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Solar and Fuel Cells Technology

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SOLAR AND FUEL CELLS TECHNOLOGY
FUNDAMENTALS & DESIGN

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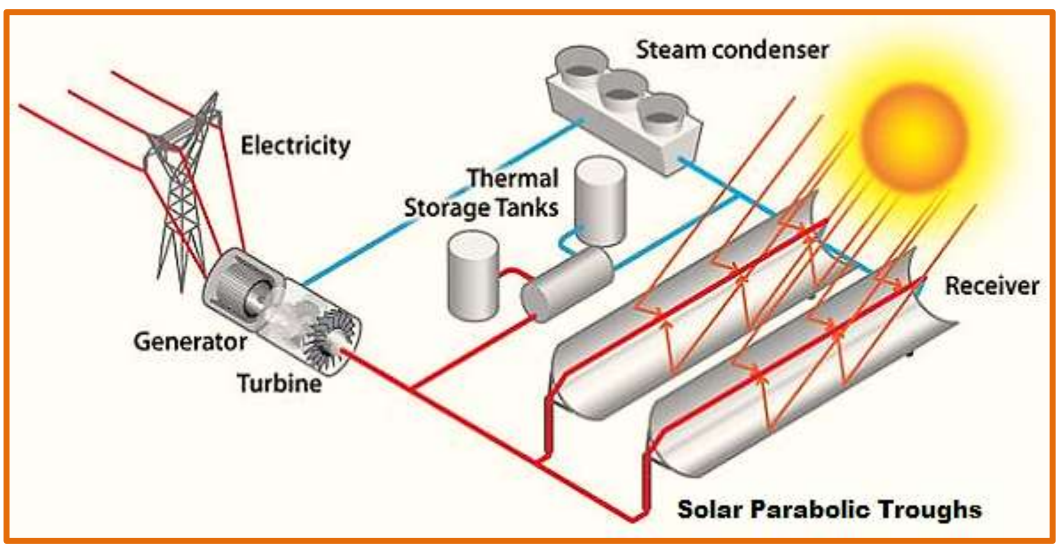
CHAPTER 1 - SOLAR ENERGY:

1. INTRODUCTION:

Solar energy is the technology used to harness the sun's energy and make it useable, using a range of ever-evolving technologies such as, solar heating, photovoltaics, solar thermal energy, solar architecture and artificial photosynthesis. It is an important source of renewable energy, whose technologies are broadly characterized as, either *passive* solar or *active* solar depending on the way they capture and distribute solar energy or convert it into solar power. The *passive* solar techniques include orienting architecture to the sun, selecting materials with favorable thermal mass or light dispersing properties, and designing spaces that naturally circulate air.

Solar energy is an inexhaustible fuel source and noise free. Solar thermal technologies can be used for water heating, space heating, space cooling and process heat generation. Many people are familiar with the so-called photovoltaic cells, or solar panels, found on things like spacecraft, rooftops, and handheld calculators. The cells are made of semiconductor materials like those found in computer chips. When sunlight hits the cells, it knocks electrons loose from their atoms. As the electrons flow through the cell, they generate electricity.

Every hour the sun beams onto Earth, more than enough energy, to satisfy global energy needs for an entire year. Today, the technology produces less than *one tenth* of one percent of the global energy demand. In one of these techniques, long troughs of U-shaped mirrors focus sunlight on a pipe of fluid oil that runs through the middle. The hot oil then, boils water for electricity generation. Another technique uses moveable mirrors to focus the sun's rays on a collector tower, where a receiver sits. Molten salt flowing through the receiver is another technology, which runs a generator.



Solar cells generate energy for far-out places like satellites in Earth orbit, and cabins deep in the Rocky Mountains, as easily as they can power downtown buildings and futuristic cars. On a much larger scale, solar thermal power plants employ various techniques to concentrate the sun's energy as a heat source. In these big solar thermal pants, the heat is used to boil water and drive a steam turbine that generates electricity, in much the same fashion as coal and nuclear power plants, supplying electricity for thousands of people.

However, solar energy doesn't work at night without a storage device, such as a battery bank, and cloudy weather can make the technology unreliable during the day. Large solar technologies are also very expensive, and require a lot of land area to collect the sun's energy at rates useful to lots of people. Despite the drawbacks, solar energy use has surged at about 20 percent a year over the past 15 years, thanks to rapidly falling prices and gains in efficiency. Japan, Germany, and the United States are major markets for solar cells. With tax incentives, for sure, solar electricity can often pay for itself in five to ten years.

Renewable energy sources, such as, *solar, wind, tidal, hydro, biomass, and geothermal* have become significant sectors of the energy market. While the average capacity of renewable energy sources was only 7% in 2010, most installation of new capacity has been with renewables. In 2011, the International Energy Agency said that "renewable sources will increase energy security through reliance on inexhaustible and mostly import-independent resources, enhance sustainability, reduce pollution, lower the costs of mitigating global warming, and keep fossil fuel prices in lower indexes".

2. SOLAR ENERGY TIMELINE:

The First Solar Oven: In 1767, Horace de Saussure, a Swiss scientist, was credited for building the world's first solar oven, later used by Sir John Herschel to cook food during his South Africa expedition in the 1830s.

The Photovoltaic Effect: In 1839, Edmund Becquerel, a French physicist, only 19 years old at the time, discovered a creation of voltage, while he was experiencing an electrolytic cell made up of two metal electrodes placed in an electricity-conducting solution. The electricity-generation increased when exposed to light. His discovery would lay the foundation of the solar power.

Solar-Powered Steam Engines: In 1860, August Mouchet, a French mathematician, proposed an idea for solar-powered steam engines. In the following two decades, he and his assistant, Abel Pifre, constructed the first solar powered engines and used them for a variety of applications. These engines became the predecessors of modern parabolic dish collectors.

Photoconductivity in Selenium: In 1873, Willoughby Smith, an English engineer, discovered photoconductivity in solid selenium.

Electricity from Light: In 1876, Professor William Grylls Adams, accompanied by his student, Richard Evans Day, discovered that selenium produces electricity when exposed to light, using two electrodes onto a plate of selenium. Although selenium solar cells failed to convert enough sunlight to power electrical equipment, they proved that a solid material could change light into electricity without heat or moving parts.

Bolometer: In 1880, Samuel Pierpont Langley, an American Professor, astronomer and physicist, invents the bolometer, which is used to measure light from the faintest stars and the sun's heat rays. It consists of a fine wire connected to an electric circuit. When radiation falls on the wire, it becomes very slightly warmer. This increases the electrical resistance of the wire.

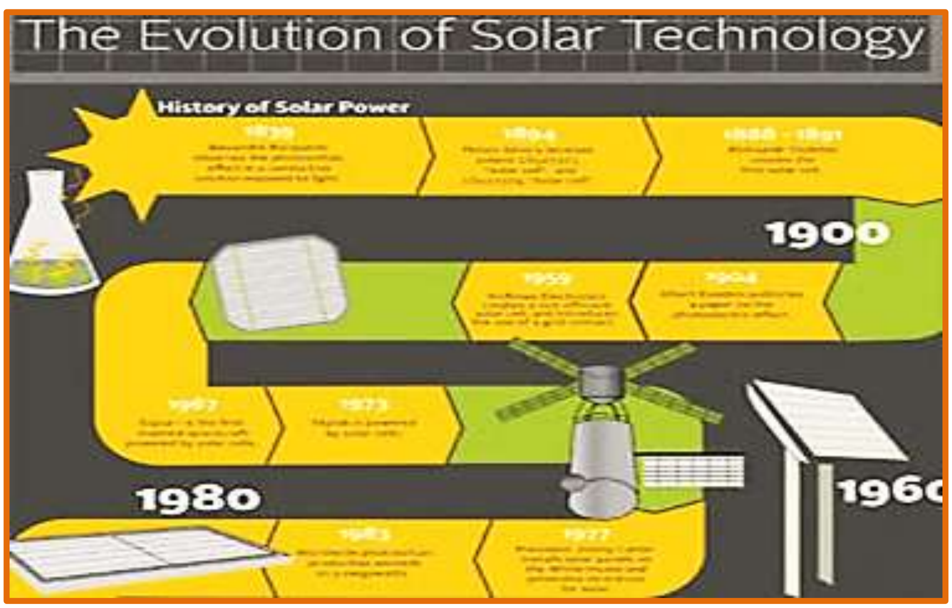
The First Design of a Photovoltaic Cell: In 1883, an American inventor, Charles Fritts, came up with plans for how to make solar cells, based on selenium wafers.

The Photoelectric Effect: In 1905, Albert Einstein, already famous for a wide variety of scientific milestones, formulated the photon theory of light, which describes how light can “liberate” electrons on a metal surface. In 1921, 16 years after he submitted this paper, he was awarded the Nobel Prize for the scientific breakthroughs he had discovered.

Single-Crystal Silicon: In 1918, Jan Czochralski, a Polish scientist, figured out a method to grow single-crystal silicon. His discoveries laid the foundation for solar cells based on silicon.

The Birth of Photovoltaics: In 1954, David Chapin, Calvin Fuller, and Gerald Pearson developed the *silicon photovoltaic (PV) cell* at Bell Labs, the first solar cell capable of converting enough of the sun’s energy into power to everyday electrical equipment. In other words, these were the men that made the first device that *converted sunlight into electrical power*. The Bell Telephone Laboratories produced a silicon solar cell with 4% efficiency and later achieved 11% efficiency.

Satellite Solar Energy: In 1958, the Vanguard I space satellite used a small (less than one watt) array to power its radios. Later that year, Explorer III, Vanguard II, and Sputnik-3 were launched with *PV-powered systems* on board. Despite faltering attempts to commercialize the silicon solar cell in the 1950s and 60s, it was used successfully in powering satellites. It became the accepted energy source for space applications and remains so today.



Photovoltaic Powered Residences: In 1973, the University of Delaware builds the “Solar One”, the first *photovoltaic (PV)* powered residences. The system is a PV/thermal hybrid. The roof-integrated arrays fed surplus power through a special meter to the utility during the day and purchased power from the utility at night. In addition to electricity, the arrays acted as *flat-plate thermal collectors*, with fans blowing the warm air from over the array to phase-change heat-storage bins.

Photovoltaic System: In 1978, the NASA's Lewis Research Center installed a *3.5-kilowatt photovoltaic (PV) system* on the Papago Indian Reservation located in southern Arizona, the world's first village PV system. The system is used to *provide water pumping and residential electricity* in 15 residences until 1983, when a large grid power reached the village. The original PV system was then dedicated to pumping water from a community well.

The First Solar Thermal Facility: In 1986, the world's largest solar thermal facility, located in Kramer Junction, California, was commissioned. The solar field contained rows of mirrors that concentrated the sun's energy onto a system of pipes circulating a heat transfer fluid. The heat transfer fluid was used to produce steam, which powered a conventional turbine to generate electricity.

Solar Power Technologies: In 1988, Dr. Alvin Marks receives patents for two solar power technologies he developed; Lepcon and Lumeloid. The Lepcon consists of *glass panels* covered with a vast array of millions of aluminum or copper strips, each less than a micron or thousandth of a millimeter wide. As sunlight hits the metal strips, the *light energy is transferred to electrons* in the metal, which escape at one end, in form of electricity. The Lumeloid uses a similar approach, but replaces *cheaper film-sheets of plastic for the glass panels* and covers the plastic with conductive polymers, or long chains of molecular plastic units.

Thin-Film Modules: In 2000, two new thin-film solar modules were developed by BP Solarex, and brought previous performance records. The company's 0.5 m^2 module achieves 10.8 % conversion efficiency, the highest in the world for thin-film modules of its kind. Inverters convert the direct current (DC) electrical output from solar systems into alternating current (AC), which is the standard current for household wiring and for the power lines that supply electricity to homes.

Spheral Solar Technology: In 2002, the ATS Automation Tooling Systems Inc., in Canada, starts to commercialize an innovative method of producing solar cells, called Spheral Solar technology. The technology, based on tiny silicon beads bonded between two sheets of aluminum foil, promises lower costs due to its greatly reduced use of silicon relative to conventional multi-crystalline silicon solar cells.

Future Direction of the Solar Technology: All buildings will be built to combine energy-efficient design and construction practices and renewable energy technologies for a net-zero energy building. In effect, the building will conserve enough and produce its own energy supply to create a new generation of cost-effective buildings that have zero net annual need for non-renewable energy.

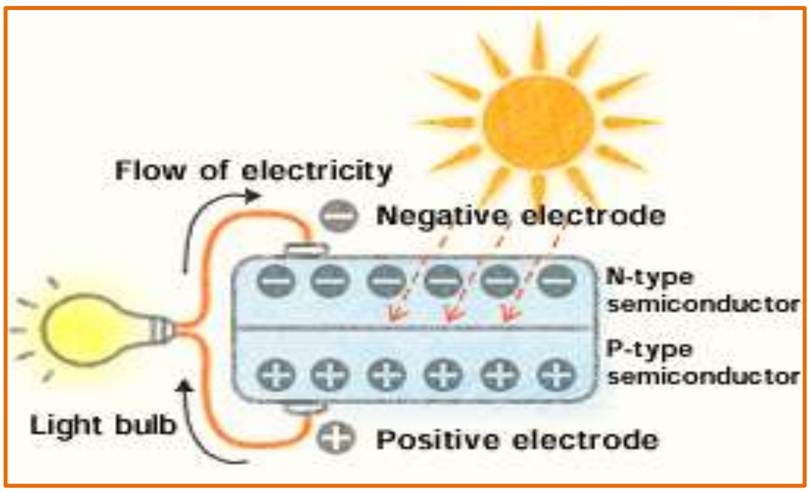
Photovoltaics research and development will continue intense interest in new materials, cell designs, and novel approaches to solar material and product development. It is a future where the clothes you wear and your mode of transportation can produce power that is clean and safe. Technology roadmaps for the future outline the research and development path to full competitiveness of concentrating solar power (CSP) with conventional power generation technologies within a decade.

A desert area **10 miles by 15 miles could provide 20,000 megawatts of power**, while the electricity needs of the entire United States could theoretically, be met by a photovoltaic array within an area *100 miles on a side*. Concentrating solar power, or solar thermal electricity, could harness the sun's heat energy to provide a large-scale, domestically secure, and environmentally friendly electricity. The price of photovoltaic power will be competitive with traditional sources of electricity, within 10 years. Solar electricity will be used to electrolyze water, producing hydrogen for fuel transportation cells, and buildings.

3. SOLAR POWER SYSTEMS:

Solar power is energy from the sun. Although the sun is 150 million kilometers away it is still extremely powerful. The amount of energy it provides for the earth in one minute is large enough to meet the earth's energy needs for one year. The problem is in the development of technology that can harness this "free" energy source. Nights and clouds can also add complications to solar energy, and not all radiation from the sun reaches earth, because it is absorbed and dispersed due to gases within the earth's atmospheres.

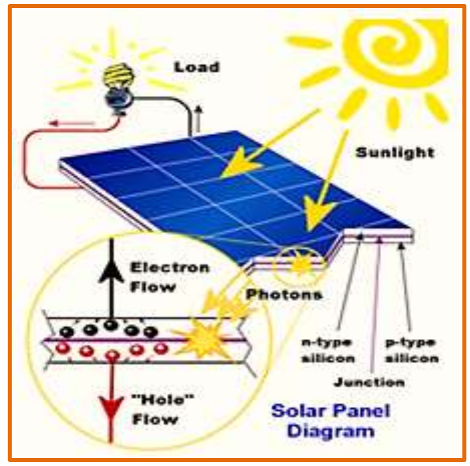
Photovoltaic panels (PV), also called solar cells, cells or photoelectric cells, are solid state electrical devices that converts *sunlight directly into electricity by the photovoltaic effect*. When sunlight hits the semiconductor, an electron springs up and is attracted to the *n-type semiconductor*. This causes negative electrons in the *n-type* and positive electrons in the *p-type semiconductor*, thus generating a flow of electricity in a process known as the "*photovoltaic effect*", as shown below:



Thus, solar PV cells, as defined above, convert sunlight into electricity using a semiconductor material (normally silicon). When the sunlight strikes the solar cell, a portion of light is absorbed within a semiconductor material, knocking electrons loose and allowing them to flow. This electron cycles results in a DC electric current and thus electricity production, when it's sunny, and then a device called as an *inverter* turns the electrons into AC electricity, if necessary.

PV panels primarily absorb the visible portion of the sunlight spectrum, and are normally connected to an *inverter to convert from DC (direct current) to AC* (alternating current) and subsequently the electricity is fed into the power grid. The DC electricity can be stored in batteries. Generally, standard PV panels are able to convert available sunlight into electricity with optimal conversion efficiency of around 15%, but some panels are able to reach as high as 20%.

It is important to note that a panel rated at *200 Watts* cannot consistently provide 200 Watts of electricity throughout the day. The 200 Watt rating is based on maximum summer sun radiation level of 1000 W/m² (317.1 Btu/ft²) in an ambient temperature of 25ºC (77ºF). So on a clear summer day a 200 Watt panel can be expected to provide around *0.7 - 0.8 kWh* of electrical energy.



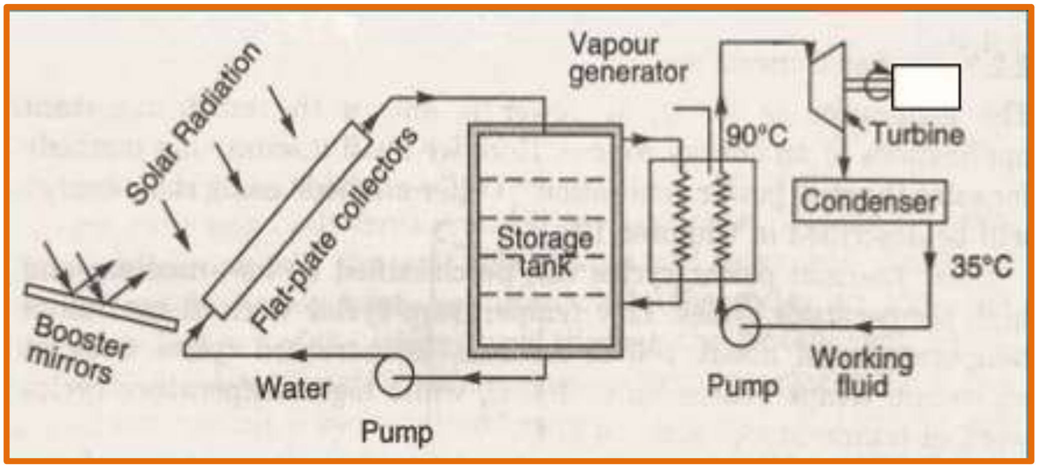
Solar Energy Systems: Solar energy systems use light energy (photons) from the sun to generate electricity through the photovoltaic effect, also known as a *second-generation technology*, where the energy received from the sun by the earth is of electromagnetic radiation. Light ranges of visible, infrared, ultraviolet, x-rays, and radio waves received by the earth through solar energy. Other types are known as solar thermal collectors, which use a fluid system to move the heat from the collector to its point of usage, and a reservoir or tank for heat storage and subsequent use.

The majority of modules use *wafer-based crystalline silicon* cells or *thin-film cells*, based on *cadmium telluride or silicon*. Most solar modules are rigid, but semi-flexible ones are available, based on thin-film cells. Electrical connections are made *in series* to achieve a desired output voltage or *in parallel* to provide a desired current capability. The conducting wires that take the current off the modules may contain silver, copper or other non-magnetic conductive. The cells must be connected electrically to one another and to the rest of the system.

The DC photovoltaic electricity produced by the solar panel or module(s) is used to charge the batteries via a solar charge controller. All DC appliances connected to the battery need to be fused but, DC lights are normally connected to the charge controller. All AC appliances are powered via a DC/AC inverter connected directly to the batteries. Most standalone solar systems need to be managed properly. Users need to know the limitations of a system and tailor the energy consumption according to how sunny it is, and the state of charge of the batteries.

The solar panels need to be configured to match the DC voltage. System DC voltages are typically, 12V, 24V, and larger systems operate at 48V. For example, a 12V battery will require a minimum of 14.4V to charge it. The solar panel must be able to deliver this voltage to the battery after power losses and voltage drops, in charge controller and cables, as the solar cells operate at a high temperature. Generally, a solar panel with a Voc of about 20V is required to reliably charge a 12V battery. Voc means Voltage Open Circuit, the output voltage of a PV under no load.

Flat-solar thermal plate systems use collectors of the non-concentrating type, generally used in architectures where temperatures below 95°C are sufficient. Due the relatively high heat losses through the glazing, flat plate collectors cannot reach temperatures above 200°C, even when the heat transfer fluid is stagnant, for efficient conversion to electricity.



Each module of solar photovoltaic panel is rated by its DC output power under standard test conditions, and typically ranges from 100 to 365 watts. The efficiency of a module determines the rated output, in watts, per module area. As example, an 8% efficiency of a 230 watt module will have twice the area of a 16% efficient 230 watt module. A common residential photovoltaic system typically includes a panel or an array of solar modules, a charge controller, an inverter, and sometimes a battery and/or a solar tracker and interconnection electrical wiring.

Solar Charge Controllers: Also called as *charge controllers, charge regulators or battery regulator*s are electronic devices that control the rate at which electric current is drawn from electric batteries, and control the power DC equipment with solar panels. It may protect the battery against overvoltage and completely draining ("deep discharging"), however, can also reduce energy performance or lifespan, and may pose a safety risk.

The terms "*charge controller*" or "*charge regulator*" commonly refer to either a stand-alone device or to control circuitry-integrated within a battery pack, battery-powered device, or battery charger. A DC/AC inverter is usually connected to the output of a solar charge controller to drive AC loads. A charge controller is designed to protect the battery bank and ensure it has a long working life without impairing the system efficiency. The main function of the charge controller is to ensure that the system battery bank is not over charged.

Maximum Power Point Tracking (MPPT): Are solar charge controllers DC to DC converters that optimizes the match between the solar array (PV panels), and the battery bank or utility grid, or putting it simply, this electronic device convert a higher voltage DC output from solar panels (and a few wind generators) down to the lower voltage needed to charge batteries. The MPPT (Maximum Power Point Tracking**)** charge controllers compare the battery voltage, and define the best power output to charge the battery, converting it to the best voltage to get maximum amperes into the battery.

Pulse Width Modulators (PWM): These solar charge controllers DC to DC, are cheaper than MPPT and the most common used in solar panel systems, slowly reduce the charging current to avoid overheating the battery after it has reached the regulation setpoint. At the same time, the system continues to send the highest amount of energy over the shortest period of time, which results in rapid charge and high efficiency. Essentially, a PWM charge controller helps to increase charge acceptance of the battery while maintaining high battery capacity for a longer period of time.

The PWM (Pulse Width Modulation) charge controller is a good low cost solution for small systems only, when solar cell temperature is moderate to high (between 45°C and 75°C). However, PWM controllers are unable to capture excess voltage because the PWM technology charges at the *same voltage* as the battery. When solar panels are deployed in warm or hot climates, their Vmp decreases, and the peak power point operates at a voltage that is closer to the voltage of a 12V battery.

Solar Inverters: Also called as *PV Inverters*, or *Solar Converters* convert the variable direct current (DC) output of a photovoltaic (PV) solar panel into a utility frequency alternating current (AC) that can be fed into a commercial electrical grid or used by a local off-grid electrical network. Solar inverters have special functions adapted for use with photovoltaic arrays, including maximum power point tracking and anti-islanding protection.

Note: *Islanding* is when a generator continues to power without the electrical grid power. Islanding can be dangerous to utility workers, who may not realize that a circuit is still powered, and it may prevent automatic re-connection of devices. For that reason, distributed generators must detect islanding and immediately stop producing power; this is referred to as anti-islanding.

Solar panels produce direct current at a voltage that depends on module design and lighting conditions. Modern modules using 6-inch cells typically contain 60 cells and produce a nominal 30 V. The power then runs to an inverter, which converts it into standard AC voltage, typically 230 VAC/50 Hz or 240 VAC/60 Hz. The main problem, with the string of panels, is when it acts as a single larger panel, with a max current rating equivalent to the poorest performer in the string.

For example, if one panel in a string has 5% higher resistance due to a minor manufacturing defect, the entire string suffers a 5% performance loss, affecting the output of the string, even if the other panels are not shaded. In the industry, this is known as the "Christmas-lights effect", referring to the way an entire string of series-strung Christmas tree lights will fail if a single bulb fails.

To maximize production, inverters use a technique called maximum power point tracking (MPPT) to ensure optimal energy harvest by adjusting the applied load. The fill factor, more commonly known by its abbreviation *FF*, is a parameter which, in conjunction with the *open circuit voltage* (V_{oc}) and *short circuit current* (I_{sc}) of the panel, determines the maximum power from a solar cell. Fill factor is defined as the ratio of the maximum power from the solar cell to the product of V_{oc} *and* I_{sc}.

Obs.: A second version, called a hybrid inverter may split the power at the inverter, where a percentage of the power goes to the grid and the remainder goes to a battery bank. The third version is not connected to the grid and employs a dedicated PV inverter to stand-alone solar panels.

Solar Micro-Inverters: Micro-inverters are small inverters rated to handle the output of a single panel, specifically designed to operate with single PV modules. The micro-inverter converts the direct current output from each panel into alternating current, which allows parallel connections of multiple, independent units in a modular way. Micro-inverters contrast with central solar inverters, connected to multiple solar modules or panels of the PV system. Modern grid-tie panels are normally rated between 225 and 275W, but rarely produce this in practice, so microinverters are typically rated between 190 and 220 W.

Each micro-inverter picks optimum power by performing maximum power point tracking for connected modules. The main advantage include single panel power optimization, independent operation of each panel, plug-and play installation, fire safety, minimized costs in a system. Small amounts of shading, debris or snow lines on any one solar module, or even a complete module failure, do not disproportionately reduce the output of the entire array. The primary disadvantage is a higher initial equipment cost per peak watt than the equivalent power of a central inverter, since each inverter needs to be installed adjacent to a panel (usually on a roof).

Solar Grid-Tie Inverters: Are solar electrical devices designed to quickly disconnect from the grid when energy supply goes down. This is an NEC requirement that ensures that in the event of a blackout, the grid tie inverter will shut down to prevent the energy it produces from harming any line workers who are sent to fix the power grid. These types of inverters contain special circuitry to precisely match the voltage and frequency of the grid.

Grid-tie inverters are available on the market with several different technologies. The inverters may use the newer high-frequency transformers, or no transformer. Instead of converting direct current directly to 120 or 240 volts AC, high-frequency transformers employ a computerized multi-step process that involves converting the power to high-frequency AC and then back to DC and then to the final AC output voltage.

Inverter Battery Chargers: Are special inverters designed to draw energy from a battery, manage the battery charge via an onboard charger, and export excess energy to the utility grid. These inverters are capable of supplying AC energy to selected loads during a utility outage, and are required to have anti-islanding protection.

Batteries: The batteries that are able to handle the constant charging and discharging are known as deep batteries. These batteries need to have a good charging efficiency, low charging currents and low self-discharge. The "Ah" (ampere hour) efficiency of a battery describes the relationship between the *amp hour* that are put into the battery and the "Ah" taken out. Under ideal conditions a new deep-cycle battery would be 90% efficient. "Ah" is one ampere of current to flow in one hour.

How standalone power system works:

- ✓ Sunlight hits the solar module, which is attached on a roof with the mounting racks;
- ✓ The solar (or photovoltaic) cells inside the module convert the sunlight into electricity;
- ✓ This electricity travels through wires to the charge controller, which regulates the battery voltage, and the photovoltaic electricity keeps the battery bank fully charged to ensure uninterruptible power;
- ✓ The inverter takes the electricity from the solar module (DC electricity) and converts into AC electricity needs, to run the residence or building appliances, lighting, etc.;
- ✓ In the event of an emergency (cloudy, rainy days or unforeseen system disruption), the stand-alone power system automatically begins to draw power from the backup generator and converts it into the necessary electricity (optional).

Note: In some cases, where it is important that power is always available, some standalone systems, known as PV-hybrid systems or island systems, may also have another source of power such as a wind turbine, bio-fuel or a diesel generator.

Types of Solar Panels: There are many types of commercial solar cells for an arrangement of a solar photovoltaic rooftop array in residences or buildings. Solar cells contain materials with semiconducting properties in which their electrons become excited and turned into an electrical current when struck by sunlight. While there are dozens of variations of solar cells, the two most common types are those made of crystalline silicon (both monocrystalline and polycrystalline) and those made with what is called thin film technology. The main types described here are:

- ✓ **Amorphous Silicon** (**a-Si**): Is the non-crystalline form of silicon used for solar cells and thin-film transistors in LCD displays. Amorphous silicon cells generally feature *low efficiency*, but are one of the most *environmentally friendly photovoltaic* technologies, since they do not use any *toxic heavy metals* such as *cadmium or lead*.

- ✓ **Cadmium Telluride** (**CdTe**): Is based on the use of cadmium telluride, a thin semiconductor layer designed to absorb and convert sunlight into electricity. Cadmium telluride PV is the only thin film technology with *lower costs* than conventional solar cells made of crystalline silicon in multi-kilowatt systems.

- ✓ **Concentrator Photovoltaics** (**CPV**): Contrary to conventional photovoltaic systems, it uses *lenses and curved mirrors* to focus sunlight onto small, but highly efficient. CPV systems also often use solar trackers and sometimes a cooling system to further increase their efficiency.

- ✓ **High-Concentrator Photovoltaics** (**HCPV**): Possess the *highest efficiency* of all existing PV technologies, and a smaller photovoltaic array also reduces the balance of system costs. Are very effective and especially have the potential to become competitive in the near future.

- ✓ **Copper Indium-Gallium-Selenide (CIGS):** Is a thin-film solar cell manufactured by depositing a thin layer of *copper, indium, gallium and selenide* on glass or plastic backing, along with electrodes on the front and back to collect current. CIGS is one of three mainstream thin-film PV technologies, the other two being *cadmium telluride and amorphous silicon*.

- ✓ **Crystalline Silicon** (**c-Si**): Is the crystalline form of silicon, or a multicrystalline silicon (multi-Si) consisting of small crystals, or a monocrystalline silicon (mono-Si), a continuous crystal. Crystalline silicon is the *dominant semiconducting* material used in photovoltaic technology for the production of solar cells. In electronics, the monocrystalline silicon is used for *producing microchips* as it contains much lower impurity levels than those required for solar cells.

- ✓ **Dye-Sensitized Solar Cell** (**DSSC** or **DSC**): Is a low-cost solar cell belonging to the group of thin film solar cells, based on a semiconductor formed between a photo-sensitized anode and an electrolyte, a *photoelectrochemical* system.

- ✓ **Hybrid Solar Cells**: Have *organic materials* that consist of conjugated polymers that absorb light and transport holes. An *electron hole* is the lack of an electron where could exist in an atom. As example, when an electron leaves a helium atom, it leaves an electron hole in its place, to become positively charged. Inorganic materials in hybrid cells are used as the acceptor and electron transporter in the structure. The hybrid photovoltaic devices have a potential for not only *low-cost*, but also for scalable solar power conversion.

- ✓ **Luminescent Solar Concentrator** (**LSC**): Is a device for concentrating radiation, as a non-ionizing solar radiation, which operate on the principle of collecting radiation over a large area, converting it by luminescence (commonly specifically by fluorescence) and directing the generated radiation into a relatively small output target.

- ✓ **Monocrystalline Silicon**: Also known as "single-crystal silicon", "mono c-Si", is commonly used in the manufacturing of high performance solar cells and electronic chips.

- ✓ **Multi-Junction Solar Cells**: Use multiple p–n junctions made of different semiconductor materials, which produce electric current in response to different wavelengths of light. The use of multiple semiconducting materials allows the absorbance of a broader range of wavelengths, improving the cell's sunlight to electrical energy conversion efficiency.

- ✓ **Nanocrystal Solar Cells:** Are based on a substrate with a coating of nanocrystals. The nanocrystals are typically based on silicon, CdTe or CIGS and the substrates are generally silicon or various organic conductors.

- ✓ **Organic Solar Cell** (**Plastic Solar Cell**: Uses organic electronics, a branch of electronics that deals with conductive organic polymers or small organic molecules. An example of an organic photovoltaic is the polymer solar cell. However, organic photovoltaic cells have lower efficiency, low stability and low strength compared to inorganic photovoltaic cells such as silicon solar cells.

- ✓ **Perovskite Solar Cell**: Is a type of solar cell that includes a "perovskite" structured compound, most commonly a hybrid organic-inorganic lead or tin halide-based material, as the light-harvesting active layer. Perovskite materials such as methyl-ammonium lead halides are cheap to produce and simple to manufacture.

- ✓ **Plasmonic Solar Cell**: Are a type of thin film solar cell which are typically 1-2 µm thick, which can use cheaper substrates than silicon, such as glass, plastic or steel. The biggest problem for thin film solar cells is that they don't absorb as much light as thicker solar cells.

- ✓ **Polycrystalline Silicon**: Is also called *polysilicon or poly-Si*, is a high purity, *polycrystalline form of silicon*. Polysilicon is produced by a chemical purification process, called Siemens process. Multicrystalline solar cells are the most common type of solar cells and consume most of the worldwide produced polysilicon. About 5 tons of polysilicon is required to manufacture 1 megawatt (MW) of conventional solar modules.

- ✓ **Polymer Solar Cell**: Is a type of *flexible solar cell* made with polymers, large molecules with repeating structural units. Polymer solar cells include the organic solar cells (plastic solar cells), others include the more stable amorphous silicon solar cell.

- ✓ **Quantum Dot Solar Cell**: Is a solar cell design that uses *quantum dots* as the absorbing photovoltaic material. It attempts to replace bulk materials such as silicon and other expensive materials. Quantum dots are metal disks on the front surface of the solar panel, which give the electrical connections.

- ✓ **Thin-Film Solar Cell**: Is a second generation solar cell that is made by depositing one or more thin layers or thin films (TF), which varies from a few *nanometers (nm)* to tens of *micrometers* (µm of photovoltaic material on a substrate, such as glass, plastic or metal.

Solar Panels Efficiency: Currently the best achieved sunlight conversion rate is around 21.5% in new commercial products typically lower than the efficiencies of their cells in isolation. The most efficient mass-produced solar modules have power density values of up to 175 W/m^2 (16.22 W/ft^2).

Manufacturer Solar Panels Data: As a sample example and become easier to understand, this below shows the average effective output to expect per day from summer to winter, either using older technology PWM (Pulse Width Modulation) charge controllers, or newer MPPT (Maximum Power Point Tracking) style controllers.

		70W	**100W**	**120W**	**150W**
SPECIFICATIO	**Cell Type**	Mono Crystalline Silicon Photo Voltaic Solar Cells	Mono Crystalline Silicon Photo Voltaic Solar Cells	Mono Crystalline Silicon Photo Voltaic Solar Cells	Mono Crystalline Silicon Photo Voltaic Solar Cells
	Cell Size	155mm x 70mm	125mm x 125mm	82.5mm x 125mm	155mm x 155mm
	Number of Cells	36 (4x9)	36 (4x9)	48 (8x6)	36 (4x9)
	Dimension of Module (mm)	776H x 675W x 35mmT	1209H x 545W x 35mmT	810H x 1061W x 35T	1470H x 680W x 35T
	Weight of Module	6.5kg	7.5kg	12kg	11kg
ELECTRICAL	Maximum Power at STC* (P_{MAX})	70W	100W	120W	150W
	Open-Circuit Voltage (V_{OC})	22.0V	22.4V	28.8V	22.0V
	Short-Circuit Current (I_{SC})	4.24A	5.85A	5.56A	9.10A
	Voltage at P_{MAX}(V_{MP})	17.7V	18.2V	23.95V	18.0V
	Current at P_{MAX}(I_{MP})	3.95A	5.49A	5.01A	8.33A
	Application	12/24/48 VDC Systems	12/24/48 VDC Systems	12/24/48 VDC Systems	12/24/48 VDC Systems
LIMITS	Fuse Rating	10A	10A	10A	15A
	Maximum System Voltage	715 VDC	715 VDC	1000 VDC	1000 VDC
	Operating Temperature	-40 to +85°C	-40 to +85°C	-40 to +85°C	-40 to +85°C
OUTPUT	Type of Output Terminal	Junction Box	Junction Box	Junction Box	Junction Box
	Cable	4mm^2	4mm^2	4mm^2	4mm^2
	Cable Lengths	800mm	800mm	800mm	800mm
	Connector	Plug Type	Plug Type	Plug Type	Plug Type

		160W	200W	250W	310W
SPECIFICATION	**Cell Type**	Mono Crystalline Silicon Photo Voltaic Solar Cells	Mono Crystalline Silicon Photo Voltaic Solar Cells	Mono Crystalline Silicon Photo Voltaic Solar Cells	Mono Crystalline Silicon Photo Voltaic Solar Cells
	Cell Size	125mm x 125mm	125mm x 125mm	155mm x 155mm	155mm x 155mm
	Number of Cells	60 (6x10)	72 (6x12)	60 (6x10)	72 (6x12)
	Dimension of Module (mm)	1328H x 808W x 40D	1580H x 808W x 40D	1650H x 992W x 40D	1958H x 992W x 50D
	Weight of Module	14kg	14kg	19kg	23kg
ELECTRICAL	Maximum Power at STC* (P_{MAX})	160W	200W	250W	310W
	Open-Circuit Voltage (V_{OC})	36.2V	44.8V	37.4V	45.0V
	Short-Circuit Current (I_{SC})	6.08A	5.71A	8.83A	8.94A
	Voltage at P_{MAX} (V_{MP})	30.2V	36.7V	30.0V	36.8V
	Current at P_{MAX} (I_{MP})	5.30A	5.45A	8.33A	8.42A
	Application	12/24/48 VDC Systems	12/24/48 VDC Systems	12/24/48 VDC Systems	12/24/48 VDC Systems
LIMITS	Fuse Rating	10A	10A	15A	15A
	Maximum System Voltage	1000 VDC	1000 VDC	1000 VDC	1000 VDC
	Operating Temperature	-40 to +85°C	-40 to +85°C	-40 to +85°C	-40 to +85°C
OUTPUT	Type of Output Terminal	Junction Box	Junction Box	Junction Box	Junction Box
	Cable	$4mm^2$	$4mm^2$	$4mm^2$	$4mm^2$
	Cable Lengths	800mm	800mm	800mm	800mm
	Connector	Plug Type	Plug Type	Plug Type	Plug Type

Specification Example: Another manufacturer, as shown below, has two types of solar panels: one Polycrystalline Solar Panel, 110 Watt, 12 Volt, and other Multicrystalline Solar Panel, 130 Watt, 24 Volt, with the following data description:

- ✓ A 110 W solar panel, which use a junction box for access to negative and positive terminals. Wire sizes 8 to 14 AWG. Constructed of tempered glass, silicon cell, EVA and polyester with tedlar and aluminum frame. Total 36 cells:

- ✓ A 130 W solar panel, suited for grid-tie applications and battery charging, to be used with any type of MPPT charge controller for charging 24 volt battery banks, but can also be configured for charging 12 volt or 48 volt battery banks. This module comes with prefabricated wire leads with MC4 connectors for easy wiring.

110 W Solar Panel, 12 V	130 W Solar Panel, 24 V
Max Power: 110 Watts Vmp: 17.0 Volts Ipm: 6.5 Amps Isc: 7.1 Amps Voc: 21.4 Volts Length: 48.15 Inches Width: 26.06 Inches Depth: 1.97 Inches Weight: 24.2 lbs	**Max Power**: 130 Watts Vmp: 34.0 Volts Ipm: 3.75 Amps Isc: 4.5 Amps Voc: 41.5 Volts Length: 57.7 Inches Width: 26 Inches Depth: 1.97 Inches

A solar panel, which is rated at 17 volts, will put out less than its rated power when used in a battery system. That's because the working voltage will be between 12 and 15 volts. Because wattage (or power) is the product of *volts multiplied by the amps*, the module output can be reduced. For example, a 50-watt solar panel working at 13.0 volts at 3 amps, can product only 39.0 watts (13.0 volts x 3.0 amps = 39.0 watts). This is important to remember when sizing a PV system.

Obs.: Solar panels can also be calculated by the MPP (maximum power point) value. The maximum power point of the solar panel consists of an MPP voltage (V mpp) and MPP current (I mpp), where the capacity and the higher value can make a higher MPP.

PV Quality Calibration: Many PV industry partners rely on NREL (National Renewable Energy Laboratory) to calibrate reference cells and modules used in measuring their products. NREL recently expanded its ISO 17025 accreditation to include primary and secondary module calibration under industry standards. Quality testing is also performed under IEC 61215, IEC 60904-1:1987, IEEE Std. 1262-1995 and BIS 14286: 1995. PV cells made of multicrystalline silicon cost less to manufacture than single-crystal silicon, but the non-uniformity and numerous crystal boundaries in multicrystalline silicon may degrade the PV cell performance.

The industry prefers using the flexible polymers to replace glass in thin-film modules, but the polymers' permeability causes some troubles. The solution was depositing a thin moisture barrier on the polymer surface, to stop moisture and adhere to the polymer. Researchers also used a specially developed tool to study surface chemistry and electronic structure during chemical-bath deposition of cadmium sulfide. The results led to a modified method for depositing cadmium sulfide in a chemical bath, which improves the performance of copper-indium-gallium-diselenide (CIGS) PV cells.

Solar STC and Solar PTC: **STC** stands for "Standard Test Conditions", for solar panels measured under lab conditions of 1000 W/m² of "sunlight", commonly with a standard spectrum. It is a nominal or nameplate value. For instance, a 180 Watt panel is 180 Watts (STC), and an array made with ten of these panels is considered 1,800 Watts (STC). When talking about the array size, the STC number is always used. It is a handy way of comparing arrays.

PTC stands for "PVUSA Test Condition", which is much closer to real installation conditions. For instance, a *180 Watt panel is 156 Watt (PTC)*. Some websites are defining PTC as "Performance Test Conditions" but is wrong. PTC was developed to test and compare PV systems as part of the PVUSA (Photovoltaics for Utility Scale Applications) project.

PTC is 1,000 Watts/m² solar irradiance, 20º C air temperature, and wind speed of 1 m/s at 10 meters above ground level. **STC** is 1,000 Watts/m² solar irradiance, 25º C cell temperature, air mass equal to 1.5, and ASTM G173-03 standard spectrum. The **PTC rating** is lower than the **STC rating**, generally recognized as a more realistic measure of PV output, as the test conditions better reflect a "real-world" solar and climatic conditions, compared to the STC rating.

4. LARGE SOLAR POWER SYSTEMS:

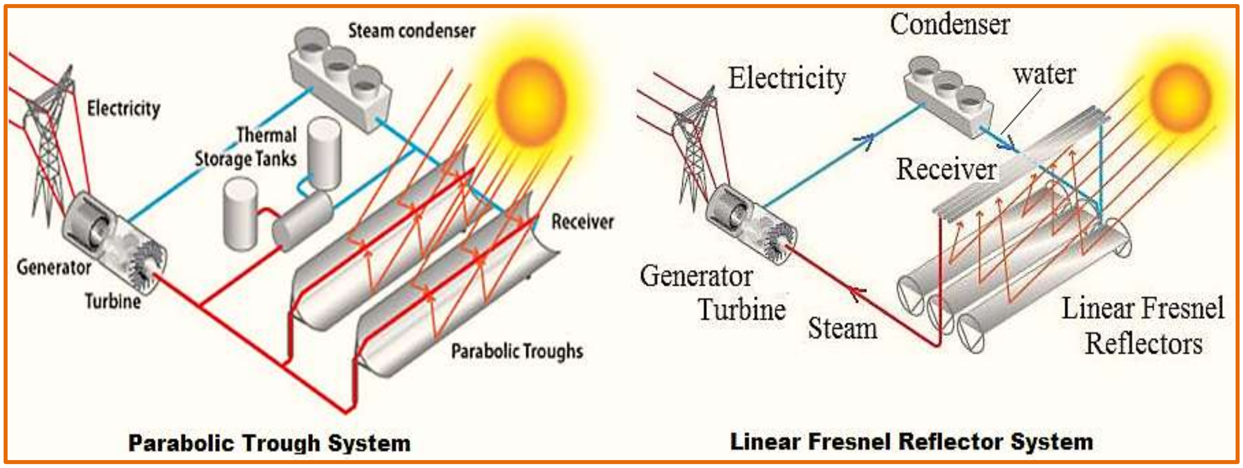
Photovoltaics were initially solely used as a source of electricity for small and medium-sized applications, powered by a single solar cell to remote homes generally as an off-grid PV system. However, as the cost of solar electricity has fallen, the number of large grid-connected solar PV systems has grown into the millions and utility-scale solar power stations with hundreds of megawatts are being built. Solar PV is rapidly becoming an inexpensive, low-carbon technology to harness renewable energy from the sun.

Concentrated Solar Power (**CSP**): These solar energy systems generate solar power by using mirrors or lenses to concentrate a large area of sunlight, or solar thermal energy, onto a small area. Electricity is generated when the concentrated light is converted to heat. The receiver is filled with a heat transfer fluid such as oil that absorbs the heat energy.

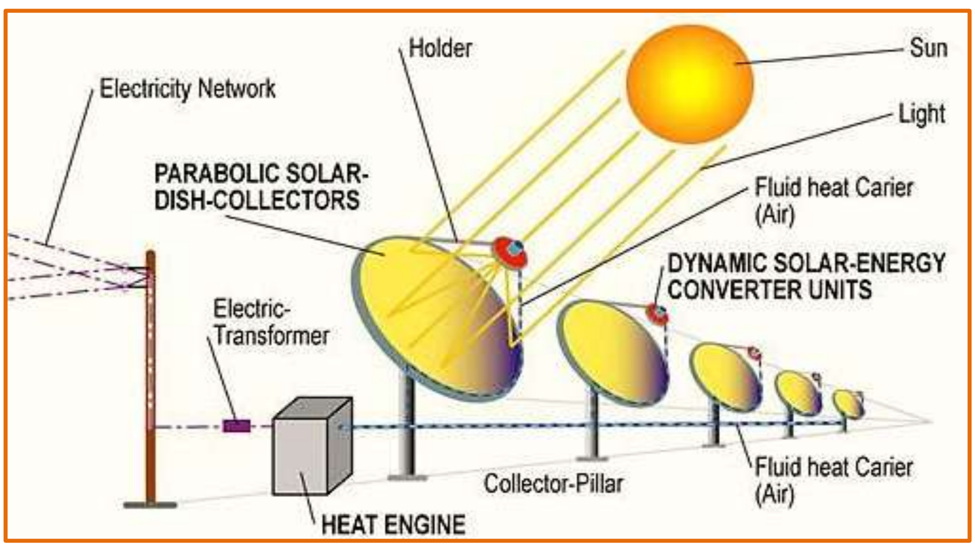
The heated oil is pumped through a heat exchanger or steam generator, which converts water on the secondary side to steam. The steam turns a turbine generator (and the pumps) to generate the electricity. When the steam exits the turbine, it returns to the liquid phase in the condenser, and the cycle repeats. There are three main types of CSPs, described below:

- ✓ **Linear Concentrators**: Collect the sun's energy using long rectangular, curved (U-shaped) mirrors. The mirrors are tilted toward the sun, focusing sunlight on tubes (or receivers) that run the length of the mirrors. The reflected sunlight heats a fluid flowing through the tubes. The hot fluid is used to boil water in a steam-turbine generator to produce electricity.

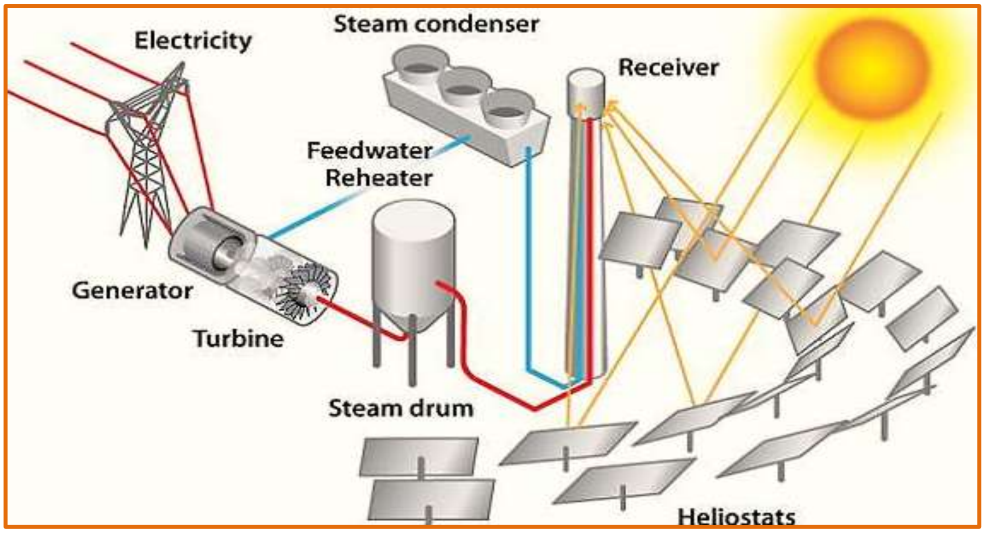
There are *two major types* of *linear concentrator systems*: *parabolic trough systems*, where receiver tubes are positioned along the focal line of each parabolic mirror; and *linear Fresnel reflector systems*, where one receiver tube is positioned above several mirrors to allow the mirrors greater mobility in tracking the sun.



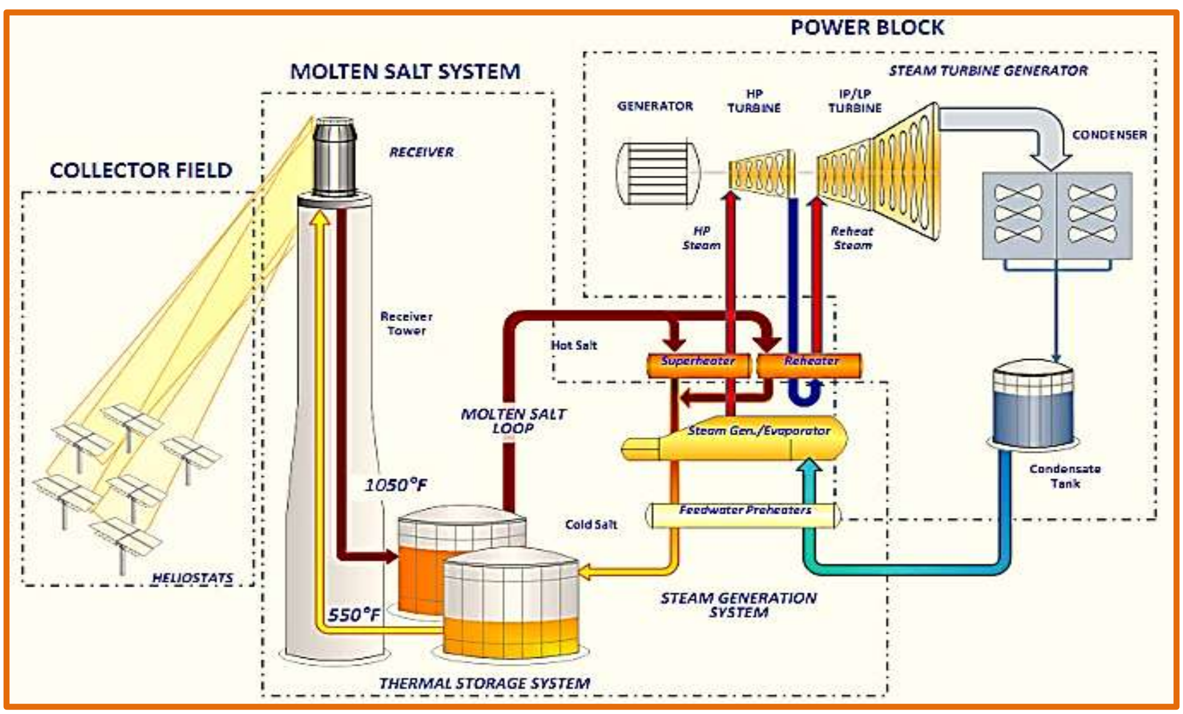
Parabolic Dish: Provides the highest efficiency of the three types. It usually contains a servo system that positions the dish in two axes to track the position of the sun while maintaining the receiver at its optimal focal point. The dish-shaped surface directs and concentrates sunlight onto a thermal receiver, which absorbs and collects the heat and transfers it to the engine generator. The most common type of heat engine used is the Stirling engine, which converts heat into mechanical energy. This system uses the fluid heated by the receiver to move pistons and create mechanical power. The mechanical power is then used to run a generator or alternator to produce electricity.



Power Tower System: Uses a large field of flat, sun-tracking mirrors known as heliostats to focus and concentrate sunlight onto a receiver on the top of a tower. A heat-transfer fluid heated in the receiver is used to generate steam, which, in turn, is used in a conventional turbine generator to produce electricity. Some power towers use water/steam as the heat-transfer fluid. Other advanced designs are *solar molten salt plants* with molten nitrate salt, due its superior heat-transfer and energy-storage capabilities. A thermal storage, allows the system to supply electricity during cloudy weather or at night. Commercial plants can be sized to produce up to 200 megawatts of electricity.



Molten Salt Power Plant: Is designed as a solar power tower, with thousands of tracking mirrors (heliostats) focusing the concentrated sunlight on a receiver that sits at the top of a central tower to collect the thermal energy. The storage medium for high-temperature heat storage is molten salt. This thermal energy system uses the *thermal energy* to heat the molten salt to store the energy. The molten salt is a mixture of *sodium nitrate and potassium nitrate* that is non-flammable and non-toxic and is efficient and inexpensive energy storage medium.



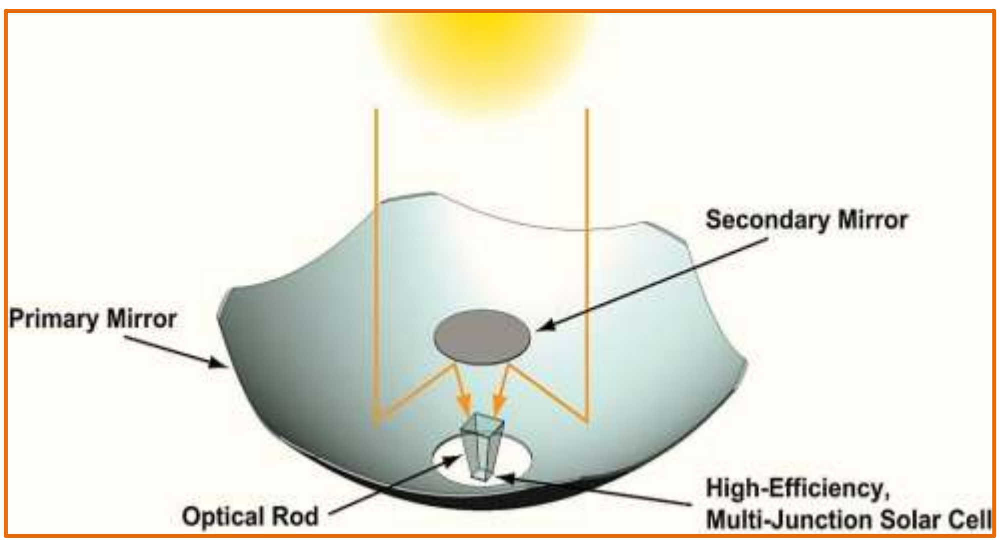
In a *molten-salt solar power tower*, liquid salt at 290ºC (554ºF) is pumped from a cold storage tank through the receiver where it is heated to 565ºC (1,049ºF) and then on to a hot tank for storage.

When power is needed from the plant, hot salt is pumped to a steam generator that produces superheated steam for a conventional turbine/generator system. From the steam generator, the salt is returned to the cold tank where it is stored and eventually reheated in the receiver. The output temperatures of non-concentrating solar collectors are limited to temperatures below 200°C.

As the temperature increases, different forms of conversion to electricity become practical. Up to 600°C, *steam turbines* have efficiency up to 41%; however, above 600°C *gas turbines* can be more efficient. Higher temperatures are problematic because different materials and techniques are needed. One proposal for very high temperatures is to use *liquid fluoride salts* operating between 700°C to 800°C, using multi-stage turbine systems to achieve 50% or more thermal efficiencies.

Due high costs, lenses and burning glasses are not usually used for large-scale power plants, and cost-effective alternatives are used, including reflecting concentrators. Generally, the reflector, which concentrates the sunlight to a focal line or focal point, has a *parabolic shape*. One-axis tracking systems concentrate the sunlight onto an absorber tube in the focal line; while two-axis tracking systems concentrate the sunlight onto a relatively small absorber surface near the focal point.

Concentrating PV (CPV): Use relatively inexpensive optics to concentrate sunlight onto a small area of high-efficiency, multijunction cells. These models of solar panels use mirrors or lenses to focus sunlight on high-efficiency cells, and employ two-axis tracking mechanisms to track the sun. CPV uses cheap lenses to leverage the costly PV modules and reach a lower cost of power, than flat panels. Due to the smaller size of the panel per kilowatt, the use of a two-axis tracking mechanism increases the overall system efficiency and capacity factors.

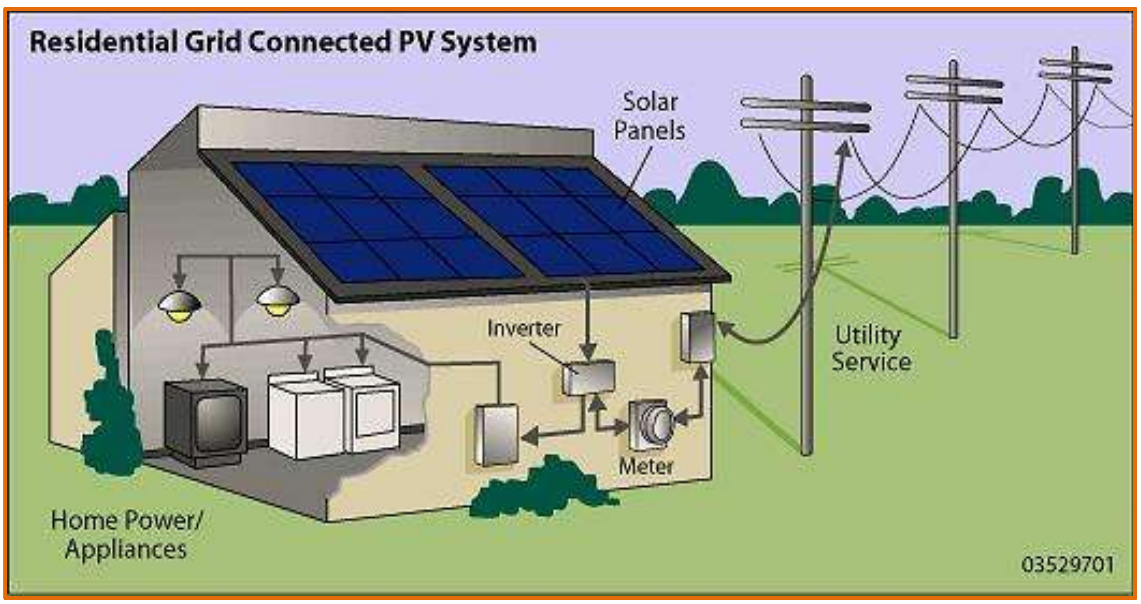


5. SOLAR ENERGY INTEGRATION:

There are two types of solar power generating systems: *grid-connected systems*, which are connected to the commercial power infrastructure; *and standalone or off-grid solar power systems*, which are completely independent from the grid electrical systems. Residential, grid-connected rooftop systems have a capacity less than 10 kilowatts, which meet the load of most consumers and feed excess power to the grid, consumed by other users. The standalone or off-grid system is a DC (direct current), from solar modules, stored in a battery and converted to AC (alternate current) by an inverter. This is a perfect choice for remote villages with continuous reliable electric power.

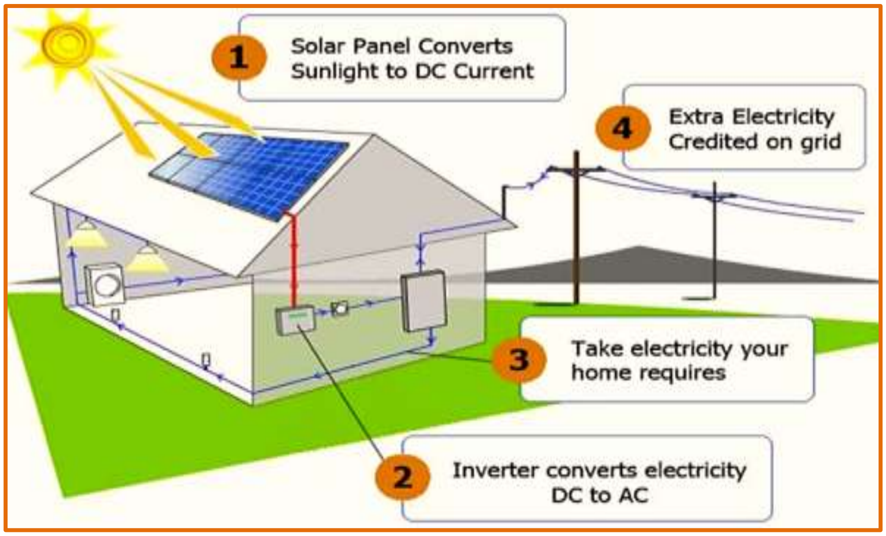
Integrating a solar energy system, whether on a home or business, with the power grid run by the city or state is another good way in provide an incentive for more consumers to get on board with solar power. This allows the consumer to produce the electricity needed to cut out the need of fossil fuel energy, and also allows selling his unused excess power to the electric companies for reuse among other areas of need. This allows the consumer to compensate some of the losses spent on installation along with a small source of income, as a resource producing power for others.

Grid-Connected Systems: Also designated as grid-connected PV system is a solar PV system that is connected to the utility grid, which consists of solar panels, one or several inverters, a power conditioning unit and grid connection equipment. This grid ranges from small residential and commercial rooftop systems, to large utility-scale solar power stations. The grid-connected system rarely includes an integrated battery-bank solution, as this is very expensive. When conditions are right, the grid-connected PV system may also supply power to the utility grid.



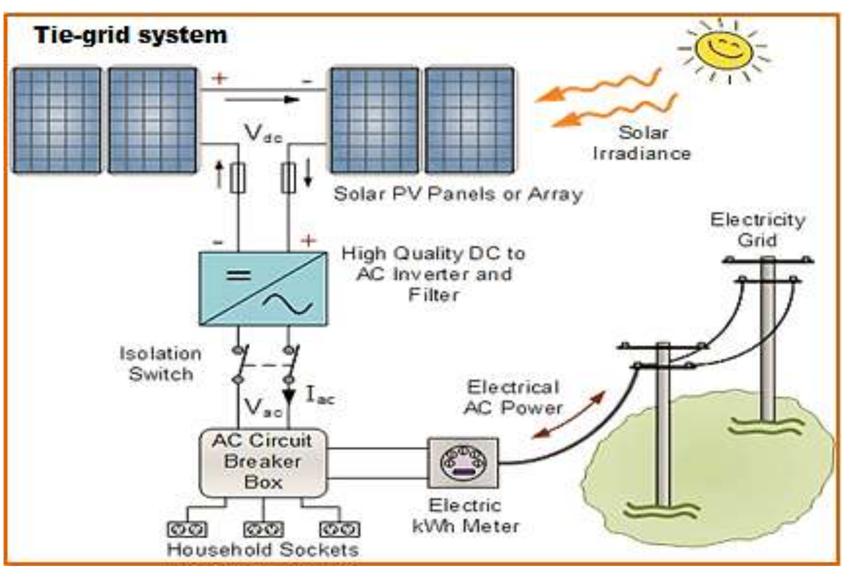
Residential, *grid-connected rooftop systems,* which commonly have a capacity less than *10 kW,* can meet the load of most consumers. This system can feed excess power to the grid to be consumed by other users. The control is done through a meter to monitor the power transferred. Photovoltaic wattage can be less than the average consumption of the consumer, and may continue to *purchase grid energy,* but in a lesser amount than before. When photovoltaic wattage substantially exceeds average consumption, the energy produced by the panels will be much in excess of the demand.

In this case, the excess power can yield revenue by selling it to the grid. Depending on agreement with local grid energy company the consumer only needs to pay the cost of electricity consumed, much less the value of the previously electricity generated. This can be a negative number if more electricity is generated than consumed. Additionally, in some cases, cash incentives are paid from the grid operator to the consumer. Connection of the photovoltaic power system can be done only through an interconnection agreement between the consumer and the utility company. The agreement details the various safety and code standards to be followed during the connection.



The most common type of solar PV system is the "*grid-tied system"* that is connected to the electrical grid, and allows residents of a building to use either solar energy or electricity from the grid. When a home or business is using energy, but the solar panels cannot produce enough energy (at night, or on a stormy day), electricity from the grid supplements or replaces electricity from the panels. Owners of a *grid-tied system* complete a net metering in agreement with their utility suppliers, generally to low their energy costs.

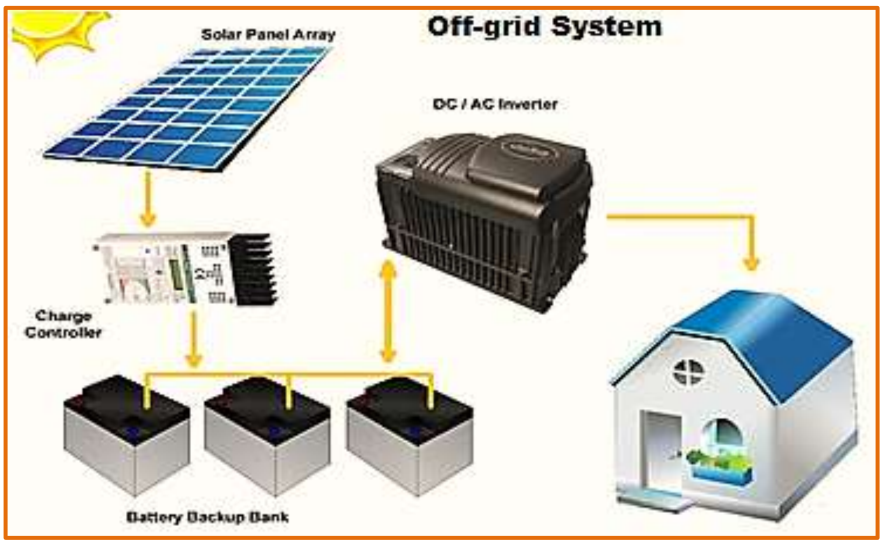
This agreement allows utility customers to receive credit for the excess energy they generate, typically credited as a *kilowatt-hour credit* on the next month's bill. Net metering policies and agreements are different for each utility. However, *grid-tied systems* do not provide protection from power outages. When the electrical grid fails, grid-tied systems may not continue to operate. This allows utility employees to fix the power lines safely without wasting time identifying solar energy systems that are still feeding electricity into the power lines, using some type of energy generators.



Note: Excess power generated over and above needs go back to the utility company for credits on power bills in areas where net-metering is available. In the event of grid blackouts, these systems can switch to the "*off-grid mode*" power stored in a battery-bank to power buildings and residences. During sunlight the solar panels are used to recharge the battery-bank.

Off-Grid Systems: When a solar system is installed independent of the electrical grid, is called an "*off-grid system*", and it requires that the solar panels are able to produce enough electricity to cover 100% of the energy needs of a residence or a building. As higher electricity demand is generally in the evening or at night, *off-grid systems* usually incorporate either a battery bank (to store energy produced during the day) or a generator), or even both. Nevertheless, *off-grid systems* are more complex and less flexible than grid-tied systems.

Standalone Solar Power Systems: As referred above, are also called as "*off-grid solar energy systems*", are completely independent of the electric utility grid. The *standalone power system* (SAPS or SPS), also known as *remote area power supply* (RAPS), is an *off-the-grid electricity system* for locations that are not fitted with a standard electricity distribution system. Typical SAPS include one or more methods of electricity generation, energy storage, and regulation.

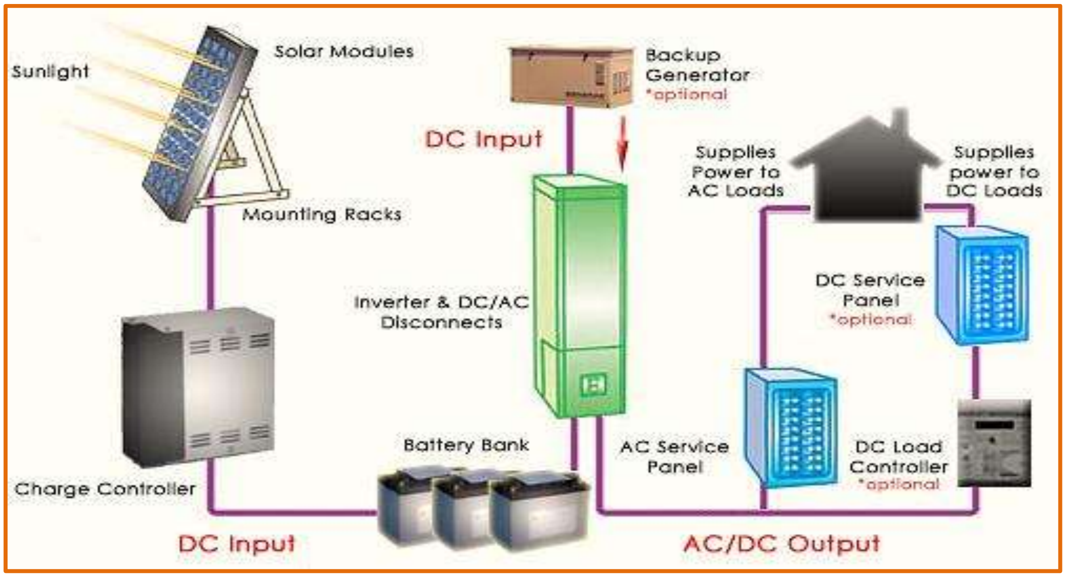


Off-grid systems are most common in remote locations without electricity grid services. Off-grid solar-electric systems operate independently, but can provide electricity to residences, buildings, boats, or remote agricultural pumps, gates, traffic signs, etc. An off-grid solar system must be large enough to produce enough electricity to cover 100% of the energy needs. In all off-grid scenarios, electrical usage must be monitored by a control panel and kept below the maximum output of the panels and batteries, as there is no grid-source to supply excess power.

For this reason, *off-grid power systems* are very popular in mountain and forests areas, cabins or homes that are far away from the electrical grid, with the additional benefit of uninterruptible energy. The electricity storage is typically implemented with a *battery-bank*, but other solutions exist including *fuel cells*. Power drawn from the battery is *direct low voltage* (DC ELV), used especially for residence or building lighting and DC appliances. A *DC/AC inverter* is used to generate *alternate current* (AC) low voltage; thus, more typical appliances can also be used.

Generally, the *standalone photovoltaic power systems* are independent of the utility grid, and may use solar panels only or may be used in conjunction with a diesel generator, a wind turbine or batteries. The battery backup will ensure the electricity when the sun is down or blocked by clouds in dark or rainy days. When the optional backup generator is added, is an excellent protection against critical loads or any catastrophic situation, mainly with a DC hookup, to use DC appliances and power devices.

The standalone power system typically can generate from 100 W/day (very small systems), up to 5 kW/day (for larger systems for buildings or multi-family homes). During the day, the electricity generated is used to power the home and charge the batteries. At night, and during dark or rainy days, all necessary power is provided by the batteries. There are *two types* of standalone power systems: standalone *direct-coupled without batteries* and standalone *with batteries*.



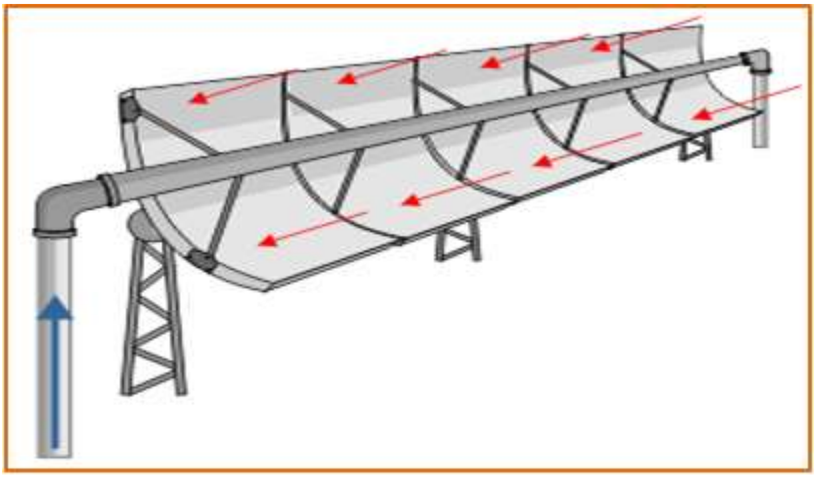
1. **Direct-Coupled System**: Consists of a solar panel connected directly to a DC load. As there are no battery banks in this installation, energy is not stored, but is capable of powering common appliances like fans, pumps etc., only during the day with sunlight.

2. **Standalone with Batteries**: This is the most common and safe installation, where the electrical energy produced by the photovoltaic panels cannot always be used directly. Solar modules are only one part, as the system works together with other components such as, batteries, inverters, transformers, power distribution panels and metering devices.

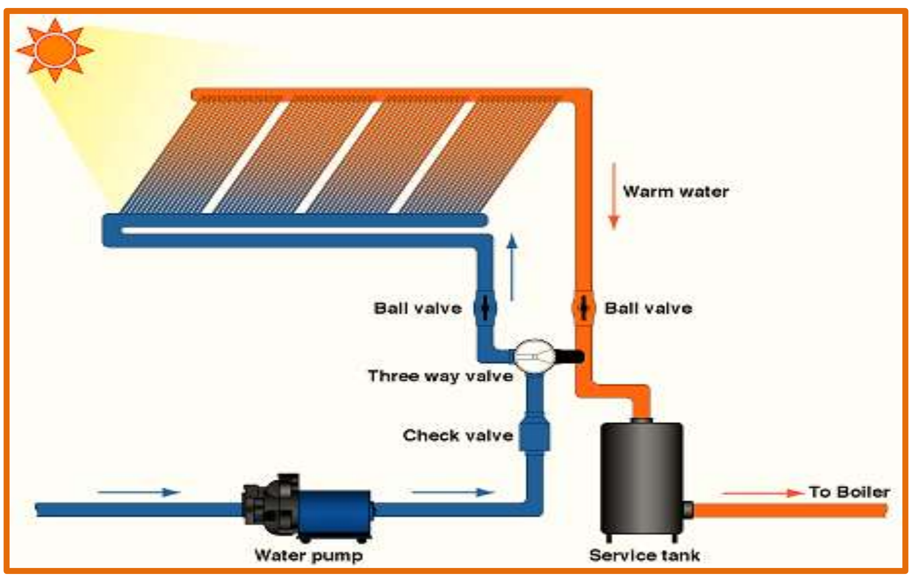
6. SOLAR THERMAL PANELS:

These are other types of solar panels that *have nothing to do with electricity*. Solar thermal panels produce *hot water for buildings, residences and swimming pools*, or provide *heat and air conditioning*. These systems use solar thermal collectors that are usually thin, flat boxes mounted on the roof, facing the sun. Individually, a transparent cover lets sunlight into the box; then, tiny tubes inside carry water or another fluid (like antifreeze) into the box to be heated. An absorber plate, painted black, helps make things hotter.

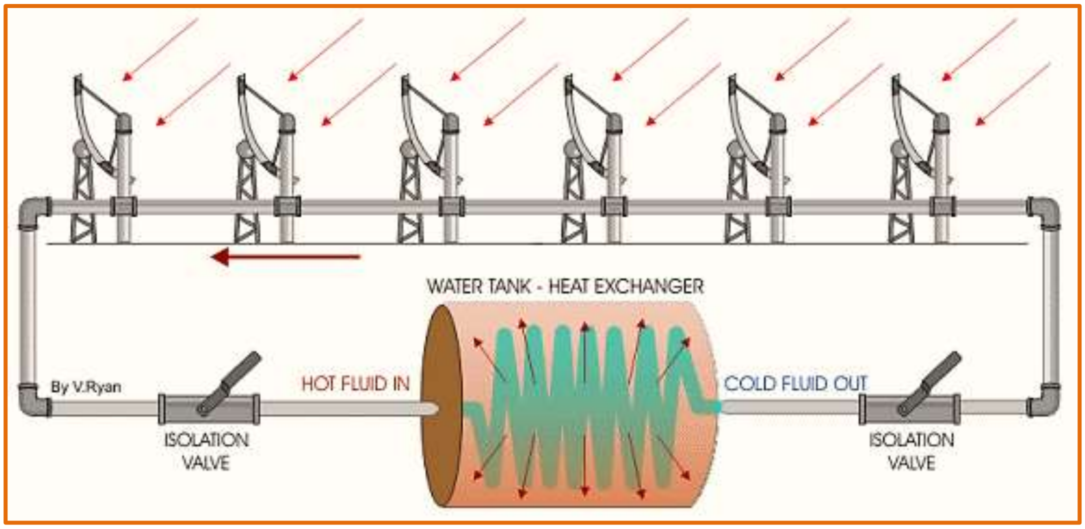
Solar collectors are one way of focusing the sun rays and heat up fluids, which are basically unusually shaped mirrors (parabolic in shape) that focus the heat of the sun on a pipe carrying a special fluid. The temperature of the fluid in the pipe increases as it flows down the pipe, along the solar collectors. The pipe extends the entire length of the mirrors.



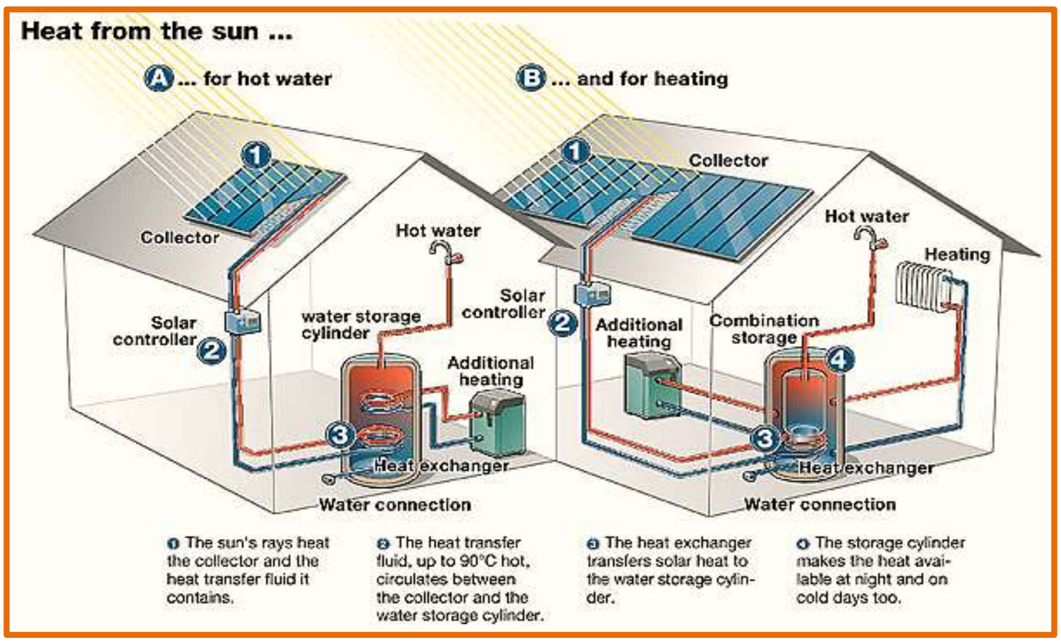
The collector sends *hot water* into a *well-insulated storage tank*. Most systems use pumps, but others, called "passive systems", only use gravity. If the system happens to use something other than water in the solar collector, the hot liquid heats the water through a coil of tubing. Solar thermal panels are referred to by a number of different names such as Solar Water Heaters, Solar Hot Water Panels, Solar Hot Water Collectors, Solar Thermal Panels or Solar Thermal Collectors. Then, solar water heaters work by absorbing sunlight and converting it into usable heat.



This type of set up works at its best in desert areas where there is no shortage of sunlight and very little cloud. The hot fluid in the pipe can be used, through a system of heat exchangers, to produce electricity or hot water. The special fluid inside the pipes can be replaced with water. The concentrated heat from the parabolic collectors turns the water into steam. The jet of steam is used to turn turbines producing electricity. This system works well in desert regions due to the hot climate. Modern systems have synthetic oil heating in the pipes. The reflected sun heats up the oil, which in turn heats up water, creating steam. The steam drives turbines which produce electricity.



Solar Thermal Collectors: Have the function to gather the heat from the solar radiation to be transported by a fluid, named as heat transport fluid (air, antifreeze or water). Solar thermal collectors are used to gather thermal energy, employed for swimming pools heating, domestic water heating, residential and commercial building heating, and HVAC systems. The collector is made up of an absorber plate, which absorbs the solar radiation, and transfers it to a fluid flowing through channels in the plate, which are often fin-tubes design.

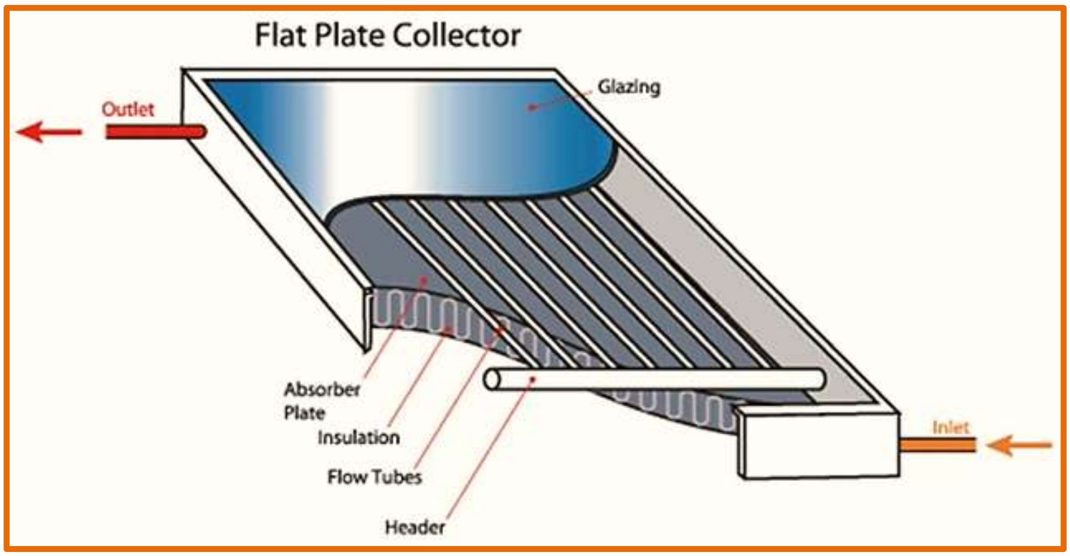


Some flat-plate solar thermal collector designs consist of an insulated box, which contains a dark absorber plate under a glass cover that hermetically seals the system to maximize the energy input. The glass cover plate transmits the sunlight, while protecting the system from harsh weather. For low temperatures such as, for swimming pool heaters, the absorber surface is often uncovered.

For intermediate to higher temperatures, a transparent cover plate may be placed above the absorber plate to add additional resistance to heat losses. High quality absorber coatings, are able to absorb up to 95% of the energy in sunlight throughout the full spectral range (PV only absorbs a portion of the spectrum). The key areas to look at are the yellow which represents solar radiation and the light blue which is how much of that sunlight is absorbed by the coating.

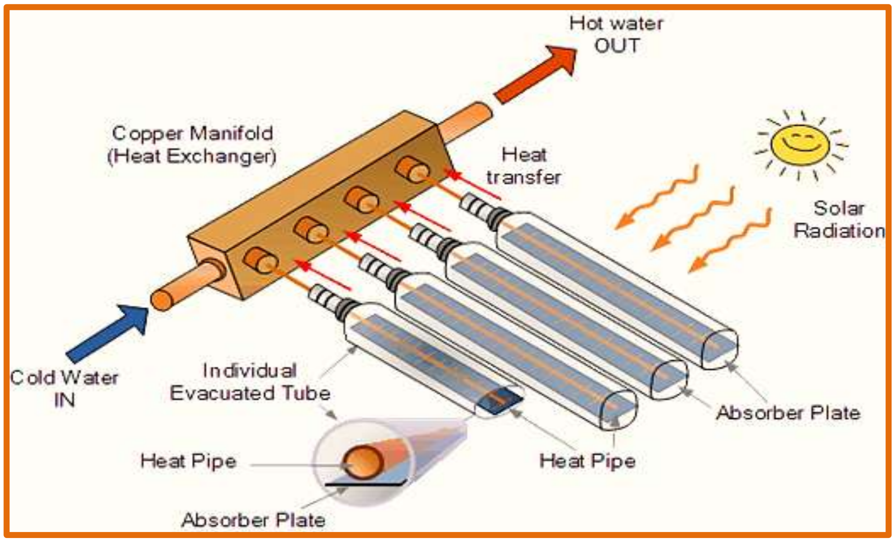
✓ **Flat-Plate Collectors**: Were developed by Hottel and Whillier in the 1950s, are the most common type. They consist of (1) a *dark flat-plate absorber*, (2) a *transparent cover* that reduces heat losses, (3) a *heat-transport fluid* (air, antifreeze or water) to remove heat from the absorber, and (4) a *heat insulating backing*.

The absorber consists of a thin absorber sheet (of thermally stable polymers, aluminum, steel or copper, to which a matte black or selective coating is applied) often backed by a grid or coil of fluid tubing placed in an insulated casing with a glass or polycarbonate cover. In water heat panels, the fluid is usually circulated through a tubing system, which transfers heat from the absorber to an insulated water tank. This may be achieved directly or through a heat exchanger.



✓ **Evacuated Tube Collectors**: Also known as *evacuated heat pipe tubes* (EHPTs) are composed of multiple evacuated glass tubes, each containing an absorber plate fused to a heat pipe. The heat is transferred to the transfer fluid (water or an antifreeze mix, typically propylene glycol) of a domestic hot water or hydronic space heating system in a heat exchanger called a "manifold".

The manifold is insulated by a protective sheet metal or plastic case. The vacuum inside the evacuated tube collectors is encapsulated in the vacuum inside of the tube, which cannot degrade until the vacuum is lost. The vacuum that surrounds the outside of the tube reduces convection and conduction heat loss, therefore achieving greater efficiency than flat-plate collectors, especially in colder conditions.



7. SOLAR ENERGY APPLICATIONS:

Electricity Production: The first main application of the solar power is the *conversion of sunlight into electricity*, either directly using *photovoltaics* (PV), which converts *light into electric current using the photoelectric effect* for small areas, or indirectly using a C*oncentrated Solar Power* (CSP), which uses lenses or mirrors and tracking systems to focus large areas.

Water Heating: The second main application of the solar power is the use of the *sunlight to heat water*. In low geographical latitudes (below 40º), 60 to 70% of the domestic hot water, the use of temperatures up to 60°C is provided by solar heating systems. The most common types of solar water heaters are tube collectors and *glazed flat plate collectors* (generally used for domestic hot water), and *unglazed plastic collectors* (used mainly to heat swimming pools).

HVAC (Heating, Ventilation and Air Conditioning): The third main application of the solar power is the use of the *sunlight to cool or warm an environment*, commonly used in commercial buildings and in residential buildings. *Thermal mass* is any material that can be used to store heat from the Sun for solar energy. The size and placement of the *thermal mass* depend on several factors such as climate, day lighting and shading conditions. Properly incorporated, thermal mass maintains space temperatures and reduce the need for auxiliary heating and cooling equipment.

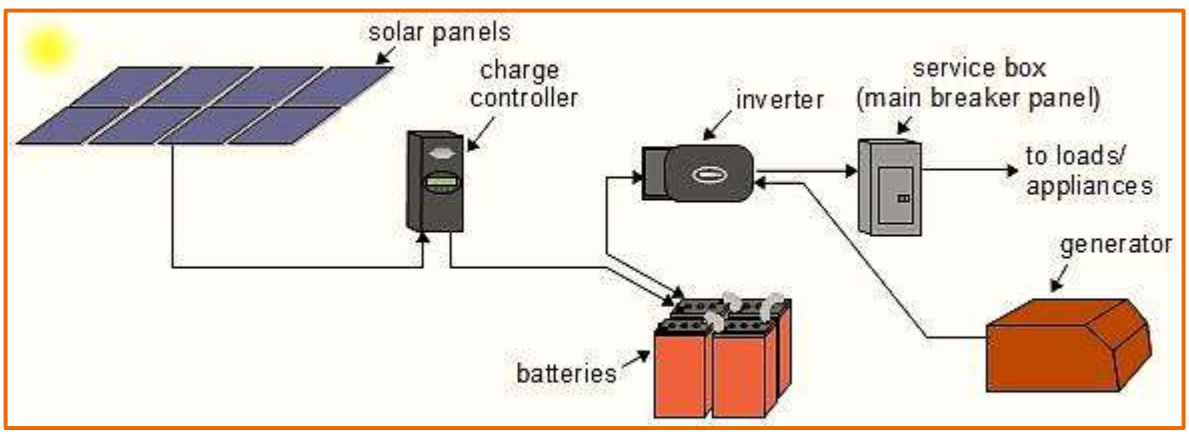
Cooking: Is another practical application for solar power. *Solar cookers* use *sunlight for cooking, drying and pasteurization*, generally grouped into three broad categories: *box cookers, panel cookers and reflector cookers*. *Box cookers* and *panel cookers* use *reflective panel*s to direct sunlight onto an insulated container and reach temperatures. *Reflector cookers* use various *concentrating geometries* (dish, trough, Fresnel mirrors) to focus light on a cooking container. These cookers reach temperatures of 315 °C (599 °F) and above but require direct light to function properly and must be repositioned to track the Sun.

Water Treatment: This is another very important use of the sunlight energy. Solar distillation can be used to *make saline or brackish water potable*. Saline water contains a significant concentration of dissolved salts (mainly NaCl) and is commonly known as *salt water*. Brackish water or briny water has more salinity than fresh water, but not as much as seawater, and may result from mixing of seawater with fresh water, as in estuaries, or it may occur in brackish fossil aquifers.

Agriculture and Horticulture: Another very important use of the solar energy, which seeks to optimize the capture of solar energy in order to *optimize the productivity of plants*. Techniques such as timed planting cycles, tailored row orientation, staggered heights between rows and the mixing of plant varieties can *improve crop yields*. Beyond from growing crops, the solar power application also includes pumping water, drying crops, brooding and drying chicken manure. More recently the technology has been embraced by *vineyards* that use the energy generated by solar panels to power grape presses, and to accelerate ripening or keeping plants warm.

Vehicles: Development of *solar-powered cars* is an engineering goal since the 1980s. A solar vehicle is an electric vehicle powered completely by direct solar energy, commonly using *photovoltaic cells and solar panels* to convert the sun's energy directly into *electric energy*. Some vehicles also use the solar panels for auxiliary power of electrical appliances and air conditioning, thus reducing fuel consumption. The term "*solar vehicle*" implies that solar energy is used to power all or part of a vehicle's propulsion, and to provide power for communications, controls or other auxiliary functions.

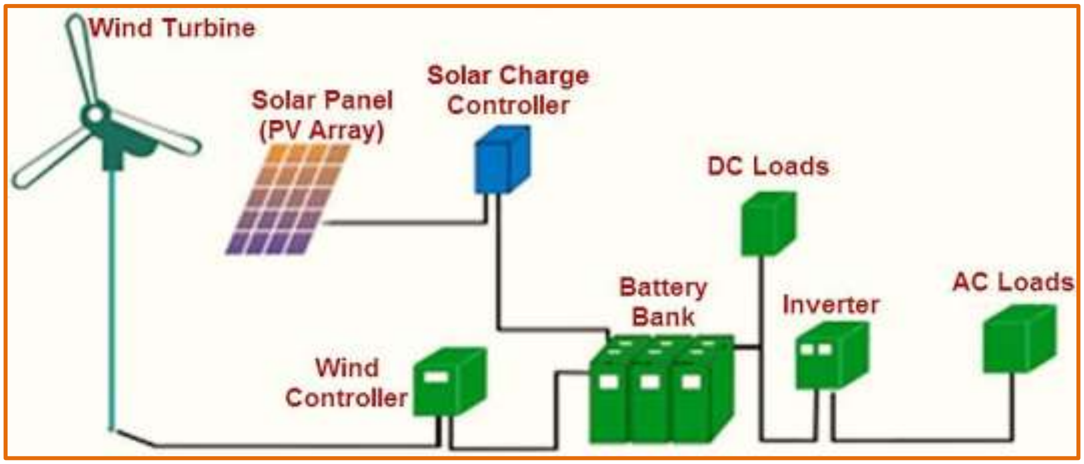
Solar and Generator Hybrid Power Systems: Are hybrid power systems that combine solar power from a photovoltaic system with another power generating energy source. A common type is a photovoltaic diesel hybrid system, which combines photovoltaics and diesel generators, or diesel gensets, or ever fuel cells generators. In order to improve the efficiency of the system further either cogeneration or trigeneration can be used.



Generally, there are three basic elements in *hybrid power systems*; the *power source, the battery, bank and the power management center*. The main sources include wind turbines, diesel engine generators, and solar PV systems. The battery bank allows autonomous operation by compensating for the difference between power production and use. The power management center regulates the power production from each source, controls the power energy by classifying loads, and protects the batteries from extreme services.

Solar and Wind Hybrid Power Systems: Are designed using solar panels and small wind turbine generators for generating electricity. Generally, these solar wind hybrid systems are capable of small capabilities, and the typical power generation capacities of solar wind hybrid systems are in the range from *1 kW to 10 kW*. Generally, wind turbines work in the range of speed between cut in and cut off speeds. Wind energy (next chapter) is another of the renewable energy resources used for generating electrical energy with wind turbines coupled with generators.

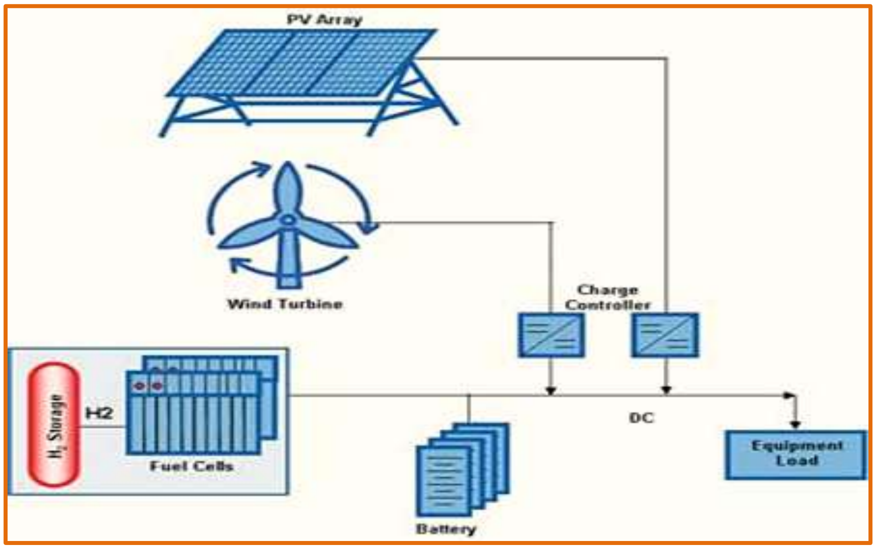
Combination of two or more modes of electricity generation together, usually use renewable technologies such as, *solar photovoltaic* and *wind turbines*. Hybrid systems provide a high level of energy security through the mix of generation methods, and often incorporates a storage system (battery, fuel cell) or small fossil fueled generator to ensure maximum supply reliability, and a security easily configured to meet a broad range of remote power needs.



To get constant power supply, the output of the renewables may be connected to a rechargeable battery bank and then to the load. If the load is alternating current (AC), then an inverter is used to convert the direct current (DC) supply from the battery to the AC load. Larger systems, nominally above 100 kW, typically consist of AC-connected diesel generators, renewable sources and occasionally include energy storage subsystems. Below 100 kW, combinations of both AC and DC-connected components are common, and the DC components may include diesel generators, renewable sources, and storage.

Solar and Fuel-Cells Hybrid Systems: Fuel cells type Proton Exchange Membranes (PEMs) can be used to generate electricity through an electrochemical reaction using *hydrogen and oxygen*, without combustion and without producing harmful emissions of by-products (the only by-products are water and heat). Fuel-cells are also a quiet, highly reliable alternative for backup power, determined by the amount of fuel storage capacity at a site. The benefit of using fuel-cells is that, since the fuel is *often hydrogen*, sites can be provisioned with fuel for hundreds of hours of runtime. Refueling allows the system to run continuously as long as needed for extended outages.

The addition of the *wind and a photovoltaic* sub-system takes advantage of “free” power from the wind & sun. During daylight hours, the PV/battery system supports the load, and when the wind blows, it adds energy to the system. When the wind/PV/battery system is exhausted, the fuel-cell system goes on operating to carry the site load, and unlike batteries, additional fuel can be delivered and deployed, while the fuel-cell system is operating, theoretically providing unlimited clean power generating capability.



Solar and Biomass Hybrid Systems: Biomass, fuel-cells, solar panels and wind power are becoming popular, for providing electricity in remote areas due to advances in renewable energy technologies and subsequent rise in prices of petroleum products. Biomass electricity is drawn from combusting or decomposing organic matter. As an example, 60% from a *biomass system*, 20% from the remainder *fuel-cells system*, combining with a *wind energy system*, may provide 100% of the power and energy requirements for the load, mainly for production business.

Solar and Carbon-Based Fuels: Solar chemical processes use solar energy to drive chemical reactions, and variety of fuels can be produced by *artificial photosynthesis*. A multi-electron catalytic chemistry can be involved in making *carbon-based fuels* (such as methanol) from reduction of carbon dioxide, and can also convert solar energy into storable and transportable fuels.

Solar and Biogas Hydrogen Production: Hydrogen is the simplest element on earth, which consists of *only one proton and one electron*, and must be produced from compounds that contain it. Aside from electrolysis driven by *photovoltaic or photochemical cells*, another approach uses the heat from solar concentrators to drive the steam reformation of natural gas to increase the overall hydrogen yield compared to other conventional reforming methods.

Thus, hydrogen can be used to maintain the temperature of the biomass reservoir in winter, in order to produce biogas in optimum amount, for controlled power generation. Taking advantage of the sunny, windy & hot days, the turbine can operate with full speed, and excess power can be consumed for the process of producing hydrogen. As biogas is a good source in summer, in this period the solar energy available is at its peak, and when the demand and supply are properly checked and calculated, the excess energy can be used in the production of the hydrogen to be stored.

Note: However, all these generating systems have some drawbacks, as *solar panels* are not available in the night or cloudy days, and the production cost of power is generally higher than the conventional process. Similarly, *wind turbines* can't operate in high or low wind speeds, and a *biomass plant* may collapse at low temperatures.

In northern hemisphere, the solar power is limited in windy days, and in summer and rainy weather, the biomass plant can work in a full operation, then the power generation can be maintained in a good stated condition. During the winter nights or cloudy winter days with very low wind speeds, here comes the activity of the *hydrogen*. As we know, the process of electrolysis can produce hydrogen by breaking water into *hydrogen and oxygen*, which can be stored, as hydrogen is also a good fuel. The cost of solar panels can be subsided by using glass lenses, mirrors to heat up a fluid that can rotate a common turbine to be used by wind and other sources.

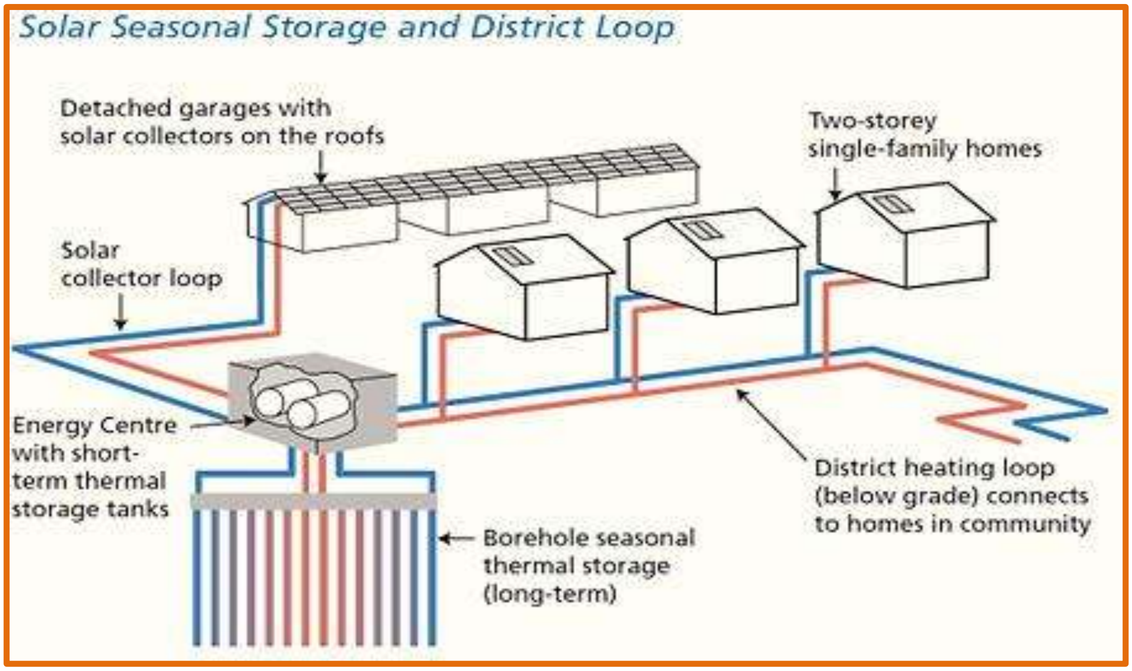
Obs.: Small DC hybrid systems are typically less than 5 kW/day and have been used commercially at remote sites for telecommunications repeater stations and other low power applications.

Largest Photovoltaic Power Plants: The Solar Star is the world´s largest photovoltaic power station near Rosamond, California, to produce 579 (MW). In terms of installed capacity uses 1.7 million solar panels of higher efficiency arrays, mounted on single axis trackers, spread over 13 square kilometers (3,200 acres). The next large plant is the Desert Sunlight Solar Farm is a 550 (MW) photovoltaic power station approximately six miles north of Desert Center, California, in the Mojave Desert. It uses approximately 8.8 million cadmium telluride modules made by the US thin-film manufacturer First Solar.

Other large photovoltaic power station in San Luis Obispo County, California, is the Topaz Solar Farm with a 550 (MW) project, which began in November 2011 and ended in November 2014. In the 1990s and early 2000s, most photovoltaic modules provided remote-area power supply, but from around 2010, industry efforts have focused increasingly on developing *building integrated photovoltaics and power plants for grid connected applications*.

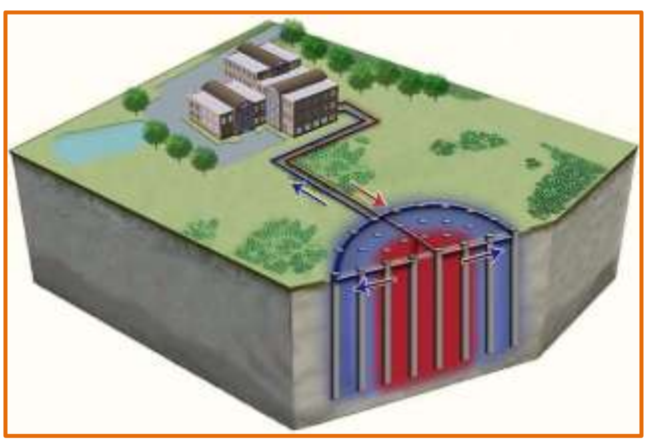
Drake Landing Solar Community (DLSC): Is a planned community in Okotoks, Alberta, Canada, equipped with a central solar heating system and other energy efficient technology. There are 52 homes in this subdivision that contain an array of *800 solar thermal collectors*. These solar collectors are arranged on the roofs of garages located behind the homes, as described below:

The glycol solution then transfers its heat to water located in the short-term storage tanks. The District Heating Loop begins with water being heated in the heat exchanger to a temperature of 40 - 50°C within the Energy Centre. This lower temperature is more energy efficient, as solar collecting is more compatible with lower temperatures. This increases the total amount of heat available to each home. In the warmer months the previously heated water is taken from the short-term storage tank to the Borehole Thermal Energy Storage (BTES).

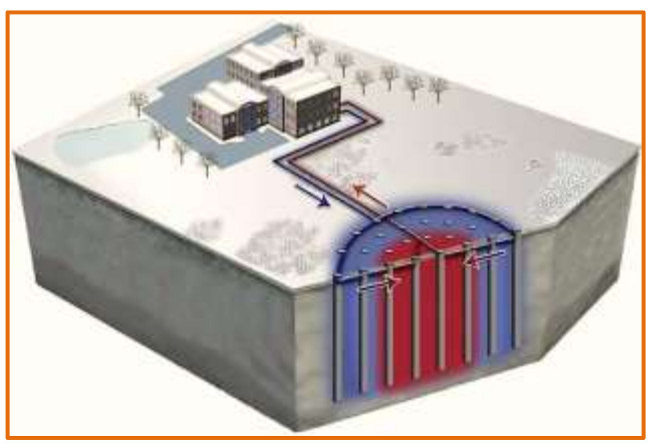


The Borehole Thermal Energy Storage (BTES) is an improvement on conventional closed-loop Ground Source Heat Pump (GSHP) geothermal systems. The Ground Heat Exchanger (GHX) array for a BTES system is designed and operated in a manner such heat is stored or abstracted seasonally, whereas conventional GSHP systems are designed to simply dissipate heat or cold into the subsurface. BTES essentially uses the Earth as a thermal battery, as opposed to a radiator.

The Borehole Thermal Energy Storage (BTES) unit is located 37 m (121 ft) with 144 holes below the ground, and stretches over an approximate area of 35 m (115 ft) in diameter. The water returns to the short-term storage tanks in the Energy Centre to be heated again in order to complete the circuit. During colder months the water from the BTES passes back to the short-term storage tank and is then directed to each home.



BTES Summer Operation – Cooling



BTES Winter Operation - Heating

8. SOLAR SYSTEMS INSTALLATION:

When someone is interested to install a solar system to produce electricity in his residence, the best place to start with, is by taking a look at his most recent energy bills. Most energy companies have a graph on the back of the energy bill, which sets out the average daily energy consumption in a building or residence. Before purchasing a photovoltaic system, it is a good idea to have a basic understanding of electricity. Simple familiarity with basic electrical terms and concepts can enable a user to better understand the solar panel energy system.

The electrical vocabularies are *voltage, amperage, resistance, watts and watt-hours*. Electricity can simply be thought of as the flow of electrons (amperage) through a copper wire under electrical pressure (voltage), analogous to the flow of water through a pipe. If we think of copper wire in an electrical circuit as the pipe, then voltage is equivalent to pressure (psi) and amperage is equivalent to flow rate (gpm).

Power: Is measured in watts (W), which is the product of *voltage* multiplied by *amperage*. Energy is measured in watt-hours or kilowatt-hours (1 kilowatt-hour equals 1000 watt-hours). For example, a 100 watt light left during 10 hours each night, will consume 1000 watt-hours or 1 kilowatt-hour of energy. The kilowatt-hour is the unit of energy measurement, which the utility company bills the users for, each month. Electrical appliances are rated in terms of how many watts (or amps) they draw when turned on. To determine how much energy is used each day, the user needs to sum the number of electrical appliances and multiply their wattages by the number of hours used each day.

Example: A **32" TV** draws 1.5 amps at 120 volts. 1.5 x 120 = **180 watts** (Amperes, A x Voltage, V = Watts, W). **Refrigerators** are based on the kilowatt-hour (kWh) use per year. A 9.6 cubic feet refrigerator uses 386 kWh per year. Then, 386 x 1000 / 365 = **1058 watt-hours** (Wh) per day.

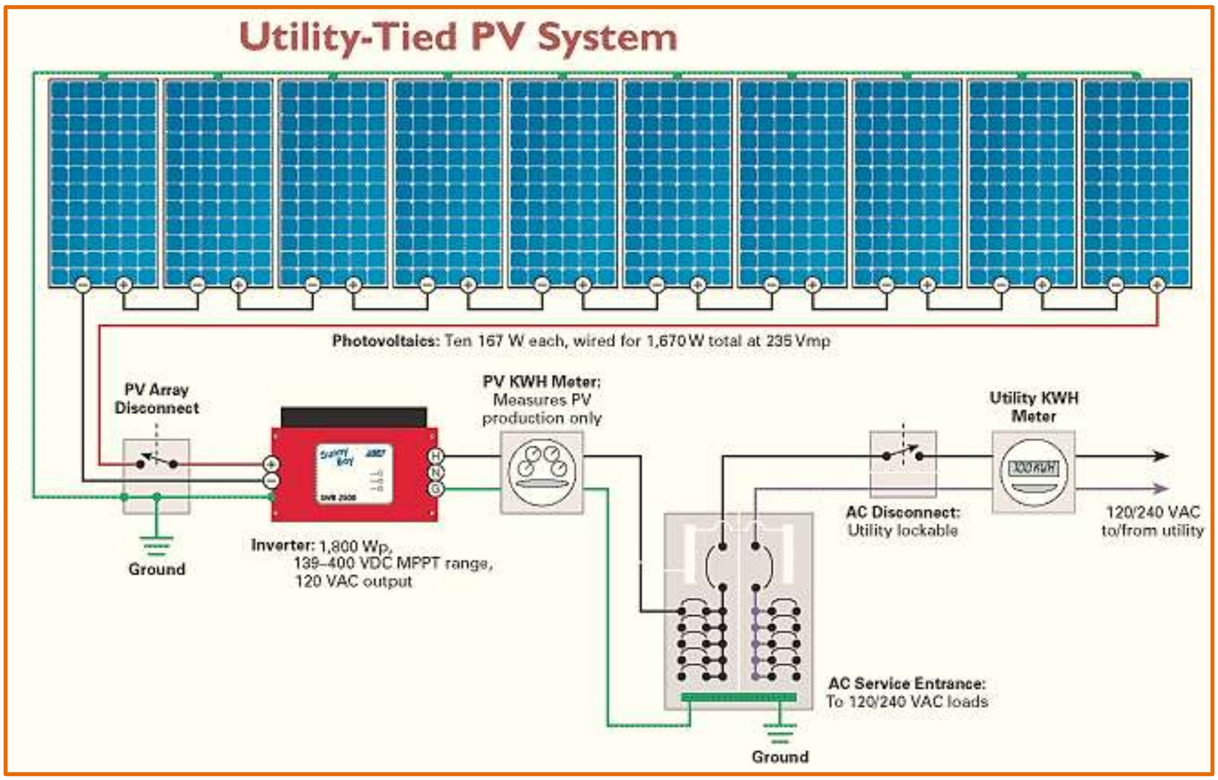
Average Solar Panel Power Rating: A typical solar panel produces around 200 watts of power, but panels with 100 to 140 watts range are the most popular. Each module is rated by its DC output power under standard test conditions, and typically ranges from 100 to 365 watts rating. The efficiency of a module determines the area of a module given the same rated output, as an 8% efficient 230 watt module has twice the area of a 16% efficient 230 watt module. More efficient panels are more expensive and usually only necessary when a user has limited space on a roof.

Basic Example: A direct single solar panel **130 W/12 V** with an output of **7.4 amps** is connected to a chosen battery, 12 volts. Then, 12 volts x 7.4 amps = **88.8 watts**. With this installation, the system lost over 41 watts, (130W – 88.8W) which goes anywhere, because there is a poor match between the panel and battery. However, using an MPPT there will be an optimization, with the same battery of 12 volts. The MPPT now and takes 17.4 volts (45% more than 12 V) from the same single solar panel, and is improved to **10.7 amps** (also 45% more. Now the power calculation becomes; battery 12 volts x 10.7 amps = **128.7 W**. Now we have almost the 130 watts solar panel output.

Note: Only few solar panels over 140 watts are available in 12 volt versions. When solar panels are intended for grid-tie applications, the panel voltages should be between 24 and 76 volts, **not suitable** using a **standard PWM** charge controller. So an **MPPT charge controller** should be used.

Simulation: As an example, depending on where the user lives in Australia (a sunny country) and how much solar light the user can receive on an average per day, 1 kW solar power system will usually produce around 4 kWh to 5 kWh of energy per day. For instance, a residence with three bedrooms, a four or five sized family with a reasonable use of air conditioning, will usually have an ***average daily*** consumption of around 12 kilowatt-hours (kWh) to 16 kWh.

The watt-hour (symbolized Wh) is a unit of energy equivalent to one watt (1 W) of electricity power expended in one hour (1 h) of time, and kWh means the Wh multiplied by 1000. The *“PV Watts Calculator” (httpp\\pvwatts. nrel.gov)* is an online application that can be used to estimate how much solar energy some user can expect to produce, in a common solar panel installation, but there are dozens of others online solar panels calculations that can be used.



As a simulation we can track some solar panel calculations data. Generally, the default PV system size is 4 kW. For a system with 16% efficient PV modules, this corresponds to an array area of approximately 25 m² (269 ft²), as **4 kW ÷ 1 kW/ m² ÷ 0.16 = 25 m².** This array area is the total module area, not the total area required by the system, which must include space between modules and spa-ce for inverters and other parts of the system. By default, “*PVWatts*” uses a DC-to-AC size **ratio of 1.1**, so that the array's DC size is 1.1 times the inverter's AC (alternating current) size.

Note: For example, the default **4 kW system** has an array size of **4 DC kW**, then the **inverter** size is **4 ÷ 1.1 = 3.63 AC kW**. The default DC-to-AC ratio value is appropriate for most analyses, but the user can change it under Advanced Parameters. The user can also either estimate the system size based on the area available for the array, or calculate it from the module nameplate size at STC and number of modules in the array:

- Size (kW) = Array Area (m²) × 1 kW/m² × Module Efficiency (%);

or

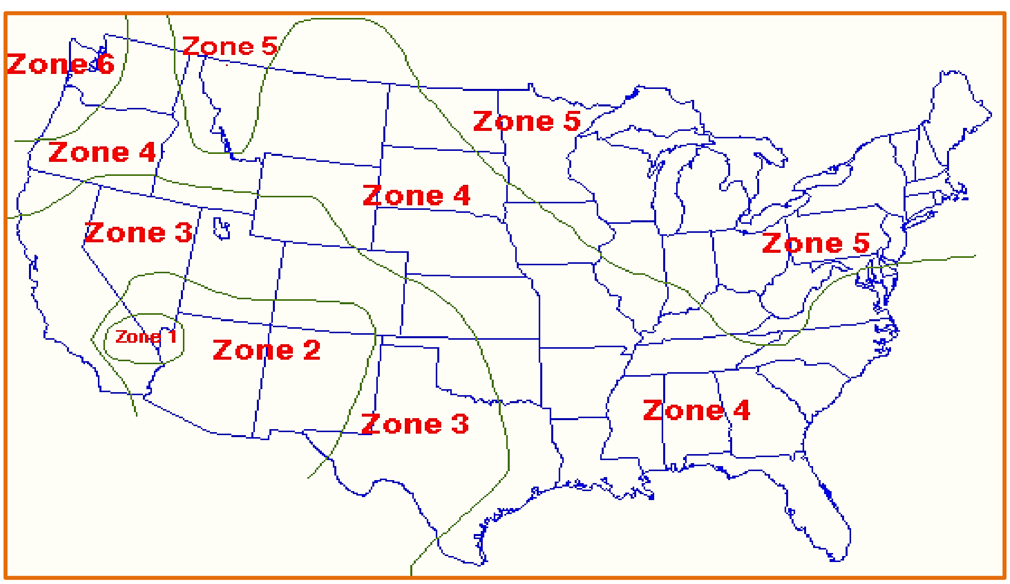
- Size (kW) = Module Nameplate Size (W) × Number of Modules ÷ 1,000 W/kW.

The electricity from solar panels flow first into appliances in use within a residence or building reducing the amount of necessary electricity to purchase from a electricity supplier (usually at a rate of 20 - 30 c/kWh, where c/kWh is *cost per kilowatt hour*). The surplus solar electricity will go into the grid, to net the consumer only 6 - 10 c/kWh. This means that the user needs a solar system that generates enough electricity to meet his *daytime* electricity usage. This can most easily be done by estimating what percentage of your total electricity consumption happens when the sun is shining.

For example, if the user needs ***20 kWh** of electricity per day* (24 hours) on average, but uses only about ***1/3** of that during daylight*, then a solar *PV system **20/3** will generate about **7 kWh** per day*. (Always consult with an accredited solar installer). Thus, with an average daily household electricity demand of 20 kWh/day, but only 33% is necessary during daylight hours, then a 2 kW solar system would probably be the best solar system size (considering 5 hours of daylight, ***2 kW x 5 h = 10 kWh*** per day) without "exporting too much into the grid" (a self-consumption rate of about 60%).

Note: A 3 kW solar energy installation, would probably be slightly too large for this installation if it's not used during the day, and needs to export nearly 50% of the energy produced on average. However, a good fit is only 30% of the solar energy going back to the grid.

Peak Sun Hours: In USA, the hourly figure indicates the average (over the course of the year) amount of insolation (full sun hours) for these zones. These figures are based on the yearly average; consequently, systems based on these figures will provide more power in summer and less in winter. Winter figures for daily solar gain may be from *25% to 50% less* than these average figures, as can be seen at the Solar Map below:



Zone 1= 6 hours; Zone 2 = 5.5 hours; Zone 3 = 5 hours; Zone 4 = 4.5 hours;
Zone 5 = 4.2 hours; Zone 6 = 3.5 hours.

9. BASIC ELECTRICITY – OHM´S LAW AND POWER:

The relationship between *Voltage, Current and Resistance* in any DC electrical circuit was firstly discovered by the German physicist Georg Ohm. Ohm found that, at a constant temperature, the electrical current flowing through a fixed linear resistance is directly proportional to the voltage applied across it, and also inversely proportional to the resistance. This relationship between the **Voltage**, **Current** and **Resistance** forms the basis of Ohms Law and is shown below.

<u>Ohms Law Relationship</u>:

$$Current, (I) = \frac{Voltage, (V)}{Resistance, (R)}\ in\ Amperes, (A)$$

By knowing any two values of the **Voltage**, **Current** or **Resistance** quantities we can use *Ohms Law* to find the third missing value. *Ohms Law* is used extensively in electronics formulas and calculations so it is "very important to understand and accurately remember these formulas".

To find the Voltage, (V):

[V = I x R]   V (volts) = I (amps) x R (Ω)

To find the Current, (I):

[I = V ÷ R]   I (amps) = V (volts) ÷ R (Ω)

To find the Resistance, (R):

[R = V ÷ I]   R (Ω) = V (volts) ÷ I (amps)

It is sometimes easier to remember this Ohms law relationship by using pictures. Here the three quantities of V, I and R have been superimposed into a triangle (sometimes also called the Ohms Law Triangle) giving voltage at the top with current and resistance below. This arrangement represents the actual position of each quantity within the Ohms law formulas.

Electrical Power in Circuits: Electrical Power, (P) in a circuit is the amount of energy that is absorbed or produced within the circuit. A source of energy such as a voltage will produce or deliver power while the connected load absorbs it. Light bulbs and heaters for example, absorb electrical power and convert it into heat or light. The higher their value or rating in watts the more power they will consume.

The symbol for power is **P** and is the product of voltage multiplied by the current with the unit of measurement being the **Watt** (W). Prefixes are used to denote the various multiples or sub-multiples of a watt, such as: **milliwatts** ($mW = 10^{-3}W$) or **kilowatts** ($kW = 10^{3}W$). Then by using Ohm's law and substituting for the values of V, I and R the formula for electrical power can be found as:

To find the Power (P):

[P = V x I] P (watts) = V (volts) x I (amps)

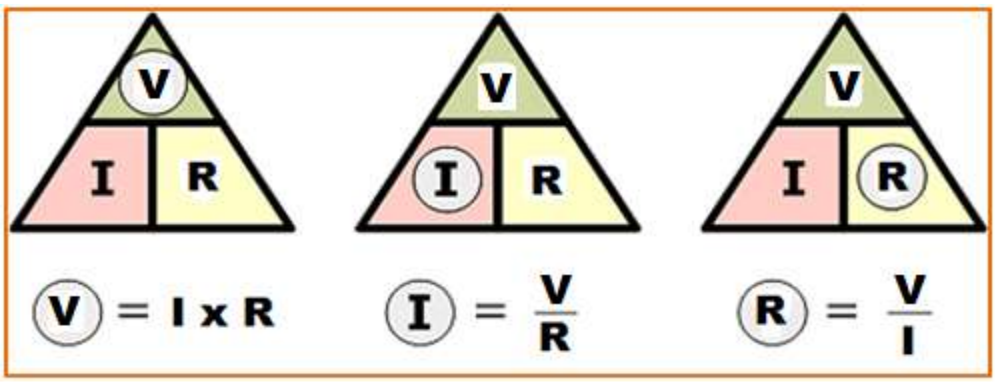
Also,

[$P = V^2 \div R$] P (watts) = V^2 (volts) ÷ R (Ω)

Also,

[$P = I^2$ x R] P (watts) = I^2 (amps) x R (Ω)

The Power Triangle: The three quantities have been superimposed into a triangle this time called a *Power Triangle* with power at the top and current and voltage at the bottom. Again, this arrangement represents the actual position of each quantity within the Ohms law power formulas. Transposing the basic Ohms Law equation above for power gives us the following combinations of the same equation to find the various individual quantities:



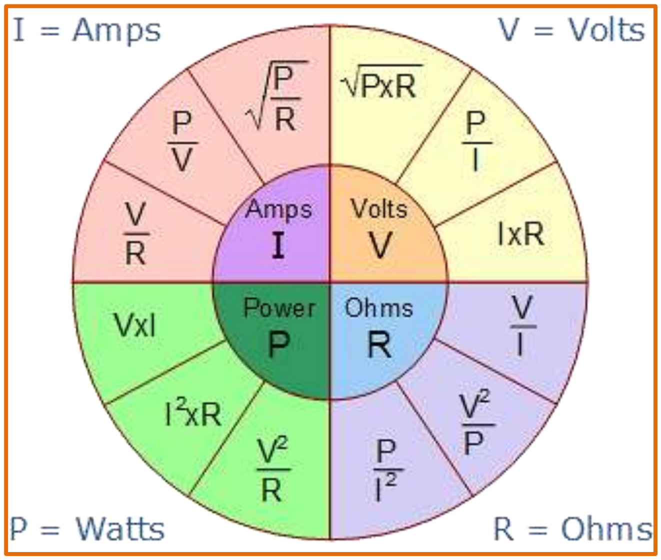
So we can see that there are three possible formulas for calculating electrical power in a circuit. If the calculated power is positive, (+P) in value for any formula the component absorbs the power, which is it is consuming or using power. But if the calculated power is negative, (-P) in value the component produces or generates power, in other words it is a source of electrical power such as batteries and generators.

Electrical Power Rating: Electrical components are given a "power rating" in watts that indicates the maximum rate at which the component converts the electrical power into other forms of energy such as heat, light or motion, for example, a 1/4 W resistor, a 100 W light bulb etc. Electrical devices convert one form of power into another. So for instance, an electrical motor will covert electrical energy into a mechanical force, while an electrical generator converts mechanical force into electrical energy. A light bulb converts electrical energy into both light and heat.

Also, we now know that the unit of power is the *WATT*, but some electrical devices such as electric motors have a power rating in the old measurement of "Horsepower" or hp. The relationship between horsepower and watts is given as: 1hp = 746 W. So for example, a two-horsepower motor has a rating of 1,492 W, (2 x 746 W) or 1.5 kW.

Ohms Law Pie Chart: To help us understand the relationship between the various values to calculate electrical devices, we can take all of the Ohm's Law equations for easily finding the Voltage, Current, Resistance and Power and condense them into a simple **Ohms Law Pie Chart** that can be used in AC and DC circuits, as shown below:

<u>Ohms Law Pie Chart</u>:



Ohms Law Matrix Table: Using the *Ohm's Law Pie Chart* shown above, we can also put the individual Ohm's Law equations into a simple matrix table, as shown below, for easy reference when calculating an unknown value.

Ohms Law Formulas				
Known Values	Resistance (R)	Current (I)	Voltage (V)	Power (P)
Current & Resistance	---	---	$V = IxR$	$P = I^2xR$
Voltage & Current	$R = \frac{V}{I}$	---	---	$P = VxI$
Power & Current	$R = \frac{P}{I^2}$	---	$V = \frac{P}{I}$	---
Voltage & Resistance	---	$I = \frac{V}{R}$	---	$P = \frac{V^2}{R}$
Power & Resistance	---	$I = \sqrt{\frac{P}{R}}$	$V = \sqrt{PxR}$	---
Voltage & Power	$R = \frac{V^2}{P}$	$I = \frac{P}{V}$	---	---

10. SOLAR PANELS DESIGN:

Solar PV system includes different components to be selected according to a system type, site location and applications. The major components for solar PV system are; solar charge controller, inverter, battery bank, auxiliary energy sources and loads (appliances). Here we can track the main considerations for a step-by-step solar panel installation.

1. Solar panels can be installed on many different types of roofs or on stand-alone racks. Shingle roofs are the easiest for solar panel installation, while waved-tile roofs tend to be more of a challenge because of their uneven surfaces.

2. Before installing solar panels, is necessary to check local building permit codes and the electricity source supplier, to legally install solar panels and take advantage of electricity bill discounts.

3. Pick an area of the residence roof in order the solar panels get sun for as long as possible each day. The solar panels can either be mounted even with the roof surface, stand, or mounted at an angle to maximize accessibility to the sun's direct rays.

4. The solar panels are attached directly on roof rafters or wood beams, generally with stainless steel bolts, with 3 to 6 inches of space for air to flow under the panels, to create a better efficiency.

5. The final step is to connect the solar panels to each other using the junction boxes and wires, according to color codes.

6. Calculate total Watt-hours per day for each appliance used. Add the Watt-hours of all appliances to get the total Watt-hours/day or check your electricity bill to see the average kWh/month, and divide per 30 days. Multiply the added Watt-hours/day times 1.3 (the energy lost in the system) to get the total Watt-hours/day, which must be provided by the panels.

7. The watt-peak (Wp) produced depends on size of the PV module and climate of site location. To determine the sizing of PV modules, calculate as follows:

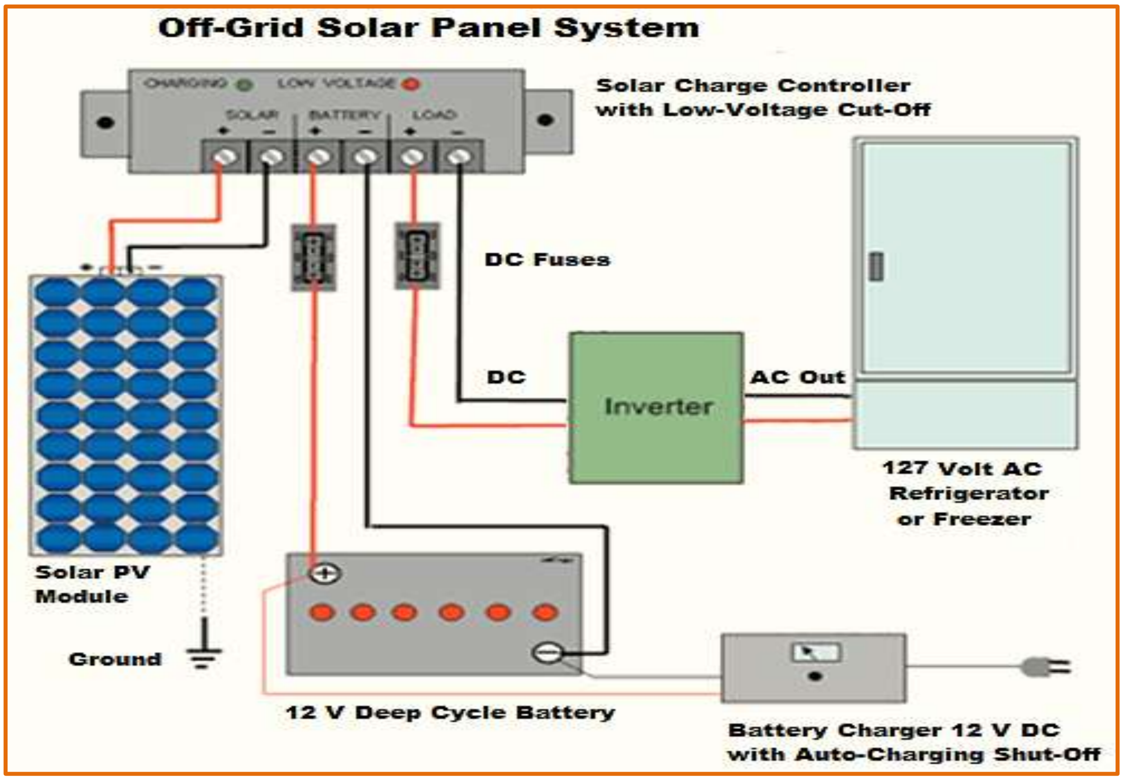
a. Divide the total Watt-hours/day needed by *3.43* to get the total Watt-peak (Wp) rating of the PV panels to operate the appliances. Increase fractional number to the next full number.
b. Result of the calculation is the minimum number of PV panels. As referred above, 1 kW solar power system will usually produce around 4 kWh to 5 kWh of energy per day. The "PV Watts Calculator" (httpp\\pvwatts.nrel.gov) is an online application that can be used to estimate how much solar energy some user can expect to produce, in a common solar panel installation, but there are dozens of others online solar panels calculations that can be used.

8. An inverter is used where AC power output is needed. The input rating of the inverter should never be lower than the total watt of appliances. The inverter must have the same nominal voltage as a battery, when used. The inverter size should be 25-30% bigger when, for instance, using electric motors or compressors, the inverter size should be minimum 3 times the capacity of these appliances to handle surge current during starting.

9. When the installation is *off-grid*, the battery type recommended is a *deep cycle battery*, which is specifically designed to reach the low energy level, and rapid recharged, or *cycle-charged and dis-charged*, day after day for years. The battery should be large enough to store sufficient energy to operate the appliances at night and cloudy days. To find out the size of battery, calculate as follows:

- ✓ Calculate total Watt-hours/day used by all appliances;
- ✓ Divide the total Watt-hours/day used by 0.85 for battery loss;
- ✓ Divide the answer obtained by 0.6 for depth of discharge;
- ✓ Divide the answer obtained by the nominal battery voltage;
- ✓ Multiply the answer obtained to get the required Ah (Amp-hour) capacity. Ah = Total Watt-hours/day used by appliances x days of autonomy (0.85 x 0.6 x nominal battery voltage).

10. The sizing of solar charge controller is to take the short circuit current (Isc) of the PV array, and multiply it by 1.3. Solar charge controller rating = Total short circuit current of PV array x 1.3.



1. **Practical Example:** A cabin has the following electrical appliances:

- ✓ One 18 Watt fluorescent lamp, used 4 hours per day;
- ✓ One 60 Watt fan, used for 2 hours per day;
- ✓ One 75 Watt refrigerator, used 12 hours on and 12 hours off;
- ✓ The system will be powered by a **12 Vdc**, **110 Wp**, PV module.

a. Power consumption demands:

Total appliances = (18 W x 4 hours) + (60 W x 2 hours) + (75 W x 24 x 0.5 hours) = **1,092 Wh/day**;

Total PV panels energy needed = 1,092 x 1.3 = **1,419.6 Wh/day**.

b. Sizing the PV panel:

Total Wp of PV panel capacity needed = 1,419.6 / 3.4 = **417.5 Wp**;
Number of PV panels needed = 417.5 / 110 = 3.76 modules = **4 modules, 110 Wp/module**.

c. Inverter sizing:

Total Watt of all appliances = 18 + 60 + 75 = **153 W**;
For safety, the inverter should be considered 25-30% bigger, thus about **190 W** or greater.

d. Battery sizing:

Total appliances use = (18 W x 4 hours) + (60 W x 2 hours) + (75 W x 12 hours) = **1,092 Wh/day**
Battery capacity = $\frac{(1,092) \times 3}{(0.85 \times 0.6 \times 12)} = \frac{3276}{6.12} =$ **535.29 Amps. hour.**

Total Ampere-hours required = **535.29 Ah**;
So the battery should be rated **12 V, 600 Ah**, for autonomy of 3 days.

e. Solar charge controller sizing (check with the manufacturer):

PV catalog specification: Pm = 110 Wp; Vm = 16.7 Vdc; Im = 6.6 A; Voc = 20.7 A; Isc = 7.5 A;
Solar charge controller rating = (4 strings x 7.5 A) x 1.3 = **39 A**. Rated **40 A at 12 V** or greater.

2. **Practical Example**. The potential to demand is 2,331 W, average about 381 kWh/ month. Summarizing the losses: Panel variance 95%; Temperature 89%; Contamination 93%; Wiring losses 95%; Inverter losses 90%. The system *loss factor* is the product of all the potential losses in the system: The loads are summarized below:

Power needs for a small remote seasonal use cabin

Qty	Appliance Characteristic			Total	
	Item	Power	kWh/Mo	Power	Kwh/Mo
1	Refrigerator/Freezer, 12 Cu Ft	575	143	575	143
1	Fluorescent Lights	250	37.5	250	37.5
1	Water heater	*Propane Gas unit*			0
1	Space heater	*Propane Gas unit*			0
1	Television	200	36	200	36
1	Radio	71	7	71	7
1	VCR	35	2	35	2
2	Ceiling fan	100	24	200	48
1	Well pump	750	72	750	72
1	Miscellaneous (outlets)	500	67	300	35
		Totals		2,331	381

a. Loss Factor = 0.95 * 0.89 * 0.93 * 0.95 * 0.90 = **0.67**;

b. Daily load = 381 * 1,000 / 30 = **12,700 Wh/day**;

c. Compensating losses = 12,700 / 0.67 = **18,955 Wh/day**;

Assume that the installation is in Atlanta, GA and the average daily solar is *6.3 kWh/m²/day* with panel efficiency of *15%*. The total area of solar panels required is:

Panel Area = 18,955 / (6.3 * 0.15 * 1,000) = **20.05 m².** Using solar panels with **1.13 m²:**
Total panels = 20.05 / 1.13 = **17.74, or 18 panels**;

d. Total 18 panels, with 175-watts: 18 x 175 = **3,150 watts panel capacity**;

Sizing the batteries. The daily load is 12,700 Wh/day. Then, 12,700/24 = **529 Wh/h**;
Choosing 24 V batteries. Battery load = 529 Wh/h / 24 V = **22 Ah (Amp-hours/hour)**;
Planning 48 hours for energy back-up, the total battery capacity requirement is:

e. Battery bank = 22 * 48 / 0.8 = **1,320 Ah.** Total capacity ~**13 batteries 24-volt, 100 Ah**.

The inverter will need maximum instantaneous load plus a 15% margin, then:

f. Inverter = 2,331 W / 0.85 = **2,742 W, total.**

3. **Practical Example** How many solar panels can be installed using a load of 800 Watts, with required backup time for batteries of 3 Hours?

a. Inverter = 800 x (25/100) = **200** (greater 25% than the total load);

b. Rating of the UPS = 800+200 = **1000 Watts**.

Install 100Ah, 12 V batteries = 12V x 100Ah = **1200 Wh**

c. Battery Hours = 1200 Wh / 800 W = **1.5 Hours**

Connect two batteries of 100Ah, 12V, with this formula = 1200 Wh x 2 Batteries = **2400 Wh**

d. Two batteries backup = 2400 Wh / 800 W = **3 hours**.

Now we will install two batteries (12V, 100 Ah) in parallel, because this is a 12V inverter system, in order to increase the Ampere Hour (Ah) rating. For 2 Batteries, 200 Ah 12V the required charging current should be 1/10 of batteries Ah:

e. Battery capacity = 200Ah x (1/10) = **20A**

Now the required No of Solar Panels;

P = VI
P = 12V x 20 A
P = **240Watts**

f. Total = **4 Solar panels** (each of 60W, 12 V, 5A) in parallel.

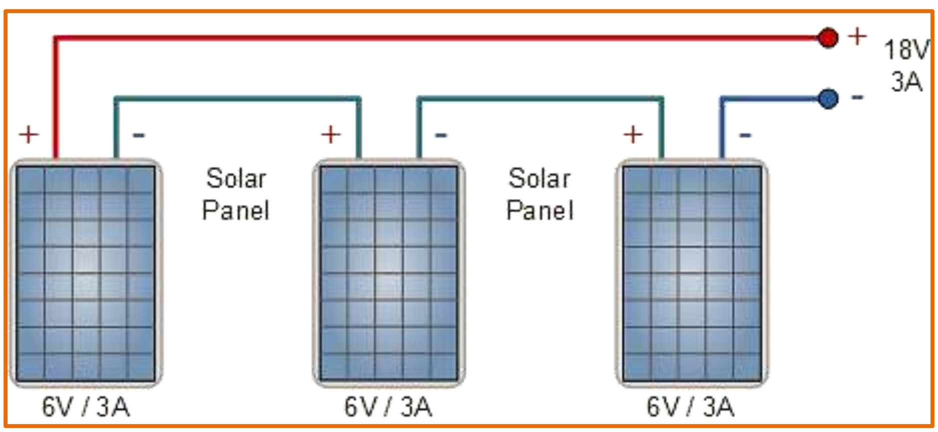
However, there is a required current of 20 A for batteries charging and 10 A for direct connected load. In this case, total current = 20A + 10 A = **30A.** Then, the required power:

g. Power = P = V x I = 12V x 30A = **360 Watts. 6 Solar panels** (each of 60W, 12V, 5A).

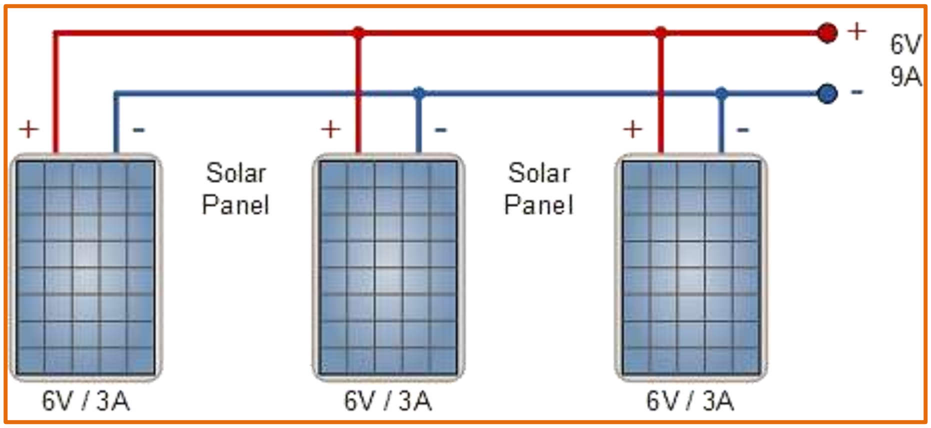
11. HOW TO WIRE THE SOLAR PANELS:

There are three basic but very different ways of connecting solar panels together and each connection method is designed for a specific purpose. For example, to produce more output voltage or to produce more current. Solar panels can be wired in a series or parallel combination to increase the voltage or amperage respectively, or they can be wired together in both series and parallel to increase both the voltage and current output producing a higher wattage array.

Connecting Solar Panels in Series: The first method for connecting solar panels together is known as "series wiring", commonly used *to increase the total system voltage*. Solar panels in series are generally used with a *grid-connected inverter* or *charge controller* that requires 24 volts or more. To wire the panels in series, the negative terminal of each panel is connected to the positive terminal, as shown below. Solar panels in series add-up or sum the voltages produced by each individual panel, giving the total output voltage of the array.



Connecting Solar Panels in Parallel: The next method is known as "parallel wiring", commonly used to *increase the total system current* (reverse of the series connection). To wire the solar panels in parallel the positive terminals are connected together (positive to positive) and the negative terminals are also connected together (negative to negative), as shown below. The single positive and negative connections are used to attach to a voltage regulator and batteries. In this wiring, the total voltage output remains the same as a single panel, but the end output current is the sum of the output of each panel.

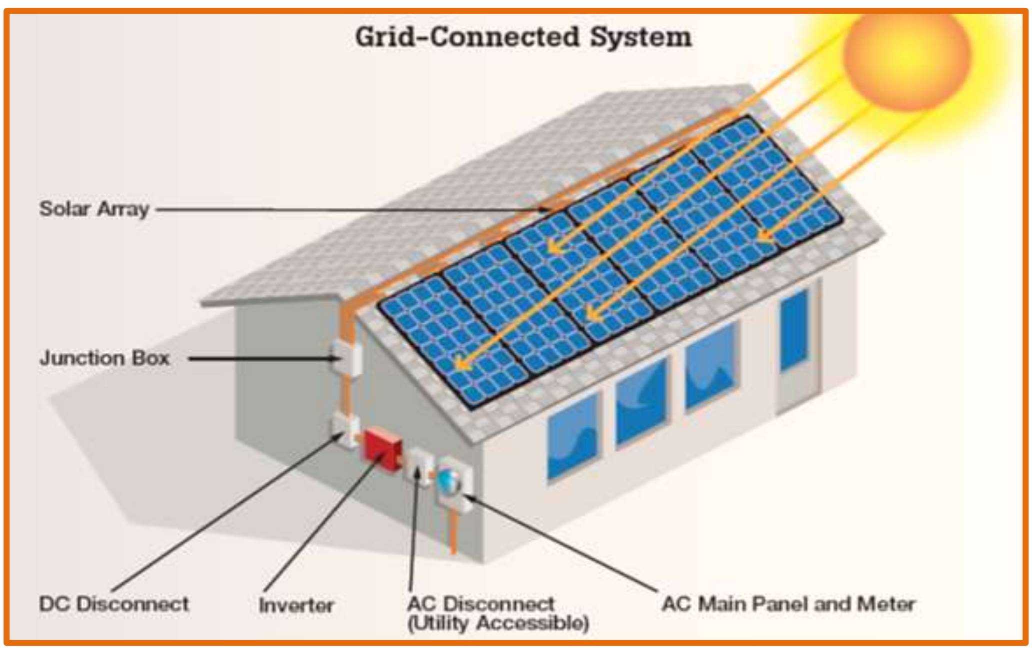


Note: Connecting solar panels in parallel with different voltage ratings is not recommended as the solar panel with the lowest rated voltage determines the voltage output of the whole array.

Solar Trackers: Are devices that track the motion of the sun across the sky ensuring that the maximum amount of sunlight strikes the panels throughout the day. Tracking systems adjust the position of PV modules can boost yields from solar installations by 40% or more. Solar panels are usually set up to be in full direct sunshine at the middle of the day facing South in the Northern Hemisphere, or North in the Southern Hemisphere.

Active Trackers: Active trackers use motors and gear trains with a controller responding to the solar direction. The Light-sensing trackers typically have two photo sensors, such as photodiodes, configured differentially so that they output a null when receiving the same light flux.

Passive Trackers: Passive solar trackers use a low boiling point compressed gas fluid that is driven to one side or the other (by solar heat creating gas pressure) to cause the tracker to move in response to an imbalance.

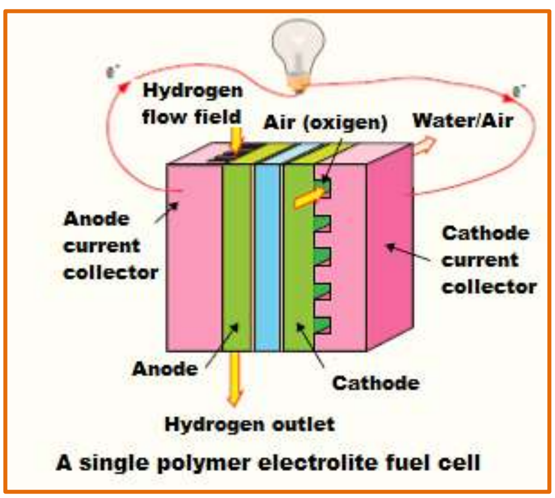


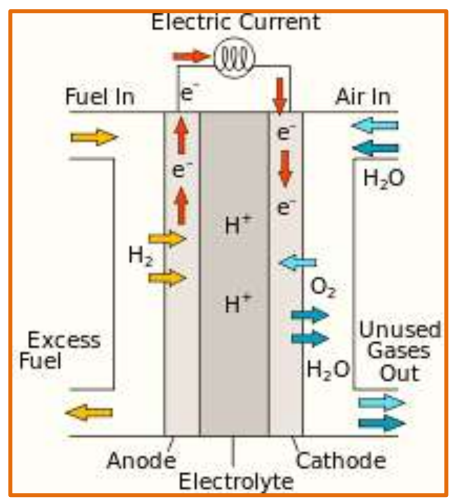
CHAPTER 2 – FUEL CELLS TECHNOLOGY:

1. INTRODUCTION:

A fuel cell is a device that converts chemical energy from a *fuel into electricity,* through a *chemical reaction* of positively charged hydrogen ions, with oxygen or another oxidizing agent. Fuel cells produce electricity, water, and heat using fuel and oxygen in the air. As hydrogen flows into the fuel cell on the anode side, a platinum catalyst facilitates the separation of the hydrogen gas into electrons and protons (hydrogen ions). The hydrogen ions pass through a membrane cell (the center of the fuel cell) and with the help of a platinum catalyst, combine oxygen and electrons on the cathode side, producing water.

An ordinary electrolyte is a substance that dissociates the charged hydrogen ions into *positively* and *negatively* in the presence of water, thereby making the water solution electrically conducting. The electrons, which cannot pass through the membrane, flow from the anode to the cathode through an external circuit or any other electric load, which consumes the power generated by the cell. Water is the only emission when hydrogen is the fuel. Beyond electricity, fuel cells produce water, heat and, depending on the fuel source, very small amounts of nitrogen dioxide and other emissions. The energy efficiency of a fuel cell is generally between 40–60%, or up to 85%, when waste heat is produced for using in cogeneration systems.





Fuel cells are classified according to the type of electrolyte used and the difference in startup time ranging from 1 second of the *Proton Exchange Membrane* fuel cells (PEM fuel cells, or PEMFC) to 10 minutes of the *Solid Oxide Fuel Cells* (SOFC). Individual fuel cells produce relatively small electrical potentials, about 0.7 volts, so cells are "stacked", or placed in series, to create sufficient voltage to meet an application's requirements. However, the voltage from one single cell, about 0.7 volts, is just enough to light a car bulb. When the cells are stacked in series the operating voltage increases to 0.7 volts multiplied by the number of cells stacked.

Note: Fuel cells have been used in many other applications, for primary and backup power for commercial, industrial and residential buildings and in remote or inaccessible areas, also used to power fuel cell vehicles, including forklifts, automobiles, buses, boats, motorcycles and submarines.

2. FUEL CELLS HISTORY:

In 1838, the German-Swiss chemist Christian Friedrich Schonbein discovered the principle of the fuel cells, and published his discovery in “Philosophical Magazine.” In 1839, using the earlier work of Schonbein, the Welsh scientist Sir William Robert Grove built the first fuel cell. It was similar in construction and material to a phosphoric acid fuel cell, having zinc and platinum electrodes separated by a porous ceramic pot. He presented this fuel cell to the Academie des Sciences in Paris in 1839 and later that year to the British Association for the Advancement of Science.

In 1842, Sir William Robert Grove based on his “correlation of physical forces” theory, developed the first fuel cell to run on hydrogen and oxygen. This is the reason that fuel cells were often called “Grove cells” during their very early development, though Grove himself referred to them as “gas voltaic batteries.” The term “fuel cell” actually wasn’t used until 1889 when two chemists, Charles Langer and Ludwig Mond, were attempting to create a practical fuel cell with air and coal gas, but never achieved long term success, due to the problem of catalyst poisoning.

In 1940, at King's College London laboratory Francis Thomas Bacon, (a Francis Bacon descendant) developed the first successful fuel cell, as double cell, with one unit for generating the hydrogen and oxygen gases and the other for the fuel cell proper, using alkaline electrolyte and nickel electrodes. In 1950, Willard Thomas Grubb, while working for General Electric in Schenectady, New York, as a chemist, made a major advance in fuel cells, originally designed by Sir William Grove in 1839.

In 1955, Grubb developed a sulphonated polystyrene ion-exchange membrane, today referred to as the Proton Exchange Membrane, or PEM fuel cell. Three years later, another GE chemist, Leonard Niedrach, working with Grubb, devised a way of depositing platinum onto this membrane to create a more efficient reaction. The improvements made through the combined efforts of Grubb and Niedrach ultimately produced the "Grubb-Niedrach fuel cell".

In 1959, Francis Thomas Bacon, with support from Marshall Aerospace, developed a 5 kW stationary fuel cell, with an operating efficiency of 60%. Further, the patents for the fuel cell were licensed by Pratt and Whitney as part of a successful bid to provide electrical power for Project Apollo Space Shuttle. After, GE and NASA used the platinum technology in the Project Gemini, the second human spaceflight program, and went on to fund over 200 fuel cell researches. Fuel cell development continued through the 1970s and 1980s, mostly alkaline fuel cells.

In the 1990’s, UTC Power was established as a subsidiary of United Technologies Corporation and began to produce a 200 kW stationary fuel cell called the PureCell 200. This fuel cell was a phosphoric acid fuel cell capable of running on hydrocarbon fuel such as natural gas, after replaced by the PureCell Model, a 400 kW stationary fuel cell, which produces both electricity and heat, making it highly efficient for use in supermarkets, hospitals, hotels, and educational institutions. UTC currently produces a polymer membrane fuel cell, entirely by hydrogen, for use in mobile applications.

In 1991, however, Roger Billings produced the first vehicle powered by a hydrogen fuel, while working for Ford Motor Company, finding that fuel cells were far more efficient and made far better use of the lower energy density of hydrogen than did internal combustion. This implementation of hydrogen fuel cells brought the idea of the “hydrogen economy” closer to reality than it had previously been.

3. MAIN FUEL CELLS TYPES:

Fuel cells operate at different temperatures and each is best suited to particular applications. The electrolyte defines the key properties, particularly operating temperature, of the fuel cell. For this reason, fuel cell technologies are named by their electrolyte. Four other distinct types of fuel cells have been developed in addition to the Polymer Electrolyte Membrane fuel cells that are: Alkaline fuel cells; Phosphoric acid fuel cells; Molten carbonate fuel cells; Solid oxide fuel cells. The main features of the most known five types of fuel cells are summarized below:

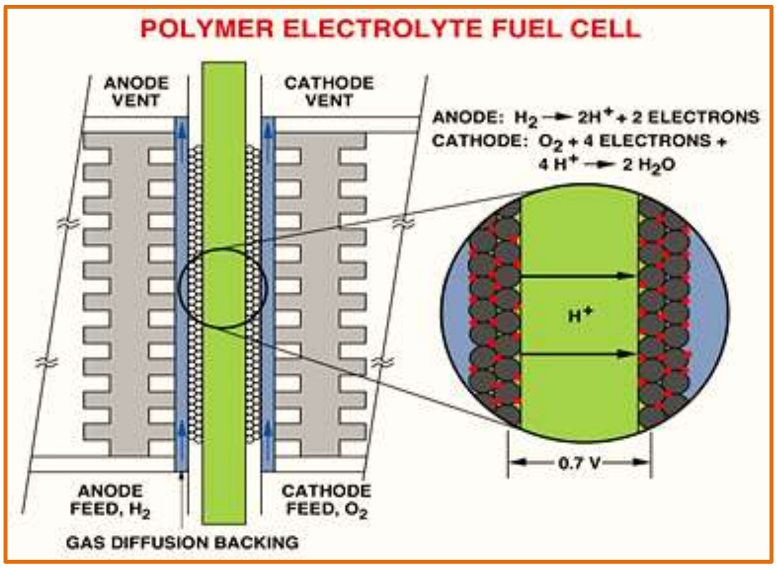
Fuel Cell	Electrolyte	Operating Temperature (°C)
Polymer Electrolyte/ Membrane (PEM)	Solid organic polymer poly-perfluorosulfonic acid	60 - 100
Alkaline (AFC)	Aqueous solution of potassium hydroxide soaked in a matrix	90 - 100
Phosphoric Acid (PAFC)	Liquid phosphoric acid soaked in a matrix	175 - 200
Molten Carbonate (MCFC)	Liquid solution of lithium, sodium and/ or potassium carbon-ates, soaked in a matrix	600 - 1000
Solid Oxide (SOFC)	Solid zirconium oxide to which a small amount of ytrria is added	600 - 1000

The NREL (National Renewable Energy Laboratory) and other organizations advance this science behind emerging hydrogen and fuel cell technologies and systems in real-world operation. The NREL hydrogen and fuel cell research focuses on developing, integrating, and demonstrat-ing hydrogen production and delivery, hydrogen storage, and fuel cell technologies for transporta-tion, stationary, and portable applications. Terrestrial applications can be classified into categories of transportation, stationary or portable power uses.

Thousands of fuel cells have been installed around the world, for primary or backup power. There are many other companies in the United States and worldwide using fuel cells at wastewater treat-ment plants, government buildings, universities, military bases, homes and hospitals, to name just a few. There are many other applications for fuel cells, including portable power, vehicles, buses and consumer electronics, which are also being researched, demonstrated and deployed by numerous organizations around the world. For instance, Polymer Electrolyte Membrane (PEM) fuel cells are well suited to transportation applications because they provide a continuous electrical energy supply from fuel at high levels of efficiency and power density.

1. Polymer Electrolyte Membrane (PEM): Also known as, Proton Exchange Membrane Fuel Cells (PEMFC) is a solid, organic polymer, usually poly [perfluorosulfonic] acid, and generally the most common used membrane of the five distinct types of fuel cells. The electrolyte used in a Polymer Electrolyte Membrane fuel cell, is a type of plastic, or a polymer, referred to as a membrane. The polymer is a substance made of giant molecules formed by the union of simple molecules, also designated as monomers.

The Polymer Electrolyte Membrane (PEM) fuel cells were mainly developed for transport vehicles, stationary fuel cell applications and portable fuel cell applications. The PEMFC is also preferred for vehicles and mobile applications, including mobile phones, because of its compactness. PEMFC is the leading candidate to replace the aging Alkaline Fuel Cell (AFC), which was used in the Project Apollo Space Shuttle.

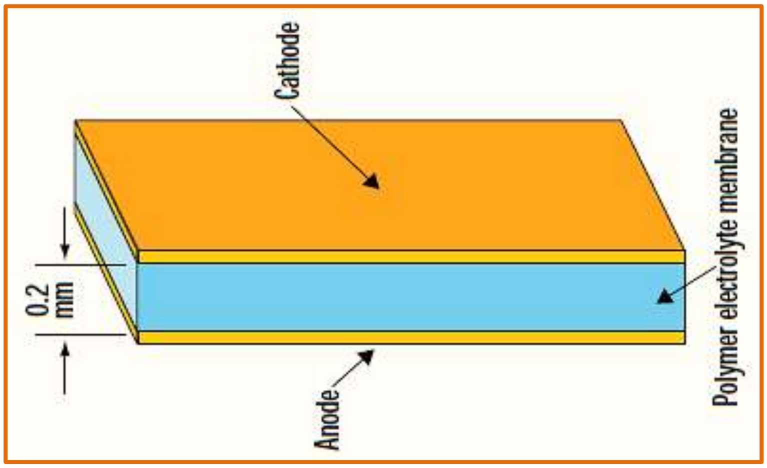


Water management stands out as one of the key engineering challenges in the commercialization of hydrogen, using PEMFCs. However, water management is crucial to performance, because water in the membrane is attracted toward the cathode of the cell through polarization. Too much water floods the membrane, too little dries it; in both cases, power output can drop, and the platinum catalyst on the membrane is also easily poisoned by carbon monoxide. Other solutions for managing the water exist, including integration of electroosmotic pumps.

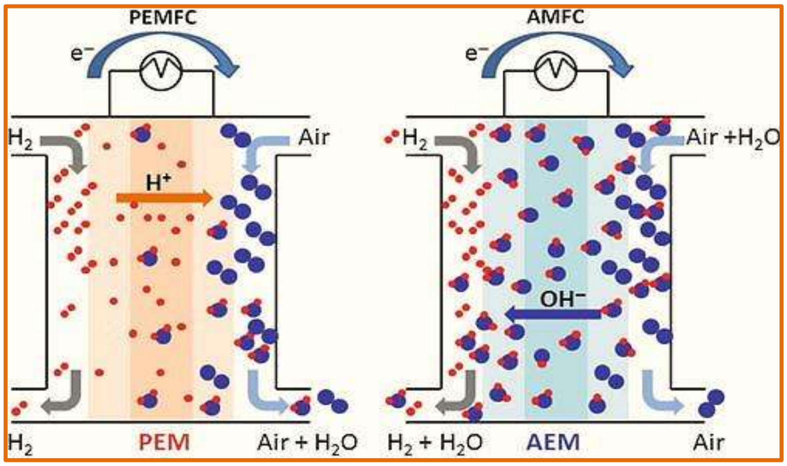
Obs.: Electroosmotic pumps are fabricated from silica nanospheres or hydrophilic porous glass. The pumping mechanism is generated by an external electric field. One application is removing liquid flooding water from gas diffusion layers and direct hydration of the Proton Exchange Membrane.

The membrane, Nafion™ (produced by DuPont), resembles a plastic wrap used for sealing foods. Typically, the membrane material is more substantial than common plastic wrap, varying in thickness from 50 to 175 microns. Thus polymer electrolyte membranes have thicknesses comparable to that of 2 to 7 pieces of common writing paper. A typical membrane material, such as Nafion™ consists of three regions:

- ✓ The Teflon-like, fluorocarbon backbone;
- ✓ The side chains that connect the molecular backbone to the third region;
- ✓ The ion clusters consisting of sulfonic acid ions, SO_3 - H+.



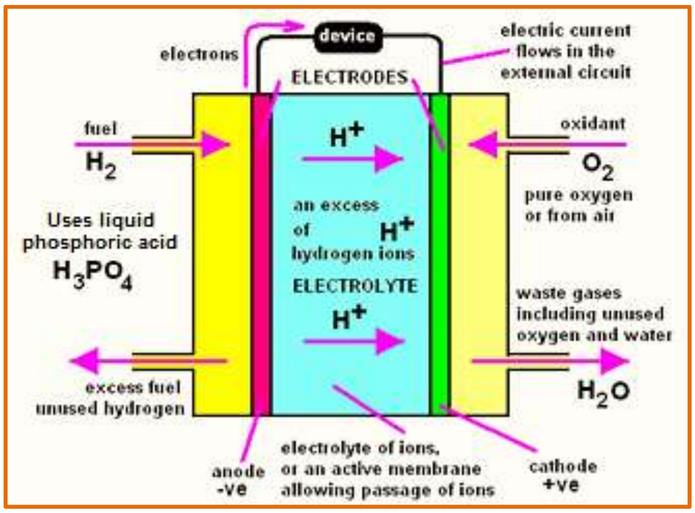
2. Alkaline Fuel Cells (AFC): Also known as *hydroxide ion exchange fuel cells or anion alkaline exchange membrane fuel cells* are all types of alkaline fuel cells (AFCs), use potassium hydroxide (KOH) as electrolyte. Alkaline fuel cells, are one of the oldest type that operate between ambient temperature and 90 °C with an electrical efficiency higher than the other fuel cells such as, Proton Exchange Membrane Fuel Cells (PEMFC), Solid Oxide Fuel Cells and Phosphoric Acid Fuel Cells.



The Alkaline Anion Exchange Membrane Fuel Cells (AAEMFCs) are functionally similar to AFCs, the difference being AAEMFCs employ a solid polymer electrolyte, while AFCs use aqueous potassium hydroxide (KOH) as an electrolyte. The large majority of membranes/ionomer that has been developed is fully hydrocarbon, allowing an easier catalyst recycling and lower fuel crossover. Methanol has an advantage of easier storage and transportation and has higher volumetric energy density compared to hydrogen. Methanol crossover from anode to cathode is reduced in AAEMFCs compared to PEMFCs, due to the opposite direction of ion transport in the membrane, from cathode to anode.

3. Phosphoric Acid Fuel Cells (**PAFCs**): These common fuel cells use liquid phosphoric acid, as an electrolyte, which is a mineral (inorganic) acid having the chemical formula H_3PO_4. The electrolyte of a pure liquid phosphoric acid (H_3PO_4) is highly concentrated, saturated in a silicon carbide matrix (SiC) operating range is about 150 to 210°C. The electrodes are made of carbon paper coated with a finely dispersed platinum catalyst. Phosphoric acid fuel cells are generally used in the initial commercialization of stationary fuel cell systems.

The Phosphoric Acid Fuel Cells were the first fuel cells to be commercialized, developed in the mid-1960s and field-tested since the 1970s, have improved significantly in stability, performance, and cost. More than 270 of these fuel cells units, 200 kilowatts each, were deployed in stationary applications in both the United States and abroad. Natural gas is the primary fuel, however; other fuels can be used including gas from local landfills, propane, or fuels with high methane content.

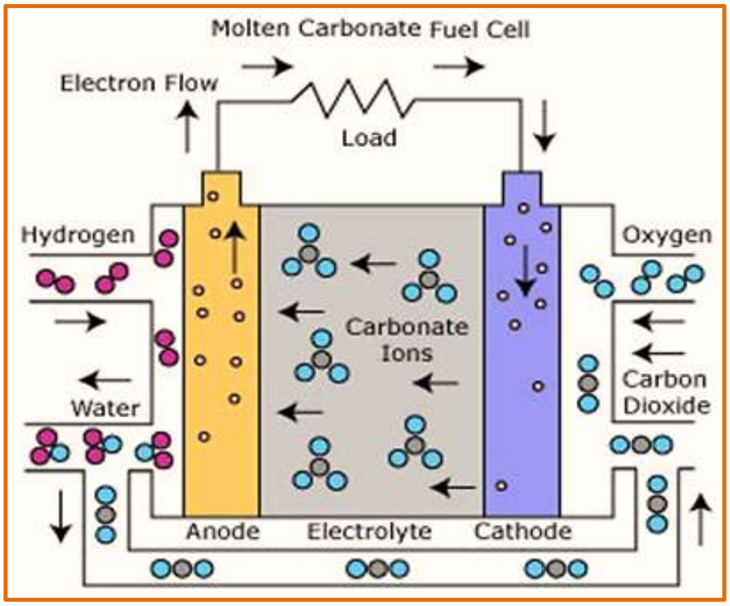


Note: The PAFCs are reformed to hydrogen-rich gas mixtures before feeding to the fuel cell stack. These environmentally friendly systems are simple, reliable, and quiet and can improve energy efficiency, as much as 60%, while reducing environmental emissions.

4. Molten Carbonate Fuel Cells (**MCFCs**): Are high-temperature fuel cells that operate at temperatures of 600 °C and above, can reach efficiency next to 60%, considerably higher than the 37-42% efficiencies of a Phosphoric Acid Fuel Cell (PAFC) plant. These fuel cells are currently being developed for natural gas, biogas (produced as a result of anaerobic digestion or biomass gasification), and coal-based power plants for electrical utility, industrial, and military applications.

MCFCs use an electrolyte composed of a *molten carbonate salt mixture* suspended in a porous, chemically inert *ceramic lithium-aluminum oxide (LiAlO2) matrix*. MCFCs operate at high temperatures, non-precious metals can be used as catalysts at the anode and cathode, and fuels are converted to hydrogen within the fuel cell itself by a process called internal reforming, and don't require an external reformer to convert more energy-dense fuels to hydrogen, then, reducing costs. Molten carbonate fuel cells can also use carbon oxides as fuel, more attractive for fueling with gases made from coal.

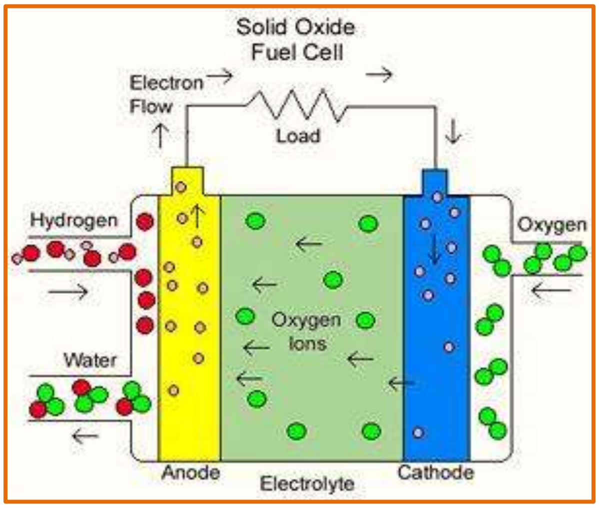
Scientists assume that MCFCs can be made resistant to impurities such as, sulfur and particulates (which results from converting coal), into hydrogen. As MCFCs require CO2 to the cathode along with the oxidizer, carbon dioxide can electrochemically be separated from the flue gas of other fossil fuel power plants, for sequestration. However, the main disadvantage is durability, as high temperatures and corrosive electrolytes used, accelerate components corrosion, decreasing cell life. Researchers are currently exploring corrosion-resistant materials to increase MCFCs life.

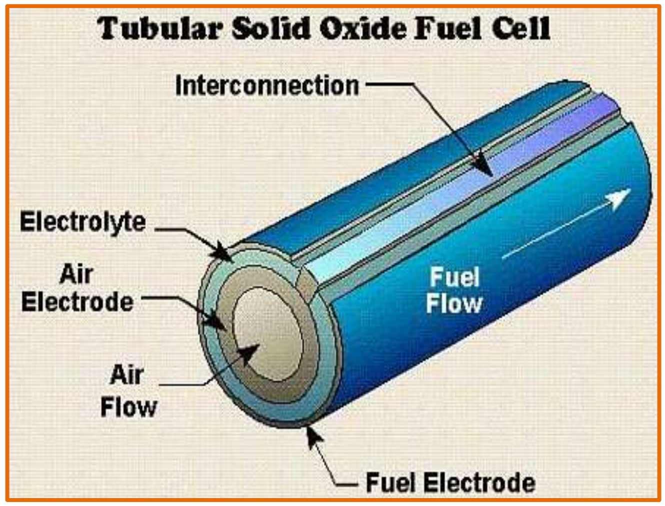


5. Solid Oxide Fuel Cell (**SOFC**): The researchers improved a type of fuel cell, which has a solid ceramic electrolyte, known as Solid Oxide Fuel Cell (SOFC), which is an electrochemical conversion device that produces electricity directly from oxidizing a fuel. The solid oxide fuel cell is characterized by their electrolyte material, as it has a solid oxide or ceramic electrolyte. The most common advantages of this class of fuel cells are the high efficiency, long-term stability, fuel flexibility, low emissions, and relatively low cost.

These cells can run on a variety of available fuels, including diesel, gasoline, and natural gas for generating power mainly for industries and buildings. SOFCs operate at very high temperatures, typically between 500 and 1,000°C, and at these temperatures, do not require expensive platinum catalyst material, and are not vulnerable to carbon monoxide catalyst poisoning. However, solid-oxide fuel cells are considered impractical for use in cars, as they're too big, and because operate at very high temperatures, typically at about 900^0C.

However, vulnerability to sulfur poisoning has been widely observed, then, sulfur must be removed before entering the cell through the use of adsorbent beds or other means. Solid oxide fuel cells have a wide variety of applications from use as auxiliary power units to stationary power generation with outputs from 100 W to 2 MW. The largest disadvantage is its high operating temperature, which results in longer start-up times and mechanical and chemical compatibility issues.

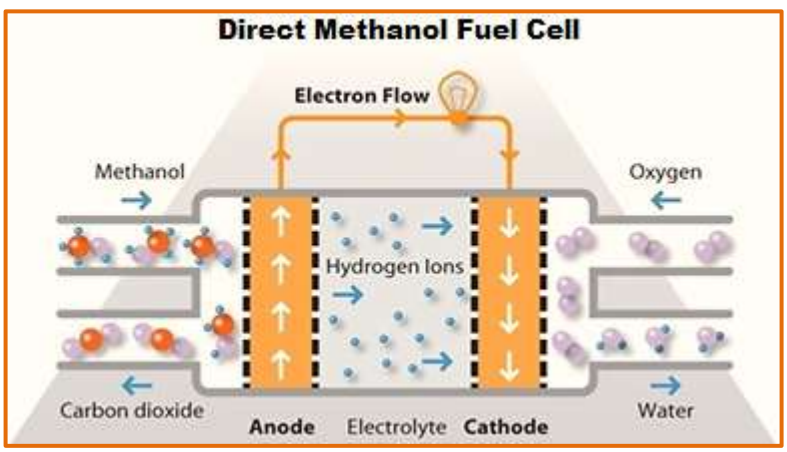




4. OTHER FUEL CELLS DEVELOPMENT:

Direct Methanol Fuel Cells (DMFCs): May be a promising power source for electric vehicles and portable electronic devices in coming years. DMFC is unique, as a low temperature fuel cell technology, which not utilizes hydrogen, but still relatively new, when compared to other hydrogen polymer electrolyte fuel cell technologies, and with several challenges remaining.

In direct methanol fuel cells, as in the hydrogen fuel cell, there is no oxidation of hydrogen. The liquid methanol is the only fuel being oxidized directly at the anode. Up to now, the most advanced DMFC, is based on the Proton Exchange Membrane, especially using the Nafion membrane. However, the anodic oxidation of methanol in alkaline media, is more feasible than in acidic media. The alkaline aqueous solutions are not stable for DMFC due to carbonation.



The advantages of *supplying methanol directly to the fuel cell* are significant, with consumer acceptance of a liquid fuel being high on the list. The more important is that a direct methanol fuel cell system does not require a bulky and heavy hydrogen storage system or a reforming subsystem. This advantage, in terms of simplicity and cost, means the direct methanol fuel cell system presents an attractive alternative to hydrogen or reformate-fed systems. By switching to fuel cells, transportation logistics can refuel their trucks in a matter of minutes, compared to the hours it would take to charge a battery. The fuel cells also eliminate the need for a battery charging infrastructure within the warehouse. Additionally, a direct methanol fuel cell is considered a zero emission vehicle.

DMFCs operate in the temperature range from 60ºC to 130ºC and tend to be used in applications with modest power requirements, such as mobile electronic devices or chargers and portable power packs. One particular application for DMFCs which is seeing commercial traction in various countries is the use of DMFC power units for materials handling vehicles. A number of these units have been sold to commercial warehouses, where the forklift trucks had been conventionally powered with battery packs.

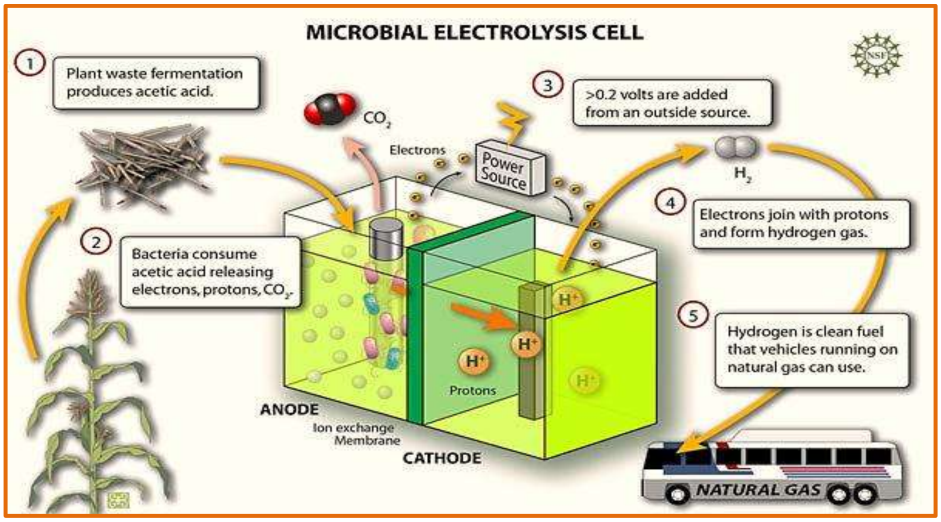
Microbial Fuel Cells (MFCs): Also known as *biological fuel cell* is a bio-electrochemical system that creates an electrical current through natural bacteria. The first MFCs used a chemical that transferred electrons from the bacteria in the cell to the anode, as a mediator. Currently, the bacteria have electrochemically active redox proteins such as, cytochromes on their outer membrane that can transfer electrons directly to the anode, used in commercial treatment of wastewater.

The idea of using microbial cells in an attempt to produce electricity was first conceived in 1911, with a professor of botany at the University of Durham, M.C. Potter. In his studies of how microorganisms degrade organic compounds, he discovered that electrical energy could also be produced. He was able to construct a primitive microbial fuel cell, but not enough was known about the metabolism of bacteria to generate electricity and his work did not receive any major coverage.

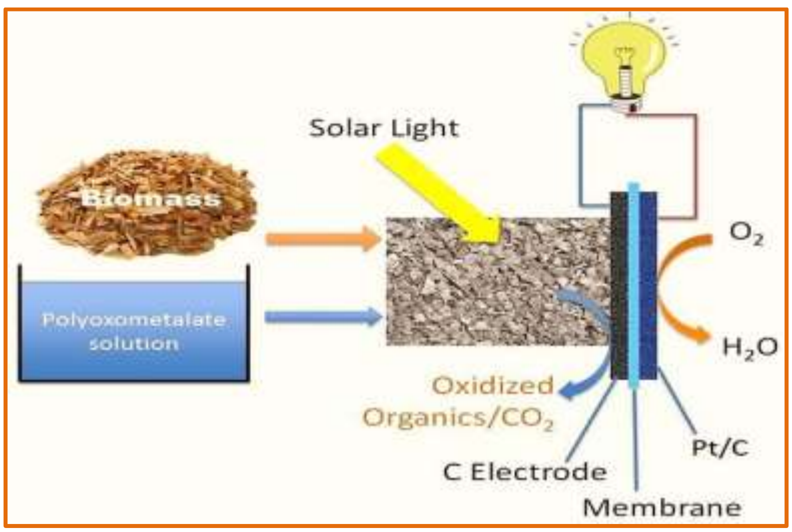
However, in 1931, Barnet Cohen, a Russian-born American bacteriologist, created a number of microbial half fuel cells that, when connected in series, were capable of producing over 35 volts, though only with a current of 2 milliamps. In 1980, M. J. Allen and H. Peter Bennetto, from Kings College in London improved the original microbial fuel cell design, motivated to provide cheap and reliable power to third world countries. They combined advancements in the electron transport chain and improvement in technology, to finally produce the basic design, still used in MFCs today.

Microbial Fuel Cell is divided into two halves; aerobic and anaerobic. The aerobic has a positively charged electrode and is bubbled with oxygen, much like a fish tank. The anaerobic half does not have oxygen. A solution containing food for the bacteria is circulated, allowing a negatively charged electrode to act as the electron receptor. This food consists of glucose or acetate, compounds commonly found in food waste and sewage.

The bacteria metabolize food by first breaking apart the food molecules into hydrogen ions, carbon dioxide, and electrons. The bacteria use the electrons to produce energy by way of the electron transport chain. The microbial fuel cell disrupts the electron transport chain using a mediator molecule to shuttle electrons to the anode. The final step of this process (oxygen, electrons, and H+ to form water) is transferred outside of the bacterial cell, from which energy can be harvested.



Biomass and Fuel-Cells Hybrid Systems: Researchers at the Georgia Institute of Technology have developed a new type of low-temperature fuel-cell that directly converts biomass to electricity, with assistance from a catalyst activated by solar or thermal energy. These hybrid fuel cells types use a wide variety of biomass sources, including starch, cellulose, lignin, grass, powdered wood, algae and waste from poultry processing. The new *solar-induced direct biomass-to-electricity hybrid fuel-cell* relies on a polyoxometalate (POM) catalyst, which changes color as it reacts with light.



The POM is chemically stable, thus, the *hybrid fuel-cell* can use soluble biomass, or organic materials suspended in a liquid. In experiments, the fuel cell operated for as long as 20 hours, indicating that the POM catalyst can be re-used without further treatment, or can also use unpurified polymeric biomass without concern of poisoning noble metal anodes. The researchers reported a maximum power density of 0.72 milliwatts per square centimeter, which is nearly 100 times higher than cellulose-based microbial fuel cells, and near that of the best microbial fuel cells. This could be used in small-scale, as well as for larger facilities where significant quantities of biomass are available.

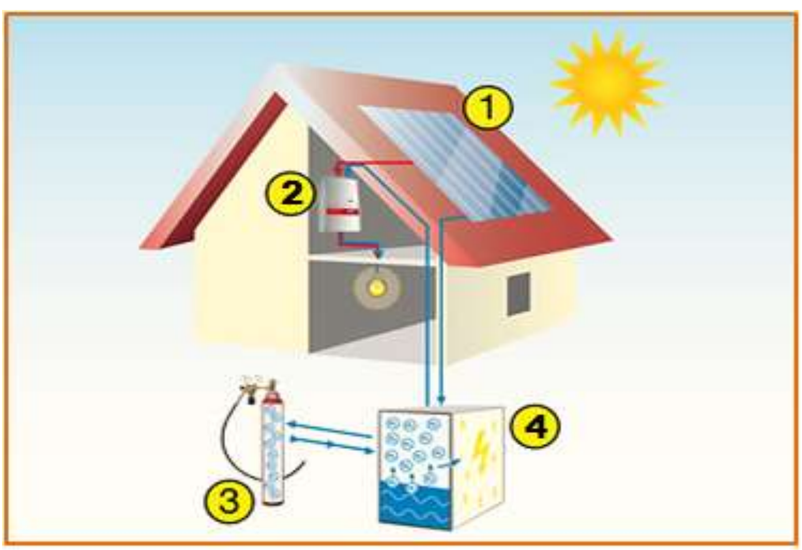
Electrons in the biomass can be transferred to the *polyoxometalate (POM)* under sunlight irradiation, and deliver the charges to the anode. These electrons are then captured by oxygen in the cathode. The system provides major advantages, including combining the photochemical and solar-thermal biomass degradation in a single chemical process, leading to high solar conversion and effective biomass degradation. It also does not use expensive noble metals as anode catalysts because the fuel oxidation reactions are catalyzed by the POM in solution.

Fronius Energy Fuel Cells: Are hydrogen-powered fuel cell systems that generate electricity without dirt emissions, and convert the energy stored in hydrogen directly into electrical power, safely and efficiently. Fronius Energy Cells are part of a total system for regenerative energy creation, supplied by a photovoltaic system. The solar energy is used straightaway if necessary, and any surplus capacity can be stored in hydrogen. From a technical viewpoint, is subdivided into two parts:

- The first part, the low-temperature fuel cell system is an electrochemical generator. The fuel cell system is fitted with a PEM (Proton Exchange Membrane) stack and converts the energy source hydrogen into direct current. The output of a Fronius 50F Energy Cell is 4,000 watts and a Fronius 25F Energy Cell is 2,000 watts.

- The second part of the Fronius Energy Cell is a high-pressure electrolysis system, used to extract hydrogen from water at a pressure of over 100 bar.

Description: A PV system (1) converts sunlight into direct current, which is converted into alternating current by an inverter (2). The hydrogen is stored in a hydrogen tank (3). The stored hydrogen is converted back into electricity (3) using the fuel cell function of the Energy Cell when it is needed, or used to decompose water into oxygen and hydrogen = electrolysis function of the Energy Cell (4). Clean, emission-free energy is always available for continuous use (blue arrow).



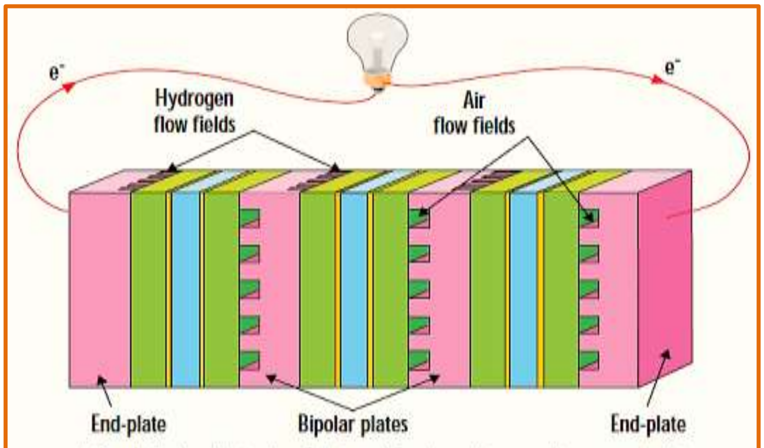
The stored energy is then available for the consumer during times of little or no sunlight. Electricity can therefore be generated locally year after year and used independently. The Fronius Energy Cell can also be used with solar panels for energy creation and storage. This version will fulfill two roles, performing electrolysis and the function of the fuel cell to be converted in useful electricity. The part of the fuel cell system that converts hydrogen into electrical energy can already be purchased as a standard product.

Stationary Fronius Energy Cells

Portable Fuel Cell Generators: Actually, there are new hydrogen fuel cells power systems, producing between 1000W to 5000W nominal electric power, using the Proton Exchange Membrane (PEM) technology, converting hydrogen into electric power and the only "pollutant" is clean water. These power generators produce high quality electric power 110V/230V AC & 12V, 24V or 48 DC. These PEMs can be used as Uninterruptable Power Systems (UPS), back-up power systems, standalone power generators providing electricity, in grid back-up for residential solar panels, hybrid solar systems, telecommunication towers, military and remote applications.

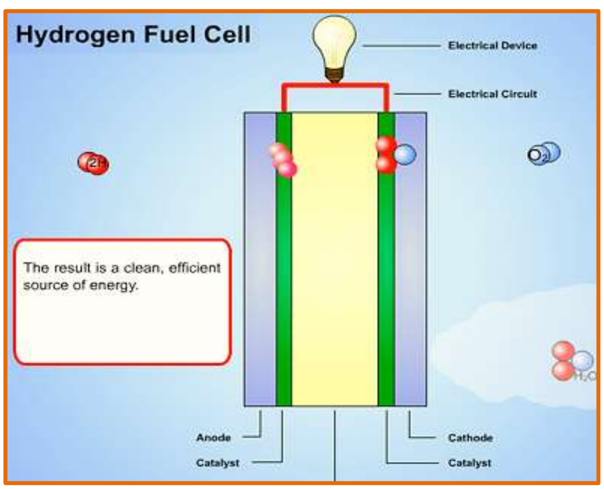
Used in backup power applications fuel cells can reduce the footprint, when compared to batteries (with a similar autonomy), and when considering larger stationary installations, fuel cells, as a clean energy, can be installed almost anywhere (urban environments). There are several companies developing fuel cells for stationary applications worldwide and many opportunities to become part of the supply chain for these systems including; distributors, sales agents and resellers, equipment manufacturers, system integrators, engineering, installation, servicing and maintenance.

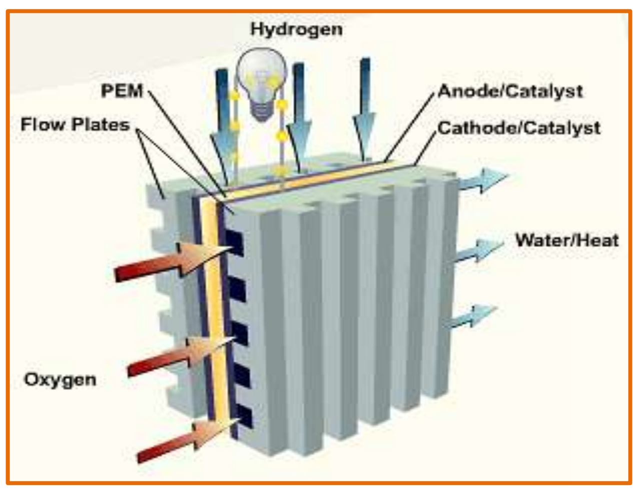
Bipolar Fuel Cell Plates: Separate one cell from the next, with a single plate serving to carry hydrogen gas on one side and air on the other. Two end-plates, one at each end of the complete stack of cells, are connected via the external circuit. The bipolar plate must also be electronically conductive because the electrons produced at the anode on one side of the bipolar plate are conducted through the plate where they enter the cathode on the other side of the bipolar plate. As most applications require much higher voltages than for example, effective commercial electric motors typically operate at 240 & 380 volts), the required voltage is obtained by connecting individual fuel cells in series to form a fuel cell.



A 3 cell fuel cell stack with two bipolar plates and two end plates

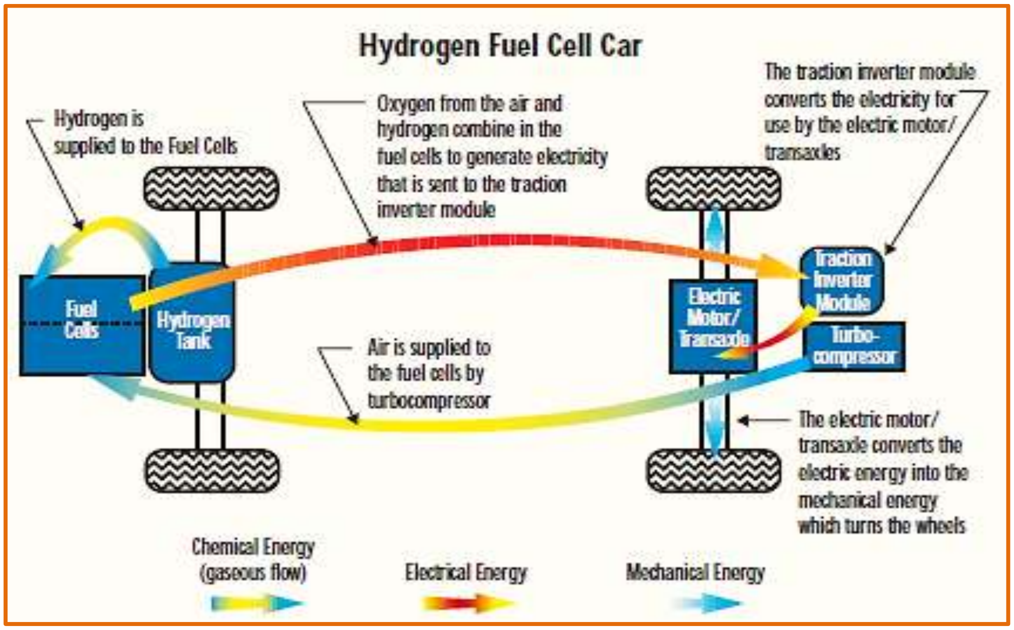
Hydrogen Fuel Cells: It´s well known that hydrogen (H2) is the most abundant element in the universe, although in combination with other elements, for example, water (H2O) or fossil fuels, such as natural gas (CH4). Therefore, hydrogen can also be manufactured from either fossil fuels or water, before it can be used as a fuel. Today, approximately 95% of all hydrogen is produced by "steam reforming" of natural gas, which is the most energy-efficient, large-scale method of production. The carbon dioxide (CO2) is a by-product of this reaction.





Hydrogen has excellent electrochemical reactivity, providing adequate levels of power density in a hydrogen/air system for automobile propulsion, and having zero emissions characteristics. The electricity required to electrolyze the water can be generated from either fossil fuel combustion or from renewable sources such as, hydropower, solar energy or wind energy. Hydrogen generation researches are also based on photobiological or photochemical methods. Nevertheless, manufacturing, distribution, and storage infrastructure are limited. Thus, an expanded system would be required if hydrogen fuel were to be used for automotive and utility applications.

Hydrogen fuel has the reputation of being unsafe. However, all fuels are inherently dangerous, as gasoline or ethanol. Proper engineering, education, and common sense reduce the risk in any potentially explosive situation. A hydrogen vehicle and supporting infrastructure can be engineered to be as safe as existing gasoline systems. Dealing with perception and reality of safety, are critical to the successful introduction of hydrogen into our energy economy.



In short terms, conservation and the use of highly efficient hybrid-electric vehicles (HEVs) can slow the overall rate of growth of oil consumption. Hybrid-electric vehicle technology is becoming commercially competitive and additional research is focused on making hybrid batteries, electronics, and materials more affordable. But, when new projects increase the number of cars on the road, and vehicle-miles traveled are taken into account, HEVs alone will not reduce oil consumption below today's level.

5. FUEL CELLS BASIC CHARACTERISTICS:

Energy Conversion of a Fuel Cell: Fuel cells typically use a fuel to be oxidized producing hydrogen ions, and through the use of a catalyst, there is an electro chemical reaction which converts the fuel to electricity, of a DC type that can be converted to AC. The by-products are water and carbon dioxide. A single, ideal H2/air fuel cell should provide 1.16 volts at zero current ("open circuit" conditions), 80°C and 1 atm gas pressure. A good measure of energy conversion efficiency for a fuel cell is the ratio of the actual cell voltage to the theoretical maximum voltage for the H2/air reaction.

Thus, a fuel cell operating at 0.7 V is generating about 60% of the maximum useful energy available from the fuel in the form of electric power. If the same fuel cell is operated at 0.9 V, about 77.5% of the maximum useful energy is being delivered as electricity. The remaining energy (40% or 22.5%) will appear as heat. The characteristic performance curve for a fuel cell represents the DC voltage delivered at the cell terminals, as a function of the current density, total current divided by area of membrane, being drawn from the fuel cell by the load in the external circuit.

Electrochemical Reaction: Is the reaction involving the transfer of electrons from one chemical substance to another, which generally has an oxidant, such as oxygen, that consumes electrons in an electrochemical reaction. All electrochemical reactions consist of two separate reactions: an oxidation half-reaction occurring at the anode and a reduction half-reaction occurring at the cathode. The anode and the cathode are separated from each other by the electrolyte, the membrane. Electrolyte is a substance composed of positive and negative ions.

In polymer electrolyte membrane the negative ions, SO_3, are permanently attached to the side chain. When the membrane becomes hydrated by absorbing water, the hydrogen ions become mobile. The ion movement occurs by protons, bonded to water molecules, to SO_3 site within the membrane. Ion is an atom that has acquired an electrical charge by the loss or gain of electrons. These two half-reactions occur very slowly at a low operating temperature, typically 80˚C, of the polymer electrolyte membrane fuel cell.

Thus, a catalyst (platinum, which is a very expensive material) is used on both the anode and cathode to increase the rates of each half-reaction. The final products of the overall cell reaction are electric power, water, and excess heat. Cooling is required to maintain the temperature of a fuel cell stack at about 80˚C. At this temperature, the product water produced at the cathode is both liquid and vapor. Then, water is carried out of the fuel cell by the air flow.

Note: Laboratory researches are performed on a variety of fuel cell types, polymer electrolyte membrane (PEMFC), alkaline membrane (AMFC), and direct methanol fuel cells (DMFC), which are generally differentiated by the fuel used.

The thickness of the membrane in a membrane/electrode assembly can vary with the type of membrane. The thickness of the catalyst layers depends upon how much platinum is used in each electrode. A membrane/electrode assembly, with a total thickness of about 200 microns (0.2 millimeters), can generate more than 0.5 ampere of current for every square centimeter at a voltage between the cathode and anode of 0.7 volts, when encased in components, as backing layers, flow fields, and current collectors.

Batteries and fuel cells are similar, as both convert chemical energy into electricity, and require minimal maintenance, due the lack of moving parts. However, unlike a fuel cell, the reactants in a battery are stored internally and, when used up, the battery must be either recharged or replaced. For larger scale applications, fuel cells have several advantages over batteries including smaller size, lighter weight, quick refueling, and longer range.

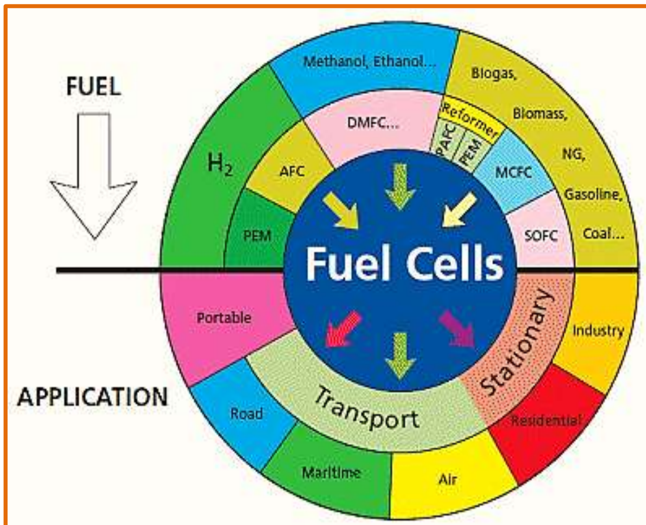
Regenerative Fuel Cells: Were developed for utility applications, use hydrogen and oxygen or air to produce electricity, water, and waste heat, as a conventional fuel cell does. However, the regenerative fuel cell also performs the reverse of the fuel cell reaction, using electricity and water to form hydrogen and oxygen. In the reverse mode of the regenerative fuel cell, known as electrolysis, electricity is applied to the electrodes of the cell to force the dissociation of water into its components.

The main drawback to the operation of the regenerative fuel cell is the use of grid electricity to produce the hydrogen, as in USA, most electricity comes from burning fossil fuels. The fossil fuel electricity hydrogen energy route generates significantly more greenhouse gases than simply burning gasoline in an internal combustion engine. Until renewable electricity, from solar or wind sources, can be readily available, this technology will not reduce greenhouse gas emissions.

6. FUEL CELLS GENERAL APPLICATIONS:

There are hundreds of applications for small or micro fuel cell systems. The first area to become commercially successful is educational kits and toys, with at least two companies selling fuel cell kits globally. The next early market area is likely to be portable battery chargers and small power packs. Military applications are another key area for portable fuel cells. There are defense forces seeking for alternatives to conventional battery packs in order to meet these future power requirements within an acceptable weight and package volume.

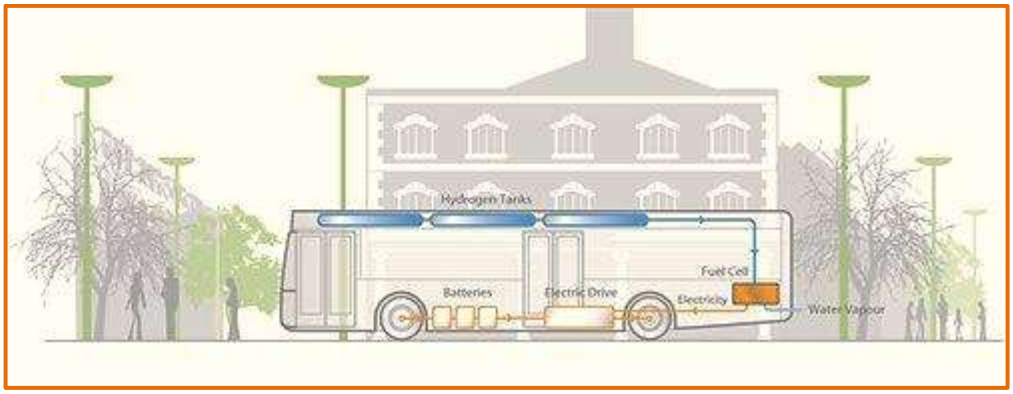
Consumer electronics are a key area for micro fuel cells, being used to power laptop computers, mobile phones, MP3 players and other such products. Generally, portable fuel cell systems tend to use either DMFC or PEM technology. However, there are many companies working on novel fuel cell solutions such as, Direct Liquid Fuel Cells (DLFCs) powered by a borohydride salt. PEMFC systems run on pure hydrogen, the hydrogen tends to be stored as a gas or in a metal hydride canister. A few players in this sector are researching alternative solutions for transporting and storing the hydrogen, such as using ammonia borane tablets.



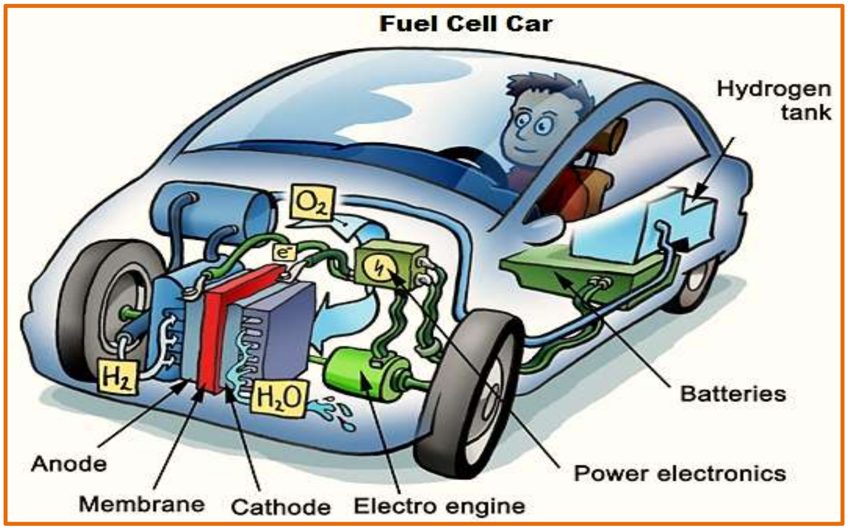
Abbreviations	
AFC	Alkaline Fuel Cell
DMFC	Direct Methanol Fuel Cell
HT PEMFC	High Temperature Proton Exchange Membrane Fuel Cell
MCFC	Molten Carbonate Fuel Cell
PAFC	Phosphoric Acid Fuel Cell
PEMFC	Proton Exchange Membrane Fuel Cell
SOFC	Solid Oxide Fuel Cell

Vehicles & Fuel Cells: Fuel cells for transportation provide propulsive power to vehicles, directly or indirectly and fuel cells bus sectors are showing year-on-year growth, more prototypes being unveiled. However, it is hoped that soon fuel cell bus prices will be comparable to diesel-hybrid bus prices. Materials handling vehicles account for over 90% of niche transport shipments, with PEMFC technology dominating. Currently, fuel cells are used in the following transport systems:

- Forklift trucks and other goods handling vehicles such as airport baggage trucks;
- Two-and three-wheeler vehicles such as scooters;
- Light duty vehicles (LDVs), such as cars and vans;
- Buses, trains, trams, ferries and smaller boats;
- Unmanned Aerial Vehicles (UAVs) and Unmanned Undersea Vehicles (UUVs).

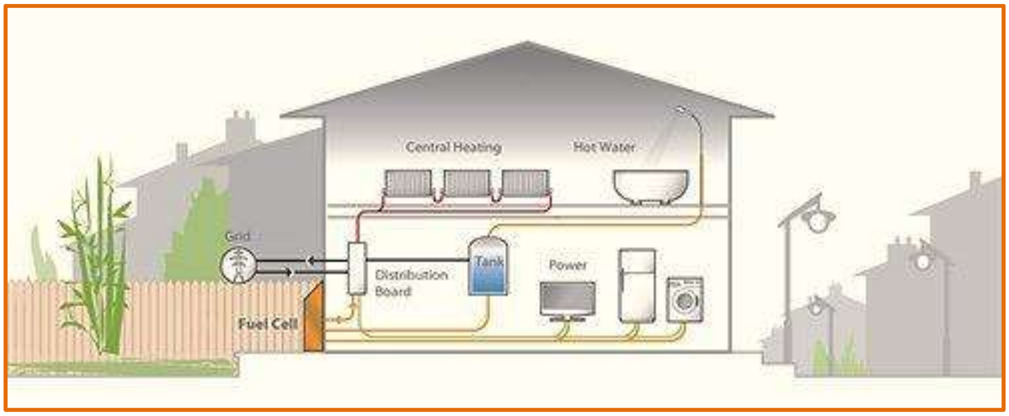


Demonstration fuel cell vehicles have been produced with "a driving range of more than 400 km (250 mi) between refueling", which was refueled in less than 5 minutes. The U.S. Department of Energy's Fuel Cell Technology Program says that, from 2011, fuel cells achieved 53–59% efficiency at one-quarter power and 42–53% vehicle efficiency at full power and a durability of over 120,000 km (75,000 mi) with less than 10% degradation.



General Motors and its partners estimated that fuel cell electric vehicles, running on compressed gaseous hydrogen produced from natural gas could use about 40% less energy and emit 45% less greenhouse gasses, than internal combustion vehicles. Some experts believe that fuel cell cars will never become economically competitive with other technologies or that it will take decades for them to become profitable. However, fuel cell buses have been deployed around the world including in Whistler, Canada; San Francisco, USA; Hamburg, Germany; Shanghai, China; London, England; and São Paulo, Brazil.

Stationary Fuel Cells: Are fuel cell units that can provide electricity (and sometimes heat) but are not designed to be moved, and work as Combined Heat and Power (CHPs), Uninterruptible Power Systems (UPSs) and general primary power units. Fuel cells are also more efficient at generating electricity, which gives CHP units overall efficiencies of 80-95%. CHP units are sized between 0.5 kW to 10 kW, use either PEM or SOFC technology, for example to make hot water.



Fuel cell manufacturers are now developing small scale polymer electrolyte fuel cells technology for individual home utility and heating applications at the power level of 1-5 kilowatts, because the potential for lower materials and manufacturing costs really could make these systems commercially viable. Telecommunications companies, gas utilities, railroad companies and many more organizations are choosing fuel cells due obvious advantages.

Data Centers, hospitals and other critical areas can utilize fuel cells as UPS devices since they can be located nearer to equipment resulting in less power loss, produce almost no noise, have clean exhausts and can run for very long run times. Like the larger fuel cell utility plants, smaller systems will also be connected directly to natural gas pipe lines not the utility grid.

These include large stationary fuel cells to power buildings; small stationary fuel cells for telecom and residential applications; portable power for military use and other mobile applications; as a replacement for battery power in materials handling applications; as primary power or auxiliary power units (APUs) and hydrogen production and storage. Large stationary fuel cells can be installed as part of the electric grid, or in parallel with it.

These systems range from 100 kW to more than 5 MW in capacity, and can provide reliable power to a site without interruption in the event of a grid failure or blackout. In a variety of transportation applications (passenger vehicles, buses, trucks), several companies around the world are collectively saving millions of dollars in electricity costs while reducing carbon emissions by hundreds of thousands of metric tons per year, using fuel cell lift trucks, or fuel cells for power generation or combined heat and power (CHP), and in many cases both.

Smaller stationary fuel cells are also ideal for residential and small commercial applications, as fuel cells generate power and heat to warm about 750 gallons of water (domestic hot water) or heat a swimming pool. Fuel cells manufacturers are developing smaller, portable fuel cell units for battery charging and auxiliary power for use in military, surveillance and emergency response applications.

Note: Fuel cells can also replace batteries or generators, and providing uninterrupted power and extended run-times to field computers, to power lighting at the NASA shuttle launch, the red carpet at several movie and music award ceremonies, and critical communications equipment.

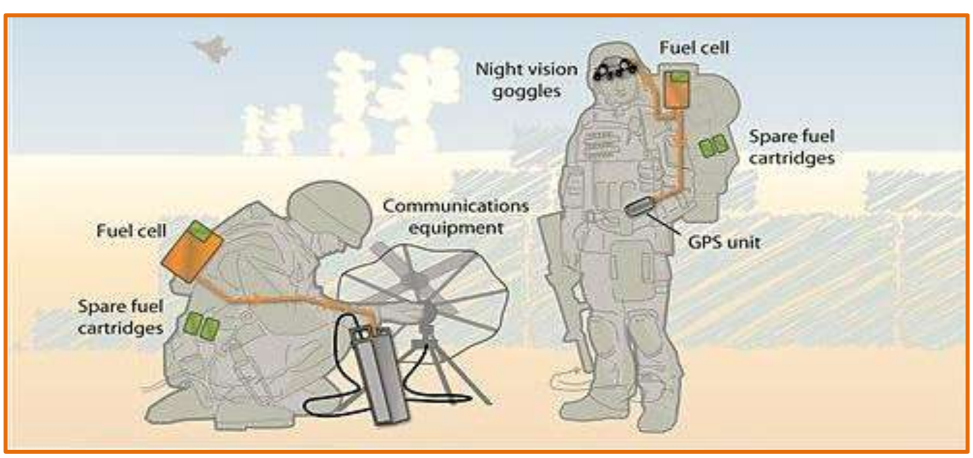
Most large stationary fuel cell systems are fueled by natural gas, but Anaerobic Digester Gas (ADG) derived from wastewater, manufacturing processes, from crops or animal waste, is being used more frequently as a feedstock. As the need for reliable cell phone and critical communication networks grows, fuel cell manufacturers have found success selling fuel cell systems that provide long-running, primary or backup power for telecom switch nodes, cell towers, and other electronic systems that require reliable, direct DC power supply, typically in the range of 1 to 5 kW.

These units are being developed to replace the grid, for areas where there is little or no grid infrastructure, and can also be used to provide grid expansion nodes. Four technology types serve the large stationary market: SOFC, MCFC, PEMFC and PAFC. The manufacturing of these units is predominately located in the USA and Japan. Fuel choice varies by region with natural gas and LPG dominating in Asia, hydrogen prevalent in the USA, and in Europe some adopters are experimenting methanol. Large stationary refers to multi-megawatt units providing primary power.

Portable Fuel Cells: Are fuel cell products that are designed to be moved from one place to another, including military applications (portable soldier power, skid mounted fuel cell generators, and so on), Auxiliary Power Units (APU), portable products (torches, trimmers), small personal electronics (MP3 players, cameras), large personal electronics (laptops, printers, radios), education kits and toys. To power this range of products, portable fuel cells are being developed in a wide range of sizes ranging from less than 5 W up to 500 kW.

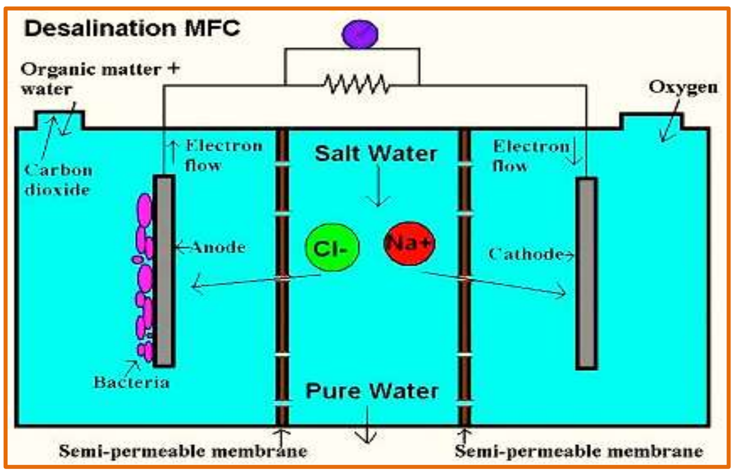
Fuel cells are being sold commercially for all these applications, classified as micro fuel cells, defined as units with power output of less than 5 W. The difference between small and large personal electronics is that the smaller devices, such as cameras or mobile phones only draw around 3 W of power, whereas a laptop can use up to 25 W, requiring a fuel cell of higher power density.

Auxiliary Power Units (APUs): Are devices on vehicles that also provide energy for functions other than propulsion, commonly found on large aircraft, naval ships, as well as some large land vehicles. The primary purpose of an APU is to provide power to start the main engines. Aircraft APUs generally produces 115 V (AC) at 400 Hz, to run the electrical systems of the aircraft.



Portable APUs also comprises the largest share of this sector, with very successful deployments of DMFC systems throughout the European leisure sector. Portable fuel cells typically replace or augment battery technology and exploit either PEM or DMFC technology. PEM fuel cells use direct hydrogen, with no point-of-use emissions, whereas DMFCs emit small quantities of CO_2.

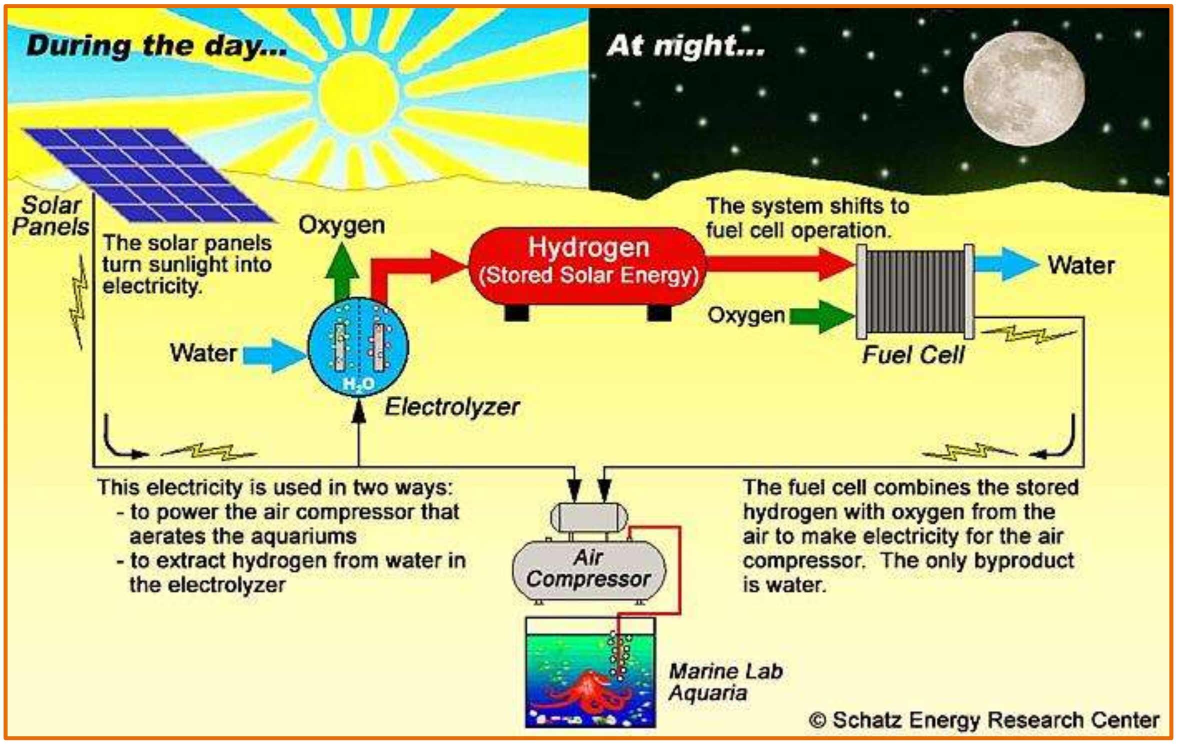
Desalination: Desalination of sea water and brackish water for use as drinking water has always presented significant problems because of the amount of energy required to remove the dissolved salts from the water. By using an adapted Microbial Fuel Cells (MFCs), this process could proceed with no external electrical energy input. Adding a third chamber between two electrodes of a standard MFC, and filling it with sea water, the cell's positive and negative electrodes attract the positive and negative salt ions in the water and, using semi-permeable membranes, filters out the salt from the sea water. Salt removal efficiencies of up to 90% have been recorded in laboratory work, however much higher removal efficiencies are required to produce drinking-quality water.



Water Electrolysis & Solar Energy: More than 20 years ago, the Schatz Energy Research Center (SERC) in Trinidad, California, launched its solar hydrogen project to aerate the aquaria at Humboldt State University's Telonicher Marine Laboratory, and demonstrate that hydrogen can be used to store solar energy. In this solar hydrogen cycle, the solar panels energy provides electricity to remove hydrogen *by the process of electrolysis of water*, in a process powered by solar photovoltaic panels, and then fed to fuel cells to create electricity, as described below:

Sunlight hits the photovoltaic panels, which convert the solar energy into electricity. This electricity is used to first power the air compressor directly. When more energy is available than the compressor needs, the excess electricity powers an electrolyzer, which splits water into oxygen and hydrogen. The oxygen gas is vented to the atmosphere, and the hydrogen gas is stored in tanks behind the lab. When the photovoltaic panels do not receive enough sunlight to power the compressor (at night or when the weather is cloudy), the system automatically shifts to fuel cell operation.

The fuel cell directly *converts chemical energy into electricity* by combining the stored hydrogen with oxygen from the air, basically the reverse of the electrolyzer. In this way water and sunlight, both natural and abundant, are used in a continuous cycle to produce power. Hydrogen stores solar energy, so the power is available whenever it is needed. The system uses energy from the sun to power a compressor directly and to produce hydrogen that powers the same compressor when the sun is not available. As a result, the creation of hydrogen fuel is powered by renewable solar energy, and the only byproduct is water. SERC and other research labs have developed renewable hydrogen-generating stations powered by wind and sunlight.



Note: In 2006, the fuel cell stack was replaced and installed maximum power point trackers, rewired the PV array from 24 Volts nominal to 48 Volts nominal to reduce power loss in the wiring, and installed DC-to-DC converters to maximize electricity and hydrogen production.

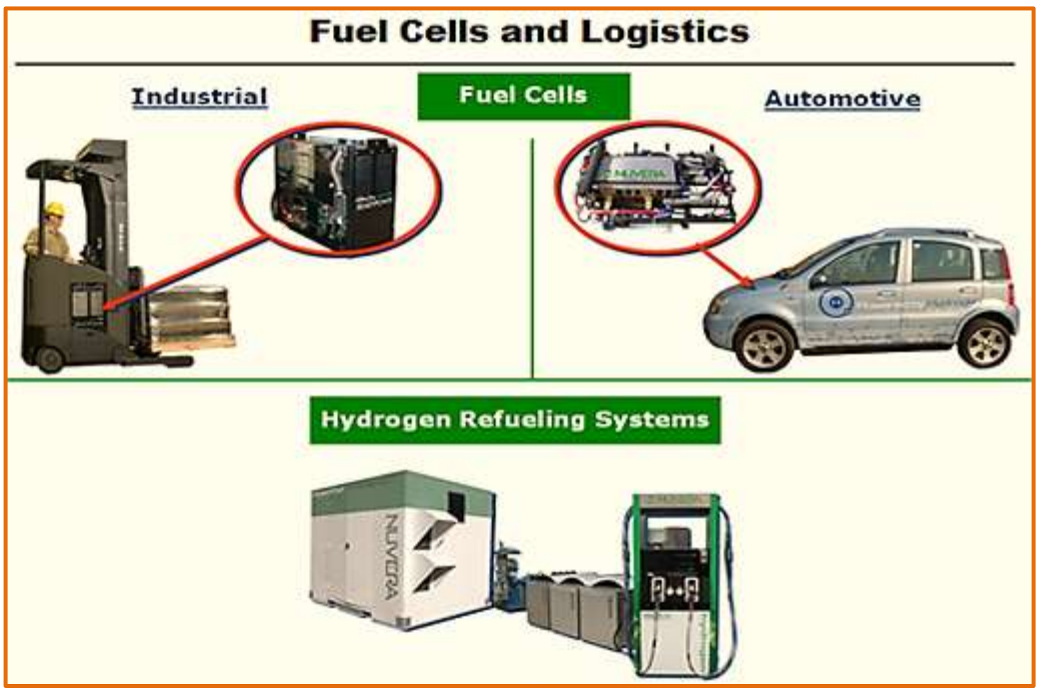
Cleaning Polluted Lakes and Rivers: Microbial fuel cells can also be used in the bio-remediation of water containing organic pollutants such as, toluene and benzene, compounds found in gasoline. The MFC design is altered, so that the fuel cell floats on top of polluted water. The anode is submerged in the water where organic pollutants feed the bacteria while the cathode floats on top of the water. The organic pollutants are decomposed to carbon dioxide and water, cleansing the polluted lake or stream. The MFC can be left alone in remote natural bodies of water. A working prototype has been deployed in a polluted marsh in Mexico, beginning a process of cleaning remote rivers.

Wastewater Treatment: Brewery, food manufacturing and can be treated by microbial fuel cells because their wastewater is rich in organic compounds that serve as food, for the microorganisms. Breweries are ideal for the implementation of microbial fuel cells, as their wastewater composition is always the same. The water treatment process is very similar to brewery wastewater treatment, with the difference being that the water must first be pretreated to remove toxins and other non-biodegradable materials.

Fuel Cells in Logistics: Fuel cell forklifts can lower total logistics costs since they operate longer, require minimal refilling and need less maintenance. Warehouses and distribution centers can install their own hydrogen fueling station in-house and take only one to two minutes to refuel forklifts, compared to the half hour or longer it takes to change out a battery. Large chemical companies are working with state agencies and companies to open hydrogen fueling stations, as well as dispensers at warehouses and forklift sites. Most major auto manufacturers are leasing fuel cell electric vehicles (FCEVs) and anticipate commercial sales of fuel cell vehicles.

PEMFCs are most suited for transportation applications, due light weight. PEMFCs for buses use fuel compressed hydrogen operating at up to 40% efficiency, generally implemented on buses over smaller cars because of the available volume to store the fuel. Technical issues for transportation involve incorporation of PEMFCs into current vehicle technology and updating energy systems. Full fuel cell vehicles are not advantageous if hydrogen is sourced from fossil fuels; however, they become beneficial when implemented as hybrids.

Additionally, increasing the use of biofuels, like ethanol, and plug-in hybrid vehicles technology, and hydrogen as an energy carrier, can provide a more efficient and diversified energy infrastructure. Hydrogen is a promising energy carrier, because it can be produced from different and abundant resources, including fossil, nuclear, and renewables. Using hydrogen, particularly for transportation needs, will permit to diversify energy supplies, with abundant, domestic resources, reducing dependence on foreign oil.



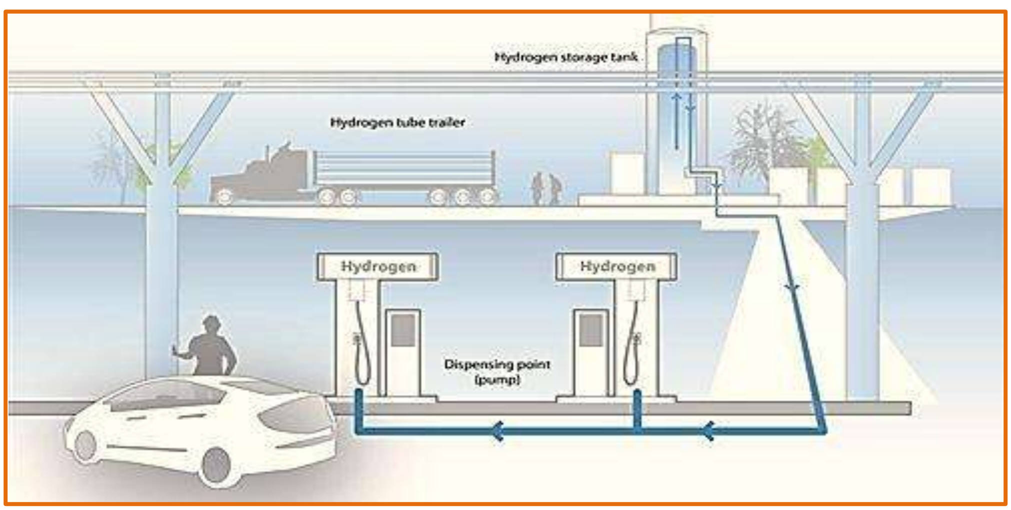
There is potential for PEMFCs to be used for stationary power generation, where they provide 5 kW at 30% efficiency; however, they run into competition with other types of fuel cells, mainly SOFCs and MCFCs. Whereas PEMFCs generally require high purity hydrogen for operation, other fuel cell types can run on methane, which are much more flexible systems. Then, PEMFCs are best for small scale systems until economically scalable pure hydrogen is available. However, PEMFCs have the possibility of replacing batteries for portable electronics, though integration of the hydrogen supply is a technical challenge particularly without a convenient location to store it within the device.

In fact, the lower operating temperature fuel cells like PEMFCs and PAFCs are particularly well suited for transportation applications where the heat is neither usable nor desirable. However, each of the fuel cell types currently being developed or manufactured has features that make it particularly attractive for certain applications. For example, the greater efficiency and higher temperature operation of MCFCs and SOFCs make them more amenable to large stationary power generation where high grade waste heat can be utilized to heat water or air or to provide cooling.

7. HYDROGEN PRODUCTION METHODS:

Producing Hydrogen by Electrolysis: Hydrogen is generally produced by the electrolysis of water, splitting water into its molecule elements (H2O), with an electrolyzer, described as a "reverse" fuel cell that is, instead of combining hydrogen and oxygen electrochemically to produce electricity, the electrolyzer uses an electrical current to produce hydrogen and oxygen. When an electric current is introduced to water (H2O), hydrogen and oxygen are separated, with hydrogen forming at the cathode and oxygen forming at the anode.

Hydrogen Fuel: Hydrogen as a fuel source currently exists worldwide, however the infrastructure to achieve this efficiently and cheaply is still under development. Hydrogen vehicle fueling stations may store hydrogen in liquid form, or receive deliveries of trucked-in hydrogen, converted to a gaseous state and compressed before being dispensed. In either case, the stations possess equipment to compress, store and dispense the hydrogen fuel. Compressing hydrogen gas to 350 (5,000 psi) or 700 bar (10,000 psi) reduces the volume, and the compressed gas is then stored onsite in high pressure or cryogenic tanks.



Electricity can be provided from any source, but using solar and wind energy to electrolyze water provides the cleanest pathway to produce hydrogen. When the electricity is obtained from renewable energy such as wind or solar power, the hydrogen can be produced in a completely carbon-free way. This model is being used in some hydrogen refueling stations and in renewable energy storage systems that utilize hydrogen.

Producing Hydrogen by Enzymes: Is another method to generate hydrogen with natural bacteria and algae. Cyanobacteria, an abundant single-celled organism, produce hydrogen through its normal metabolic function. Cyanobacteria grow in the air or water, and contain enzymes that absorb sunlight for energy and split the molecules of water, thus producing hydrogen. Since cyanobacteria take water and synthesize it to hydrogen, the waste emitted is more water, which becomes food for the next metabolism. Sodium borohydride (NaBH4) is an inorganic compound that can dissolve in water in the absence of a base. Hydrogen can be generated through a catalytic decomposition.

Producing Hydrogen by Steam Reforming: Is a method for producing hydrogen from hydrocarbon fuels such as, natural gas, in a processing method called as reformer, which reacts steam at high temperature with the fossil fuel. The steam methane reformer is widely used in industry to produce hydrogen. Small-scale steam reforming units to supply fuel cells are currently in development, involving the reforming of methanol, but other fuels are also being considered such as propane, gasoline, autogas, diesel fuel, and ethanol. Fuel is mixed with steam in the presence of a base metal catalyst to produce hydrogen and carbon monoxide.

Producing Hydrogen by Fuel Reforming: Reformers are hydrocarbon fuels such as, methanol, ethanol, natural gas, petroleum distillates, liquid propane, and gasified coal, used to produce hydrogen in a process called reforming. Steam reforming is endothermic, where heat is supplied to the process. This type of reforming combines the fuel with steam by vaporizing them together at high temperatures. Hydrogen is separated using membranes. There are two different kinds of reforming; the *external reforming*, carried out before the fuel reaches the fuel cell, and the *internal reforming*, which is processed within the fuel cell stack.

Natural gas, for example, contains methane (CH4), which produces hydrogen via a thermal process, known as steam-methane reformation. In steam-methane reforming, methane reacts with steam in the presence of a catalyst to produce hydrogen, carbon monoxide, and a relatively small amount of carbon dioxide. Another type of reformer is the partial oxidation (POX) reformer. Some CO2 is emitted in the reforming process, but the emissions of NOX, SOX, particulates, and other smog producing agents are cut to zero.

Partial Oxidation Reforming: This method involves the reaction of the hydrocarbon with oxygen to liberate hydrogen, and produces less hydrogen for the same amount of fuel than steam reforming. The reaction is, however, exothermic and therefore generates heat. This means that the reaction can be initiated by a simple combustion process leading to quick start-up. Once the system is running it then requires little external heating to keep going. The technology is preferred where there is little access to natural gas or an abundance of oil. Partial oxidation can be used for converting methane and higher hydrocarbons, but is rarely used for alcohols.

Autothermal Reforming: Autothermal reforming combines the endothermic steam reforming process with the exothermic partial oxidation reaction, therefore balancing heat flow into and out of the reactor. For high temperature systems such as molten carbonate and solid oxide cells, it is possible to supply a hydrocarbon (natural gas or methanol) directly to the fuel cell without prior reforming. The high temperature allows the reforming stage to take place within the fuel cell structure, then, pure methanol is generally used as fuel.

Hydrogen Storage: Hydrogen is non-toxic, odorless, colorless, and tasteless and safe to breathe, but like all fuels, hydrogen is flammable and must be handled properly. Since it cannot be odorized like natural gas, hydrogen detection and ventilation systems must be employed. Hydrogen can be stored as either a liquid or a gas cooled to -423 °F. Produced in large quantities is usually pressurized as a gas, and then stored in caverns, gas fields, mines and containers, designed and certified to withstand the pressures involved, before being piped to the consumer as natural gas is today.

Hydrogen can also be stored in solid form in chemical combination with other elements (there are a number of metals which can “absorb” many times their own weight in hydrogen), and then the hydrogen is released from these compounds by heating or the addition of water. Other storage mediums are being investigated, for example carbon nanotubes and glass microspheres. In the U.S., hydrogen is transported safely through 700 miles of pipelines, and 70 million gallons of liquid hydrogen is transported annually by truck over U.S. highways without incident.

8. HYDROGEN USE IN FUTURE:

The UTC Power was a fuel cell company based in South Windsor, Connecticut, as part of United Technologies Corporation. UTC Power began as a division of Pratt & Whitney in 1958. The company became specialized in manufacturing fuel cells for buildings, buses and automobiles, and also developed fuel cells for space and submarine applications. In 1966, the company supplied fuel cells to NASA for the Apollo project space missions, to supply electric power and drinking water for the astronauts on board, and later for the Space Shuttle missions until 2010.

The UTC Power’s stationary phosphoric acid fuel cell main product is the PureCell Model 400 System, which provides 400 kilowatts of electricity and 1.7 million Btu/hour of heat, considered a good match for combined heat and power applications for supermarkets, hospitals, hotels and educational institutions. This UTC Power fuel cell system uses natural gas which is converted in a "catalytic reformer" into hydrogen, carbon dioxide, carbon monoxide, and water. The hydrogen is used to run the four fuel cell stacks to produce electricity and to convert the exhaust heat into cooling and heating, turning potential waste into usable energy.

The PureMotion Model 120 System was an UTC Power’s zero-emission Proton Exchange Membrane (PEM) fuel cell, used for powering a fleet of transit buses in Connecticut and California. The company also worked with BMW, Hyundai and Nissan as well as the U.S. Department of Energy on demonstration programs, developing PEM fuel cells for automobiles. Fuel cell manufacturers as Bloom Energy, FuelCell Energy, and UTC Power also developed combined heat and power (CHP) primary power applications for corporations, municipalities, and state and local governments. In February 2013, UTC Power was purchased by ClearEdge Power.

As described before, CHP systems range from 100 kW to more than 5 MW in capacity. These stationary fuel cells can be installed as part of the electric grid, and provide reliable power to a site without interruption in the event of a grid failure or blackout. Most large stationary fuel cell systems are fueled by natural gas. However, Anaerobic Digester Gas (ADG), derived from wastewater, manufacturing processes, or from crop or animal waste is being used at several wastewater treatment plants, as well as at breweries and agricultural processing facilities.

Other uses such as, smaller stationary fuel cells are also ideal for residential and small commercial applications. For instance, the ClearEdge Power manufactures fuel cells to generate power and heat to warm about 750 gallons of water (domestic hot water) and swimming pools. The fuel cells are quiet, rugged and durable, generating reliable, long-running power at hard-to-access locations or sites subject to harsh or inclement weather, typically in the range of 1 to 5 kW.

As more consumers are using cellular phones, wireless laptops, and other mobile devices, telecommunications companies are meeting the need by installing towers and substations at a phenomenal rate worldwide. As the need for reliable cell phone and critical communication networks grows, fuel cell manufacturers have found success in selling fuel cell systems that provide long-running, primary or backup power for telecom switch nodes, cell towers, and other electronic systems that require reliable, on-site, direct DC power supply.

Fuel cell forklifts can lower total logistics costs since they operate longer, require minimal refilling and need less maintenance compared to electric forklifts. Batteries are heavy and provide on average six hours of run time, while fuel cells last more than twice as long (12-14 hours). Warehouses and distribution centers can install their own hydrogen fueling stations and fuel cell forklifts take only one to two minutes to refuel, compared to the half hour or longer it takes to change out a battery.

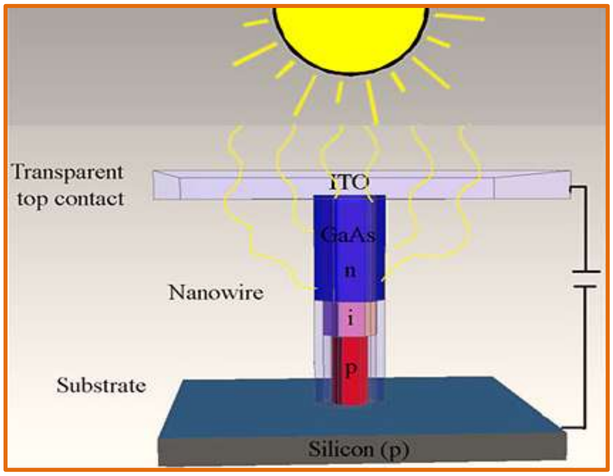
Daimler and Honda are leasing Fuel Cell Electric Vehicles (FCEVs) in California, and the other automakers have vehicles on the road in various states, including New York and Connecticut. Toyota announced it will place more than 100 of its fuel cell vehicles at universities, private companies and government agencies in both California and New York. With fuel cell buses and vehicles already on the road, several companies are focused on dispensing hydrogen to service them. Large chemical companies such as Air Products and Linde are working with state agencies and companies to open hydrogen fueling stations, as well as dispensers at warehouses.

Solar Nanowires Fuel Cells: A nanowire is an extremely thin wire with a diameter on the order of a few nanometers (nm) or less, where 1 nm = 10^{-9} meters (1 x 10^{-9} m = 0.000.000.001 m, see scientific notation). As comparison, a 1 mm wire diameter (0.000.0001 nm) could be made with 1 million nanowires. According to The Physics Factbook, the diameter of human hair ranges from 17 to 181 µm (0.017 to 0.018 mm).

Most solar cells uses silicon based semiconductors to generate electricity from the sun, more recently gallium phosphide has emerged as a new material. According to researchers, for nanowires solar cells are necessary ten thousand less of the precious gallium phosphide material, than in cells with a flat surface. The gallium phosphide can convert sunlight into electricity and split the water all in one, producing a solar fuel cell, as it is also able to extract oxygen from the water, to become a fuel cell and temporarily store solar energy.

This could be used to directly split the water and could boost the yield of hydrogen by a factor of ten, to achieve a record for solar cell electrochemical hydrogen production. Nanowires show a large surface area, and therefore a low current density, meaning that an earth-abundant catalyst should yield promising results. Nanowires act as an effective photocathode, due to a direct band, with increased light absorption, and the geometry allows a good charge-carrier separation. Energy can be released from the fuel cell by converting the hydrogen and oxygen back into water, releasing electricity. This could lead to new compact solar-powered fuel cells technologies that can be used on vehicles.

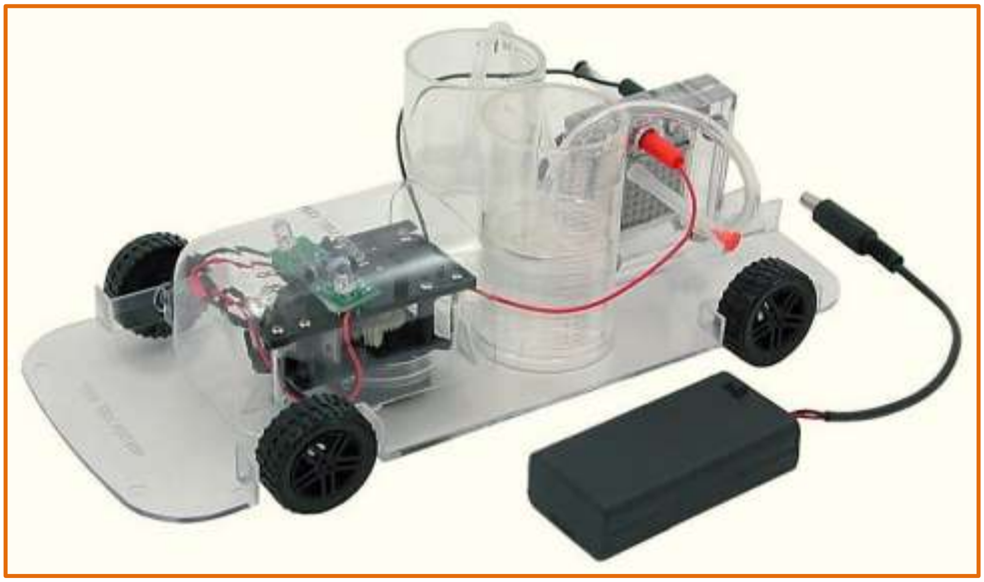
Researchers used computational chemistry models to predict the electronic and optical properties of three types of nanoscale (billionth of a meter) amorphous silicon structures, with a potential application for solar energy collection; *a quantum dot, one-dimensional chains of quantum dots and a nanowire*. Amorphous Silicon nanowires also facilitate harvesting of solar energy in the form of a photon, as in the process of light absorption a pair of mobile charge carriers is created. The energy of these directed nanowires motion is then transformed into electricity, maximizing the efficiency of silicon nanomaterials to absorb light and transport charge throughout a photovoltaic system.



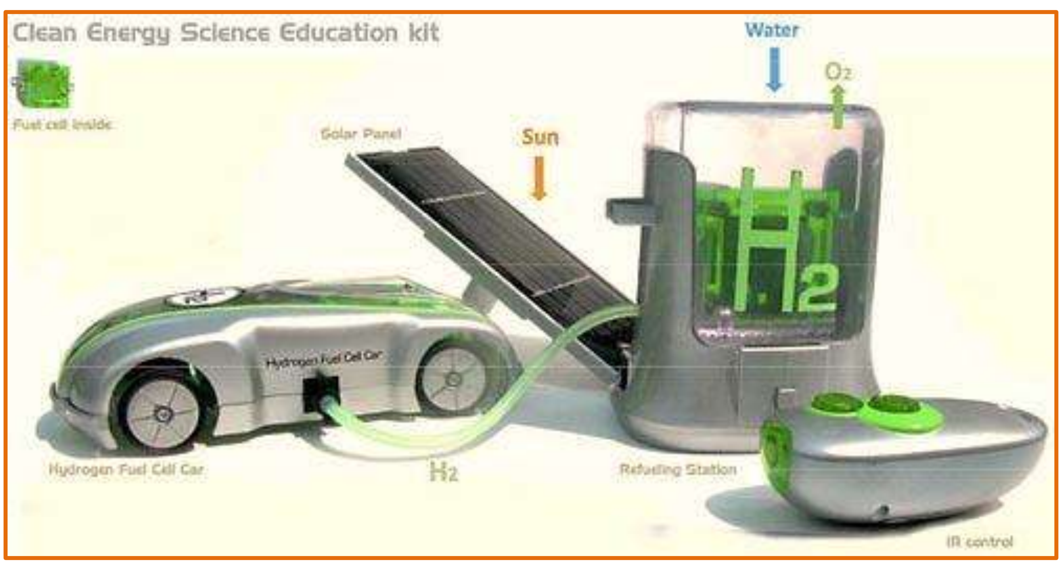
The FuelCell Science Kit: Was designed for a "hands on" experience with solar hydrogen energy technology for both students and teachers. Using the very latest renewable energy technology, students can learn standard science and engineering topics aligned to the NGSS and STEM standards. So, students can build their own energy system, learn relevant Science and STEM topics and get introduced to renewable energy technology, preparing for a greener future.

This exciting technology is the same technology being used to build hybrid energy systems, power schools, homes and cars. In addition to covering standard curriculum topics in chemistry and physics, this durable, high quality product also allows students to investigate important renewable energy topics such fuel cells, solar energy, hydrogen and energy conversion and storage.

Each kit includes a four-volume set of text books that contain over 20 experiments that cover topics such as electrochemistry, thermodynamics, energy conversion and efficiency, molecules and chemical reactions and measuring and interpreting characteristic curves. Perform experiments for topics such as Faraday's First Law, Avogadro's Constant, Electrolysis, System Efficiency, Greenhouse Effect, Solar Cells (Light Source, Shadow Effects, Angle, Efficiency), Parallel and Series Circuits, Energy Storage and Conversion, and Creation of a Characteristic Curve, to name a few.



Among other latest inventions at the FC Expo 2009, there was the Yamaha's hydrogen fuel cell motorbike, powered by fuel cell, which uses methanol, or by an external li-ion battery. Several hydrogen powered gadgets were presented at the exposition. One of them was a hydrogen powered assisted-drive bicycle, which features hydrogen packs that generate power when needed. Additionally, there were a number of hydrogen powered toys along with fuel cell/energy generation learning kits, such as the H-racer 2.0, which features a solar cell and a "hydrogen station".



The following is a list of fuel cell resources for students of all ages:

Build Your Own Fuel Cells: Illustrated instructions on how to build a PEM fuel cell;
Discovering the Principle of the Fuel Cell: Overview of fuel cells and a science project;
Energy Quest: Includes a science project on electrolysis from California Energy Commission;
EPA: Students for the Environment: The U.S. Environmental Protection Agency's student's page;
Filters Fast: A collection of science and energy projects for students;
Hydrogen Technology: This module was developed by SEPUP of The Lawrence Hall of Science;
Increase Your H2 IQ: Links to Department of Energy's Fuel Cell Technologies program;
UCSB Science Line: Enables K-12 students and teachers about science questions;
The History of the Electric Vehicle: Includes links to other sites about hydrogen and fuel cells.

9. LINKS AND REFERENCES:

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