the amount of energy released by the combustion of a given fuel is the result of the subtracting the energy required to break the bonds of the reactants from the energy released by the formation of bonds in the products. One measure of the chemical energy of a fuel is the 'heat of combustion'.*

When chemical reactions take place and bonds form, break, and reshape, the atom nuclei don't change in any way. What happens is that the electrons jump between atoms or groups of atoms and change orbits. The different orbits are bound by different energies and you can start with a configuration of atoms and electrons and end up with another configuration but the total energy stays the same. This is really all there is to it, and thinking about that will give you a lot of intuition in particular with "energetic" chemistry. The potential energy in the bonds becomes kinetic [thermal] energy.

> **NOTE:** *The energy density of a fuel (e.g., hydrocarbon) will vary depending upon its molecular makeup.*

Of note, energy per unit volume has the same physical units as pressure, and in many circumstances, it is a synonym for pressure. One could go so far as to say that energy, in every form, is simply pressure mediation. For example, the energy density of a magnetic field may be expressed as (and behaves as) a physical pressure. Similarly, the energy required to compress a compressed gas a little more may be determined by multiplying the difference between the gas pressure and the external pressure by the change in volume. Hence, pressure [in a fluid] may be considered to be a measure of energy per unit volume (energy density).

Using a battery as an example, 'energy density' is a measure of how much energy the battery can store, in a given size or mass, a characteristic of the battery chemistry and its packaging. A battery with a higher 'energy density' can power a load for longer than one with a lower 'energy density' and the same physical size or mass (and composition). Its units are in Wh/kg or Wh/cm^3. Note the use of hours in the unit: power x time = energy. Also, it has to be stressed that the calculated 'energy density' is related to a given discharge rate, temperature, battery size, average discharge voltage, and cut-off voltage. A battery can, for instance, have a higher 'energy density' when discharged at a lower discharge rate or to a final lower cutoff voltage:

1. Energy density of a battery = ((drain in amperes x service hours = capacity in amp-hours) x average discharge voltage) / volume of battery in liters = Watt-hours/liter
2. Specific energy of a battery = ((current amperes x service hours = capacity in amp-hours) x average discharge voltage)/weight of battery in kilogram = Watt-hours/kilogram

16.2 Rate of energy transfer [power] in relation to spatial region

> **NOTE:** *Power is not sub-classified as potential or kinetic. Power is the rate of energy transfer. Power is measured in units: Watts = joules/ seconds*

Having a measure for 'energy density' or 'specific energy' does not give information on how quickly the energy can be used/transferred. This information is contained in the measure of 'power density' and 'specific power', which describes the rate at which energy can be released and/ or transferred. Hence, whereas 'energy density' refers to the capacity to do work, 'power density' refers to the speed at which work can be done. 'Power density' and 'specific power' are measures of power output as a time rate of energy transfer per spatial unit (volume or mass). Power density answers the question: How fast can a volume/mass of space deliver energy? There are two calculated classifications for the rate at which energy can transfer between regions of space (measured as volume or mass):

1. 'Power density' - volume is the unit-region of space.
    - Power density (W/cm^3 or W/m^3) = power / volume
2. 'Specific power' - mass as the unit-region of space.
    - Specific power (W/g or W/kg) = power / mass

'Power density' (a.k.a., volume power density) and 'specific power' (a.k.a., mass specific power) are the power correlates of 'energy density' and 'specific energy' -- the amount of power (time rate of energy transfer) between regions of space. 'Power density' and 'specific power' refer to the ability of a given system or region of space to deliver, or to take on, power. Power is transferred between regions of space via energy transforming systems (a.k.a., energy conversion devices), such as turbines, turbine-generators, batteries, fuel cells, motors, power supplies, combustion systems, and photovoltaic panels. Energy transformers convert a volume (volume power density) or mass (mass specific power) of energy at a specific rate.

NOTE: *Since they release their energy quickly, in general, high power density systems can also recharge quickly.*

In terms of electrical energy, 'power density' (volume) and 'specific power' (mass) refer to the maximum current that can be drawn from a region of space (e.g., battery as volume and mass).

16.2.1 Power density and lasers

The power density of a laser beam can be determined by:

power density (W/cm^2) = ($250/d^2$) • power (W)

- where,
    - d, typically refers to the distance from the laser source to the surface or area target, where the power density is being calculated, in centimeters.
- assuming,
    - The beam profile is uniform.

16.2.2 Power density and batteries

For a battery, "power density" refers to the rate of energy release per unit of battery volume or weight. In other words, "power density" of a battery refers to the rate at which energy can be delivered or released from the battery per unit of volume or weight. It is a measure of how quickly a battery can deliver/transfer/convert its stored "energy". The formula for power density can be expressed differently based on whether it's in terms of volume or weight:

1. **Power density in terms of volume:**

    power density (volume-based) = energy / volume

    A. Units: Typically measured in watts per liter (W/L) or milliwatts per cubic centimeter (mW/cm^3).
    B. Energy: The total amount of energy stored in the battery (measured in watt-hours or Wh).
    C. Volume: The total volume of the battery cell or pack (measured in liters or cubic centimeters).

2. **Power density in terms of weight:**

    power density (weight-based) = energy / weight

    A. Units: Usually measured in watts per kilogram (W/kg) or milliwatts per gram (mW/g).
    B. Energy: The total amount of energy stored in the battery (measured in watt-hours or Wh).
    C. Weight: The total weight of the battery cell or pack (measured in kilograms or grams).

NOTE: *A battery system can only supply the maximum power for a restricted period of (seconds or less) over the total amount of time it is supplying energy.*

16.2.3 Power density in non-battery machines

Power density is used by radio engineers ("light" engineers) to express power densities of isotropic antennas as a quotient of the transmitted power and the surface area of a sphere at a given distance (for instance, W/m^2). Similarly, the power density of heat engines, electromagnetic cells (e.g., photovoltaic solar panels, and electromagnetic turbines is typically measured in W/m^2 or kW/m^2.

16.2.4 Power density and energy flux

A broader approach is to measure power density through the more universal measure of 'energy flux' as W/m^2 of horizontal area of land or water surface, rather than per unit of the working surface of a converter. In other words, power density is expressed as electricity generated per m2 of the area occupied (per period of time).

Wind power density, for example, refers to the energy flux across a turbine or to diffusion rates in fuel cells. Power density has been used recently in this sense in order to calculate a flux across the (vertical) area swept by a wind turbine (more on this in the wind power density section).

In terms of combustion to electrical energy, power density (as W/m^2) refers to the volume of raw material that would have to be extracted (relative to the material's specific energy) in order to meet the combustion system's desired production capacity (per period of time). The power density of the material could be calculated (per period of time), and then the power density of the entire system (including the technical combustion system and raw material) could be calculated.

In terms of a solar panel to electrical energy, power density (as W/m^2) refers to the power output of the panel relative to the surface area of the panel. Subsequently, the power density of the entire arrayed system can be calculated. Note that the power density of solar installations must also account for space between panels, either for servicing in solar farms or for spacing between houses in rooftop solar installation.

In terms of a wind turbine, power density measures the flux of wind's kinetic energy moving through the working surface (the area swept by blades).

17 Energy and power safety

Energy and power production is a support system that produces a potentially dangerous set of deliverables including heat, light, and electricity.

17.1 Warnings

Warnings take the form of communications and knowledge about what could harm safety. Warnings can be signposted (graphically shown) to signal to someone the danger of some or other action.

17.2 Incidents types

A.k.a., Failures.

Types of energy/power incidents include, but are not limited to:

1. All types of power:
    A. Fire (burning).
        1. Death caused by burning is referred to as immolation
2. Electrical power:
    A. Shock and/or electrocution.
        1. Death caused by an electric shock is referred to as electrocution.
3. Electromagnetic power:
    A. Non-ionizing radiation burns, erythema, and lesions (non-ionizing electromagnetic burns).
4. Mechanical, fluid, and combustion power:
    A. Suffocation.
    B. Crushing.
    C. Dismemberment.
    D. Thermal burn.
5. Nuclear power:
    A. Ionizing radiation burns (ionizing electromagnetic burns).

17.2.1 Native and non-native electromagnetic radiation

Native (i.e., "natural") electromagnetic radiative energy is all around us. The three primary source of native EMR for us on earth are: 1) the earth; 2) the sun; and 3) the cosmos. All life on earth needs this native electromagnetic radiation (or at least a portion of it), and cannot function without it. In addition to native EMR, humankind has begun engineering electromagnetic radiation (i.e., non-native EMR or EMF). Biological organisms on earth have learned how to use EM radiation from the sun, and our species has learned how to use electromagnetic processes from reality to expand our functioning (e.g., radio telecommunications).

Humans are salt water, and they present a low-resistance path for electrical current, which will preferentially redirect through their bodies rather than through other substances.

1. Skin effect, inductances and capacitance are negligible at 60hz.
2. Emergency de-energization.

"System Emergency" means the condition in the Electricity System when, due to the occurrence of one or more incidents, a part or the whole of the Electricity System experiences excessive frequency deviations or transmission voltage deviations, and in the opinion of the System Operator circumstances exist such that: (a) the safety of the Transmission System is at risk; (b) the reliable transmission of electricity is at risk; or (c) there exists a danger to life or property as a consequence of (a) or (b).

> **NOTE:** *The effects of EMR upon biological systems (and also to many other chemical systems, under standard conditions) depend both upon the radiation's power and its frequency.*

Hazardous energy is defined by the Canadian Standards Association (CSA) as: "any electrical, mechanical, pneumatic, chemical, nuclear, thermal, gravitational, or other energy that can harm people" (CSA Z460 "Control of Hazardous Energy - Lockout and Other Methods"). Some energy sources are obvious, such as electricity, heat in a furnace, or something that might fall. Others may be hidden hazards such as air pressure in a system or a tightly wound spring.

Not properly assessing and dissipating stored energy is one of the most common causes for workplace incidents that involve hazardous energy. Control of hazardous energy includes isolating the system from its primary power source and residual energy.

1. Hydraulic potential energy is the energy stored within a pressurized liquid. When under pressure, the fluid can be used to move heavy objects, machinery, or equipment. Examples include: automotive car lifts, injection moulding machines, power presses, and the braking system in cars. When hydraulic energy is released in an uncontrolled manner, individuals may be crushed or struck by moving machinery, equipment or other items.
2. Pneumatic potential energy is the energy stored within pressurized air. Like hydraulic energy, when under pressure, air can be used to move heavy objects and power equipment. Examples include spraying devices, power washers, or machinery. When pneumatic energy is released in an uncontrolled manner, individuals may be crushed or struck by moving machinery, equipment or other items.
3. Chemical energy is the energy released when a substance undergoes a chemical reaction. The energy is normally released as heat, but could be released in other forms, such as pressure. A common result of a hazardous chemical reaction is fire or explosion.
4. Radiation energy is energy from electromagnetic sources. This energy covers all radiation from visible light, lasers, microwave, infra red, ultraviolet, and X-rays. Radiation energy can cause health effects ranging from skin and eye damage (lasers and UV light) to cancer (X-rays).
5. Gravitational potential energy is the energy related to the mass of an object and its distance from the earth (or ground). The heavier an object is, and the further it is from the ground, the greater its gravitational potential energy. For example, a 1 kilogram (kg) weight held 2 metres above the ground will have greater gravitational potential energy then a 1 kg held 1 metre above the ground.
6. Mechanical energy is the energy contained in an item under tension. For instance, a spring that is compressed or coiled will have stored energy which will be released in the form of movement when the spring expands. The release of mechanical energy may result in an individual being crushed or struck by the object.

In most cases, equipment or systems will have safety devices built in. These safety devices include barrier guards and safeguarding devices to help protect workers during normal operations. However, during maintenance or repairs, these devices may have to be removed or by-passed. In these situations, a hazardous energy control program is needed.

A hazardous energy control program is used to maintain worker safety by preventing:

1. Unintended release of stored energy.
2. Unintended start-up.
3. Unintended motion.
4. Contact with a hazard when guards are removed or safety devices have been by-passed or removed.

Lockout is generally viewed as the most reliable way to protect an individual from hazardous energy because you are bringing the system to a zero energy state. When a system is in a zero energy state the hazard has been eliminated; thus, no hazardous energy exists. However, in some cases, using lockout is not practical because of its impact on operations and various other functions. Therefore, other controls can be implemented as long as adequate risk reduction of the hazard is obtained. This type of control means following a full set of steps to determine the hazards and risks of each task being performed, and determining what controls can be used to minimize and reduce risk to an adequate level. If an adequate level of risk cannot be achieved, then lockout will be the default method of control.

A voltage applied to a human body causes an electric current through the tissues, and although the relationship is non-linear, the greater the voltage, the greater the current. The threshold for perception varies with the supply frequency and with the path of the current, but is about 0.1 mA to 1 mA for mains-frequency electricity, though a current as low as a microamp can be detected as an electrovibration effect under certain conditions. If the current is sufficiently high, it will cause muscle contraction, fibrillation of the heart, and tissue burns. The lack of any visible sign that a conductor is electrified makes electricity a particular hazard.

17.2.2 Does it hurt more to be shocked by 110v or 240v AC?

One reason AC is more deadly is that any path which cause the current to pass through the body and cross the heart (i.e., left-hand-to-right-hand or hand-to-foot) will cause the heart to attempt to synchronize its beat to 60 Hz. The heart goes into fibrillation, and unless someone gets an AED on you within a couple minutes, that's the end. Heat is also generated by the flow of electrical current through body tissues, resulting in direct thermal injury (electrical burns) and possibly physical injury (entrance and exit wounds). In addition, the alternating current locks the muscles in a spasm, so you can't pull away. With DC, your greatest danger is thermal-physical injury at very high voltages, or just thermal injury at lower voltages. The reason DC feels much worse is that it causes the muscles to contract abruptly (whereas AC causes them to lock), so the physical effect is more painful. AC will freeze your muscles while DC will contract them. So if you hold a wire in your hand, DC will make you hold it even stronger, while AC will just "freeze" your muscles.

A higher voltage breaks down a poor insulator (e.g., the thin layer of non-conductive dry skin that covers the body), and once that insulator breaks down, the inner layers of the skin, and the muscles, are highly conductive. 15 mA is the lethal dose. That is why ground fault circuit interrupters (GFCI) can help prevent electrocutions, and are set to trigger at a 5 mV differential.

> **"***I have not tried the experiment, but I have read that a 9 V battery connected to two sharp needles will, if the needles are stuck into the skin, be very painful."*

Higher voltages are more dangerous because they break down poor dielectrics faster. Remember, at all times, 15 mA across the heart is all it takes. Current pushed/fed through the human body by voltage causes the body to react unpleasantly. Current is measured in amps, A. In the energy storage technology known as a battery, 'capacity' indicates how much power the battery pack can hold and is indicated in milliamp hours (mAh). In other words, mAh describes the measurement of how much load or drain (measured in milliamps) can be put on the battery for 1 hour, at which time the battery will be fully discharged.

However, DC tends much more to arcing than AC at points where current-carrying contacts are separated. The danger of fire and burning is significantly higher with DC compared to AC. The reason: an AC arc will be more efficiently extinguished due to the zero-crossings of current, 100 to 240 times a second (50 / 60 Hz). DC has no zero crossings, so an arc will form even at low voltages, around 40 - 50 volts. 250 VDC can easily cause an arc of one or more inches in length, if current is interrupted. Hybrid mechanical/electronic circuit breakers have only recently been developed for these DC current contact connections.

Of note, DC tends much more to arcing than AC. Any mechanical DC current connector, relay -- basically a mechanical current interrupter -- is dangerous, because of the DC arc, which will happen during the opening or closing of any DC current contact. Hybrid mechanical/electronic circuit breakers have been developed for these connections.

18 Power symbols

A power symbol is a symbol indicating that a control activates or deactivates a particular powering or powered device. Universal power symbols are described in the International Electrotechnical Commission 60417 standard, Graphical symbols for use on equipment, appearing in the 1973 edition of the document (as IEC 417) and informally used earlier.

The well known on/off power symbol was the result of the logical evolution in user interface design. Originally, most early power controls consisted of switches that were toggled between two states demarcated by the words On and Off. As technology became more ubiquitous, these English words were replaced by the universal numeral symbols 1 and 0 (typically without serifs) to bypass language barriers. This “1” and “0” standard is still used on toggle power switches.

To create the symbol for a single on/off button, the “1” and “0” symbols were super-imposed onto each other to create the universally recognized power symbol used today. Because of widespread use of this symbol, a campaign was launched to add the set of characters to Unicode. February 2015, the proposal was accepted by Unicode and as of late 2015 the IEC power symbol family was in Stage 7 of Unicode character development and either in ISO approval ballot or pending ISO publication.

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TABLES

Table 21. Life Support > Power > Primary: *Primary energy "generating" sources accompanied by a description of where the energy is derived from.*

Primary Energy Generating Sources			
Energy source generators	**Energy from / transport by**	**Conversion process**	**Power depends on (Conversion rate of generator and ...)**
Geothermal (thermal)	Heat from inside the earth	Turbine	Temperature
Wind (atmospheric current)	Atmospheric currents derived from the earth's rotation and exposure to radiant energy from the sun	Turbine	Wind speed ~v^3
Wave (water + wind)	Wind waves in a body of water	Wave device / Turbine	Wave height (H^2) and wave period
Tidal (water + solar system gravity/electrostatic force)	Daily cyclical movement of a body of water	Tidal device / Turbine	Height squared (H^2) and flow speed (cubic)
Hydro (water + planetary gravity/electrostatic force)	Uni-directional flowing movement of water	Dam / Turbine	Height squared (H^2) and flow speed (cubic)
Hydrolysis (water)	Chemical reaction of an organic molecule breaking down in water	Reactor	Delocalization across the C9-N15 bond and steric effects
Solar (radiation)	Solar non-thermal radiation from the sun	Photovoltaic	~ annual radiation
Solar (thermal)	Solar thermal radiation from the sun	Collector	~ annual radiation
Animate (animal)	Animal movement	Animal movement	Species, sex, and strength/health of organism
Coal (solid hydrocarbon)	Combustion of organic rocks	Combustion	Heat content of the fuel
Oil (liquid hydrocarbon)	Combustion of organic liquids	Combustion	Heat content of the fuel
Gas (gas hydrocarbon; a.k.a., "natural gas")	Combustion of organic gases	Combustion	Heat content of the fuel
Biomass (plants & animal waste)	Combustion of plant-derived materials	Combustion	Heat content of the fuel
Nuclear (atomic)	Heat from fission of large atoms or fusion of small atoms	Reactor	Temperature

Table 22. Life Support > Power > Energy Conversion: *Example conversions with efficiency notation.*

Energy Conversions			
Converter	**Form Of Input Energy**	**Form Of Output Energy**	**Efficiency**
petrol engine	chemical	mechanical	η
diesel engine	chemical	mechanical	η
electric motor	electrical	mechanical	η
boiler & turbine	thermal	mechanical	η
hydraulic pump	mechanical	potential	η
hydro turbine	potential	mechanical	η
hydro turbine	mechanical	electrical	η
generator	mechanical	electrical	η
battery	chemical	electrical	η
solar cell	radiation	electrical	η
solar collector	radiation	thermal	η
electric lamp	electrical	light	η
waterpump	mechanical	potential	η
water heater	electrical	thermal	η
gas stove	chemical	thermal	η

TABLES

Table 23. Life Support > Power > Energy Type *Elaborated list of energy forms and energy types with accompanying descriptions. Note that wave energies (such as radiant or sound energy), kinetic energy, and rest energy are each greater than or equal to zero because they are measured in comparison to a base state of zero energy: "no wave", "no motion", and "no inertia", respectively.*

Types of energy	Description of energy Type
Kinetic	(≥0), that of the motion of a body.
Potential	(≥0), that of the position of a body relative to the zero plane of inertia of that body.
Forms of Energy	Description of energy Form
Mechanical	The sum of (usually macroscopic) kinetic and potential energies. The energy of motion (every moving object). Usually visible.
> Mechanical [wave]	(≥0), a form of mechanical energy propagated by a material's oscillations -- 'acoustic energy' is called sound.
Chemical	That contained in molecules (molecular bonds).
Electric	That from electric fields.
Magnetic	That from magnetic fields.
Electromagnetic	(≥0), that of electromagnetic radiation including light -- 'optical energy' is called light; 'radiant energy' carried by light.
Nuclear	That of binding nucleons to form the atomic nucleus.
> Ionization	That of binding an electron to its atom or molecule.
Thermal	A microscopic, disordered equivalent of mechanical energy. Expressed as heat.
> Heat	(≥0), the microscopic motion of molecules. An amount of thermal energy being transferred (in a given process) in the direction of decreasing temperature -- heat is a form of energy; temperature is a measurement of heat.
Forms of power *(Thermodynamically, only 2 forms of power)*	Description of power type
Mechanical power (work[ing])	The rate at which "work" is done. Mechanical energy used per unit time.
Thermal power (heat[ing])	The rate at energy is transferred via heat. Thermal power is the measure of thermal energy used per unit time. It is the rate of heat transfer or heat flow rate.

Table 24. Life Support > Power > Energy Kinetic*: Forms of kinetic energy (classified by type of motion).*

Kinetic Energy Forms	Motion	Examples And Subtypes Of This Form Of Energy
Mechanical [motion]	motion of macroscopic objects/substances;	machines, muscles, projectiles, wind, flowing water, mechanical waves, sound (acoustic, longitudinal waves), ...
Thermal [motion]	vibratory motion (vibration) of microscopic particles of matter (molecules, atoms, ions) --	heat, fire, geothermal, ...
Electrical [motion]	flow of charges (electrons, protons, ions)	electric current, AC and DC circuits, ...
Electromagnetic [motion]	disturbance propagating through electric and magnetic fields or the motion of photons	the electromagnetic spectrum [banded into radio waves, microwaves, x-rays, ...]

Table 25. Life Support > Power > Energy Potential*: Forms of potential energy (classified by type of mathematical field).*

Potential energy forms "Forces"	Quantity in field	Examples and subtypes of this form of energy
Gravitational [force field]	mass	roller coaster, waterwheel, hydroelectric reservoir, ...
Electromagnetic [force field]	charge	electric, magnetic, chemical, elastic, ...
Strong nuclear [force field]	color charge	nuclear reactors, nuclear weapons, ...
Weak nuclear [force field]	lepton number	radioactive decay, mass change, ...
Chemical [force field]	ion[ic charge] - atoms and molecules separated into ions (ionic bonds)	endothermic and exothermic reactions

TABLES

Table 26. Life Support > Power > Energy Flow: *Energy flow breakdown examples.*

Energy Flow Breakdown Examples		
Energy Stage	**Technology Used**	**Example of objects in stage of flow**
Primary	-	coal, wood, hydro, dung, oil, etc
-	Conversion	power plant, kiln, refinery, digester
Secondary	-	refined oil, electricity, biogas
-	Transport/Transmission	carriage, pipes, wires
Final	-	diesel oil, charcoal, electricity, biogas
-	Conversion	motors, heaters, stoves
Useful	-	heat, shaft power

Table 28. Life Support > Power > Energy Transformation: *Energy transformation: coal fired power plant example.*

Coal-Fired Power Plant Example Of Energy Transformations	
Energy Transformation	**Description Of Transformation**
Chemical energy	coal converted to thermal energy in the exhaust gases of combustion
Thermal energy	the exhaust gases converted into thermal energy of steam through the heat exchanger
Thermal energy	steam converted to mechanical energy in the turbine
Mechanical energy	turbine motion converted to electrical energy by the generator, which is the ultimate output
In such a system, the first and fourth step are highly efficient, but the second and third steps are less efficient. The most efficient gas-fired electrical power stations can achieve 50% conversion efficiency. Oil- and coal-fired stations achieve less.	

Table 27. Life Support > Power > Energy Transformation: *Energy transformation types and descriptions.*

Energy Type	Description of Energy Transformation
Thermoelectric	Heat > electric energy
Geothermal power	Heat > electric energy
Heat engine	Heat > mechanical energy
Ocean thermal power	Heat > electric energy
Hydroelectric dams	Gravitational potential energy > electric energy
Electric generator	Kinetic energy or mechanical work > electric energy
Fuel cells	Chemical energy > electric energy
Battery	Chemical energy > electric energy
Fire	Chemical energy > heat and light
Wave power	Mechanical energy > electric energy
Wind power	Mechanical energy > electric or mechanical energy
Piezoelectrics	Mechanical ("strain") energy > electric energy
Acoustoelectrics	Mechanical ("acoustic/sound") energy > electric energy
Friction	Kinetic energy > heat
Heater	Electric energy > heat

TABLES

Table 29. Life Support > Power > Physics > Electrostatics > Charges: *Opposite charges attract. When there is an equal # of opposite charges there is "balance", giving the atomic system an overall neutral (zero) charge.*

Name	Signifier	Unit	Relationship
Proton	+ (positive)	charge	
Electron	- (negative)	charge	
Name	**Signifier**	**Unit**	**Relationship**
Positive charge		Cations	Possesses more protons than electrons; higher electric potential
Negative charge		Anions	Possesses more electrons than protons; lower electric potential
Uncharged / electrically neutral		Neutrino	Equal numbers of protons and electrons; no net electrical charge; equipotential throughout

Table 30. Life Support > Power > Physics Energy*: This table depicts the different conceptualizations of energy, the incorrect and correct scientific conceptions, and their information analogues.*

Conception	Incorrect idea	Scientific concept	Information Analogue
Energy as agent	Energy causes things to happen. It makes an action happen and can be stored inside a physical thing.	Energy does not cause events to happen. However, when events happen, there is always a transfer of energy between interacting physical things.	Information does not cause events to happen. However, when events happen, there is always a transfer of information between interacting physical things.
Energy as action	Energy is an action or activity, like burning, bubbling, running, and bouncing.	Actions are visible experiences that energy is transferring.	Actions are visible experiences that information is transferring.
Energy as form	Energy has multiple forms depending upon its location in the physical world.	Energy does not have different forms or location in the physical world, but there are different types (or modes) of energy transfer - energy is transferred within and between "carriers" in different ways.	Information does not have different forms or location in the physical world, but there are different types (or modes) of information transfer - information is transferred within and between "carriers" in different ways.

Table 31. Life Support > Power > Domains: *This is an axiomatic power/energy mapping table. Table shows the real-world energy/ power domains, the name of the effect as a static concept (effort) and dynamic concept (flow). The SI Units are also shown.*

Energy domain	Generalized Effort (static concept)	SI Units	Dimensions	Generalized Flow (dynamic concept)	SI Units	Dimensions
Human	Force	Newton	MLT^{-2}	Velocity	m/s	LT^{-1}
Biological	Pressure	Pascal	$ML^{-1}T^{-2}$	Volumetric flow	m3/s	$L3T^{-1}$
Electrical	Voltage	Volt	$ML^{2}T^{-3}A^{-1}$	Current	ampere	A
Hydraulic	Pressure	Pascal	$ML^{-1}T^{-2}$	Volumetric flow rate	m^3/s	L^3T^{-1}
Mechanical (rotational)	Torque	Nm	ML^2T^{-2}	Angular velocity	rad/s	T^{-1}
Mechanical (translational)	Force	Newton	MLT^{-2}	Linear velocity	m/s	LT^{-1}
Chemical	Affinity	J/mol	$M^2L^2T^{-2}mol^{-1}$	Reaction rate	mol/L/s	$L^{-1}T^{-1}mol$
Pneumatic	Pressure	Pascal	$ML^{-1}T^{-2}$	Volumetric flow rate	m^3/s	L^3T^{-1}
Optical	Intensity	W/m^2	MT^{-3}	Velocity	m/s	LT^{-1}
Magnetic	Magnetomotive force	A-turns	A	Magnetic flux rate	Wb/s	$ML^2T^{-2}A^{-1}$
Thermal	Temperature difference	Kelvin	t	Entropy flow rate	J/ks	ML2T-3t-1

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Table 32. Life Support > Power > Types: *Power types and their properties.*

	Power Type			
Property	Electrical	Mechanical	Pneumatic	Hydraulic
Energy transition	Turbine	IC engines, electrical energy is used to drive motors	Electrical energy is used to drive compressors and other equipment	IC engines, electric motor, air turbine used to drive hydraulic pump
Medium	Energy is transferred wirelessly or wired	Energy is transferred through levers, gears, and shafts	Compressed air/gas in pipes and hoses	Pressurized liquid in pipes and hoses
Energy storage	Batteries	Variable frequency drives	Reservoir, air tank, pneumatic valves	Accumulators, hydraulic valves
Transmitters	Wireless and wired transmitters	Transmitted through mechanical components like levers, gears, cams, screws, etc.	Transmitted through pneumatic cylinders, rotary devices, and rotary actuators	Transmitted through hydralic
Leakage	Stray voltage and ground currents	N/A	Contamination relative to gas used	Contamination relative to liquid used
Energy transmission/ distribution	Unlimited with power loss	Short distance	Up to 100m flow rate v = 2-6 m/s signal speed up to 1000 m/s	Up to 1000m flow rate v = 20-40 m/s signal speed 20-40 m/s
Operating speed			v = 0.5 m/s	v = 1.5 m/s
Power supply input	Low	Variable	High	Very high

Table 33. Life Support > Power > Circuit/Ground: *Grounding system comparison table. In the 1999 Edition of the NEC, impedance grounded systems were considered to be ungrounded systems.*

Grounded Systems				
NEC reference	Required grounded systems	Pros	Cons	Use
Article 250.20(A)	(Solidly grounded) ac systems less than 50V	Greater safety Prevents insulation damage from over-voltages from line-to-ground faults during resonant ground faults Easy detection; faster mean time to repair	Higher fault levels; validate circuit breakers rated for bolted fault	Equipment such as window shades, BAS, and some fire alarm systems
Article 250.20(B)	(Solidly grounded) ac systems 50V to 1,000V			Residential single-phase 120V/240V Commercial and light industrial facilities with 3-phase, 480V:208 Y/120Vsystems
Article 250.20(C)	(Solidly grounded) ac systems 1,000V and above			Medium-voltage transmission lines
Article 250.20(D)	Impedence grounded systems	Provides operational continuity during a line-to-ground fault; equipment doesn't shut down Introduction of the resistance can control the higher fault levels present in the solidly grounded system	Must be engineered to match facility capacitance	Industrial plants; mills Large data centers Medium-voltage cables
Ungrounded Systems				
NEC reference	Allowed ungrounded systems	Pros	Cons	Use
Article 250.21(A)	General: systems deemed to be a higher safety risk to automatic shut down, suich as blast furnaces	Provides operational continuity during a line-to-ground fault. Equipment doesn't shut down Cheaper to install	Primary line-to-ground transietns are passed through transfomers unattenuated	Steel manufacturing Industrial plants Pulp and paper

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Table 34. Life Support > Power > Mechanical Electric: *Difference Between Induction and Synchronous motors and generators is explained with the help of various factors.*

Basis Of Difference	Synchronous Motor	Induction Motor (Asynchronous Motor)	Synchronous Generator (Alternator)	Induction Generator (Asynchronous Generator)
Type of excitation	A synchronous motor is a doubly excited machine.	An induction motor is a single excited machine.	-	-
Frequency	-	-	Frequency is determined by the rotational speed of the generator's shaft -- faster rotation of the shaft generates a higher frequency.	-
Supply system	Its armature winding is energized from an AC source and its field winding from a DC source.	Its stator winding is energized from an AC source.	-	-
Speed	It always runs at synchronous speed. The speed is independent of load. Synchronous motors are used where constant running speed is the governing factor. In a synchronous motor the rotor and magnetic field rotate at the same speed.	If the load increases, the speed of the induction motor decreases. It is always less than the synchronous speed. The operation of the induction motor depends on relative motion as the difference in speed between the rotor and the rotating magnetic field. This relative motion induces and EMF in the rotor.	-	-
Starting	It is not self starting. It has to be run up to synchronous speed by any means before it can be synchronized to AC supply.	Induction motor has self starting torque.	-	Usually not started without an energized connection to the electric power grid, unless they are designed to work with a battery bank energy storage system.
Operation	A synchronous motor can be operated with lagging and leading power by changing its excitation.	An induction motor operates only at a lagging power factor. At high loads the power factor becomes very poor.	-	-
Usage	It can be used for power factor correction in addition to supplying torque to drive mechanical loads.	An induction motor is used for driving mechanical loads only.	-	-
Efficiency	It is more efficient than an induction motor of the same output and voltage rating.	Its efficiency is lesser than that of the synchronous motor of the same output and the voltage rating.	-	-

Table 35. Life Support > Power > Solar Electric: *Direct solar to electric conversion types.*

No	Types	Characteristics
1	Photoemissive	Light interacting with a cathode causes electrons to be emitted from the cathode surface.
2	Photoconductive	The resistance of a material is changed when it is illuminated.
3	Photovoltaic	Light interacting with the junction of two exposed substances generates an output voltage proportional to light intensity.
4	Photomagnetic	Light interacting with a dynamic magnetic field causes a voltage.
5	Photogalvanic	Light interacting with a material produces a chemical action that causes voltage.
6	Photoelectrochemical	Light interacting with a material produces a chemical action that causes voltage.
7	Bio-photoelectrochemical	Light interacting with an organic material produces a chemical action that causes a voltage.

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Table 37. Life Support > Power > Storage: *Typical values of specific energy and energy density.*

Common storage materials (fuels)				
Energy source	**Energy reaction type (to release)**	**Density Kg/m3**	**Specific energy mj/kg**	**Energy density Mj/m3**
Coal (anthracite)	Chemical	1350	-27	-36,450
Coal (lignite)	Chemical	801	-15	-12,015
Wood	Chemical	600	-15	-9,000
Common storage hydrocarbons (fuel alkanes)				
Hydrocarbon (alkane) storage	**Energy reaction type (to release)**	**Density Kg/m3**	**Specific energy mj/kg**	**Energy density Mj/m3**
Methane (ch4)	Chemical	423	-55.5	-23,529
Ethane (c2h6)	Chemical	545	-51.8	-28,246
Propane (c3h8)	Chemical	585	-50.3	-29,449
Butane (c4h10)	Chemical	601	-49.5	-29,729
Pentane (c5h12)	Chemical	621	-48.7	-30,223
Hexane (c6h14)	Chemical	655	-48.3	-31,633
Heptane (c7h16)	Chemical	680	-48.1	-32,690
Octane (c8h16)	Chemical	698	-47.9	-33,433
Decane (c10h22; kerosene)				
Common storage alcohols (fuels)				
Alcohol storage	**Energy reaction type (to release)**	**Density Kg/m3**	**Specific energy Mj/kg**	**Energy density Mj/m3**
Methanol (ch3oh)	Chemical	787	-22.7	-17,855
Ethanol (ch3ch2oh)	Chemical	785	-29.7	-23,278
1-Propanol (ch3(ch2)2oh)	Chemical	800	-33.6	-26,902
Common storage devices (battery-like devices)				
Device storage	**Energy reaction type (to release)**	**Density Kg/m3**	**Specific energy Mj/kg**	**Energy density Mj/m3**
Lithium battery (non-rechargeable)	Electrochemical		1.8	4.32
Lithium-ion battery (rechargeable)	Electrochemical		0.36–0.875	0.9-2.63
Alkaline battery	Electrochemical		0.5	1.3
Lead-acid battery	Electrochemical		0.17	0.56
Nickel-metal hydride battery	Electrochemical		0.288	0.504-1.08
Supercapacitor (EDLC)	Electrical (electrostatic)		0.01-0.036	0.06-0.05

Table 36. Life Support > Power > Prime: *Primer movers as types of work and power.*

Prime mover	Type of work	Type of power
Force	Mechanical work	Mechanical power
Pressure	Fluid work	Fluid power
Voltage	Electrical work	Electric power

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Table 38. Life Support > Power > Storage: *Functional differences between a battery and capacitor.*

Function	Capacitor	Battery
Charge time	1-10 sec	10-60min
Cycle life	1 million or 30,000 h	500 and higher
Cell voltage	2.3 to 2.75V	3.6-3.7V
Specific energy (Wh/kg)	5 (typical)	100-200
Specific power (W/kg)	Up to 10,000	1,000-3,000
Service life (in place) in years	10-15 years	5-10 years
Charge temperature (between two values)	-40 to 65˚C	0 to 45˚C
Discharge temperature (between two values)	-40 to 65˚C	-20 to 60˚C

Table 39. Life Support > Power > Storage: *Overview of sensible, latent, and thermochemical processes using salt.*

Temperature level	Salt type	Test type
<0 ˚C	Water-salt mixtures	PCM slurry
0-100 ˚C	Melting of salt hydrates in crystallization water	PCM
40-300 ˚C	Dehydration of salt hydrates	TCS
40-150 ˚C	Absorption in concentrated salt solutions	TCS
120-500 ˚C	Solid–liquid conversion in anhydrous salts	PCM
100-800 ˚C	Anhydrous molten salts	Sensible
100-800 ˚C	Anhydrous solid salts	Sensible
100-800 ˚C	Solid–solid conversion in anhydrous salts	PCM

Table 40. Life Support > Power > Storage: *Electrochemical capacitor types.*

Electrochemical capacitor type	Symmetric aqueous	Symmetric organic	Asymmetric aqueous	Asymmetric organic
Energy density				
Power performance				
Self discharge rate				
Low-temp discharge				
Packaging				
Voltage balance				
Cell voltage				
Operating temperature limits				

Table 41. Life Support > Power > Conversion: *Energy "transformation".*

Energy Resources	>>>	**Technological Equipment**	>>>	**Usable Energy**
For example, moving water, biomass, wind, sunshine, the Earth)		For example, hydroelectric and wind turbines, stoves and furnaces, photovoltaic panels)		For example, electricity, steam, heat, biofuels

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Table 42. Life Support > Power > Load: *Energy requirements of a device/load.*

Device/load (examples)	Instantaneous power requirement/ demand/usage "rating" P=E/t	Energy requirement/usage:		
		If run for 1 second (energy consumed)	If run for 1 minute (energy consumed)	If run for 1 hour (energy consumed)
60W light bulb	60w 60J/s	60w 60J/s		
Laptop	40-80w 40J/s - 80J/s	0-80w 40J/s - 80J/s		

Table 43. Life Support > Power > Load: *Example electrical energy demand profile.*

Name and amount of device	x	Device's required POWER (rate of demand in 1 minute in Watts)	x	TIME the device is used (in hours)	=	Total energy consumption of device (in watt-hours)	Power usage in time
1 Light bulb	x	100 Watts (1x100 = 100W or .1kW)	x	10 hours	=	1,000 Watt-hours or 1kWh	1kW used in 10 hours
10 Light bulbs	x	100 Watts (10x100 = 1000W or 1kW)	x	1 hour	=	1,000 Watt-hours or 1kWh	1kW used in 1 hour; 10 times more demand than 1 light bulb over 10 hours

Table 44. Life Support > Power > Conversion Electric: *Electric power conversion classified according to whether the input and output are alternating current (AC) or direct current (DC). A power converter is an electrical or electro-mechanical device for converting electrical energy.*

Electric power conversion			
DC to DC	DC to AC	AC to DC	AC to AC
Dc-to-DC converter	Inverter	Rectifier	Transformer / autotransformer
Voltage regulator		Mains power supply unit (PSU)	Voltage converter
Linear regulator		Switched-mode power supply	Voltage regulator
			Cycloconverter
			Variable-frequency transformer

Table 45. Life Support > Power > Electricity: *AC and DC device differences.*

AC Devices (~1950)	DC Devices (~2000)
Electric typewriters and adding machines	Computing and printing equipment
Teleprinter	Telecommunication systems
Early fluorescent lighting	Advanced fluorescent lighting with electronic ballast, gas discharge lighting, LEDs
Radios, early televisions	HDTV's, CD Players, smartphones
Record players	CD players and game consoles
Electric ovens	Microwave ovens
Fans and furnaces	Electronically controlled HVAC

Life Support: Medical Service System

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Abstract

Human life, like all biological life, is composed of consciousness animating a biological life [organism] form. In this dimension of reality, given the technologies available, the human biological form can be injured and will not become whole again instantly [and through mental thought alone]. Injury and dis-ease can degrade the quality of life of an individual at the same time degrading the quality of life of those in interrelationship with the injured and/or intensely suffering individual. Even in a community-type society, it is still possible for social conflict to emerge such that medical services may need to include individuals trained to stop violence. A community-type society perceives violence as an accident in society to be individually recovered from and socially restored to a dynamic where the violence is unlikely to present itself in the future. Violence is a medical issue, as are physical injuries, skills and knowledge are similar in some regards and different in others. Here, there are no police-type roles as seen in the market-State. Issues that cause harm and trigger life-oriented restorative processes and protocols are likely to be handled different depending on what values (on a values circumplex) are being actively encoded within that society. Some values are more likely to engage punitive-type behaviors; whereas other values are more likely to engage restorative-type behaviors. A medical service is, by definition, of the restorative type. A medical service provides the capability of dealing with medical problems. A medical service is, in part, a disaster recovery plan for life forms. A medical system involves medical knowledge, medical procedures, and medical drugs, but healthy well-being is primarily achieved by facilitating individual happiness with respect to whatever might have distressed them into illness. Thus, good health-care places enormous emphasis on dealing with the cause of illness, as opposed to remedial treatment of the symptoms. Humans can be injured physically and mentally, together.

Graphical Abstract

Image Not Yet Associated

1 Medical system overview

APHORISM: *Prevention is the best medicine.*

In its scientific context, medicine is the science of creating and restoring healthy functioning and facilitation of biological resilience. Pain means something is wrong; pain has a function. Pain is a signal of something, often, tension. The more a source of pain continues to generate the pain, the more disease there will be. There are emergency cases of pain, such as a vehicular accident where humans are physically injured, and there are cases of pain, such as overeating and arthritis. Some medical problems are life-threatening, and others are not. Because there are life-threatening medical problems, there is the necessity for a medical service to be continuously operative and available to respond. Some medical procedures can be carried out remotely, but others require structures and technologies positioned at fixed locations. The medical habitat service system seeks help people during and after medical incidents, and to restore people to a place of health. Health is a real physical and felt state where all the systems of the body – mental, nervous, muscular, skeletal, circulatory, digestive, lymphatic, hormonal, etc. – are working in an optimal way. Health can be restored in many ways, from setting a broken bone to restoration of proper light cues so that sleep and metabolism regulation are optimized.

The fundamental purpose of medicine is to restore someone to a healthy bio-physiology. Herein, the medical services of a habitat involve the following primary functions (the medical service system encompasses):

1. Emergency medicine (a.k.a., hospital care). When a medical incident occurs, emergency medicine teams and procedures are activated.
2. Health and fitness restoration (a.k.a., primary care, out-patient care, outpatient care). Over time, individuals are restored to their state of optimal health.
3. Symptom care (a.k.a., symptom management). Symptom management may help a person feel more comfortable, but it does not treat or cure the disease.
4. Monitor and evaluate medical actions and on-going medical conditions (a.k.a., medical "surveillance").
5. Facilitation of the prevention of medical emergencies and illness.
6. End of life facilitation (a.k.a., death transition).

The medical service system represents the unified health system for a community-type society, focused on medical care and quality-of-life restoration. The unified medical system coordinates the develops medical standards, operates medical services, and evaluates medical actions in a habitat.

The medical system of a habitat involves the following key elements:

1. Direct medical incident response (Read: emergency medicine).
   A. Direct "police"-medical incident response (Read: "law enforcement"). This category refers to what are known in the early 21st century as police (a.k.a., law enforcement) personnel, their tasks and actions. In community, the function formerly completely by "police" or "law enforcement" is instead completed by some form of medical-led intersystem team, and are treated with prioritization as medical incidents involving some form of violation of the decision system of community.
2. Restorative care after a medical incident (which, may or may not be chronic).
   A. Restorative justice practice by restorative justice counsellors, facilitators, and other medical personnel. After there has been a violation of the standards for community, a medical-led restoration teams seeks to restore well-ness to those involved in the incident of violation.
3. End-of-life care, after someone cannot care for themselves, medical habitat services will care for this person.

A community medical system facilitates restoration of individual's and the social (in the case of restorative justice) to wholeness, and togetherness. Science and ancestral wisdom can be used together to address the whole person, and their experience throughout time.

Medical-type functional spaces and activities include, but may not be limited to:

1. Medical incidents response centers (i.e., hospitals).
2. Medical recovery response centers (i.e., diagnostic and therapy centers).
3. Medical emergency technology access points.
4. Medical technology production and cycling centers.
5. Computational, architectural, and power systems are required.

It is important to know that the human body has innate repair and restoration systems that exist and can be enhanced and optimized, if "you" know how.

In any medical system, medical concerns can be categorized into three primary types of medical issues:

1. **Acute medical issues:** These are conditions that require immediate attention, often characterized by their sudden onset. They are also known as emergency medical issues or incident medical issues, and they can include events like heart

attacks, strokes, accidents, or acute infections.

2. **Cumulative medical issues:** These develop over time and can be the result of aging, repetitive activity, or prolonged exposure to harmful factors. Cumulative medical issues often progress slowly and may not be immediately life-threatening but can lead to significant long-term health problems.
3. **Lifestyle medical issues:** These are health problems that arise as a direct result of an individual's lifestyle choices, such as diet, exercise, substance use, and stress management. Conditions like type 2 diabetes, obesity, and certain heart diseases fall under this category.

Note that in the context of healthcare, primary, secondary, and tertiary care represent different levels of medical services provided to people, ranging from basic to specialized care. It could also be said that there are three forms of medical care:

1. **Primary medical care** - is the first point of contact for individuals entering the healthcare system. It typically involves general medical care provided for common health problems and preventive measures.
   A. **Medical role (a.k.a., medical providers):** This level of care is usually delivered by general practitioners, family physicians, internists, pediatricians, or community health providers.
   B. **Services:** Services include health maintenance, disease prevention, patient education, diagnosis and treatment of acute and chronic illnesses, and management of overall patient care.
2. **Secondary medical care** - is more specialized than primary care. Patients are often referred to this level by primary care providers when a condition requires more specialized knowledge or equipment for diagnosis or treatment.
   A. **Medical role (a.k.a., medical providers):** Specialists such as cardiologists, dermatologists, or surgeons provide secondary care. It often takes place in hospitals or specialized clinics.
   B. **Services:** This includes specialized medical or surgical care for specific diseases or parts of the body, outpatient surgery, and more complex diagnostic services.
3. **Tertiary medical care** - is an even more specialized level of healthcare, typically involving complex procedures and treatments that are not widely available. It's provided to patients with severe or life-threatening conditions.
   A. **Medical role (a.k.a., medical providers):** Tertiary care is delivered by highly specialized providers in facilities such as specialized hospitals or advanced medical centers.
   B. **Services:** Services encompass advanced medical and surgical procedures, trauma care, complex treatments for cancer, neurosurgery, cardiac surgery, and care for rare or complex diseases.

The concept of toxicity is intricately related to the types of medical issues previously discussed. Toxicity can be categorized into two main types:

1. **Single dose toxicity:** This pertains to whether a one-time exposure to a substance can be harmful or fatal. It is closely associated with acute medical issues, which are emergencies requiring immediate attention. In these cases, a single, high-level of exposure can lead to rapid onset of symptoms and health deterioration.
2. **Cumulative dose toxicity:** This refers to the effects of a substance over an extended period. Similar to cumulative medical issues, this form of toxicity arises from repeated exposure to a toxin at doses that may not be harmful in the short term but can lead to significant health problems over time. This aligns with the adage "the dose makes the poison," meaning that the toxicity of a substance is dependent on its concentration and the cumulative amount received over time.

2 Health

CLARIFICATION: *Fitness is "the physical ability to perform athletic activity". Fitness means being fit to do a task.*

Health is a state of no emotional suffering, no physical pain, and no disease. Health is an emergent state wherein energy and harmony provide a platform from which someone's will, and life purpose, are capable of being realized. The health state of someone includes the physical body as well as the psychological (mental) state of the individual. The mental state includes all thoughts, emotions, understandings, and perceptions/filters of the environment. The body of a person includes all physical systems. As a lifestyle, health is a state of being, wherein one has the innate capacity to flow (act) and recover. It is possible to apply systems engineering principles to the state of the health of an individual, to the homeostatic (and homeodynamic) maintenance of overall resistance in the body, and the progression of its ability to adapt beneficially to new environments. In general, good health comes from a good lifestyle, good food, and ultimately, a good life-radius.

There exist a set of system performance measures capable of being assessed in relation to known optimal states of health. There also exist a set of factors that are not well defined and therefore not well understood. When a factor is not well understood there cannot exist any optimal known states of that factor, and therefore, no assessment can take place. And therefore, it does not involve community action beyond its study.

Health is composed of, at least the following factors:

1. **Genotype:** a person's genotype is their unique sequence of DNA.
2. **Phenotype:** a person's current genetic expression based upon environmental factors.
3. **Individual-type:** a person's conscious.
4. **Societal-type:** the type of (configuration) a person lives in.

NOTE: *Human health is inextricably linked with the health of its larger, planetary ecosystem.*

2.1 Health and personal decisioning

The decisioning of individual effects the entire community, the entire system. One individual's decisions about their health and medical situation effects not only themselves, but the entire community. Sick people pull down the potential of society.

The common indicators of health are:

1. **Anxiety** - the feeling of a possibility of pain; anxiety signals the possibility of damage. It is also possible for someone to feel anxiety when there is an overwhelming expansion of complexity associated with their near future life (e.g., flat tire). Anxiety can have psychological (e.g., expected future bad event) and physiological (e.g., heart valve issue) influences.
   A. In the context of first response and feelings of anxiety, first responders ought to:
      1. Be well trained, and therefore calm under otherwise potentially stressful situations.
      2. Be calm, and that will make others feel calm.
2. **Pain** - the feeling of physical pain. Pain signals actual, physical, real-world damage.
   A. **Depression** - a pain continued feeling of psychological pain.
   B. **Trauma** - the continued feeling of psycho-somatic pain.
3. **Health span (healthspan, health-span, years of quality of life)** - the proportion of life that someone lives in good health. Health span is the number of years someone is healthy without chronic disease. The period of time for which someone is free of disability and disease.
4. **Life span and aging (life-span, lifespan, years of life)** - how long someone has lived from birth to death. Lifespan (in *years*) is the number of years someone lives from birth until death.
   A. Average lifespan.
   B. Factors influencing lifespan.
   C. Year of life[span] and cellular age.
5. **Medical system usage** - the percentage of the population (of a habitat) that uses the medical system (every day, week month, quarter, year), including:
   A. For a yearly check-up.
   B. For incident care.
   C. For chronic care.
   D. For continuous medication.

Lifespan is the total number of years we live whereas healthspan is how many of those years we remain healthy and free from disease. And herein, pain is an indicator of a lack of well-being. Someone can have a long lifespan, but the ratio healthy years sickly years could be short (i.e., having a short healthspan).

2.1.1 Health quality assurance

Assuring health has requirements. Significant questions in concern to assurance of high-quality health are:

1. What are the environments (socio-technical configurations):
   A. That drive health in the right direction.
   B. That drive health in the wrong direction.
2. What are the individual behaviors (and psychologies):

   A. That drive health in the right direction.
   B. That drive health in the wrong direction.
3. What are the lifestyle patterns:
   A. That drive health in the right direction.
   B. That drive health in the wrong direction.
4. What are the reduction factors (a.k.a., risk factors) for driving health in the wrong direction?
5. What are the amplification factors for driving health in the right direction?

2.1.2 Human health and the environment

> **QUESTION:** *What is an individual medical problem, and what is a medical-type societal problem?*

The 'cell' is a useful metaphor for an individual human. The cell membrane is an information processor -- the membrane reads the environment and adjusts the [homeodynamic state of the cell's] biology. The cell membrane, as part of the cell body, is an environmental recognition system. The nucleus of the cell, with its genes, represents a hard disk, and the genes are programs. The old belief system is that the genes were read only, and hence, whatever the genes are, then that would be the person's fate. However, new discoveries have revealed that the nucleus is not read-only, but it is in fact, read-write -- it is a programmable device, you put it into an environment and it will read the environment and adjust the expression of the genes to match the needs of that environment.

Essentially, cells are programmable in response to environmental information. If you put a culture dish of cells into a sufficiently adverse environment, then the cells will get sick and start dying, but if you take that same culture dish of cells and move it into a "healthy environment" the same cells will recover, proliferate, and flourish. The human body is essentially a skin covered petri dish. There are many more bacterial cells than there are human cells "in" the body (with the understanding that the digestive track is both internal and external to the body). Hence, a state of health (or disease) is really a reflection of the environment that we live in and the environment that we perceive.

Everything occurs [in reality] through a cause and the cause has to have the right conditions for its occurrence. Impulse signals (as environmental triggers) cause effects. And, those triggers can be external and internal.

2.1.3 Death and decline

Humans die from reasons similar to all other animals, and mammals in particular.

Animals die because of:

1. Lack of food.
2. Disease.
3. Genetic issues.
4. An accident - Humans can die from physical trauma (and, another human's aggression/defense).
5. Old age - A human dies of old age when it has no ability to make new stem cells. A structure ceases to exist when it has no ability to replace itself.

In the early 21st century, the following medical-type events are the leading causes of death:

1. Cardiovascular and cerebrovascular disease inclusive of all dementias.
2. Cancer inclusive of metabolic disease.
3. Accidental death (primarily falls, automotive, overdose).
4. Orthopaedic injury and physical decline.
5. Genetic disorders.
6. Age accumulated decline.

2.2 Harm (suffering)

In a medical context, "harm" refers to any negative consequence, injury, damage, or adverse effect caused to an individual's physical or mental health.

Harm can manifest in various ways, such as:

1. **Physical harm:** Any injury, impairment, or negative impact on the body's structure or function due to medical treatment. This can include complications from surgery, adverse reactions to medications, infections acquired in healthcare settings, etc.
2. **Psychological harm:** Emotional distress, mental anguish, or negative psychological effects resulting from medical treatment or healthcare interactions. This can include anxiety, stress, trauma, or other mental health issues triggered by medical procedures or diagnoses.
3. **Social harm:** Negative impacts on an individual's social well-being or interactions due to medical treatment. For instance, stigma, discrimination, or social isolation resulting from a medical condition or its treatment.

Stabilizing after harm and restoring from harm is a fundamental principle in medical care, and medical services aim to provide care that maximizes benefits while minimizing potential adverse effects or risks.

2.2.4 Aggression

Humans like any animal will have days where they have "displaced aggression", because they might be compromised physically due to things like inflammation, fulfillment hunger, or competition for resources and territory. In community, humans will naturally have less aggression, because they are no longer competing for resources, fulfillment is appropriately complete, and inflammation is sought resolution to through self-understanding.

2.2.1 Suicide

In community, suicide is robustly discouraged, with everyone expected to live life to the fullest. To that effect, the causes of suicide are readily identified and addressed.

2.3 Disease (dis-ease)

Disease is a feeling and real physiological context of not being in a state of health. Humans feel healthy when they don't feel in a state of dis-ease. There are many sources of disease. Dis-ease can even come from a bad configuration of the environment. For instance, there is no moderation when humans are surrounded by, and consume, hyper-palatable foods, which they are wired to eat more of. It is basic biological wiring to eat the available and to overeat on highly palatable foods (especially hyper-palatable food that is also nutrient poor). In general someone where to make their meals enjoyable, full of real food, but not over the top palatable (i.e., to the point that overeating becomes more likely). In place of this type of food, some societal arrangement make food with hyper-palatability and low nutrients more accessible, thus leading to behaviors that generate dis-ease states within the environment, because real signals are being obstructed. Humans are designed to crave substances that are good for them (i.e., that the body needs). But when food service systems are designed outside of nature, then the bodies craving mechanism (taste) can quickly become misinformed and aberrant such that people crave foods and food-like substance that do not satisfactorily meet their bodies needs.

Health is about not having signs or symptoms of a disease. There are three types of diseases:

1. **Phenotype diseases** - health conditions or traits that are observable and manifest physically or functionally in an individual due to the interaction between genetic factors (genotype) and environmental influences. The phenotype represents the visible characteristics or traits resulting from the expression of an individual's genes, environmental factors, and their interaction
   A. **Self-induced diseases (a.k.a., lifestyle diseases)** - not eating a species specific/ appropriate diet and not living a species aligned lifestyle. Non-ancestral food-like substances can lead to lifestyle diseases, including but not limited to type 2 diabetes, some cancers, obesity, fatigue, a weak musculoskeletal system, etc.
2. **Genetic diseases** - are disorders caused by abnormalities or mutations in an individual's genetic material (DNA), inherited from parents, which can lead to structural or functional abnormalities in proteins, cells, or bodily systems, resulting in various health conditions or disorders. These diseases can range from single-gene disorders to complex conditions influenced by multiple genes and environmental factors.
3. **Pathogen diseases** - infection by an external pathogenic organism.
4. **Toxic exposure diseases** - refers to a health condition or illness resulting from exposure to harmful substances or toxins in the environment. These diseases occur when individuals come into contact with chemicals, pollutants, radiation, or other hazardous materials that can adversely affect health.
5. **Age-related diseases** - accumulation of insufficiently-repaired harm done to the body.

In a bio-physiological sense, health is about metabolic energy, metabolic flexibility, and overall body resilience. Herein, there are certain key natural principles and biochemical pathways that apply to all human beings, and yet, there is also some degree of biochemical individuality.

2.3.1 The international classification of diseases (ICD)

The international classification of diseases (ICD) is a list and knowledge base on the causes and consequences of human diseases and death worldwide. Clinical terms coded with ICD are the main basis for health recording and statistics on disease in primary, secondary and tertiary care, as well as on cause of death certificates. The use of ICD codes across these levels of care enables a uniform approach to cataloging diseases and health conditions. It aids healthcare providers in tracking patient outcomes, facilitates research, helps in public health surveillance, and ensures consistency in the classification and reporting of diseases and health conditions. This, in turn, improves the quality and efficiency of the healthcare system, supports healthcare policy development, and enhances resource allocation.

The latest version of the ICD, ICD-11, was adopted by the 72nd World Health Assembly in 2019 and came into effect on 1st January 2022.

2.3.2 Aging

Aging is an intrinsic side effect of the normal operation of the human body. The normal operation of a materiel system generates side effects, generates damages, molecular and cellular (in living systems) changes to the structure and composition, and those changes accumulate throughout the life of the system. Hence, aging in a system is inevitable and there is a minimum rate at which these changes will occur, and are generated as a side effect of even simple operations that are non-negotiable to the system. What is not inevitable is that this damage should remain unrepaired. Medicine is supposed to be about restoring health to a system, in particular, the human body system. The normal human body naturally repairs the ongoing and accumulating molecular and cellular damage; and thereby keeps it below the level that causes "disease", disability, and malfunction.

Some systems are set up to tolerate a certain amount of damage, and it is only when the damage accumulates beyond a certain threshold that things start to go wrong. In this sense, aging well (a.k.a., anti-aging) involves preventative maintenance, preventing damage before it builds up, and where there is buildup of damage, repairing and removing the buildup of damaged tissues.

3 The medical system inventory

Medical technology and inventory includes, but is not limited to:

1. **Medically trained personnel:**
   - A. Paramedic doctors (a.k.a., medic, emergency medical responder) - doctors specializing in emergency medicine. Someone who is trained to give medical treatment to people at the place where an accident has happened.
   - B. Doctors (and physician assistants) - general doctors and those specializing in specific systems of the human body. Someone who can give medical care generally.
   - C. Nurse (a.k.a., nurse practitioner, etc.) - trained to use specific medical technologies and provide limited medical care.
2. **Medical technologies (a.k.a., medical equipment):**
   - A. Laboratory diagnostic equipment.
     1. Clinical chemistry.
     2. Hematology and endocrinology.
     3. Pathology.
     4. Microbiology.
   - B. Imaging diagnostic equipment:
     1. Radiographic.
     2. Magnetic resonance.
     3. Ultrasound.
   - C. Minimally invasive or non-invasive monitors:
     1. Electrocardiograph, blood pressure, oxygen saturation, etc.
     2. Equipment and protocols to provide rescue, resuscitation, stabilization, and transport.
   - D. Surgery:
     1. Microsurgery/micro-therapeutics equipment and protocols.
     2. Specialized surgery.
   - E. Fluid therapy systems including infusion pumps, on-site production of fluids, nutritional support, blood, and blood component replacement.
   - F. Methods for biomonitoring.
   - G. Medical waste management.
   - H. Medical storage systems for samples, pharmaceuticals, and other perishable items.
   - I. Medical energy management.
3. **Medical documentation (medical manuals):**
   - A. Medical procedural manuals (medical operations manuals).
   - B. Medical diagnostic [and statistical] manuals.
     1. Physical.
     2. Mental [disorders].

3.1 Medical area infrastructure and intermediary productions

It is relevant to note here, that medical team operations use a lot of technology (that requires electrical power) in their operations. Medical services requires specialized and precision equipment. Medical services turn-over (dispose of) a lot of equipment due to contamination issues with medical sciences.

3.2 Medical manuals

Medical manuals are essential for understanding medical conditions and providing crucial information on medical operations/procedures, and the proper care of patients and use of medical technologies.

3.2.1 Diagnostic and Statistical Manual of Mental Disorders (DSM)

The Diagnostic and Statistical Manual of Mental Disorders (DSM) is a reference book on mental health and brain-related conditions and disorders. The American Psychiatric Association (APA) is responsible for the writing, editing, reviewing and publishing of this book. There are the equivalent for physical disorders. In concern to mental disorders and the DSM, the psychiatric diagnoses are mostly considered social constructs -- most of the diagnostic categories in psychiatry in the DSM[-V] are social constructs. There are no biomarkers or biological tests that can be taken to acquire a particular [mental disorder] diagnosis. The psychiatric diagnoses in the DSM are not based on objective biological markers (like physical diagnoses), but rather on a consensus among early 21st century industrial mental-health professionals (psychiatric industrial authorities) about how to define and classify mental disorders. The diagnoses in this Diagnostic and Statistical Manual are decided by political committees of industrial professions. It is a collaboration among psychological associations around the world and the for-profit pharmaceutical industry. The DSM acts as an insurance document for feeding the profits of the pharmaceutical industry. Often, it does more harm than good by creating labels, stigmas, and false role identities.

> **NOTE:** *It is extremely profitable and makes for the best sales to label people as "dysfunctional", or to find that they have a pharmaceutical deficit or some other pharmaceutically treatable and life-long disorder.*

Given the aberrant socio-economic conditions present in the early 21st century, it could be found that the origin of many (if not most) psychological disorders actually originate from (environments that induce anxiety and depression):

1. Unmet needs (including, physical nutrition).
2. Inflammation.
3. Adverse reactions to toxic substances (and also toxic environments).
4. Social suffering and social distress.
5. Situational distress.
6. Sane reaction (to e.g., poverty, abuse, overwork, inequality, bureaucratic torment).
7. Complex trauma.
8. Meaninglessness (lack of life purpose).
9. Existential dread [of varying kinds].
10. Loneliness.
11. Lack of access to nature (Read: green spaces such as forests, gardens, pastures, non-polluted lakes and rivers, etc.).
12. Just surviving syndrome and chronic coping.

The DSM's disorders fundamentally ignore human needs, particularly the universally common psycho-social needs (as well as human needs for nutrition):

1. Love/attachment.
2. Being un/heard.
3. Social belonging.
4. Making a difference.
5. Meaning and purpose.

4 Medical response

INSIGHT: *People are more likely to heal faster when they have an aesthetic view from their window as opposed to a hospital bed with a view over the parking lot.*

When there is a medical incident among the individuals of the habitat population, then there must be a medical response.

A medical service response to a medical incident generally involves, at least, the following:

1. Human personnel.
2. Pharmaceutical medications (medical drugs).
3. Decision support (for humans).
4. Technological systems for medical diagnosis and procedures:
   A. Semi-automated technological systems.
   B. Fully-automated technological systems.

4.1 Medically trained personnel

In community, doctors (along with artificial intelligent agents):

1. Assessment of situation and individual conduct diagnosis.
2. Planning and conducting procedures.
3. Administering follow-up care for patients.
4. Communicate to all stakeholders. To patients (and caregivers), transparently communicate risk. This communication should be given free of coercion, free of profit incentive, and free of manipulation (of everyone's anxieties, particularly, the patients).

At the population level it is possible to look at rational epistemological studies and make general broad statements, but at the individual level to do anything other than ask the question specifically about that individual person (patient, individual) is to do the individual a disservice.

"The doctor of the future will give no medicine, but will interest his patients in the care of the human frame, in diet and in the cause as well as the prevention of disease." - Thomas Edison

4.1.1 The Hippocratic Oath

The first principal of medical care has historically been known as the "Hippocratic Oath". Traditionally, the Hippocratic Oath is an agreement/contract a certifying doctor makes to, "First, do no harm". And yet, to do any form of cutting surgery necessitates cutting into the body, which is certainly a form of harm. The first principle of doctoring in community could also be called a "Hippocratic oath", and is really about following scientifically informed and evidence-based standards, and prioritizing treatments that have a very good chance of giving restoration, but that have a very low chance of causing harm. There is a balance between harm (risk) and benefit (reward), that needs to be considered in each contextual situation where harm has occurred and medical services are required.

4.1.2 Responding to violence

Under conditions where there is violence, or violence likely, medically trained personnel should:

1. Not assume bad intent.
2. Ask questions.
   A. To acquire missing information.
   B. To signal that the interlocutor is being heard.
3. Stay calm and investigate safely following procedures.
4. When team decisions must be taken beyond what protocol decides, then make an intelligent argument for one solution selection over the others.
5. Triage people and assets.

4.2 The first responders (emergency response, ER)

A.k.a., The first responding intersystem team, trauma medicine, paramedics, emergency medical systems, emergency response, etc.

A first responder is a person with specialized training who is among the first to arrive and provide assistance or incident resolution at the scene of trauma or medical related incident. First responders and incident responders provide trauma medicine and care. Trauma medicine is essentially conventional medicine for acute based care.

InterSystem Team personnel working as medical first responders require:

1. Emergency personnel
2. Emergency equipment access.

Every habitat has medical emergency equipment and personnel appropriately localized for human trauma/incident response. Of note, in community, all incidents of safety are "medical" incidents; whereas, in the market-State, some incidents of safety are "police" incidents.

The medicine of first responders eventually gives over to restorative practices and following natural principles that restore and optimize physiology (and psychology). As a community, "we" choose medical care that returns us to a state of restored [human need fulfillment] optimization.

NOTE: *It is important to note here the* *pharmaceutical use is essential for emergency medicine.*

4.3 Self-health monitoring

Self-health monitoring positively influences healthy behavior change. If someone is seeing the data, then they are seeing the trends, and typically, their behavior will just naturally change in a direction that will benefit them, given the opportunity. When shifts in behavior affect the data produced and users observe the shifts in data, then it much easier to change behavior, know what behavior to change to, and maintain a positively changed behavior. Naturally users of these technologies, formerly disconnected from healthy behaviors, will start to realize and understand what impacts what, and from there, behavior change becomes easier and most naturally. Self-health monitoring tools are a tool that drives behavior change and allows you to live a healthy lifestyle.

Common self-health monitoring devices in the early 21st century include, but may not be limited to:

1. Sleep tracking.
2. Blood glucose tracking.
3. Heart and pulse tracking.
4. Blood oxygen tracking.

4.4 Drug development and usage

A.k.a. Pharmaceuticals.

Pharmaceutics is the science of medicinal molecules (a.k.a., "drugs"), or their preparations and use. In the market-State, the development of drugs is interconnected with their sale, in business (and the larger pharmaceutical industry). Pharmaceutical companies in the market-State are not interested in developing chemicals into drugs if they can't patent it. In order for a drug company to move forward with the development of a molecule, it has to fully own it and hold the patent for the molecule, which is understandable from a commercial perspective because no business wants to invest millions of money into something they won't fully own. In community, drugs are developed and used where there is scientific evidence to do so.

4.4.1 Symptom care

Most medical care in the early 21st century is symptom care, and not holistic facilitation to a restored state of human being (i.e., not restoration). Pharmaceuticals are used to treat symptoms.

4.5 Medical code information

In the early 21st century, HL7 [hl7.org] provides the most well-known framework (and related standards) for the exchange, integration, sharing, and retrieval of electronic health information. FHIR (Fast Health Interoperability Resources, fhir.org) is an HL7 specification for Healthcare Interoperability. The standards are licensed as CC0 (public domain, P0). Note that it is a living dataset, and ought not be considered complete yet.

Relevant HL7.org hyperlinks include:

1. HL7 Terminology Version History (FHIR IG; directory of published versions):
   - https://terminology.hl7.org/history.html
2. HL7 Terminology (THO):
   - https://build.fhir.org/ig/HL7/UTG/toc.html
3. HLL7/ UTG on GitHub:
   - https://github.com/HL7/UTG/

4.5.1 Medical coding

A.k.a., Medical coding and payment.

In the market-State, when doctors sit down with a patient and evaluate them, they have to generate a billing slip in order to get paid. The way this is done is with medical [billing] codes for:

1. What was wrong with the patient (ICD11 codes in U.S.A., etc.), and
2. What the doctor did (CPT codes).

It is the combination of the ICD11 and CPT codes that determines how much State insurance/welfare (e.g., medicare, medicaid, etc.) or paid-for insurance will reimburse the doctor for his/her work. Medical codes in the market-State are principally for billing customers. In community, these codes are not tied to a doctors lifestyle and access fulfillment. In the market-State, these codes are inextricably linked to the lifestyle and socio-economic access of a doctor. It is relevant to note that natural processes like autophaghy, sun exposure, and eating less ultra processed food, and also "biohacking"/ physio-enhancement technologies, are not a possible box/code that a doctor can check off.

4.6 Systems of the human body

INSIGHT: *In a society that sees itself as whole, medical services treat the whole person (patient).*

The interoperating primary systems of the human body are:

1. Digestive.
2. Endocrine.
3. Nervous.
4. Respiratory.
5. Circulatory.
6. Muscular.
7. Skeletal.

8. Reproductive.
9. Immune.
10. Urinary.
11. Mitochondrial.

The principal bio-chemical parameters for physiological health are (proteins, hormones, enzymes):

1. Proteins are structures, and some proteins act as chemical-signaling molecules.
    - A. Hormones are biochemical messengers (chemical-signaling molecules) that induce action - hormones trigger actions.
        1. Peptides - shorter amino-acid chain lengths.
            - i. Neuropeptide hormones (shorter amino-acid chain lengths). Neuropeptide hormones are secreted by nervous t issue and act as signaling molecules to neighbouring cells.
            - ii. Peptide hormones (shorter amino-acid chain lengths). Peptide hormones are secreted by endocrine cells and travel to distinct tissues to evoke a response.
        2. Proteins - longer amino-acid chain lengths.
            - i. Protein hormones (longer amino-acid chain lengths).
2. Enzymes are catalysts for action - enzymes control the rate of a reaction.

Life Support: Cultivation Service System

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Abstract

Human life, like all biological life, is composed of prior animated life and minerals. Food is organisms (i.e., their bodies), including animal, vegetable, fungal, and bacterial, or it is things that come out of the bodies of these organisms. In nature everything is food for something else. It is possible to produce a service that cultivates food and other useful materials from organisms (e.g., textiles). Here, the mimicking of natural patterns is often the optimal strategy. Technology can be used to provide means and timeframes for cultivation that are impossible without the technology (e.g., hydroponics). Food has flavor. Food can, or cannot, be appropriate in nutrient content for the consuming organism. Textile and food products are the output of the cultivation service. Some foods are processed prior to distribution and others are not. In a community-type society, individuals can prepare and cook their own food, or they can rely on automated services. Similarly, material cultivation system may rely on human effort (e.g., such as personal gardens), others may involve a combination of human team and machine interaction, and even others may be fully automated operations. In general, the cultivation service involves the cultivation of resources from other organisms. There is a second dimension to the cultivation service, mining. Mining isn't really a form of cultivation because it doesn't involve the cultivation of living organisms. However, it does involve the "cultivation" of minerals (including hydrocarbons) from the earth. Hence, the cultivation service involves both the cultivation of other organisms and the extraction (mining) of compounds from the earth. Mining may include the collection of matter in its various forms (e.g., gaseous, liquid, and solid). Humans are mutually dependent upon other organisms in their environment. These other organisms can be selected and cultivated to facilitate human fulfillment and ecological flourishing.

Graphical Abstract

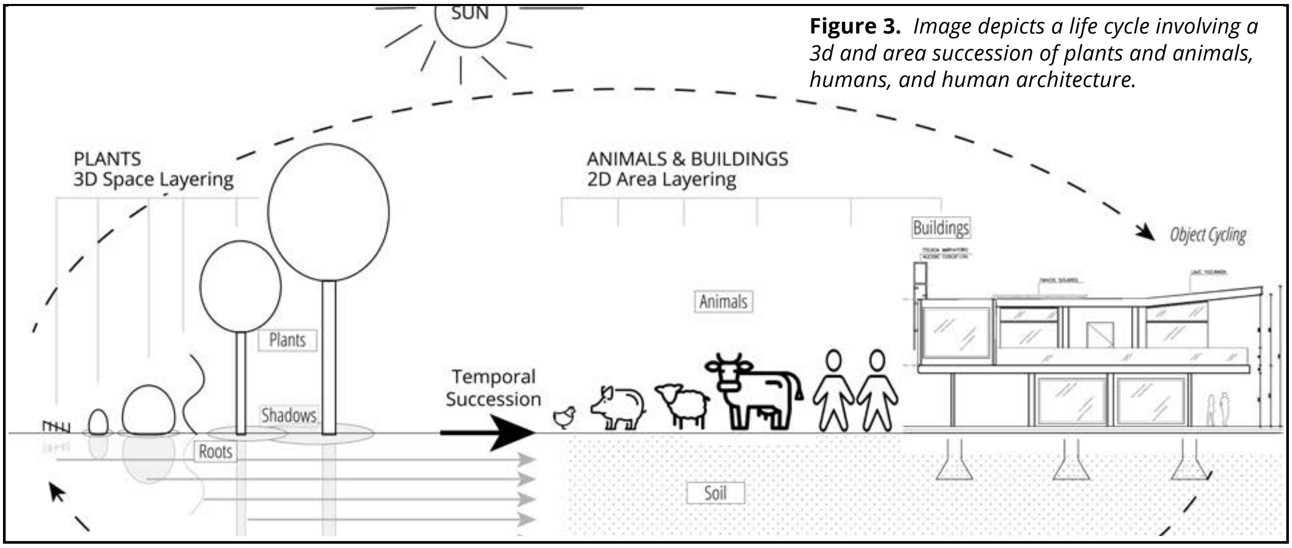

Figure 3. *Image depicts a life cycle involving a 3d and area succession of plants and animals, humans, and human architecture.*

1 Life cultivation overview

Life cultivation is the act of caring for, raising, and harvesting life and life's organisms. Farming is growing, caring for, and harvesting plants and animals. Harvesting means to take the life of, and then use, some organism. The wise tending and cultivation of nature will lead to greater fulfillment and abundance of organisms in nature. Through habitat service system design (the master planning of cities), cities may become unique ecosystems that facilitate the caretaking of the total planetary ecological system, produce food, material resources, and beauty. By highly controlling and coordinating the flow of resources within the city (habitat service system), it is possible to utilize the principles of natural systems in to cycle and regenerate the continuous flow of resources upon the planet for global human fulfillment. It is possible to grow food embedded within the living habitat service system environment. It is possible to plan for the cultivation of organismal and mineral resources requirements for materials, for food, and for beauty around cities. Fundamentally, different ecosystems can support different species and different numbers of species; wherein, species refers to living organisms.

Cultivation-type functional spaces and activities include, but may not be limited to:

1. Area exposed to bio-sphere:
   A. Pasture cultivation area.
   B. Architecturally controlled cultivation area.
2. Area for animals and plants:
   A. Animals.
   B. Plants.
   C. Fungi.
   D. Bacteria.
3. Animal slaughterhouse.
4. Plant and animal processing areas.
5. Plant and animal product packaging areas.
6. Plant and animal material resources and technological tools production areas.
7. Computational, architectural, and power systems are required.

1.1 Living organisms for cultivation

On earth, the kingdom of organism has two views:

1. 4 Kingdoms (simple view):
   A. Animals.
   B. Plants.
   C. Fungi.
   D. Bacteria.
2. 6 Kingdoms (biological sciences):
   A. Animals.
   B. Plants.
   C. Fungi.
   D. Eubacteria.
   E. Archaebacteria.
   F. Protista.

The systematic cultivation of organisms for a habitat service system includes, but may not be limited to, the following types of organisms:

1. Animal culturing (heteroroph cultivation):
   A. Pasture (normal) grazing *(and life placement in general).*
   B. Pasture (woodland) grazing *(and life placement in general).*
   C. Wilderness grazing *(and life placement in general)*
   D. Grazing internal habitat service system land *(short duration placement, often to provide an ecological cleaning service).*
2. Plant culturing (horticulture, autotroph cultivation):
   A. Annual culturing.
   B. Perennial culturing.
   C. Agroforestry (tree farming, tree-cropping, and forest farming).
   D. Hydroponics (water organism farming).
   E. Floriculture (flower farming), is a discipline of horticulture concerned with the cultivation of flowering plants.
3. Agriculture:
   A. Density properties (density scale):
      1. Mono-cropping agriculture.
      2. Ecological-diversity agriculture.
   B. Continuity properties (time scale):
      1. Annuals agriculture.
      2. Perennial agriculture (permanent agriculture, permiculture).
      3. Poly-agriculture (perennial- and annual-mixed agriculture).
4. Aquaculture:
   A. Plant culturing.
   B. Fish culturing.
   C. Amphibian culturing.
   D. Reptile culturing.
   E. Insect culturing.
5. Fungal culturing.
6. Insect culturing.
7. Algae culturing.
8. Bacterial culturing *(a secondary function/ requirement).*
9. Artificial photosynthesis *(not a technology yet accessible to humans).*

Note here that agriculture is the practice of cultivating plants and livestock. There are many different types of agricultural names and practices, which sometimes overlap. A farm is an area of land used for growing crops and raising animals.

The fundamental difference between animals and plants is the way animals and plants take in carbon to form organic compounds. Plants are autotrophs, which means that they meet their carbon requirements solely from carbon dioxide in the atmosphere, or from water in the case of water-dwelling plants. Animals, being heterotrophs, are unable to make their own organic molecules and so must take them in ready-made by eating plants and other animals.

The following organic primary compounds are shared by all living organisms and are central to life processes.

1. Carbohydrates.
2. Lipids (fats).
3. Nucleotides.
4. Peptides (proteins).

1.1 Cultivation for food, fuel, fiber, and aesthetic nature beauty

Plants, animals, and fungi, can be cultivated for food and other materials. There are four primary reasons for cultivation of organisms:

1. Cultivation for materials:
    A. Cultivation for food.
    B. Cultivation for fiber.
    C. Cultivation for fuel.
    D. Cultivation for a diversity of other [chemical] materials.
2. Cultivation for friendship (a.k.a., "pets").
3. Cultivation for aesthetics (for beneficial human feelings; biomimetic sensations).
4. Cultivation for ecological support; ecological service support and organismal diversity (i.e., a caretaken ecology).

These different types of cultivation all include and can be sourced from:

1. Animals.
2. Plants.
3. Fungi.
4. Bacteria.

The organisms herein can be:

1. [Re-]Produced across a landscape.
2. Cultivated continuously (perennially) or annually across a landscape.
3. Harvested from a landscape.

1.2 Cultivation service location planning

Places where food and other materials are cultivated may determine the flow of persons (or other animals) over a landscape. Food could be seen as 'place', and connection to 'place' - eating the landscape someone lives in. Placement of cultivation systems throughout a landscape can alter walking circulation patterns. For example, fruit trees in an environment may cause humans to use those paths when they intentionally travel within the city to acquire that type of food on any given day at any given hour. The effect of cultivating specific organisms in specific areas may have an effect on human locomotion (circulation) flow and ought to be accounted for at the level of the habitat service system master plan. It is possible to imagine whole cities as [cultivated plant] parks and pastoral (livestock and plant synergy) environments.

1.3 Organismal control and harvesting

A.k.a., Killing organisms, cultivation environmental control.

There are several ways of controlling organisms, include:

1. Placing other organisms in the same environment.
2. Some organisms may be controlled with fencing (barriers).
3. Some organisms may be controlled by chemicals (molecules).
4. Some organisms may be controlled with light alterations (shading and lasering).

The ways of killing, culling, and harvesting organisms, include:

1. Mechanical:
    A. Animals eating organisms.
    B. Crushing.
    C. Cutting.
    D. Projectile.
    E. Human hands harvesting.
    F. Robotic harvester.
2. Chemical "-icides":
    A. Pesticide - to kill insects.
    B. Fungicide - to kill fungi.
    C. Insecticide - to kill insects.
    D. Larvicide - to kill insects.
    E. Herbicide - to kill plants.
    F. Rodenticide - to kill rodents.
    G. Controlled burning - fire.
3. Light cover:
    A. Shade (i.e., cover that blocks out light, and thus killing, typically plant, organisms).

1.3.1 Bioaccumulation of chemicals

Bioaccumulation means that the organism accumulates a higher concentration of that chemical than is found in the environment in which it lives. Most toxic metals, besides mercury and organic forms of lead, do not bioaccumulate. Something can be toxic and cause health problems without bioaccumulating.

Necessary terms for understanding bio-accumultion include:

1. **Bio-magnify** - at each step along the food web, each tropic level, that chemical will accumulate to a higher concentration.
2. **Persistence** - how long a chemical remains in the environment.
3. **Cycle of dependency** - when you have to use more of it, and more chemicals because the pests evolve resistance to it.
4. **Global distillation** - for persistent organic chemicals, they can undergo long range transport in the atmosphere. Persistent means they persist in the environment for months to decades.

A common type of bioaccumulating chemical pesticide is:

- Organochlorin pesticides are lipophilic (fat soluble), which means they will bioaccumulate and biomagnify.

Identifying sources of bioaccumulation:

1. Identify sources of input of chemical.
2. Was there pesticide use on this land prior?
3. Is there pesticide drift? Drift refers to chemicals drifting or moving because of wind, water, and other forms of motion that migrate pesticides to locations other than originally indented.

Some pesticides remain on the skin and other get incorporated into the tissues. Pesticides cannot always be washed off plants. Some pesticides become systemic, often through uptake by the roots of the plant where up they are delivered throughout the plant by the plants circulatory system.

Pesticide residue has to do with pesticides use, the behavior of the farmer, the physiology of the plants, how quickly the pesticides break down and what are the environmental variables that influence the breakdown:

1. Temperature.
2. Humidity/moisture.
3. What is the concentration of the pesticide.
4. When is the harvesting taking place relative to the prior questions.

2 Cultivation for food

A.k.a., Cultivation for food, food cultivation, nutritional cultivation service, diet.

Every ecosystem has a food chain. Food defines carrying capacity for a species. Any biological organism exists as long as a stream of nutrition (and energy) passes through it in the form of food for animals or electromagnetic radiation in combination with inorganic and organic compounds for plants. Food is lifeforms or things secreted by lifeforms. When humans eat food they eat the tissues of living, or recently living, things. Humans eat life and life eats life, and there is no present way around that. In terms of food, organisms can be bred for flavor, texture, nutrition, and disease resistance. Food is an instructor to the genome, to hormones, and to the microbiome. Food is species specific (a.k.a., species appropriate). Fundamentally, all animals have a species specific diet - all animals have a diet they are adapted to eat. Food (diet) is a direct link between an animal and its habitat, and it is the basis of all of economics.

> **INSIGHT:** *In the early 21st century, there is a profound separation of human beings from their food that pervades society, and includes its food cultivation, preparation, and consumption practices.*

When an organism eats food, it is eating other organisms (their bodies), or it is eating things that come out of other organisms, as well as raw physical elements. Essentially, food is bodies or excretion from bodies (organisms). Life feeds on life. The human organism eats living things or formerly living things, necessarily, to remain alive. Material bodies consume and make use of material substances, and when the amounts are off or the substances are not right, then the conscious organism doesn't feel its best.

> **INSIGHT:** *No matter what you eat, you prey upon other species and make your body from them. In a closed ecosystem (the earth) nothing goes to waste; not even waste (e.g., excrement). Excrement is food for other organisms.*

2.1 Food in a cultivation system

A total cultivation system must provide food for a diversity of species, including:

1. Food for humans.
2. Fodder for various classes of livestock.
   A. Mammals.
   B. Fish.
   C. Reptiles.
   D. Insects
   E. Etc.
3. Medicines for humans and livestock.

In a total cultivation system, food comes in the form of the [dead] bodies of organisms, including (the tissues of):

1. Mammals.
2. Plants.
   A. Stems.
   B. Roots.
   C. Tubers.
   D. Leaves.
   E. Fruit.
   F. Seeds (a.k.a., nuts, grains, beans; are all just the seeds of plants)
   G. Flowers.
   H. Sap.
   I. Pollen.
3. Insects.
4. Fungi.
5. Bacteria.

It is relevant to note here that most food is considered food because it contains species-appropriate micro- and macro-nutrition. However, there are also medicinal foods, which act as medicines for species in case of disease. Additionally, there exist certain food-like substances that have the capability to alter the consciousness of their consumers, affecting perceptions, emotions, and behaviors in various desired ways. Hence, food could be separated at a high-level into:

1. Nutritious food.
2. Medicinal food (a.k.a., medicines).
3. Psychoactive substances (e.g., coffee, tobacco, etc.).

3 Cultivation for fiber and fuel materials

A.k.a., Materials cultivation, materials cultivation service.

Plants and animals can be selectively cultivated for material purposes. Plants and animals can be valuable sources of fiber and fuel.

The sources of fiber and fuel cultivation:

1. **Fiber:** Makes clothes, paper, rope, building supplies, and many other materials.
   A. Plant fiber production - the most common cultivation fiber is wood (Read: wood fiber). Other common fibers are grasses, such as cotton and hemp.
      1. Cotton fiber comes from the cotton shrub plant.
      2. Linen is made from the fibers of the flax grass plant.
      3. Hemp fiber is made from the hemp grass plant.
      4. Ramie and jute are other plant fibers that may be used to make fabrics and ropes.
   B. Animal fiber production - Animal fur and skins are a source of fiber. A variety of animals provide fibers (for cloth).
      1. Wool comes from sheep, goats, lama, alpaca, guanaco, and vicuña. Of note, goat fibers, wool, alpaca and angora rabbit fiber are all inherently flame-resistant.
      2. Angora fiber comes from angora rabbits.
      3. Mohair fiber comes from angora goats.
      4. Cashmere comes from Kashmir goats (also, pashmina and some other breeds).
      5. Silk comes from the large white moth caterpillar, commonly called the silkworm.
      6. The fur and skins from animals such as mink, beaver, muskrats, and rabbits can also be found in clothing.
      7. Hide comes from most livestock animals at the time of their deaths.
2. **Fuel:** Comes from biomass to produce biofuel and biogas (a product of decomposition) that can be combusted.
   A. Some tree nuts (e.g., hazelnuts) are a reasonable source of biofuel.
   B. The decomposition of biomass (organic wastes) can produce biogas.
   C. Wood can be used for fuel (fuelwood and wood fuel pellets). Note that firewood is the original biofuel. It is possible to create firewood derived charcoal as fossil-coal substitute (used in the

steel industry).

D. Ethanol produced by sugar-derived alcohol (for use in motor vehicles), as an adjunct to fossil fuel based petroleum.

4 Holistic cultivation masterplan

A.k.a., Restoration agriculture masterplan, agro-ecological masterplan, agro-ecological zone plan, agroforestry farm plan, restorative farm plan, permaculture farm plan, closed-loop farming, closed-loop agriculture, circular agriculture, ecological farming, ecological service agriculture, planet-based agriculture is animals and plants together.

Animals and plants form a symbiotic and synergistic relationship with humankind and are essential in humankind's survival and flourishing. Here, there is a holistic cultivation plan for a the creation and operation of a pasture-based rotational succession of animals and plants, including terrain modification (e.g., earthworks) and terrain operations (e.g., a pond network and animal rotation). Cultivating animals on pasture is better for the well-being of the animals and provides higher amounts of nutrition than animal cultivation in confined feed-lots and other built environments. A holistic cultivation system consists primarily of a rotational pasture grazing system with a combination of the following animals: cows and bulls, goats or sheep, pigs and ducks. Other animals (livestock) may be included. The pasture is planted with a 3D plant succession landscape where the animals will forage and humans can collect an abundance of food, fuel, and fiber. The plants consist mostly of perennials that produce food, fuel, and fiber, but annuals are included also. The plants may need to be protected as they grow in the pastures from the grazing animals. This 3D temporal planning of the plants must include sun shading-specific categories of plants: trees, shrubs, vines, ground covering, and underground. The pasture lot areas (a.k.a., fields) need to be planned out -- the number of pastures, dimensions of pastures, and types of plants and water features in each pasture. The rotation of animals through the pasture needs to be planned, given that pasture conditions may change and thus affect animal rotation (there must be a start, and best practices to follow afterward). A pasture is separated into a set of smaller paddocks (a.k.a., fields, which may then be separated into smaller fields), allowing animals to graze each paddock well before shifting them over to fresh forage, and allowing the grazed pasture to re-grow. Earthworks and terrain modification will need to be done to improve water infiltration and retention on the landscape for the animals and plants. Other earthworks may be required, such as sub soiling, etc.

INSIGHT: *The challenge is to create a [predominantly perennial] food-feed-fibre-fuel [nature mimicking] animal-cycling ecosystem. The early 2st century cultivation system has a "food versus fibre versus fuel" approach to thinking about cultivation without synergy. The holistic cultivation approach has a "food and fuel and fiber" thought process where habitat cultivation is designed to seek synergies in food and fibre and fuel production with a long term,* *mostly perennial, perspective.*

The phases of the development of the masterplan include:

1. Needs analysis for users:
    A. Food (human).
    B. Feed (livestock).
    C. Fuel.
    D. Fiber.
2. Site and geospatial analysis and assessment (biophysical site assessment).
3. Hydrological design concept.
    A. Identification of water on the landscape and where it should optimally go, to produce a hydrological plan.
4. Landscape detailed design.
    A. Drawings.
    B. Lists.
    C. Procedures.
    D. Written descriptions and explanations.
    E. Calculations.
5. Life-cycle analysis:
    A. On plants.
        1. Inputs.
        2. Processes.
        3. Outputs.
    B. On animals.
        1. Inputs.
        2. Processes.
        3. Outputs.
6. Implementation.
    A. Survey work done in front a bulldozer (or similar machine) that excavates behind the surveyor.
        1. Common time estimates are: one month of bulldozer work for 40 to 80 hectares,with a surveyor present; and, one to three weeks to seed and plant.
7. Evaluation.

A highly simplified version of cultivation system development is:

1. Keyline water/hydrological terrain modification (watershed/water cycle integration).
2. 3D succession planting (plan integration).
3. Mob animal rotation (animal integration).

4.1 Master plan deliverables

The detailed design deliverables requires in order to implement the holistic cultivation masterplan include:

1. Pasture drawings:
    A. Pasture landscape drawings and plans:
        1. Rocks plan - soil re-covering plan (i.e., cover the rocks with soil).
        2. Water design plan (keyline design, hydrological design plan) - spread water from valleys out to ridges.
        3. Pasture perimeter fence - pasture for aminals as one fence around a perimeter(s).
        4. Paddock fences - Paddocks for animals and rotation (determine paddocks on landscape).
            i. Paddock perimeter fences.
            ii. Paddock plant protection [from animal] fences.
        5. Access pathways - design based on the width of your tools (tractor, mechanical harvester, farm cart, arm length etc).
    B. Livestock pasture support drawings and plans:
        1. Water.
        2. Food.
        3. Shelter.
2. Organism Lists (fill-in Organism Cultivation Lists):
    A. List of plants.
        1. Plant cultivation list.
            i. Name of plant:
                1. Predominantly perennial plants.
                2. Fewer annuals plants.
                3. Genetics.
                4. Produces and/or functions for what: food (for humans, medicine for animals, or feed for non-human animals), fuel, and/or fiber, climactic function (e.g., wind barrier), etc.
            ii. Spatial:
                1. Location of plants (determine placement of plants on landscape).
                2. Location requirements (including but not limited to: light, nutrients, water). Must account for:
                    a. Soil type.
                    b. Water availability year round.
                    c. Heat and cold.
                    d. Terrain.
                    e. Human preference.
                3. Quantity (number of).
                4. Polyculture grouping (including, allelopathy accounting).
                5. Plant protection requirements (fencing, fencing type, fencing duration).
            iii. Temporal:
                1. Success of plants (determine succession of plants on the landscape). Growth of plants over time (producing shade coverage).
                2. Plant production over time (producing fuel, fiber, and food for the livestock and humans).

        iv. Expected production over time.
    B. List of animals.
        1. Animal cultivation list.
            i. Animal type and genetics.
            ii. Food requirements (including area).
                1. Light requirements.
                2. Temperature requirements.
                3. Terrain requirements.
            iii. Life duration.
            iv. Quantity (stocking rate; number of).
3. Organism drawings:
    A. Drawings of plants.
        1. Draw the location of plants on the landscape when full sized (and how many months/years until it reaches that point). It is also possible to show:
            i. The change in dimensions of the plant as it grows.
            ii. The likely harvesting dates into the future.
        2. If there is succession, draw the succession of plants as 'layers' (i.e., overlays).
    B. Drawings of animals.
        1. Draw the animals and their location(s) over time.
4. Procedures:
    A. Steps in procedures for creating the cultivation system.
    B. Steps in procedures for operating the cultivation system.
5. Written:
    A. Descriptions of primary cultivation systems.
    B. Explanations for selections of:
        1. Plants.
        2. Animals.
        3. Terrain modification.
6. Calculations:
    A. Formulas.
    B. Sources of data.
7. Life-Cycle analysis (complete with written part and flowchart part).
    A. On plants.
    B. On animals.

Design considerations include, but are not limited to:

1. Woodland (forest) thinned to allow light to the under-story for pasture establishment.
2. Young trees fenced from livestock and guarded against other wildlife.
3. Periodically trample grass or mulch around young establishing trees.
4. A 3 meter or more buffer zone from sources of running water.

Determine the rough location of where to place the following objects/structures throughout the landscape:

1. The swale and berm or terrace structures across the sloped landscape.
2. Retention ponds and spillways over the landscape.
3. The paddocks and animal corridors between paddocks (if there are any).
4. Agroforestry silvopasture restorative line polycultures. In other words, determine where to put lines of perennial plants selected to be in that location under account of their height and shade tolerance.
5. Fencing to fence in animals into paddocks and to fence off trees to protect them from animals.
6. Human waste processing pond network.
7. Structures/buildings for animals (including in pastures/paddocks):
    A. Feeding.
    B. Watering.
    C. Sheltering.
    D. Processing (e.g., for milk).

4.2 Masterplan execution

The execution of the masterplan generally follows the following steps:

1. Complete master plan:
    A. Earthworks and hydrological plan.
    B. Plants plan.
        1. Decide species.
        2. Identify required soil ecology.
        3. Lookup standard spacing and heights.
        4. Design access paths.
        5. Block in canopy based on mature crown width of the largest tree in the design. Forest garden spacing are usually open savannah biomes which means 1.5 crown width diameter in a tight spacing with little understory or 2x crown width in a more multistrata system.
        6. Find the understory plants that fit in that niche. Build out the layers in order (canopy, subcanopy, vining, shrub, herbaceous, groundcover, fungal).
    C. Animals plan.
        1. Decide species.
        2. Identify required landscape ecology.
        3. Lookup relationships between species.
2. Complete earthworks:
    A. Fill erosion gullies with earth.
    B. Construct ponds (note: ponds are the biggest time expense).
    C. Construct swale and berm (or terrace) structure.
    D. Remove trees and other plants (i.e., silvopasture by removal of trees and other plants).

3. Seed with grass.
4. Plant trees and other plants (i.e., silvopasture by removal of trees and other plants).
5. Install fencing (and other required architectural structures).
6. Install infrastructure (where necessary, which may only be a temporary installation; for example, a temporary irrigation system until plants have taken hold).
7. Introduce animals.

4.3 Holistic landscape cultivation planning

A.k.a., Holistic cultivation mapping and flowcharting, terrain and micro-climate modification planning.

The holistic land cultivation planning process involves:

1. Identification of the local biome and key plant species (some of which may not be native to the biome).
2. Identification of water sources and movements.
3. Planning of water movements.
4. Planning the spatial and temporal layout of plants. Accounting for ecological succession (where applicable).
5. Identification and planning of plant harvesting.
6. Planning of animals and their movements.
7. Taking action with earthworks in conjunction with planting and livestock introduction.

Herein, it is desirable to identify the type and location of organisms) through time in space. The inputs, processes, and outputs of a cultivation system can be planned and visualized, for example:

1. Fruit (from plants) is a **food**, converted into a juice, then vinegar, then alcohol. Alcohol is formed from the chemical process of rectification, also known as distillation.
2. Oil (nuts of plants) + alcohol = **fuel**.

The whole farm/landscape cultivation assessment, planning, and development process involves the following service steps:

1. When doing earthworks that could significantly modify the microclimate of the whole farm, the whole farm and its environmental landscape must be considered.
   A. Where is the farm located and what are the environmental characteristics of the land and atmosphere?
   B. What are the goals of the farm, of the cultivation operation?
   C. What is the approach to cultivation, what tools are available and usable?
2. In the case of most landscapes, there is an optimal earth and plant pattern; in general, the optimal pattern all around the landscape is:
   A. Create a swale, then berm, then position a tree downhill from the swale, and then an alley gap, and repeat: Swale > berm > trees > alley, then the pattern repeats, swale > berm > tree > alley, ...
   B. Earth modification that changes hydrological flows (dynamics, including, dams, swales, and ponds) can significantly alter a micro-climate and dramatically increase forage production, but they aren't without risks.
3. Landscape measurements that may be used to assess a landscape (for acquisition and continuous coordination) include, but are not limited to:
   A. Penetrometer testing - Look at soil compaction with a soil penetrometer.
   B. Soil mineral composition test.

4.3.1 Whole ecological farm planning

To plan the ecological integration of a cultivation (farming) system requires the following accountabilities:

1. Earth shaping for hydrological optimization.
2. Food system selection (plants and animals).
3. Crop and livestock development.
4. Farm installations and processing equipment.
5. Manuality and automaticity.

The following activities can be manual or automatic:

1. To spread out livestock manure when it becomes to concentrated in specific areas.
2. Finish mowing.
3. Moving the animals from paddock to paddock.
4. Observing paddocks for change.
   A. Adding plants and/or culling plants.
   B. Adding animals and/or harvesting animals.
   C. Changing the rotation of the animals.
5. Harvesting fruit and nuts and distributing it to the animals.
6. Giving supplemental feed and water. In some cases it is possible to not give any supplemental feed (during the grazing season).

4.3.1.1 Grazing season

The animal grazing season refers to the period when livestock, such as cattle, sheep, or goats, are allowed to feed on pastures or grazing lands. It typically corresponds to the time of the year when grasses, forage crops, or other vegetation are available and actively growing in sufficient quantities to provide adequate nutrition for the animals. The grazing season can vary depending on factors such as climate, geographical location, and agricultural practices. In regions with distinct seasons, the grazing season often occurs during the warmer months of the year when grass and other vegetation thrive. In contrast, in areas with milder climates, where vegetation remains green year-round, the grazing season may extend for a more extended period or even throughout the year.

It is important to recognize and account for the fact that many locations on the planet have a grazing season where animals can graze freely. Outside of the grazing season, the climactic and pasture conditions are often such that the animals do not have enough food on pasture to survive and/or the climate is not conducive to their well-being (and survival).

4.3.2 The ecologically integrated design process

The ecological landscape must be planned as a whole, including plants, animals, and other organisms as a whole system.

An ecologically integrated cultivation system must complete the following planning objectives:

1. Identify the biome in order to select genetics (i.e., select keystone species).
2. Identify the landscape in order to perform earthworks which optimize the hydrological system on the land (i.e., earthworks for water management).
3. Build fences, roads, utilities and pipelines.
4. Establish edible woody polycutures, as well as other plants and animals, using agroforestry techniques.

4.3.3 Common holistic cultivation design techniques

Holistic cultivation practices (e.g., restorative agriculture techniques) include, but are not limited to:

1. **Permaculture** analysis and design.
   - A. **Polyculture (a.k.a., companion planting, consortium planting, consortium spacing)** - plants that grow well together are planted near each other.
     1. **Companions** - plants that grow well together.
     2. **Allelopath ("bad neighbors")** - plants that do not grow well together.
     3. **Succession (a.k.a., natural sequence farming)** - plants occupying the same space at different points in time. Thinking about and designing a system where plants use different strata space at different times (without overlap).
     4. **Planting density** - refers to the optimal number of plants in a given area; the appropriate spacing between the same and different plants. All plant culturing requires an account of planting density.
     5. **Perennial polyculture** - perennial plants that will grow well together over time.
   - B. **Annual culturing** - selective use of annuals. Annual alley monocropping may be pure monocropping or polycropping with different annual/perenial companion plants. Polycropping will produce less of each cultivated crop/plant, but the sum total is more diversity of production per area.
2. **Ecological aquaculture** analysis and design.
3. **Agroecology** analysis and design.
4. **Agroforestry** analysis and design.
5. **Soil food web** analysis and design.

There are a set of strategies to create an optimal holistic cultivation system:

1. **Earthwork strategy:**
   - A. Water coordination over the landscape (using keyline water/hydrological planning).
   - B. Keyline subsoiling.
2. **Succession strategy:**
   - A. Polyculture and full-time succession planting of multiple and inter-crop plantings.
   - B. Natural sequence farming.
3. **Planting strategy:**
   - A. Perennial crops (primarily). Perennial row and annual alley planting.
   - B. Organic annual cropping and crop rotations. Cover crops and multi-species cover crops.
   - C. Borders planted for pollinator habitat and other beneficial insects.
   - D. Conservation farming, no-till farming, minimum tillage, and pasture cropping.
4. **Breeding strategy:** Strategic, total and utter neglect (STUN) breeding.
5. **Seeding strategy:** Strategic seeding, culling, and neglect where appropriate.
6. **Livestock strategy:**
   - A. Well-managed grazing, animal integration, rotation, and holistically managed mob grazing.
   - B. Grassfed livestock.
   - C. Silvopasture.
7. **Fertilization strategy:**
   - A. Compost, compost tea, animal manures and thermal compost (few supplements).
   - B. Biochar/terra preta.
   - C. Mineral amendments.

4.3.4 Fencing control

Fences can be made out of a wide-variety of materials and can be shaped into a wide-variety of forms.

1. **Living fences (a.k.a., plant fences)** - are fences made from living plants, like a bamboo fence, or an interwoven willow fence.
2. Organic material fences.
3. Mineral fences.
4. Some combination of the above.

Fences can have a wide variety of functions on the landscape, including but possibly not limited to:

1. Aesthetics.
2. Shade and soil improvement.
3. Stream restoration.
4. Erosion control.
5. Animal forage.
6. Animal control.

Animal paddocks should always be fenced. The rougher and rockier the terrain, the more difficult the fencing requirements. With fencing it is possible to create a common lane for animals as they move between paddocks (the "lane"). The banks of bodies of water (e.g., ponds and streams) may need to be fenced in order to prevent damage and erosion to the land water interface by grazing and treading of animals. In concern to gates within fences, gates between paddocks and/or a lane are generally located in or nearby a corner of each paddock.

Fencing consists of at least the following elements:

1. Appearance.
2. Fencing wire or border material.
3. Fencing posts or fencing support structure.
   A. Artificial stuck in (engineered into) the ground.
   B. Rooted naturally in the ground.
4. Fences may also include the following additional functions:
   A. Surface functions.
   B. Automation.
   C. Transportation.
   D. Electrification.
   E. Plant hosting.
5. Sharpness (i.e., barbs, thorns).

Fencing may be used to separate a general pasture for a specialized pasture:

1. Only for the those of a specific reproductive age (e.g., the young).
2. Only for one species.
3. Only for stockpiling.
4. Only for extreme climactic weather events.

There are different types of fencing and fencing configurations, including but not limited to:

1. **Permanent fencing** - Often the choice for perimeter fencing. Permanent fencing will can be used to create a permanent paddock.
2. **Lightweight movable fencing** (dynamic fencing, temporary fencing) - Moveable electric fencing allows easy moving of a fence line, it is light weight and easy to take down and re-install - it can be done by one person in a matter of an hour. Allows for the changing of paddock size and area. These fences are often made with portable wires and tapes composed of polyethylene embedded in stainless steel strands. Polywire is braided wire and is frequently used as a moveable electric fence material. Lightweight plastic or fiberglass posts can be used to hold up polywire.
3. **Strip grazing wires** - A system that uses two wires that are moved along two permanent fences. Move the front wire according to animal needs and pasture coordination decisions. The back wire follows the front to prevent movement of animals in the reverse direction.

Type of fencing by fence material and function include, but may not be limited to:

1. Natural ecological fencing (weaving a plant as it grows to create a natural plant-based ecological fence; a.k.a., hedge). The two best types of plants for fencing are: bamboo and the willow plant, which will need to be woven prior (and possibly during) growth.
2. Wood fence.
3. Stone fence.
4. Wire fence.
5. Barb-wire fence (warning: never electrify barb-wire fencing).
6. Electric fence (note: fencing can be constructed so some or all of a fence is electrified).
   A. An electric fence line must be clear so that the charge does not short out anywhere along the line. A short will render the whole fence useless.
   B. The charger for an electric fence must be well grounded. If there are issues being experienced with the fence, it's likely the grounding of the charger. The depth of a grounding rod can vary depending on the type of charger being used and the soil type. In general, grounding rods should be rooted relatively deep into the earth.

The following are the most common categories of fence:

1. Non-electrified.
2. Electrified.
3. Barbed.
4. Non-barbed.

5. Gapped.
6. Non-gapped.

The most common type of fencing for pastured animals include:

1. Piled stones.
2. Four-strand, high-tensile electric fence around the perimeter of the grazing land, powered by a solar fence charger.
3. Six to eight strands of high tensile cord to confine animals (e.g.,goats and sheep).

The maintenance and monitoring of fences include:

1. Is the fence intact?
2. Do plants near the fence need trimming?
3. Is there debris building up beneath the fence?
4. Is there erosion around the fence?
5. Do parts of the fence need replacing?
6. If electric, is the electricity flowing when required (i.e., is there a short in the fence or has the energizer broken).

The design of some fences can be dangerous to specific animals. For example, goats can easily stick their heads through a fence with gaps, get their horns caught, and either starve or become a predators food. In some cases, goats are de-horned goats to eliminate this risk.

4.3.4.1 Animal specific fencing

In concern to electric fencing, different animals may require differently charged electric fences:

1. Pigs.
   A. Pigs can be kept in with two strands of polywire.
   B. Pigs can be kept with netting, which is less likely to succumb to the pigs will throw some turf over the fence and shorting it out.
2. Goats.
   A. Goats need netting and their fencing should be at least 40” tall so they don’t jump it; some species might try to jump it anyway.

4.3.4.2 Fencing and gating control

Movement of livestock and the opening of gates can occur in the following ways:

1. Manually:
   A. Humans open the gates.
   B. Human operation of tumble wheel for fencing.
2. Automatically:
   A. Using a batt latch automated computer operated gate opener. No humans have to be there when the gate opens and the livestock move to the next paddock.
   B. Automated electric (or non-electric) tumble wheel for fencing.

4.3.4.3 Fence opening control for restricted passage of four legged animals

Cattle grid (a.k.a., cattle stop, stock grid, cattle guard, cattle grate, vehicle pass, stock gap floor grill, donkey killer, mata-burros, etc.) is a type of obstacle used to prevent livestock (generally, four legged) from passing along a road or railway, which penetrates the fencing surrounding an enclosed pasture. It is fixed into the ground and prevents the escape of livestock on farms, even when the gate is open. These devices are platforms that function as bridges, usually made of wood, concrete or steel with gaps in between beams or rods, under which there is a depression in the earth. The gaps between the grid of bars or tubes are wide enough for an animal's feet to enter, but sufficiently narrow not to impede a wheeled vehicle or human foot. This provides an effective barrier to animals without impeding wheeled vehicles, as the animals are reluctant to walk on the grates. These devices are installed as a mechanism to discourage animals from crossing, even if a gate is open. Animals fear to cross the grill shaped object because of the gaps and the potential for falling into a gap and breaking a leg. To a four legged animal, the breakage of a leg means certain death, and so, they are reluctant to pass such an area.

4.1 Other agricultural techniques

There are a set of other agricultural techniques commonly used in the early 21st century that may or may not apply to cultivation in community.

4.1.1 Historic three field system method

A.k.a., Three field crop rotation, 3-field system.

The three-field system is an agricultural system of crop rotation in which a large field is divided into three smaller fields. One of the smaller fields is planted with one set of crops one year, a different set in the second year, and left fallow in the third year. The fallow field is opened to grazing animals that would graze on the weeds and other plants that grow in the field during the fallow year.

The [historic] three field method may be used in a holistic cultivation system. An alley crop row(s), can be planted with a first crop on year one, a second type of plant crop on year two, and year three be left (or more) be left for pasture grazing by animals. Alley crops that remain an alley for decades will have to be fertilized by either: animals moving through, or the physical movement of soil and animal excrement onto the alleys over time.

4.1.2 Early 21st century industrial agricultural methods

Early 21st century farming techniques are listed here to make readers aware of their presence. The conventional agricultural techniques are:

1. **Conventional agriculture (a.k.a., conventional monocropping, monoculture crop, mono-cropping, monocropping, mono-agriculture, cash cropping, monoculture)** - monocropping places a single crop species over a large land area, resulting in a lack of diversity in terms of plant (and animal) types (i.e., lack of diversity of life, lack of a thriving and balancing ecosystem). This uniformity can make crops (and animals) more vulnerable to pests, diseases, and environmental changes that specifically affect that particular plant (or animal). The same crop may, or may not, be planted in the same location over consecutive growing seasons (note: the three field system is a historic mono-cropping system. This practice can deplete soil nutrients specific to that crop and may lead to soil erosion and degradation. Monocropping can make certain aspects of cultivation, such as harvesting and pest control, more straightforward and easier to manage on a large/industrial scale. To monocrop on an industrial scale (i.e., not holistic and specifically restorative scale) relies heavily on synthetic and isolated chemical inputs. It is also fairly fossil fuel intensive. Most conventional plant farmers raises one plant crop on a single acre in a single year. In the early 21st century, the majority of plant agriculture is this type of agriculture. Generally, there is tillage of the soil to grow annual crops. However, newer technologies can implant seeds in the soil without tillage. This type of implantation is also known as no-till farming (a.k.a., zero tillage, direct drilling). If there is tillage, it could occur multiple times a year. Without animals, there is a reliance on synthetic fertilizers to create some reasonable degree of fertility in the soil, to give nutrients to the plants and acquire the desired yields. In large area monocropped environments there is heavy reliance on synthetic fertilizer, pesticides, herbicides, insecticides, fungicides, and electrical power. Given early 21st century technology, over time, there is a need to increase the quantity and/or toxicity of these -icides in order to sustain production as herbs (weeds), insects, and fungi become resistant to their application. Light technologies (e.g., lasers that user electrical power are increasingly being used as pest prevention). Convention agriculture makes heavy use of genetically modified (GM) crops, which have been modified in laboratories for different traits. Conventional farms generally require three to five passes of an energy powered machine for preparation and planting. Three to five passes of equipment are required for fertilization to -icides application, to planting; all of which require fuel/electricity and labor.
   A. **Organic monocropping agriculture** - focuses on whether or not the agriculture uses disallowed inputs. Those disallowed inputs are, in general, synthetic fertilizers and specific types of -icides. In general organic agriculture allows almost any type of manure. There are organic pesticides that are used in organic production to control weeds. These pesticides have to be OMRI listed (a.k.a., organic materials review institute; i.e., the list of organic materials allowed for organic agriculture). Anything used in organic agriculture has to be OMRI approved, or it cannot be used. However, there are no restrictions on the set number of times the soil can be tilled on an annual basis. Note that tillage can be used as a form of weed control. Hence, organic farmers often till the soil more per year than a conventional farmer. It can be as much as twice annually what a conventional farmer does. Almost any animal manure fertilizer can be used in organic agriculture. Hence, a farmer could go to a convention feed-lot livestock operation and use that manure in a certified organic operation, and not be in violation. Farmers do not have to use certified organic or OMRI listed manure. If the chickens ate food fertilized and sprayed with synthetics, their manure can still be used as fertilizer for organic agricultural crops. The animals may have been given subtherapeutic antibiotics, leading to antibiotic residue in their manure. These are allowed under current organic regulations.
2. **Regenerative monocropping agriculture (a.k.a., alleycropping, intercropping)** - farming and ranching in synchrony with nature and the four ecosystem processes to repair, restore, and revitalize life. Starting with life beneath the soil and expanding to life above the soil. The big difference between regenerative and both conventional and organic is the difference in input intensity. Both organic and conventional are highly input intensive. Regenerative agriculture is, in part, about reducing a reliance on external allied inputs and on mechanical (machine) action. Regenerative agriculture creates much healthier soil and more diverse and vibrant ecosystems. On average an organic farmer will make more passes with a machine than a conventional farmer. The organic farm makes the most passes, the conventional farm comes next, then comes

regenerative farming, and then comes restorative farming with perennial. A regenerative farm harvests multiple crops on a single hectare over a single year. Regenerative farms can still use any of the tools available to conventional and organic farms. In other words, regenerative farms have all of the agricultural tools available in the toolbox. However, the goal with regenerative is not to have that reliance on theses added input and added purchase tools. The goal is to reduce all of these inputs over time while building resilience and a naturally sustaining ecosystem. Regenerative mono-crop farming requires less equipment than conventional and conventional organic agriculture. Typically, in a regenerative (restorative) cultivation system, mono-copping is still done, it is just that it is done on a smaller scale within paddock units containing a diverse ecology. This process process of mono-cropping inside a perennial agricultural environment goes by several names, including: alley cropping, inter-cropping, inter-cropping. Rows of an annual plant are planted with companion perennial crop ecologies in between. Annuals and perennials (e.g., grape vines and tomatoes) can be cultivated between ecological rows of perennial plant ecologies. Note: the perennial ecologies might also include agricultural annuals on the 3D landscape.

5 Holistic cultivation of land

READ: Holistic land cultivation.

A.k.a., Holistic agriculture, holistic pasture cultivation, holistic landscape cultivation, holistic land cultivation, ecological mimicking pasture cultivation of plants and animals, restoration agriculture, restorative agriculture, regenerative agriculture, intentional ecological cultivation, ecologically sustainable cultivation, ecologically regenerative cultivation, holistic cultivation, holistic land management, permaculture, perennial agriculture, perennial ecosystem, perennial polyculturing, perennial agriculture, permanent agriculture, syntropic farming, syntropy farming, syntropic/syntropy agriculture, circular symbiotic farming, agroforestry, pastoral agroforestry, agro-silvo-pastoral, whole eco-farm planning, natural agriculture, ecological agriculture, polyface agriculture, biodynamic agriculture, natural foraging agriculture, etc.

NOTE: The techniques described here (ecologically-based, perennial crop[ping], pastoral livestock focused, agroforestry, organic, etc.) meet the definition for many of the above a.k.a. terms. All of these "also known as" (a.k.a.) terms are essentially related.

Holistic land cultivation includes, but is not limited to the cultivation of plants, animals, and fungi within a supportive ecological service environment. Holistic land cultivation allows for the growing an abundance of food, fuel, and fiber, with significantly less human input, by imitating natural ecosystems. A holistic cultivation system is significantly composed of a self-sustaining habitat food, fuel, and fiber producing ecosystem that is also aesthetic for the local population. Herein, there is the intentional selection and cultivation of plants, animals, and fungi and the intentional design/introduction of natural ecosystem services into the cultivation system itself, involving:

1. Pasture cultivation of plants.
2. Pasture cultivation of animals who derive their nutrition from natural/wild foraging on the pasture.
3. Pasture cultivation of fungi.
4. Ecological design for the considered habitat of wild insects and other animals.

Holistic land cultivation (i.e., permaculture) is an ecological design methodology whereby humans alter the landscape in such a way as to create relationships between materials, plants, animals, and humans so that their function and harvestable yield are optimized. Permaculture (permanent agriculture, permanent culture) is the use of perennials and animals on a landscape to produce a permanent culturing ecosystem. In other words, permaculture is the intentional design of perennial agriculture. Society can obtain staple foods from fully functional, perennial, ecological systems. The aim is to create systems that are ecologically sound and meet the needs of humans, while not exploiting or polluting. Holistic land cultivation is an approach to landscape cultivation that adopts arrangements observed in flourishing natural [perennial] ecosystems. It includes a set of design principles derived using natural ecologies and whole systems thinking. It uses these principles in fields such as regenerative agriculture, re-wilding, and community resilience. This is a approach to grow food, soil, and reforest landscapes simultaneously. This is approach to create a sable staple food producing predominantly perennial ecosystem. Through the intentional repeating of patterns found in nature in an engineered cultivation system it is possible to design and develop a natural perennial ecosystem that performs ecosystem services effortlessly, optimally, and with minimal inputs, while simultaneously providing a portion of outputs to serve human nutrition and material needs. A cultivation system ought to restoring health and vitality to the earth, plant, animal system. It is important to question that once the system is planted, how long can it subsist there? Here, permanent means that they system continues year after year, that it is restorative, regenerative, and sustainable. Annual systems do not convey those characteristics. Currently, in order to farm annual plants on large scale, because of the growth context of annual plants, the farmer must destroy a 3D perennial ecosystem in order to expose the large land patches of soil. This can be done by mulching the environment, cutting, burning, ploughing, or using herbicides. In order to cultivate annual plants over a wide scale of land, the local perennial ecology must be destroyed. Over time, and by its very nature, annual cropping destroys the living resource base of the planet. However, it is possible to include annual plants in a perennial-based holistic land cultivation system. As the land size of this cultivation system increases, so will the amount of annuals, which could be designed and harvest to meet a populations actual needs.

Holistic cultivation refers, in general, to a permanent form of agriculture using perennial systems (primarily), instead of annuals. This methodology (Read: selection of methods) is sometimes known as permanent agriculture, perennial agriculture, and restorative agriculture. Herein, carbon farming comes naturally through woody plants that remove excess carbon dioxide and store it in the form of perennial woody vegetation, and organic matter, in the soil.

> **NOTE:** *All species require the support of others. A natural community is defined as an assemblage of interacting plants and animals and their common environment recurring across the landscape. Natural communities are what protect and spread biological diversity (Read: diversity of life); they are units that repeat across the landscape.*

Holistic land cultivation uses [ecological] process-based agriculture, as opposed to [agrochemical] input-based agriculture, typical to industrial systems in the early 21st century. There would be no agriculture input industry if society does not need agricultural inputs. Early 21st century society needs agricultural inputs because the type of agriculture practiced is degrading the resource base. A holistic cultivation system is biologically diverse, and relies on the regenerative/restorative inputs of: animal husbandry, agroforestry, and perhaps editions of mined substances (e.g., calcium when deficient). It is possible to imitate nature's successional pathway.

There is a contribution-related section on the website. Coordinators generally recommend reading the standards and observing the models for the standards to gain a comprehensive understanding of the envisioned proposal.

In the context of food, agriculture means to produce staple (and, stable) food and forage crops for nutrition and material compounds for materialization. "Farms" coordinate agricultural operations.
In the context of food, agricultural products (for nutrition and calories) include, but are not limited to:

1. Fruit and nut bearing trees.
2. Fruit and nut bearing shrubs.
3. Fruit bearing vines.
4. Grasses (for herbivory)
5. Fungi

In the context of materials, agricultural products (for materialization) include, but are not limited to:

1. Wood.
2. Textiles and fabrics.
3. The breakdown products of carbohydrate bodies (fruit > juice > vinegar > alcohol).

A viable ecological cultivation system must be based on natural patterns and relationships that are perennial, and provides (produces) the following staple and societally required elements:

1. **Foods** - nutrition and calories [for humans and other organisms]. Food for other organisms is most commonly known as "feed".
2. **Fuels** - combustion power [for the habitat life support service system].
3. **Medicines** - medical [for the habitat life support service life].
4. **Fibers (and other materials)** - materialization [for the habitat technological support service system].
5. **Chemical materials** - materialization [for the habitat technological support service system]; such as, lubricants and natural hydrocarbon polymers (e.g., natural rubber also known as latex).
6. **Ecological niches** for domestic and wild animals, plants and other organisms - ecological services [for the whole planetary biosphere].

It is possible, and likely more sustainable to obtain staple foods from fully functional, perennial, ecological systems. Humankind can achieve all of the benefits of natural perennial ecosystems. This can be done by creating agricultural ecosystems that imitate natural systems in form and function, while still providing for human nutritional needs. The design of farms to produce staple food crops with perennial plants and livestock. A farm is an area of land used for growing crops and raising animals. Ecological polycultures require animal polycultures. It is possible to design a farm that mimics natural ecological [perennial] service systems. It is useful to follow natural patterns and resource flows when designing a cultivation system. A cultivation system that is easy to maintain by humans is one that doesn't require weeding. A weed is a plant in the wrong place. Because the ecological cultivation system is fit for the ecological biome (through time) the system should be able to be planned for 100 years of harvests (and soil regeneration). (Shepard, 2013)

One way in which holistic land cultivation coordination (i.e., restoration agriculture) can produce more calories per acre than annual crops is by creating overyielding polycultures. Overyielding polycultures are intentionally designed plant and animal systems that may produce lower yields per item, but the total per hectare/acre yield exceeds that which any one crop would have produced. In perennial polycultures there will be fewer of each element than if that element were raised in a monoculture, and because of competition effects with neighbouring plants and animals, yields per plant may be less than in a mono-cropped system. The farmer's goal is to create a system where the total yield is greater in a polyculture than a monoculture and hence the name "overyielding polyculture." The average perennial polyculture farmer is not striving to grow the most of any one crop. A perennial polyculture farmer is striving to coordinate and optimize an ecological system for human cultivation purposes. The cultivation system is modeled after nature, and the system is designed to optimize its total system yield. (Shepard, 2013, p107)

> **NOTE:** *Herein, restoration does not mean what it commonly means in the early 21st century, which is, to take a piece of land and return it to some past state. Herein, then research a snapshot of the land in the past, and then, conform the land to the restorers idea of what nature was back in the snapshotted past, the plant species and spend money to force it to stay in that form I stead of living with the natural cycle.*

Every action taken in a holistic cultivation system is taken with thought to other systems, and the action often carries with it a, secondary useful purpose. The landscape produces food, but it also produces medicines and stabilizes the ecology, produces smells, and produce nutrients for the local ecology. Humans can design ecological cultivation systems that mimic what nature wants to move toward and allow the system to take care of itself, an automated agriculture system managed by nature.

5.1 *Natural ecosystem mimicking food production systems*

A.k.a., Nature mimicking cultivation system for food and materials.

Food production systems can be designed like natural ecosystems. These natural ecosystem food (fuel and fiber) production systems should, in theory, show the same resistance to pests and diseases as wild landscapes, while conserving and increasing top soil, and increasing in fertility over time. Fertility (through fertilization) comes from livestock raised and grazed on the landscape. In the early 21st century, soil fertilization comes in a bag from an agrochemicals company. Using landscapes in this way it is possible to play an active part in restoring and healing land to a state of greater productivity.

The coordination of a perennial farm involves the following five main element:

1. Water coordination (i.e., water management).
    A. Earth shaping (by means of).
2. Maintaining perennial ground cover.
3. Diverse 3-dimensional perennial woody crop plantings.
4. Diverse animals.

It is possible to design a cultivation system when animals and plants are arranged according to lifecycle and strata, how they relate through the multiple effects of the influence of time, creating a dynamic environment, and then managing this through species succession, continually increasing the quantity and quality of useful life. Using this method, the inputs costs and growing period for a crop can be predicted precisely, and therein, farms can be built wherever people need fresh produce.

5.1.1 Ecological succession

A.k.a., Natural succession.

Ecological succession is the observed process of change in the species of an ecological system over time. Part of how ecosystems work is through ecological succession (or, natural success). For instance, if there is a bare land surface, that surface will generally be colonized by lichens first, then mosses, then grasses, etc. Annual grains and legumes have a place in the ecological succession of nature. They follow disturbances in the soil. They grow and colonize rapidly, while making hard seeds that last a long time to protect themselves from adverse environmental conditions. And then, eventually, thorny plants and shrubbery are likely to take over, slowly, sun loving trees will become established. After the sun loving phase is established, then shade-tolerant trees will grow underneath. Following ecological succession it may take more or less than 1800 years to get to a closed canopy growth, shade-tolerant forest. Humans can quicken the process of creating a closed canopy, shade-tolerant forest by planting specific species and harvesting (pruning and cutting) trees and other plants year after year.

Natural succession can start with a bare planet. It goes through a phase where it is colonized by lichen and mosses, then a grassland phase, then flowers and shrubs, then sun-loving trees, then shade-tolerant trees. This happens across the planet at different rates of speed based on local conditions, like water availability, temperature, pests, etc.

> **IMPORTANT:** *Through natural succession, soil can be built quickly during the grassland phase with animals.*

It is possible to plant a landscape planned over time to mimic, though more rapidly the natural process of ecological success. Natural Succession is an ecological process. Natural success can be accelerated through "synchronization". "Synchronization" refers to the act of removing plant biomass, through harvesting and pruning, in order to obtain a yield, open up space for the next succession of species, and to encourage new growth through the release of different root hormones that occur after pruning.

It is possible to use the natural succession of plants for:

1. Fertilization.
2. Irrigation.
3. Pest control.
4. Food production.

It is possible to graph a successive plant species (that starts with bare ground) and extends out in time:

1. Bare ground (start)
2. "Pioneer plants" (1-3 years)
3. "Secondary plants" (3-30 years)
4. "Climax stage" (over 30 years)

5.1.2 Ecological stratification

A.k.a., Ecological strata.

Ecological stratification deals with the basic principle that limited space equals limited plant growth. The definition of strata is the vertical level a plant occupies in its natural environment. It is related to how high a plant grows and how much sunlight a plant needs. For example, strawberry is a low strata plant, but has high light needs. Typically low strata plants are more shade tolerant, but not all. Emergent strata is the highest strata (cannot have anyone on top of it for shade, such as sweet-corn).

Stratification is analyzed to make sure that every crop planted gets the right amount of light for that crop, and doesn't overlap in space and time with another or other plants. Some crops need a lot more light than others, and a large part of the challenge in arranging plants (and possibly, rows) is making sure that every crop has adequate light. Stratification basically ignores all other differences plants have, and separates plants into five different categories, or strata, based significantly on sunlight needs and vertical location. When planting crops together, farmers have to understand the amount of light taken up by each plant and the growth of each plant.

Stratification divides all plants into 5 main categories, or “strata”:

1. **Emergent strata plants** - need constant or near constant sunlight. Emergent plants are also normally quite tall, because they are reaching up towards the sun.
2. **High strata plants** - need a lot of sunlight, but less sun than emergent.
3. **Medium strata plants** - need occasional sunlight.
4. **Low strata plants** - need some sunlight, or scattered sunlight.
5. **Ground cover plants and underground plants** - need the least amount of sunlight.
6. **Vine-type plants** - plants that climb on other plants.

Emergent plants require the most sunlight and need constant sun to thrive. They are also typically tall plants, such as corn or eucalyptus, but there are always exceptions. Plants under the designation “high” need a lot of sunlight to survive, but less sunlight than emergent plants.

Some percentage of the total layering is taken up by emergent plants could take up about 20% of the space available to them. Plants with the designation high could take up about 40% of their available space. Plants with the designation medium require a medium amount of light and could take up around 60% of their available space. Plants can be arranged in space based on the principle of stratification, which refers to where a plant grows in its optimal habitat.

Practically, this means that you can’t plant an emergent plant next to a high plant, because the emergent plant will block out all of the sun for the high plant. However, you could plant an emergent plant with a low plant, because the sunlight filtering through the emergent plant would be enough for the low plant. In this scenario, the emergent would actually shield the low plant from getting too much sun, so they work together really well. The same relationship works for high plants and medium plants.

5.1.3 Plant-leaf photosynthesis and sunlight

Photosynthesis occurs under a fairly narrow band of temperatures, and when grasses are growing in the shade, their leaf temperature is lower than if they were in the full sun. Partially shaded grasses continue to photosynthesize and grow when their full-sun compatriots have shut down to wait for cooler temperatures. In addition to a longer growing season the partial shade cast by the evenly scattered trees helps the grass to grow more during the day.

Leaf temperatures aren't the only thing that shuts down photosynthesis in forages. The chlorophyll in a leaf can be thought of as a sponge. This green sponge soaks up sunlight as fast as it can while some of that sunlight is being used as the energy to manufacture basic carbohydrates. Once photosynthesis is happening as fast as it can and reaches its maximum, it can only convert sunlight into simple sugars at that fixed, maximum rate. If more sunlight is striking the leaf than the chloroplasts can use, then that leaf has become "light saturated." Additional light striking the leaf surface does not result in more photosynthesis. Some is reflected by the leaf and some is converted into heat which can further slow photosynthesis. Leaf temperatures can become so hot that moisture loss causes wilting and a further reduction in photosynthesis. (Shepard, 2013, p113)

5.1.4 Materials waste cycling internal to the cultivation system

Agriculture can take the waste from other parts of agriculture and cycle it. For instance, food scraps can be fed to pigs, and various other agricultural products (not of animal origin) can be fed to cattle. Agricultural waste products cannot only be fed to animals, they can also be used to support the dwelling of livestock, for example, peanut shells can be used for bedding for calf's. The excrement of animals (including insects) can be added to soil for fertilization (and signaling in the case of insect frass).

5.2 Water sources and distributions on the landscape

A.k.a., Water flow through storage and distribution.

Plants and animals live through water. A landscaped cultivation system must have some form of water distribution (Read: irrigation) system over the landscape. The source of that distribution system may be from (simplified view):

1. Rainwater directly.
2. Water body (or, bodies) on the landscape (e.g., ponds, wells, swales, springs, pools, etc.).
3. Water body (or, bodies) external to the landscape (e.g., municipality, river, etc.).

Water sources on a landscape include:

1. Natural rivers.
2. Natural ponds and lakes.
3. Natural springs.
4. Vertical wells - these come from deep holes dug in the ground.
5. Horizontal wells - are similar in concept to ancient "qanats" found in Persia and throughout the Middle East. The modern interpretation is to bore a hole into a mountainside and let gravity deliver the water for you. This method largely eliminates the need for vertical wells and pumps. Dig contour trenches on slopes at higher elevation and you can turn every hillside into a giant water collection system (much like a tent or a building roof). Every inch of rain will yield about 2/3 gallon of water per square foot of relatively impermeable surface area (like steep, rocky slopes). Capture this water with trenches (i.e., get it underground fast) and use horizontal bores to retrieve the water. Let Nature and gravity do the work.

5.2.1 Irrigation on pasture.

Irrigation can occur on pasture via a variety of control techniques.

1. Irrigation via a pond (network). Use gravity or a siphon and pump to irrigate.
2. Irrigation via a river or stream. Use a pump to irrigate.
3. Irrigation via a well. Place the submersible pump in the well, connected to water piping, which is connected to an algae filter and pressure tank. Pipes and taps are then installed everywhere water is required. The irrigation can be powered by means of a generator and/or solar system. It is often best protect pipes from the elements, which can cause a degradation of their material over time.

Note here that irrigation may only be required while treelings and the pasture are growing and the landscape hydrological system hasn't had time to stabilize at greater saturation. Earth modifications should improve hydrological conditions over multiple seasons.

5.3 Landscape modification using earthworks (land for agriculture)

A.k.a., Earth shaping, land shaping, land re-shaping, earthworks.

The elemental considerations for earth re-shaping include, but may not be limited to:

1. **Account for water movement:** The primary