

UNIT-1

INTRODUCTION TO HYBRID ENERGY SYSTEMS

What is hybrid electrical power

Hybrid power systems are those that generate electricity from two or more sources, usually renewable, sharing a single connexion point. Although the addition of powers of hybrid generation modules are higher than evacuation capacity, inverted energy never can exceed this limit. In that way, a hybrid generation plant can, therefore, use, for example, photovoltaic energy when the sun shines and another source, such as wind, in cloudy weather, thus ensuring a more stable and efficient supply. Hybrid installation may or may not always include storage systems.

Types of hybrid electrical power

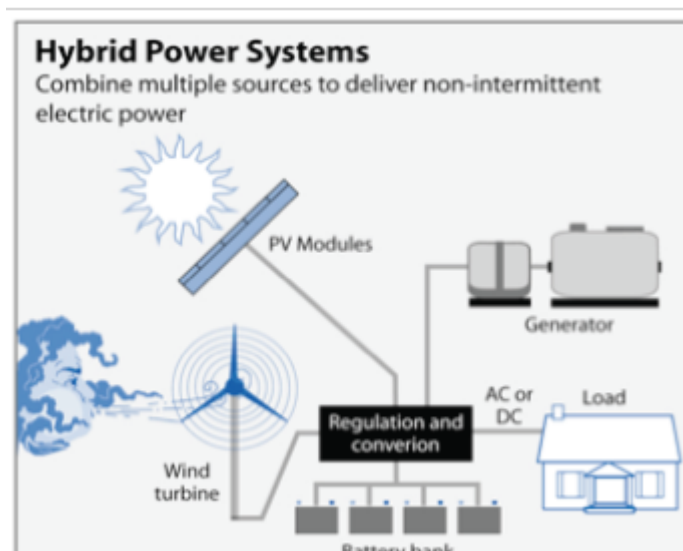
Leaving aside hybrid installations with diesel generators, the most common types of hybrid electrical power combinations are:

Photovoltaic + Wind.

Photovoltaic + Hydraulic.

Hydraulic + Wind.

Solar Thermal + Biomass.



How it works

Hybrid energy systems can capitalize on existing energy infrastructure and add components to help reduce costs, environmental impacts and system disruptions. Planning a hybrid electricity system has a market focus rather than a technology focus: the priority is to choose a mix of energy technologies that is the most efficient and reliable way to meet users' needs. Generally, at least one source of the fuel used to power a generator is renewable. Such a system is designed to increase the reliability (and thus usability) of renewable energy sources by providing redundant energy production from conventional sources or, more efficiently, by providing storage for electricity produced by intermittent sources.¹ Computer applications automatically increase or reduce conventional generation or battery usage as needed to respond to fluctuations in production from the renewable resources to maximize the amount of renewable energy in the system.² An important issue in renewable energy development has been the inability to rely on intermittent renewable sources, such as wind and solar, for base load power. It is not economical to ramp up or reduce production at large conventional base load power plants; so even if wind or solar plants are producing enough electricity to supply both peaking and some base load demand, it does not generally offset fossil fuel-based or nuclear base load energy generation. Small, agile hybrid energy systems are one way to allow energy production from intermittent renewable sources into the grid more reliably. To respond accordingly to peaks and dips in renewable energy production, hybrid systems are best implemented on a small scale because small generators are more flexible. These agile systems can, when possible, be interconnected into the central grid system and function as small power plants.

Opportunities in Asia and the Pacific

- Hybrid energy systems are particularly well suited for use in remote locations. Hybrid systems can serve standalone mini-grids, thus avoiding costly transmission costs. The increased capability of

integrating renewable energy production into the electricity mix reduces the costs of transporting fuel to remote areas.

- Applicable for combined heat and power and district heating: As technology systems that can be used for distributed generation, isolated grids or on-site application, hybrid energy systems are generally well suited for combined heat and power production or district heating.

Strengths in using a hybrid system

- Hybrid systems can reduce reliance on fossil fuels and increase the share of renewable energy resources, including intermittent ones, thus increasing the eco-efficiency of energy production and energy security.
- Hybrid systems can reduce energy costs in the long run by offsetting fossil fuel use with renewable production.
- Setting up isolated grids can help provide modern energy access to remote areas and avoid the cost of expensive transmission and distribution lines from the central grid. Particularly in poor areas using diesel gensets, for which fuel price fluctuations can mean no electricity for a period of time, hybrid systems can help provide more reliable modern energy access.

Challenges to using a hybrid energy system

Financial

- The multiple components required to form a hybrid system generally make them expensive to build.

Technical

- There is no single optimal hybrid energy system configuration. Rather, optimizing is based on the availability of renewable and non-renewable resources, on site-specific energy infrastructure, production costs and incentive policies. Planning a hybrid system thus necessitates an adequate study period for each proposed project site. Because many hybrid systems rely on the flexibility of small conventional power production facilities that can be dispatched as needed and/or on small storage devices to deal with intermittent renewable energy sources, these systems have limited scalability with the currently available technologies.
- Not all energy production and storage technologies that are potential hybrid system components are fully developed. It is risky to invest in long-term, expensive infrastructure that may improve significantly in the medium term.
- Implementing hybrid energy systems can create market opportunities for the deployment of energy technologies that are not yet mature.⁵ If a particular technology, such as a new type of fuel cell, is not

yet efficient or reliable enough to produce electricity in a stand-alone system, it may fit well as an additional component to a hybrid system in which other components can cover possible bumps in the production process.

Institutional

- Transmission interests and large electric utility interests may rely on political clout or financial assets to try to limit the expansion of hybrid energy systems development because they encourage more decentralized energy production.

Need for Hybrid System

Hybrid renewable energy systems (HRES) are becoming popular as stand-alone power systems for providing electricity in remote areas due to advances in renewable energy technologies and subsequent rise in prices of petroleum products. A hybrid energy system, or hybrid power, usually consists of two or more renewable energy sources used together to provide increased system efficiency as well as greater balance in energy supply.

A combination of different but complementary energy generation systems based on renewable energies or mixed, is known as a hybrid power system. It describes any power system that combines two or more energy conversion devices, or two or more fuels for the same device, that when integrated, overcome limitations inherent in either.

Hybrid systems capture the best features of each energy resource and can provide “grid-quality” electricity, with a power range between 1 kilowatt (kW) to several hundred kilowatts. They can be developed as new integrated designs within small electricity distribution systems (mini-grids) and can also be retrofitted in diesel-based power systems.

Hybrid systems can provide a steady community-level electricity service, such as village electrification, offering also the possibility to be upgraded through grid connection in the future. Furthermore, due to their high levels of efficiency, reliability and long-term performance, these systems can also be used as an effective backup solution to the public grid in case of blackouts or weak grids, and for professional energy solutions, such as telecommunication stations or emergency rooms at hospitals.

Many hybrid systems are stand-alone systems, which operate “off-grid” — not connected to an electricity distribution system. For the times when neither the wind nor the solar system are producing, most hybrid systems provide power through batteries and/or an engine generator powered by conventional fuels, such as diesel. If the batteries run low, the engine generator can provide power and recharge the batteries.

Adding an engine generator makes the system more complex, but modern electronic controllers can operate these systems automatically. An engine generator can also reduce the size of the other components needed for the system. Keep in mind that the storage capacity must be large enough to supply electrical needs during non-charging periods. Battery banks are typically sized to supply the electric load for one to three days.

Environmental Impacts of Renewable Energy Technologies

All energy sources have some impact on our environment. Fossil fuels—coal, oil, and natural gas—do [substantially more harm](#) than renewable energy sources by most measures, including air and water pollution, damage to public health, wildlife and habitat loss, water use, land use, and global warming emissions.

However, renewable sources such as wind, solar, geothermal, biomass, and hydropower *also* have environmental impacts, some of which are significant.

The exact type and intensity of environmental impacts varies depending on the specific technology used, the geographic location, and a number of other factors. By understanding the current and potential environmental issues associated with each renewable energy source, we can take steps to effectively avoid or minimize these impacts as they become a larger portion of our electric supply.

[Environmental Impacts of Wind Power](#)

Wind power generates electricity without toxic pollution or global warming emissions, but it does have some environmental impacts that should be recognized and mitigated.

Wind power

Harnessing power from the wind is one of the cleanest and most sustainable ways to generate electricity as it produces no toxic pollution or global warming emissions. Wind is also abundant, inexhaustible, and affordable, which makes it a viable and large-scale alternative to fossil fuels.

Despite its vast potential, there are a variety of environmental impacts associated with wind power generation that should be recognized and mitigated. They include land use issues and challenges to wildlife and habitat.

[Environmental Impacts of Solar Power](#)

The potential environmental impacts associated with solar power depend on the technology, which includes two broad categories: photovoltaic solar cells and concentrating solar thermal plants.

Like wind power, the sun provides a tremendous resource for generating clean and sustainable electricity.

The environmental impacts associated with solar power can include land use and habitat loss, water use, and the use of hazardous materials in manufacturing, though the types of impacts vary greatly depending on the scale of the system and the technology used—photovoltaic (PV) solar cells or concentrating solar thermal plants (CSP).

Environmental Impacts of Geothermal Energy

The environmental impacts of geothermal energy vary depending on the technology used to generate electricity and the type of cooling system utilized.

The most widely developed type of geothermal power plant (known as hydrothermal plants) are located near geologic “hot spots” where hot molten rock is close to the earth’s crust and produces hot water.

In other regions enhanced geothermal systems (or hot dry rock geothermal), which involve drilling into the earth’s surface to reach deeper geothermal resources, can allow broader access to geothermal energy.

Geothermal plants also differ in terms of the technology they use to convert the resource to electricity (direct steam, flash, or binary) and the type of cooling technology they use (water-cooled and air-cooled). Environmental impacts differ depending on the conversion and cooling technology used.

Biomass Resources in the United States

This analysis details the biomass resources that could be sustainably produced and utilized in the United States for energy and fuel, focusing on energy crops, agricultural residues, waste materials, and forest biomass.

Biomass for electricity

Biomass power plants share some similarities with fossil fuel power plants: both involve the combustion of a feedstock to generate electricity. Thus, biomass plants raise similar, but not identical, concerns about air emissions and water use as fossil fuel plants. However, the feedstock of biomass plants can be sustainably produced, while fossil fuels are non-renewable.

Sources of biomass resources for producing electricity are diverse, ranging from energy crops (like switchgrass), to agricultural waste, manure, forest products and waste, and urban waste. Both the type of feedstock and the manner in which it is developed and harvested significantly affect land use and life-cycle global warming emissions impacts of producing power from biomass.

Environmental Impacts of Hydroelectric Power

Hydroelectric power includes both massive hydroelectric dams and small run-of-the-river plants, both of which have associated environmental impacts.

Hydroelectric power includes both massive hydroelectric dams and small run-of-the-river plants. Large-scale hydroelectric dams continue to be built in many parts of the world (including China and Brazil), but it is unlikely that new facilities will be added to the existing US fleet in the future.

Instead, the future of hydroelectric power in the United States will likely involve increased capacity at current dams and new run-of-the-river projects. There are environmental impacts at both types of plants.

Environmental Impacts of Hydrokinetic Energy

Hydrokinetic energy includes wave and tidal power and encompasses an array of energy technologies, many of which are still in the experimental stages or in the early stages of deployment.

Hydrokinetic energy, which includes wave and tidal power, encompasses an array of energy technologies, many of which still in the experimental stages or in the early stages of deployment. While actual impacts of large-scale operations have not been observed, a range of potential impacts can be projected.

Despite these environmental impacts, renewable energy technologies compare extremely favorably to fossil fuels, and remain a core part of the [solution to climate change](#).

Ocean energy:

Wave energy:

What is Wave Energy?

Wave energy is a form of renewable energy that can be harnessed from the motion of the waves. There are several methods of harnessing wave energy that involve placing electricity generators on the surface of the ocean.

How Does Wave Energy Work?

Did you know that waves are actually caused by tides, which vary depending on the lunar cycles? That's right – you can blame the moon for those days of rough surf on the beach.

Depending on the lunar cycles, tides, winds, and weather, waves can vary in size and strength. As waves roll through the ocean, they create kinetic energy, or movement. This movement can be used to power turbines, which, in turn, create energy that can be converted into electricity and power. There are also several ways of harnessing wave energy that utilize the up and down motion of the waves to power pistons/turn generators.

What Makes Wave Energy a Renewable Energy Source?

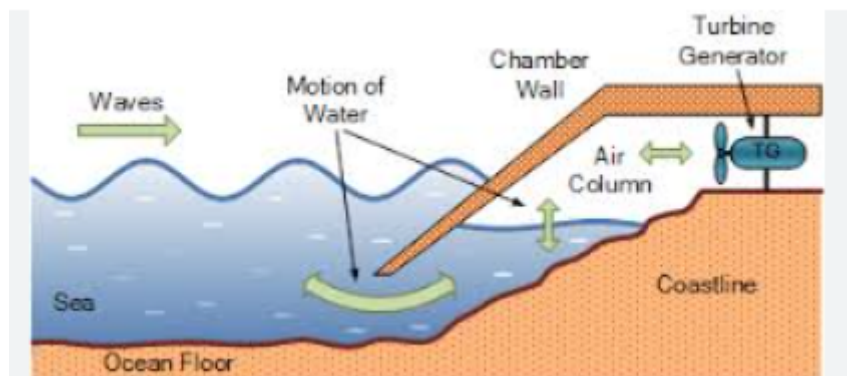
Similar to solar, wind, and geothermal energy, wave energy is a renewable source. As long as the Earth continues to track around the sun, and the moon around the Earth, waves will continue to be a viable source of kinetic energy. Wave energy also produces fewer carbon emissions than energy from traditional fossil fuels, such as coal or oil, making it a more **eco-friendly option**.

What's the Catch with Wave Energy?

One of the bigger roadblocks to wave energy is that most wave energy systems are fairly small, and aren't suitable for powering large buildings or structures.

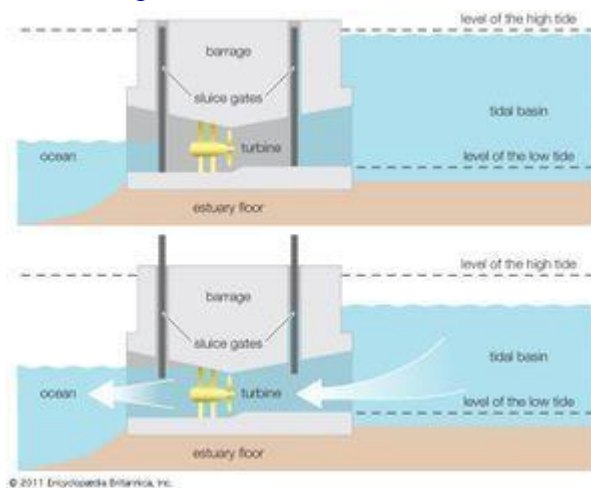
Another problem with wave energy is that, similar to solar or wind power, the amount of energy that can be harnessed is contingent upon the size of the waves at any given time. Variable factors that go into wave energy include the wave height, wave speed, wavelength, and wave density – all of which can be unpredictable.

As technologies develop, scientists and experts are looking at ways to harness more power from waves and the ocean.



Tidal energy:

Tidal power, any form of [renewable energy](#) in which [tidal action](#) in the [oceans](#) is converted to [electric power](#).



There are a number of ways in which tidal power can be harnessed. Tidal [barrage](#) power systems take advantage of differences between [high tides](#) and [low tides](#) by using a “barrage,” or type of [dam](#), to block receding [water](#) during ebb periods. At low [tide](#), water behind the barrage is released, and the water passes through a [turbine](#) that generates [electricity](#).

Tidal stream power systems take advantage of [ocean currents](#) to drive turbines, particularly in areas around [islands](#) or coasts where these currents are fast. They can be installed as tidal

fences—where turbines are stretched across a channel—or as tidal turbines, which resemble underwater wind turbines (see [wind power](#)). (See also [wave power](#).)

Electricity generation potential

Many tidal power technologies are not available at an industrial scale, and thus tidal energy contributes a negligible fraction of global [energy](#) today. There is, however, a large potential for its use, because much usable energy is contained in water currents. The total energy contained in [tides](#) worldwide is 3,000 gigawatts (GW; billion [watts](#)), though estimates of how much of that energy is available for power generation by tidal [barrages](#) are between 120 and 400 GW, depending on the location and the potential for conversion. By comparison, a typical new [coal](#)-based generating plant produces about 550 megawatts (MW; million watts). Although total global electricity [consumption](#) approached 21,000 terawatt-hours in 2016 (one terawatt [TW] = one trillion watts), energy experts speculate that fully built-out tidal power systems could supply much of this demand in the future. Estimates of tidal stream power—which uses [ocean](#) currents to drive underwater blades in a manner similar to wind power generation—in shallow water is capable of generating some 3,800 terawatt-hours per year.

Environmental concerns raised about tidal power stations are largely focused on the tidal barrage systems, which can disrupt estuarine ecosystems during their construction and operation. Tidal fences and [turbines](#) are expected to have minimal impact on ocean [ecosystems](#). Tidal fences do have the potential to injure or kill migratory [fish](#), however, but these structures can be designed to minimize such effects.

Ocean thermal energy conversion

OTEC is a way of getting useful [energy](#) from the world's [oceans](#). The [sun](#) shines on the oceans of the world and in the hot parts near the water at the sea's surface can be quite warm, sometimes as high as 30°C.

Many oceans are very deep and the water at depths of 1,000 meters can be around 5 °C.

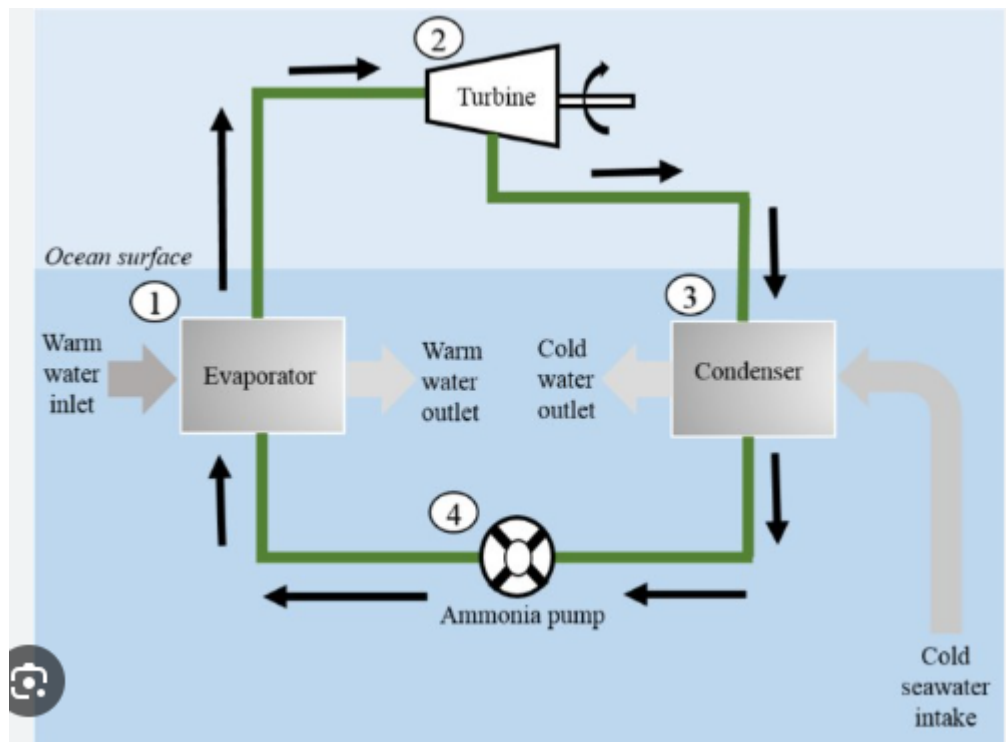
If a pipe is put down into the ocean we can bring the cold water to the surface where we also have warm water available.

The difference in [temperature](#) between the warm surface water and the cold deep water may only be around 15 °C. But we can build a [machine](#) called a [heat engine](#), which can use this difference to generate power that can be used by people that live in that place. A machine which can do this is called an OTEC machine which stands for *ocean thermal energy conversion*.

Because the difference in temperature is small we will need to get large quantities of warm and cold water to go through the machine to get a useful amount of work, but large quantities are available in the ocean.

It has been estimated that OTEC could give amounts of energy that are 10 to 100 times greater than the other ocean energy source, [wave power](#).

OTEC can also supply quantities of cold water as a by-product. This can be used for [refrigeration](#) and can help crops and fish grow. OTEC can also produce large amounts of salt-free water, which can be useful on mid-ocean islands as [drinking water](#).



Hydel energy:

Hydropower is one of the cheapest ways to generate electricity and is used by more than 60 countries worldwide, meeting half of their electricity demand. It also provides the added benefits of being a clean energy source, providing energy ‘on demand’ and creating thousands of jobs across the globe.

What is hydropower?

Hydropower is energy generated from water sources like the ocean, waterfalls and rivers. Because water constantly moves through a global cycle, it’s movement can be harnessed to generate electricity or to drive machinery. Because water is an infinite resource, its cycle provides an endless recharging system, making it a renewable energy source.

There are several types of hydropower facilities and they’re all powered by the movement of flowing water. Turbines and generators are used to convert the water’s kinetic energy into electricity, which is then fed into the electric grid to supply homes, businesses and industries. A new technology called microhydro is increasingly being used in remote areas to power homes and businesses. The technology makes it possible for small holdings to generate their own energy, independent from large hydropower plants. Microhydro uses smaller water flows to run small generators that produce enough energy to power a home, or run on-site equipment.

How does hydropower work?

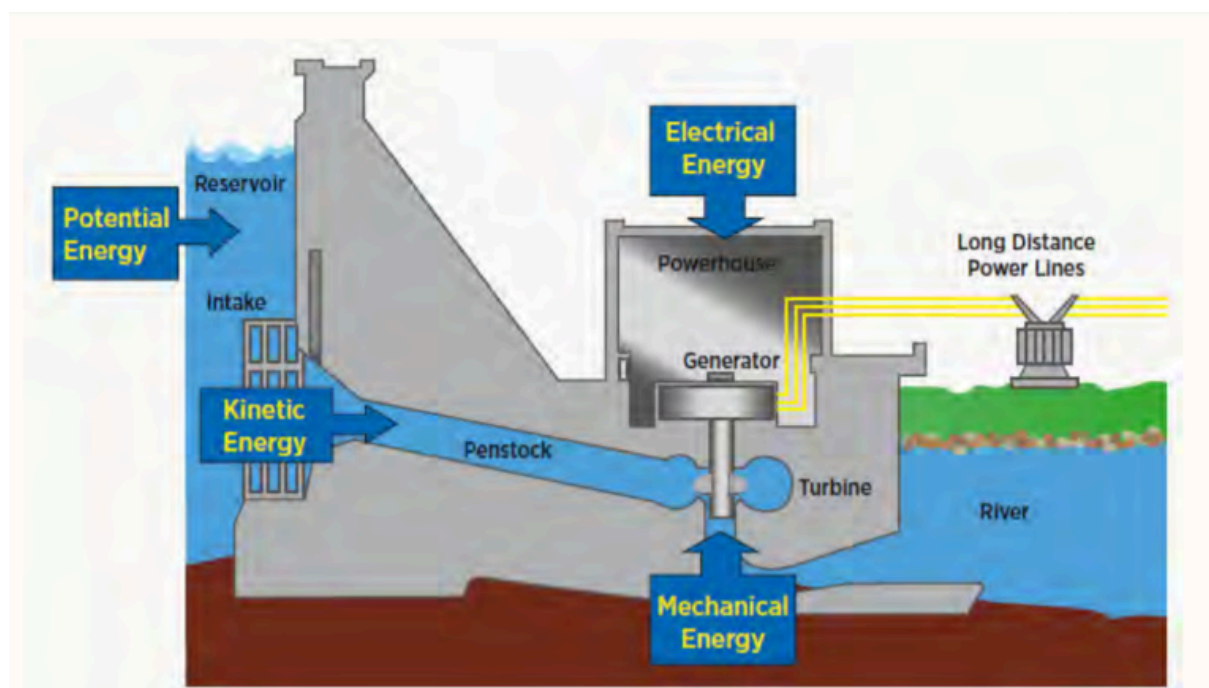
Hydropower works by harnessing the energy that comes from the flow of water through a turbine connected to a generator, thus turning it into electricity. Most hydropower plants store

water in a dam, which is controlled by a gate or valve to measure the amount of water that flows out. The greater the elevation of the dam, the more energy can be generated.

Just before the water flows over the dam, it gains potential energy, which is converted into kinetic energy as it flows downhill. The water is used to turn a turbine, which is connected to an electric generator that distributes the power to the end users.

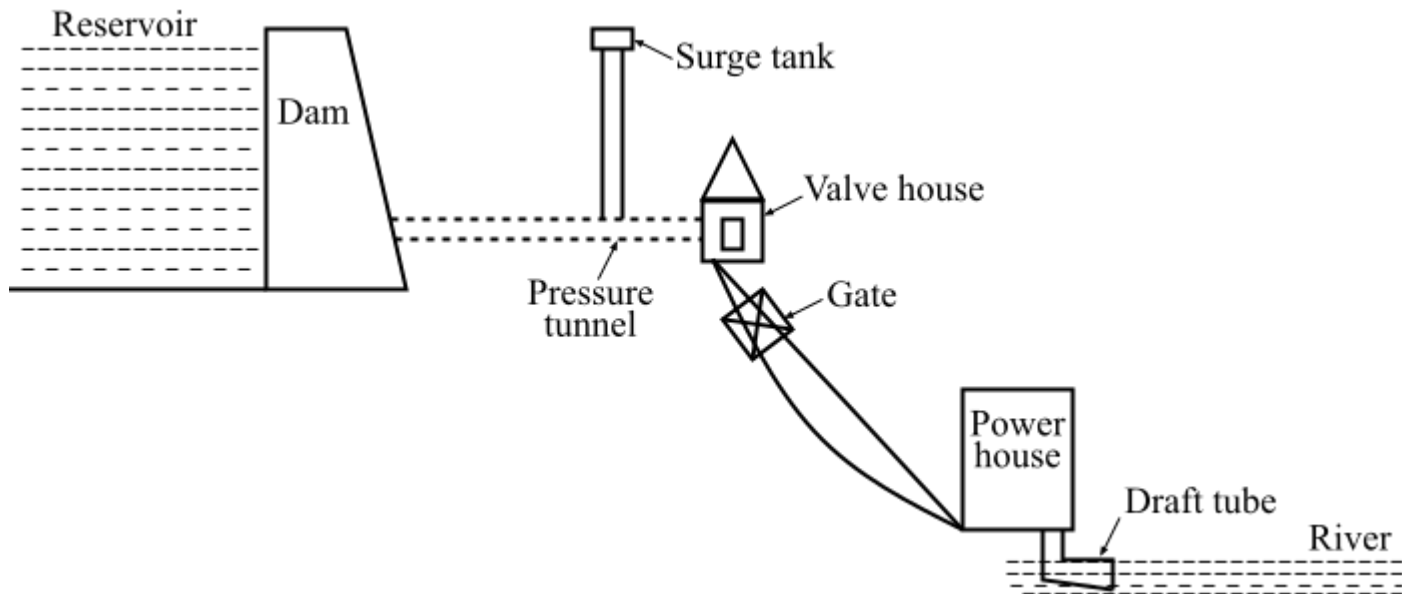
There are four main types of hydropower facilities:

1. **Impoundment** – The most common type of hydropower facility is impoundment, which makes use of a reservoir. The water is stored in the reservoir and when released, it's channelled through a turbine. The turbine spins, which then activates a generator that produces electricity. The reservoir itself doesn't need to be large, as is the case with microhydro facilities.
2. **Pumped storage** – This method works in a similar way to impoundment, except two reservoirs are used to harness the movement of the water. The reservoirs are situated at different elevations and provide electricity 'on demand'.
3. **Run-of-the-river** – This type of facility is used for smaller-scale power generation. As water flows down a river, it turns a turbine in a similar way to a dam. The turbine is connected to a generator and the electricity is then distributed. To be effective, this method requires a river that has a constant stream of water.
4. **Tidal power** – This method uses the flow of water from the sea to generate energy. Because tides have predictable movements, large amounts of energy can be generated from tidal facilities twice a day.



Schematic Diagram and Working of Hydroelectric Power Plant

A hydroelectric power plant simply involves the conversion of hydraulic energy of falling water into electrical energy. For the proper and efficient working, the hydroelectric power plant has many arrangements. A schematic diagram of a typical hydroelectric power plant is shown in the figure.



- In a hydroelectric power plant, the dam is constructed across a river or lake. Water from the catchment area collects at the back of the dam to form a *reservoir*.
- A pressure tunnel is formed between the reservoir and the valve house and water is brought to the valve house at the start of the penstock (a *penstock* is huge steel pipe which carries water from valve house to the turbine).
- The valve house contains *main sluice valves* which control the water flow to the power house and *automatic isolating valves* which cut off supply of water when the penstock bursts.
- Water from the valve house is taken to the water turbine through the penstock. Now, the water turbine converts the hydraulic energy of falling water into mechanical energy. The turbine drives an alternator which converts the mechanical energy of the turbine into electrical energy.
- In a hydroelectric power plant, a surge tank, which is open from the top, is also built just before the valve house. The surge tank protects the penstock from bursting in case the turbine gates suddenly close due to electrical load being thrown off. When the turbine gates close, there is a sudden stopping of water at the lower end of the penstock which can burst the penstock. The surge tank absorbs these pressure swings (i.e. water surges) by increasing its water level.

Is hydropower renewable?

Hydropower is a renewable energy because it uses the earth's natural water cycle to generate electricity. No direct emissions are released into the atmosphere during the process, so it's considered a clean form of energy generation.

However, no process that disrupts the natural balance of ecosystems is without its negative impact. For example, some consider the large volumes of water stored in hydropower plants controversial due to the global water shortage.

Hydropower can also block the migration of fish to their spawning grounds. This often results in the decline of the number of fish in rivers and in some cases, can cause extinction of species.

There's also the argument that vegetation gets trapped in reservoirs and releases carbon dioxide and methane, which contributes to global warming.

How is hydropower used?

Hydropower is used to provide homes and businesses with electricity. It's also used to power machinery. Traditionally, hydropower was used to drive mills to grind grain.

Nowadays, with the right terrain and financing, hydropower systems can be set up to generate electricity for homes and businesses in rural locations. Homeowners and businesses can also make use of government tariffs and agreements and sell the energy they don't use back to the grid.

As well as generating energy, the reservoirs created at hydropower plants provide recreational opportunities like boating, swimming and fishing. They can also be used to provide water supply, flood control and irrigation.

What effects does hydropower have on the environment?

The impact that a hydropower project has on the environment depends on its size. A small-scale run-of-the-river project will have less of an impact than a larger impoundment project.

There are other variables that can impact hydropower projects like the type of technology being used and how much additional infrastructure is required in the surrounding area.

Of course, every hydropower project requires careful planning and adherence to best practices and compliance. Although the development of hydro sites does require some disruption to the environment, the process is carefully monitored.

Site Selection for Hydroelectric Power Plant

The following factors should be considered while selecting the site for a hydroelectric power plant –

- **Availability of Water** – Since water is the main requirement for a hydroelectric power plant. Hence, the hydroelectric power plant should be built at a place a huge amount of water is available at a good head.
- **Storage of Water** – The site selected for the hydroelectric power plant should provide adequate facilities for constructing a dam and storage of water to ensure the generation of power throughout the year.
- **Type and Cost of Land** – The bearing capacity of the land should be adequate so that heavy equipment can be installed. Also, the land for the construction of the hydroelectric power plant should be available at reasonable price.
- **Transportation Facilities** – A hydroelectric power plant requires transportation of equipment and machinery. Therefore, the site selected for the power plant should be well connected to other parts of the country by rail, road, etc.

Advantages of Hydroelectric Power Plant

The following are the primary advantages of a hydroelectric power plant –

- Water is used for the generation of electrical energy. Therefore, it requires no fuel.
- No smoke and ash is produced, hence it is quite neat and clean.
- As water is the source of energy which is available free of cost. Thus, the hydroelectric power plant requires very small running cost.
- Hydroelectric power plant is simple in construction and requires less maintenance.
- Hydroelectric power plant is robust and has a longer life.
- The hydroelectric power plants can be put into service instantly, i.e. it does not require a long starting time.
- Apart from the generation of electrical energy, the hydroelectric power plants also help in irrigation and controlling floods.

Disadvantages of Hydroelectric Power Plant

The disadvantages of the hydroelectric power plants are listed below –

- The capital cost of the hydroelectric power plants is high because it involves the construction of dam.
- There is uncertainty about the availability of water because it depends upon the weather conditions.
- In case of hydroelectric power plant, the cost of transmission lines is high because the power plant is located in hilly area which are quite away from the load centres.
- For the construction of hydroelectric power plants, skilled and experienced personals are required.

Wind energy:

What is wind energy

Wind energy is energy obtained from the force of the wind. Through a wind turbine that transforms the kinetic energy of air currents into electrical energy. The energy is mainly extracted with the rotor, which transforms the kinetic energy into mechanical energy, and with the generator, which transforms this mechanical energy into electrical energy. We are talking about a [renewable](#), efficient, mature and secure energy that is key to the [energy transition](#) and the [decarbonisation](#) of the economy.

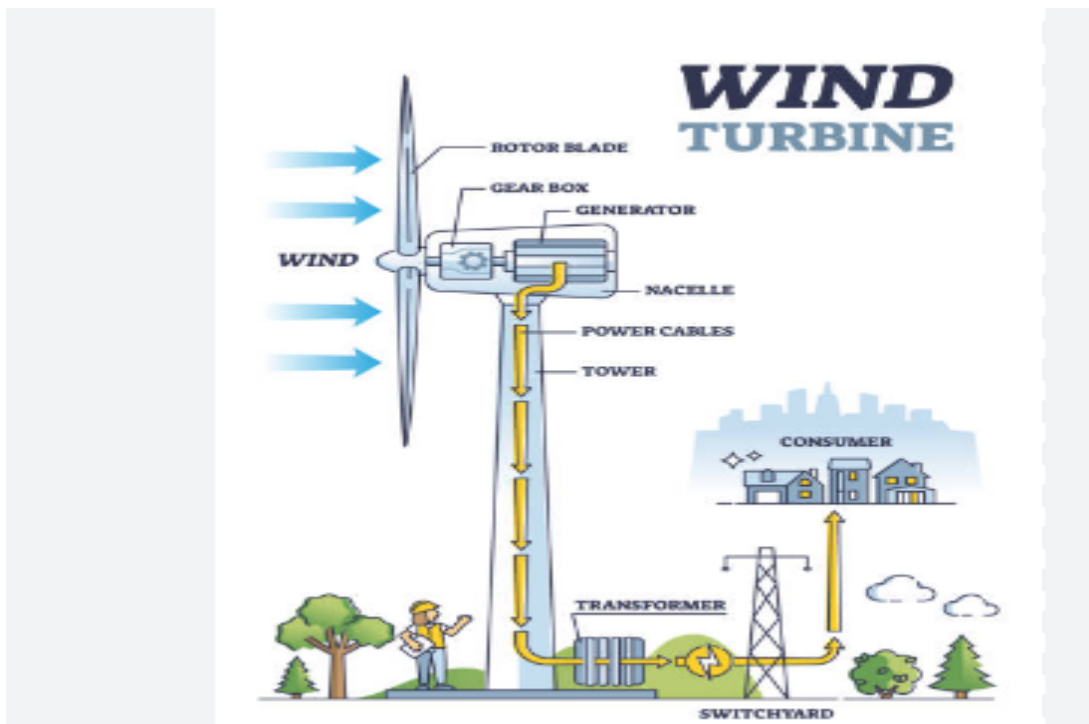
Wind Turbines

As we have already mentioned, in order to utilise the kinetic energy of the wind and convert it into electrical energy, it is necessary to use a wind turbine. The optimal use of these *giants*, (they are usually between 80 and 120 metres high) depends on the strength of the wind. For this reason, **wind farms, which pool a large number of wind turbines and make it possible to obtain this energy in large quantities, must be set up in places where windy conditions are predominant.**

The wind turbines have to be oriented in the direction of the wind, which is done by means of a vane on the nacelle. From there, the force of the air currents will **set the three main parts of the wind turbine in motion:**

- **The rotor:** composed of three [blades](#) and the bushing that joins them together, its function is to capture the force of the wind and convert it into mechanical rotational energy.
- **The multiplier:** connected to the engine by means of a shaft, its function is to increase the rotational speed from 30 revolutions per minute (rpm) to 1500 rpm.
- **The generator:** this element is responsible for converting the mechanical energy of rotation into electrical energy.

Each of the wind turbines that make up a wind farm are **linked together by underground cables that carry the electricity to a transformer substation.** From there it is transported to homes, factories or schools, among other recipients, through the distribution networks of the various electricity companies.



The terms "wind energy" and "wind power" both describe the process by which the wind is used to generate mechanical power or electricity. This mechanical power can be used for specific tasks (such as grinding grain or pumping water) or a generator can convert this mechanical power into electricity.

A wind turbine turns wind energy into electricity using the aerodynamic force from the rotor blades, which work like an airplane wing or helicopter rotor blade. When wind flows across the blade, the air pressure on one side of the blade decreases. The difference in air pressure across the two sides of the blade creates both lift and drag. The force of the lift is stronger than the drag and this causes the rotor to spin. The rotor connects to the generator, either directly (if it's a direct drive turbine) or through a shaft and a series of gears (a gearbox) that speed up the rotation and allow for a physically smaller generator. This translation of aerodynamic force to rotation of a generator creates electricity.

Types of Wind Turbines

Horizontal-axis wind turbines:

Horizontal-axis wind turbines are what many people picture when thinking of wind turbines.

Most commonly, they have three blades and operate "upwind," with the turbine pivoting at the top of the tower so the blades face into the wind.

Vertical-axis wind turbines :

Vertical-axis wind turbines come in several varieties, including the eggbeater-style Darrieus model, named after its French inventor.

These turbines are omnidirectional, meaning they don't need to be adjusted to point into the wind to operate.

Advantages of wind energy:

- ☐ No pollution.
- ☐ One of the cleanest forms of energy
- ☐ Doesn't disrupt farmland operations.
- ☐ Don't produce atmospheric emission like acid rains and green house effects.

Disadvantages of wind energy:

- ☐ Dangerous to wild life. Many birds are killed when flying into the blades of the rotor.
- ☐ It is noisy.
- ☐ It is expensive. Initial cost is high.
- ☐ It is unreliable or unpredictable.

Biomass Energy:

Biomass can be defined as any organic material or waste that contains chemical building blocks like carbon, hydrogen, and other components that are vital to our modern energy and materials economy. Biomass is the single largest supply of carbon on planet earth and is a sustainable and renewable source for the products that are currently made from petroleum. Here's how it goes from waste to watts.

Trees and plants absorb energy from the sun through photosynthesis. The energy is trapped inside until the organic material is converted into other products that are used as sources of energy and materials.

There are several kinds of biomass such as agricultural residues, purpose-grown energy crops, and wood.

For hundreds of thousands of years, humans have used wood, or charcoal made from wood, for fuel to heat homes and cook food.

To make bioenergy from wood, scraps or sawdust can be collected from farms and forestry manufacturers. There are several ways to convert biomass into usable energy. It can even be turned into fuels to power cars, trucks, and airplanes

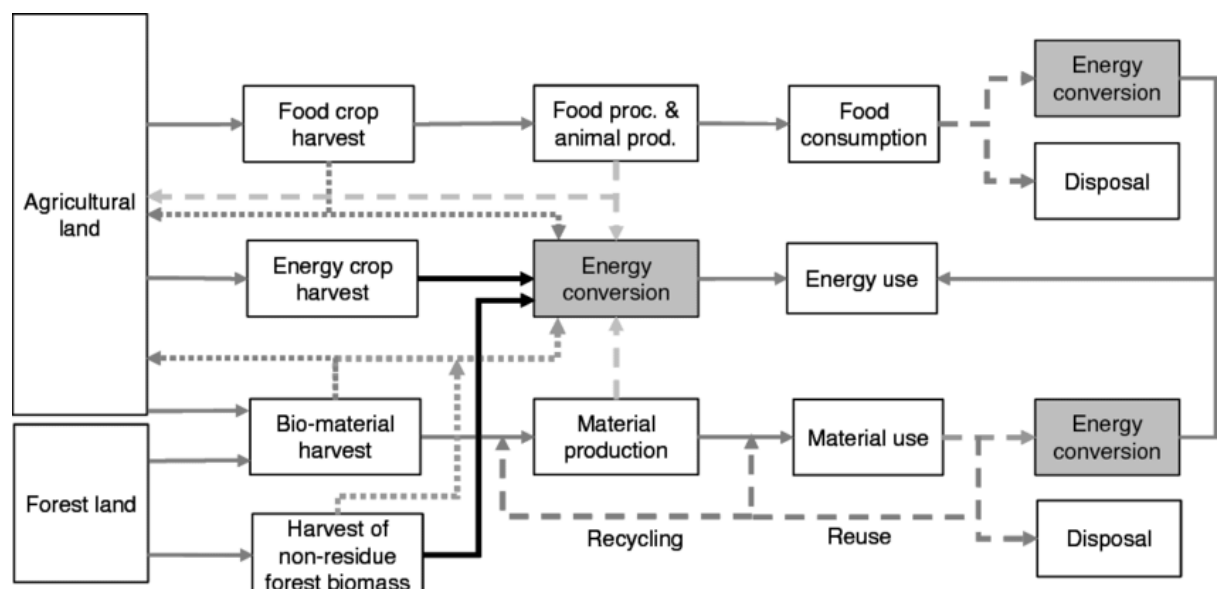
To make fuels, wood is converted first to an intermediary gas or liquid that can be upgraded to make a final product such as gasoline, diesel, and jet fuel. It's almost like putting a tree trunk in your gasoline tank!

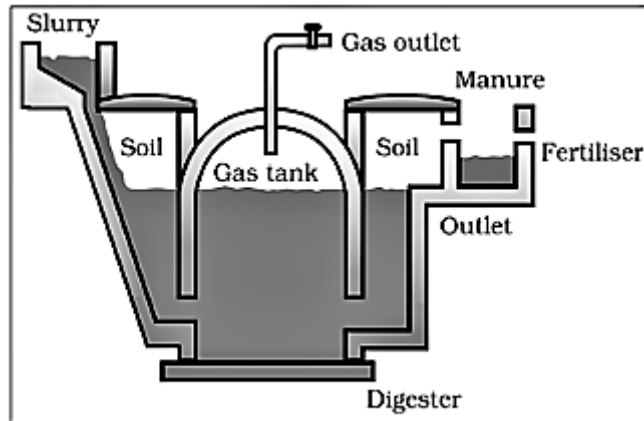
Biomass also includes wastes, and there are processes that work for many types of waste biomass, like animal waste. Manure from farm animals, mostly cows, is put into a big tank called a digester. Like your own gut, a digester has bacteria that eats waste and turns it into methane gas. The methane is burned to heat water, and the water creates steam, the steam creates pressure that spins a rotor inside a turbine, the turbine powers a generator and the generator produces electricity.

Methane can also be captured from landfills. When biomass decomposes it emits a gaseous product called bio-gas. Bio-gas is rich in methane and after some cleanup and upgrading, the methane gas can be captured and burned in the same process to make electricity or to heat your home and cook your food.

Biomass can also be used to make products like polymers and plastics that are made from renewable sources of carbon and are either recyclable or biodegradable. This will help solve the problem of plastic waste.

Yes, biomass isn't so glamorous, but it is a clean, renewable source of energy and materials that are essential to our modern society.





Schematic diagram of a bio-gas plant

What is Biomass?

A renewable energy source that comes from living or recently living creatures is called biomass. It is created by biological systems' metabolic processes (those of plants and animals) and/or by the byproducts of those systems' breakdown or conversion. These materials' chemical and energy worth is dependent on the bonds between carbon atoms and hydrogen atoms. Utilizing biomass energy significantly minimizes our reliance on outside energy sources. It improves national security and offers a wider variety of fuel. Biomass can be utilized as an energy source directly by being burned to produce heat or indirectly by being transformed into different types of biofuel.

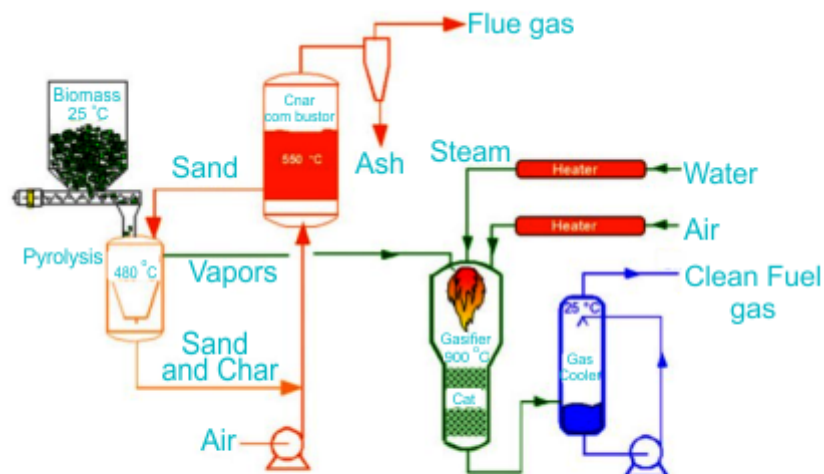


Fig : Biomass energy diagram

Biomass power plants

The major source of renewable energy on Earth, biomass, is gaining popularity. The combustion of plant or animal matter to produce energy and heat is known as biomass. As opposed to fossil fuels,

this method of energy generation has the main advantage of using an unlimited resource because it is produced in an environmentally friendly manner.

Biomass can be converted to energy in different ways

Biomass is converted to energy through various processes, including:

- Direct combustion (burning) to produce heat
- Thermochemical conversion to produce solid, gaseous, and liquid fuels
- Chemical conversion to produce liquid fuels
- Biological conversion to produce liquid and gaseous fuels

Direct combustion is the most common method for converting biomass to useful energy. All biomass can be burned directly for heating buildings and water, for providing industrial process heat, and for generating electricity in steam turbines.

Thermochemical conversion of biomass includes *pyrolysis* and *gasification*. Both processes are thermal decomposition processes wherein biomass feedstock materials are heated in closed, pressurized vessels called *gassifiers* at high temperatures. The processes mainly differ in the temperatures and in the amount of oxygen present during conversion.

- [Pyrolysis](#) entails heating organic materials to between 800° F and 900° F (400° C and 500° C) in the nearly complete absence of free oxygen. Biomass pyrolysis produces fuels such as charcoal, bio-oil, [renewable diesel](#), methane, and hydrogen.
- [Hydrotreating](#) is used to process bio-oil (produced by *fast pyrolysis*) with hydrogen under elevated temperatures and pressures in the presence of a catalyst to produce renewable diesel, renewable gasoline, and renewable jet fuel.
- [Gasification](#) entails heating organic materials to between 1,400° F and 1,700 F (800° C and 900° C) with injections of controlled amounts of free oxygen or steam into the vessel to produce a carbon monoxide- and hydrogen-rich gas called synthesis gas or *syngas*. Syngas can be used as a fuel for diesel engines, for heating, and for generating electricity in gas turbines. It can also be treated to separate the hydrogen from the gas, and the hydrogen can be burned or [used in fuel cells](#). The syngas can be further processed to produce liquid fuels using the [Fischer–Tropsch process](#).

A chemical conversion process known as *transesterification* is used for converting vegetable oils, animal fats, and greases into fatty acid methyl esters (FAME) to produce [biodiesel](#).

Biological conversion of biomass includes fermentation to make [ethanol](#) and anaerobic digestion to produce [biogas](#). Ethanol is used as a vehicle fuel. Biogas, also called *biomethane* or *renewable natural gas*, is produced in anaerobic digesters at sewage treatment plants and at dairy and livestock operations. It also forms in and may be captured from solid waste landfills. Properly treated renewable natural gas has the same uses as fossil fuel natural gas.

Components of Biomass

- o Equipment for managing and storing fuel.
- o Pumps; Combustor/furnace
- o Boiler;
- o Fans.
- o Steam engine.
- o The generator
- o The condenser.
- o Refrigerating tower
- o Controls for emissions and exhaust.
- o System settings (automated).

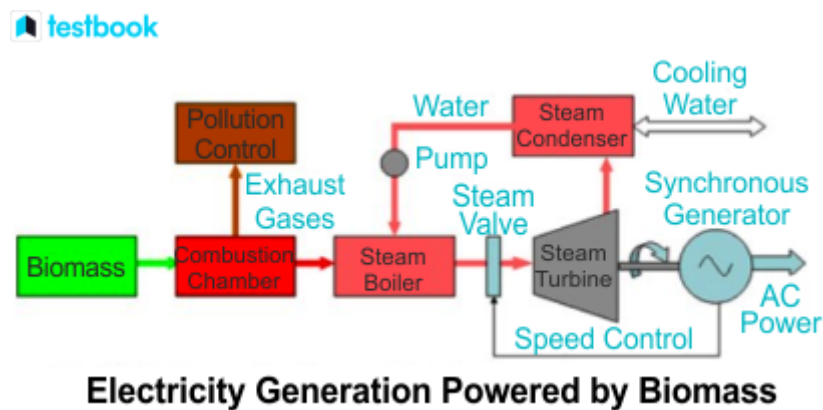


Fig : Components of Biomass

Working of Biomass plant

A biomass plant is a construction that burns organic waste, to produce electricity or heat. Steam is created during combustion, and this steam powers a turbine to provide energy. Because the carbon dioxide generated during the burning process is balanced by the carbon absorbed during the growth of the organic materials used as fuel, biomass plants are regarded as renewable energy sources. Certain types of biomass feedstocks, nevertheless, raise questions regarding their environmental impact and long-term viability.

Biomass Power Generation modes

Biomass energy can be converted to useful power i.e., Electricity using the following techniques

- o Combustion
- o Gasification Combustion
- o Mixed Burning
- o Gasification Mixed burning Combustion

Biomass gasification

The word gasification implies converting a solid or liquid into a gaseous fuel without leaving any solid carbonaceous residue.

Biomass Gasifier: It is an equipment which can gasify a variety of biomass such as wood waste, agricultural waste like stalks, and roots of various crops, maize crops, etc. The gasifier is essentially a chemical reactor where various complex physical and chemical processes take place. Biomass gets dried, heated, pyrolyzed, partially oxidized, and reduced, as it flows through it.

The gas produced in the gasifier is a clean burning fuel having a heating value of about **950-1200 kcal/m³**. Hydrogen (**18-20%**), and carbon monoxide (**18- 24%**) are the main constituents of the gas.

Methods of converting biomass into useful forms of energy can be broadly classified as:

- o Biochemical and
- o Thermochemical

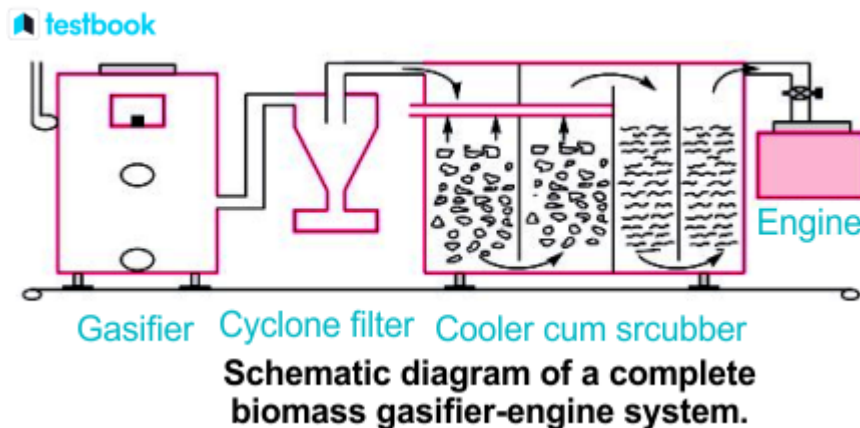


Fig : Biomass gasification diagram

In some cases the gasifiers can be installed without any heat recovery system. In special cases, the gasifier systems can have recovery in the form of hot water.

Energy conversion from Biomass

As biomass energy is a renewable source and not mostly used we can instead have some possible conversions as follows.

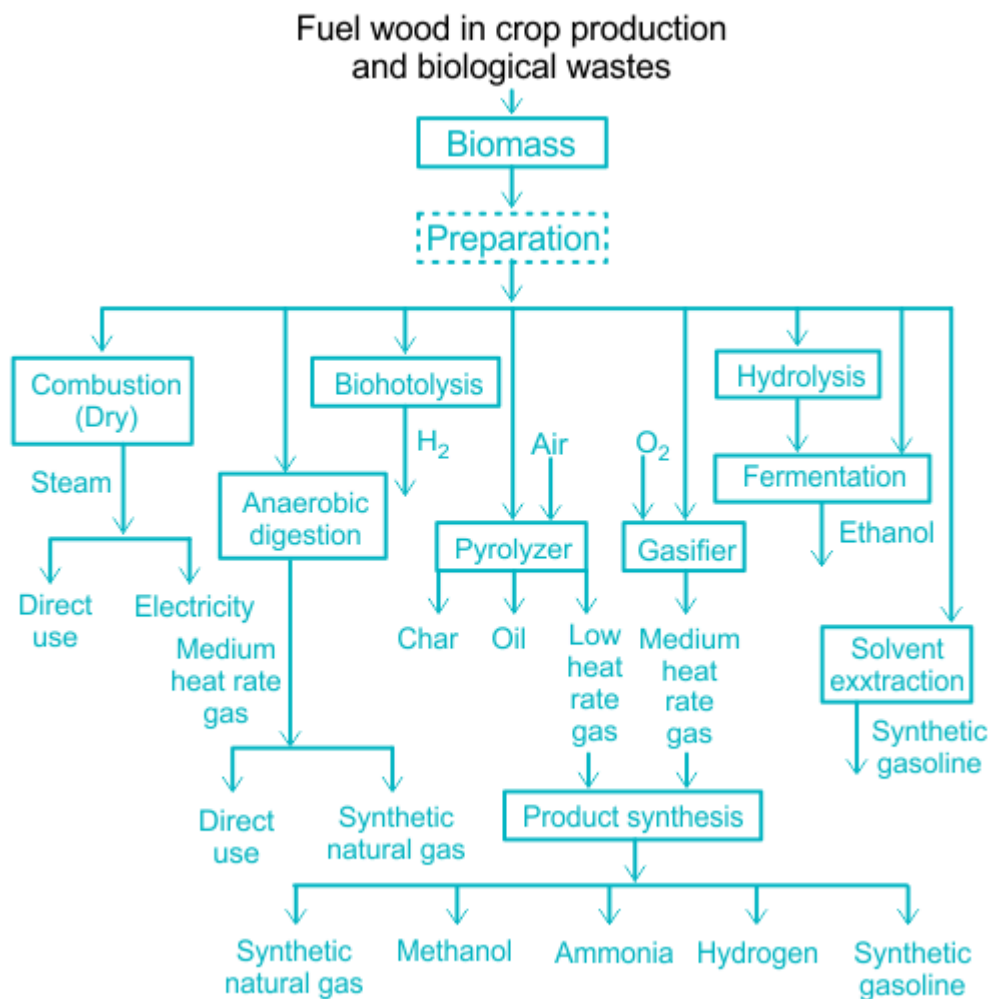


Fig: Energy conversion from Biomass

Advantages and Disadvantages of Biomass

Till now we have studied the concepts related to biomass let's have an overview of biomass energy advantages and disadvantages

Advantages of Biomass Energy

- o Its a type of recycled fuel, and the left-out waste and emitted products can be used as manure,
- o The running cost of the plant is less, we can even be operated easily.
- o The power obtained from Biomass is Reliable and domestically produced, it is economically competitive and sustainable.
- o It minimizes the costs involved with waste disposal,
- o It helps in providing opportunity in rural areas

Disadvantages of biomass

- o It is comparatively inefficient when compared to fossil fuels
- o The combustion of Biomass fuel requires a lot of space and creates smells.
- o It may be harmful to the environment sometimes when the bacteria comes out
- o High investment and maintenance cost

Hydrogen Energy:

Hydrogen is a clean fuel. It is an energy carrier that can be used for a broad range of applications. Also it could serve as a possible substitute to liquid and fossil fuels. Its physical properties could be stated as following. At standard temperature and pressure, hydrogen is a nontoxic, nonmetallic, odorless, tasteless, colorless, and highly combustible diatomic gas with the molecular formula H_2 .

Occurrence and storage

Speaking of its natural occurrence, it is the most abundant element in the universe. The sun and other stars are composed largely of hydrogen. Astronomers estimate that 90% of the atoms in the universe are hydrogen atoms. Hydrogen is a component of more compounds than any other element. Water is the most abundant compound of hydrogen found on earth.

Molecular hydrogen is not available on Earth in convenient natural reservoirs. Most hydrogen on Earth is bonded to oxygen in water and to carbon in live or dead and/or fossilized biomass. It can be created by splitting water into hydrogen and oxygen. Water is again formed, when hydrogen is used.

On the other hand, its preparation could be done by breaking the chemical bonds from compounds. A few common methods include electrolysis, from steam and hydro carbon or carbon, reaction of metals with acids, ionic metal hydrides with water, etc. Currently, global hydrogen production is 48% from natural gas, 30% from oil, and 18% from coal; water electrolysis accounts for only 4%.

Its storage is important because it has wide range of applications. They range from stationary power, portable power to transportation, etc. Also it has the highest energy per mass of any fuel. However, its low ambient temperature density results in a low energy per unit volume, therefore requiring the development of advanced storage methods that have potential for higher energy density.

Hydrogen can be stored physically as either a gas or a liquid. Storage of hydrogen as a gas typically requires high-pressure tanks (350–700 bar [5,000–10,000 psi] tank pressure). Storage of hydrogen as a liquid requires cryogenic temperatures because the boiling point of hydrogen at one atmosphere pressure is $-252.8^{\circ}C$. Hydrogen can also be stored on the surfaces of solids (by adsorption) or within solids (by absorption).

Hydrogen as a fuel

Hydrogen is considered an alternative fuel. It is due to its ability to power fuel cells in zero-emission electric vehicles, its potential for domestic production, and the fuel cell's potential for high efficiency. In fact, a fuel cell coupled with an electric motor is two to three times more efficient than an internal combustion engine running on gasoline. Hydrogen can

also serve as fuel for internal combustion engines. The energy in 2.2 pounds (1 kilogram) of hydrogen gas contains about the same as the energy in 1 gallon (6.2 pounds, 2.8 kilograms) of gasoline.

Hydrogen energy systems involve several key components and processes, including production, storage, transportation, and utilization. Here's an overview of each:

1. **Production:** Hydrogen can be produced through various methods:

- **Electrolysis:** In this process, water (H_2O) is split into hydrogen (H_2) and oxygen (O_2) using electricity. Renewable energy sources such as solar or wind power can be used to generate the electricity needed for electrolysis, making it a clean and sustainable method.
- **Steam Methane Reforming (SMR):** This is the most common method of industrial hydrogen production. It involves reacting methane (CH_4), typically obtained from natural gas, with steam at high temperatures to produce hydrogen and carbon monoxide. The hydrogen is then separated and purified.
- **Biomass Gasification:** Biomass, such as agricultural or forestry residues, can be converted into hydrogen-rich gas through a process called gasification. The gas can then be purified to extract hydrogen.
- **Thermochemical Water Splitting:** High-temperature processes can be used to split water into hydrogen and oxygen without the need for electricity. These processes typically involve the use of heat from sources like concentrated solar energy or nuclear reactors.

2. **Storage:** Hydrogen is typically stored in one of three forms:

- **Compressed Hydrogen:** Hydrogen gas is compressed and stored in high-pressure tanks.
- **Liquid Hydrogen:** Hydrogen is cooled to very low temperatures ($-253^{\circ}C$) to liquefy it, allowing for more compact storage.
- **Hydrogen Chemical Storage:** Hydrogen can be chemically stored in materials such as metal hydrides or ammonia, which release hydrogen when needed.

3. **Transportation:** Once produced and stored, hydrogen needs to be transported to where it will be used. This can be done via pipelines, similar to natural gas transportation, or through trucks, ships, or railcars.

4. **Utilization:** Hydrogen can be used in various applications, including:

- **Fuel Cells:** Hydrogen fuel cells combine hydrogen with oxygen from the air to produce electricity, heat, and water. Fuel cells are used to power vehicles, provide backup power for buildings, and even generate electricity for grid applications.
- **Combustion:** Hydrogen can be burned in internal combustion engines or gas turbines to produce mechanical power or electricity. The only byproduct of hydrogen combustion is water vapor, making it a clean fuel option.
- **Industrial Processes:** Hydrogen is used in industries such as refining, chemical production, and food processing as a feedstock or reducing agent.

Potential Applications

- Production of electricity, heat and water for various end uses
- Industrial applications
- Vehicular transportation
- Residential applications
- Commercial applications, including in telecom towers for providing back-up power

Advantages and disadvantages of Hydrogen fuel cells

- **It is readily available.** It is a basic earth element and is very abundant. However, it is time consuming to separate hydrogen gas from its companion substances. While that may be the case, the results produce a powerful clean energy source.
- **It doesn't produce harmful emissions.** When it is burned, it doesn't emit harmful substances. Basically, it reacts with oxygen without burning and the energy it releases can be used to generate electricity used to drive an electric motor. Also, it doesn't generate carbon dioxide when burnt, not unlike other power sources.
- **It is environmentally friendly.** It is a non-toxic substance which is rare for a fuel source. Others such as nuclear energy, coal and gasoline are either toxic or found in places that have hazardous environments. Because hydrogen is friendly towards the environment, it can be used in ways that other fuels can't even possibly match.
- **It can be used as fuel in rockets.** It is both powerful and efficient. It is enough to provide power for powerful machines such as spaceships. Also, given that it is environmentally friendly, it is a much safer choice compared to other fuel sources. A fun fact: hydrogen is three times as powerful as gasoline and other fossil fuels. This means that it can accomplish more with less.
- **It is fuel efficient.** Compared to diesel or gas, it is much more fuel efficient as it can produce more energy per pound of fuel. This means that if a car is fueled by hydrogen, it can go farther than a vehicle loaded with the same amount of fuel but using a more traditional source of energy. Hydrogen-powered fuel cells have two or three times the efficiency of traditional combustion technologies. For example, a conventional combustion-based power plant usually generates electricity between 33 to 35 percent efficiency. Hydrogen fuel cells are capable of generating electricity of up to 65 percent efficiency.
- **It is renewable.** It can be produced again and again, unlike other non-renewable sources of energy. This means that with hydrogen, you get a fuel source that is limited. Basically, hydrogen energy can be produced on demand.

Disadvantages

- **It is expensive.** While widely available, it is expensive. A good reason for this is that it takes a lot of time to separate the element from others. If the process were really

simple, then a lot would have been doing it with relative ease, but it's not. Although, hydrogen cells are now being used to power hybrid cars, it's still not a feasible source of fuel for everyone. Until technology is developed that can make the whole process a lot more simpler, then hydrogen energy will continue to be an expensive option.

- **It is difficult to store.** Hydrogen is very hard to move around. When speaking about oil, that element can be sent through pipelines. When discussing coal, that can be easily carried off on the back of trucks. When talking about hydrogen, just moving even small amounts is a very expensive matter. For that reason alone, the transport and storage of such a substance is deemed impractical.
- It is not easy to replace existing infrastructure. Gasoline is still being widely used to this day. And as of the moment, there just isn't any infrastructure that can support hydrogen as fuel. This is why it becomes highly expensive to just think about replacing gasoline. Also, cars need to be refitted in order to accommodate hydrogen as fuel.
- **It is highly flammable.** Since it is a very powerful source of fuel, hydrogen can be very flammable. In fact, it is on the news frequently for its many number of risks. Hydrogen gas burns in air at very wide concentrations – between 4 and 75 percent.
- It is dependent on fossil fuels. Although hydrogen energy is renewable and has minimal environmental impact, other non-renewable sources such as coal, oil and natural gas are needed to separate it from oxygen. While the point of switching to hydrogen is to get rid of using fossil fuels, they are still needed to produce hydrogen fuel.

Applications of Hydrogen as an energy source in India

Current sources of Hydrogen production in India

- Current hydrogen utilization in India accounts for 6 million tonnes
- The refinery sector accounts for almost 3 million tonnes of hydrogen demand, representing 46% of the total hydrogen demand in the country
- Ammonia production contributes to 48% of the current hydrogen demand
- Steel production via natural gas-based DRI-EAF (Direct Reduced Iron in Electric Arc Furnace) contributes to 0.3 million tonnes of hydrogen demand currently.
- Fuel cell vehicles are unlikely to hit the road on a commercial scale, at least until 2030, subject to the concurrent development of Hydrogen supply infrastructure (under the consideration of competitive pricing)
- Regarding the use of Hydrogen in conventional engine technology, there are 50 CNG (18% Hydrogen and 82% Compressed Natural Gas) buses plying on the roads of New Delhi, and there are plans afoot to expand the footprint of such buses across the country.

Solar Photovoltaic system:

- **Solar Cell Definition:** A solar cell (also known as a photovoltaic cell) is an electrical device that transforms light energy directly into electrical energy using the photovoltaic effect.
- **Working Principle:** The working of solar cells involves light photons creating electron-hole pairs at the p-n junction, generating a voltage capable of driving a current across a connected load.
- **Construction Details:** Solar cells consist of a thin p-type semiconductor layer atop a thicker n-type layer, with electrodes that allow light penetration and energy capture.
- **Material Characteristics:** Essential materials for solar cells must have a band gap close to 1.5 eV, high optical absorption, and electrical conductivity, with silicon being the most commonly used.
- **Practical Uses:** Solar cells power devices from small calculators and wristwatches to large-scale applications in spacecraft, highlighting their versatility and growing importance in renewable energy systems.

What is a Solar Cell?

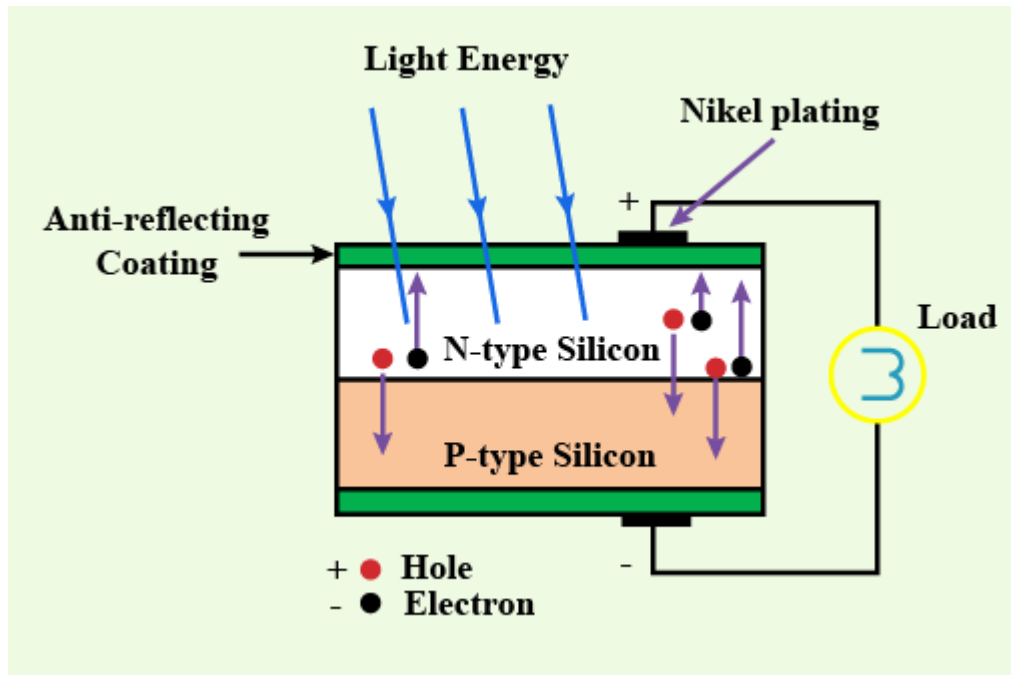
A **solar cell** (also known as a photovoltaic cell or PV cell) is defined as an electrical device that converts light energy into electrical energy through the photovoltaic effect. A solar cell is basically a p-n junction diode. Solar cells are a form of photoelectric cell, defined as a device whose electrical characteristics – such as current, voltage, or resistance – vary when exposed to light.

Individual solar cells can be combined to form modules commonly known as solar panels. The common single junction silicon solar cell can produce a maximum open-circuit voltage of approximately 0.5 to 0.6 volts. By itself this isn't much – but remember these solar cells are tiny. When combined into a large solar panel, considerable amounts of renewable energy can be generated.

Construction of Solar Cell

A solar cell functions similarly to a junction diode, but its construction differs slightly from typical p-n junction diodes. A very thin layer of p-type semiconductor is grown on a relatively thicker n-type semiconductor. We then apply a few finer electrodes on the top of the p-type semiconductor layer.

These electrodes do not obstruct light to reach the thin p-type layer. Just below the p-type layer there is a p-n junction. We also provide a current collecting electrode at the bottom of the n-type layer. We encapsulate the entire assembly by thin glass to protect the **solar cell** from any mechanical shock.



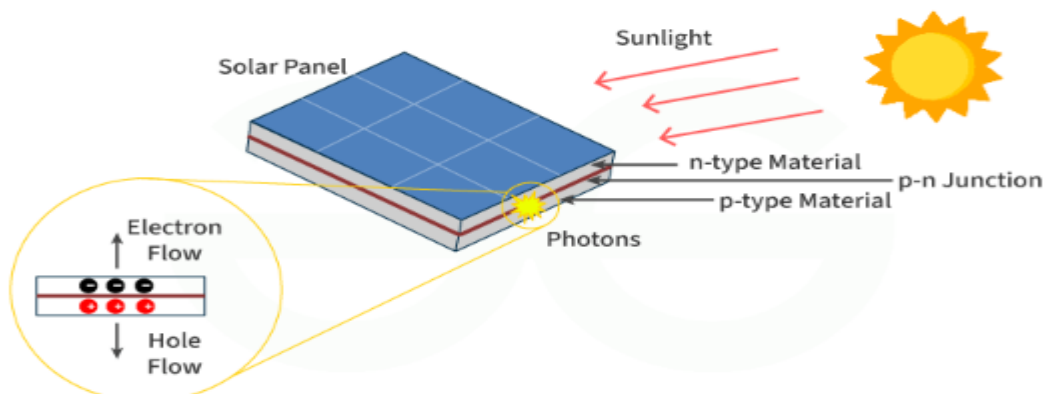
Working Principle of Solar Cell

When light photons reach the p-n junction through the thin p-type layer, they supply enough energy to create multiple electron-hole pairs, initiating the conversion process. The incident light breaks the thermal equilibrium condition of the junction. The free electrons in the depletion region can quickly come to the n-type side of the junction.

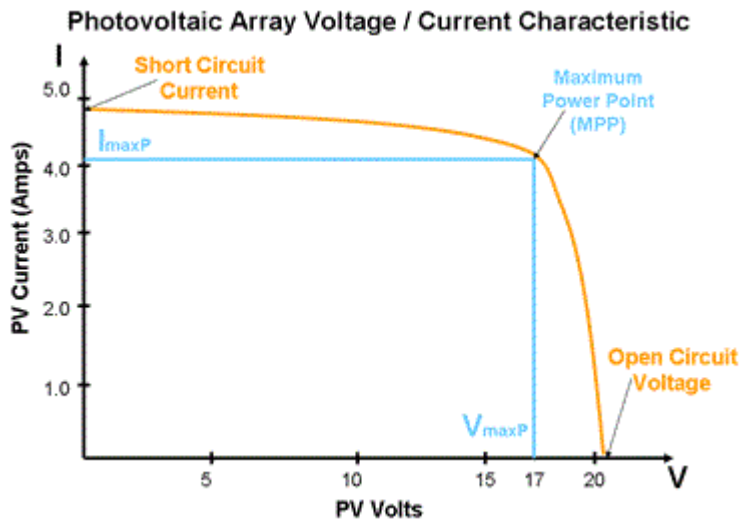
Similarly, the holes in the depletion can quickly come to the p-type side of the junction. Once, the newly created free electrons come to the n-type side, cannot further cross the junction because of barrier potential of the junction.

Once the newly created holes reach the p-type side, they cannot cross back over the junction due to the barrier potential. This separation of electrons and holes across the p-n junction allows it to function like a small battery cell.

A voltage is set up which is known as photo voltage. If we connect a small load across the junction, there will be a tiny current flowing through it.



V-I Characteristics of a Photovoltaic Cell



Materials Used in Solar Cell

Materials used in solar cells must possess a band gap close to 1.5 eV to optimize light absorption and electrical efficiency. Commonly used materials are-

1. Silicon.
2. GaAs.
3. CdTe.
4. CuInSe_2

Criteria for Materials to be Used in Solar Cell

1. Must have band gap from 1 eV to 1.8 eV.
2. It must have high optical absorption.
3. It must have high electrical conductivity.
4. The raw material must be available in abundance and the cost of the material must be low.

Advantages of Solar Cell

1. No pollution associated with it.
2. It must last for a long time.
3. No maintenance cost.

Disadvantages of Solar Cell

1. It has high cost of installation.
2. It has low efficiency.
3. During cloudy day, the energy cannot be produced and also at night we will not get solar energy.

Uses of Solar Generation Systems

1. It may be used to charge batteries.
2. Used in light meters.
3. It is used to power calculators and wrist watches.
4. It can be used in spacecraft to provide electrical energy.

Fuel Cells:

Fuel cell can be defined as an electrochemical cell that generates electrical energy from fuel via an electrochemical reaction.

What is a Fuel Cell?

Fuel cells require a continuous input of fuel and an [oxidizing agent](#) (generally oxygen) in order to sustain the reactions that generate the electricity. Therefore, these cells can constantly generate electricity until the supply of fuel and oxygen is cut off.

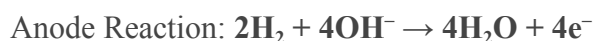
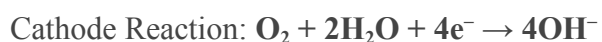
A fuel cell is similar to [electrochemical cells](#), which consists of a cathode, an anode, and an electrolyte. In these cells, the electrolyte enables the movement of the protons.

Working of Fuel Cell

The reaction between hydrogen and oxygen can be used to generate electricity via a fuel cell. Such a cell was used in the Apollo space programme and it served two different purposes – It was used as a fuel source as well as a source of drinking water (the water vapour produced from the cell, when condensed, was fit for human consumption).

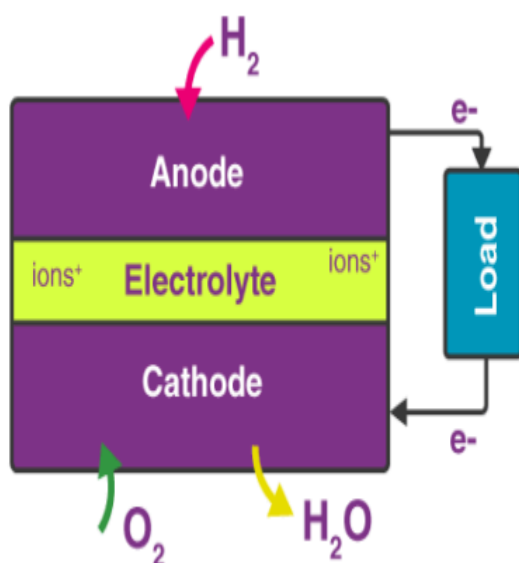
- At the anode, [Hydrogen](#) atoms are introduced. These [atoms](#) are known to carry a positive [electric charge](#). However, these atoms are stripped of their [electrons](#) at this stage. These negatively charged electrons move and create a current through the wires.
- At the cathode, [Oxygen](#) atoms are introduced. These atoms combine with the leftover electrons of the hydrogen atoms. It can combine with it after it passes through the anode or at this stage itself. It all depends on the type of cell.

The working of this fuel cell involved the passing of hydrogen and oxygen into a concentrated solution of sodium hydroxide via carbon electrodes. The cell reaction can be written as follows:



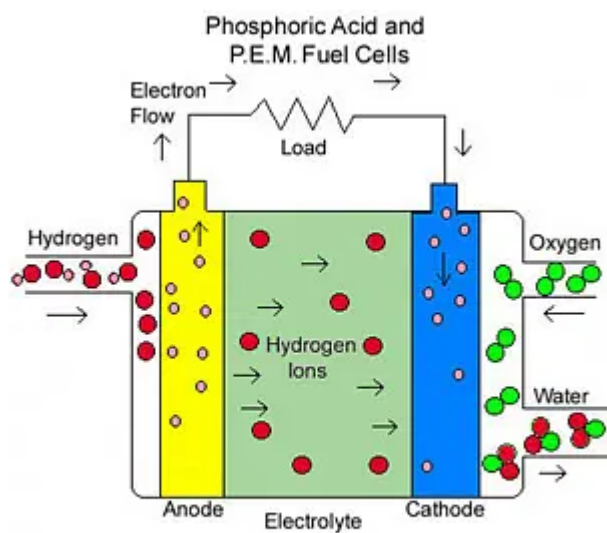
However, the reaction rate of this electrochemical reaction is quite low. This issue is overcome with the help of a catalyst such as platinum or palladium. In order to increase the effective surface area, the catalyst is finely divided before being incorporated into the electrodes.

A block diagram of this fuel cell is provided below.



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The efficiency of the fuel cell described above in the generation of electricity generally approximates to 70% whereas thermal power plants have an efficiency of 40%. This substantial difference in efficiency is because the generation of electric current in a thermal power plant involves the conversion of water into steam, and the usage of this steam to rotate a turbine. Fuel cells, however, offer a platform for the direct conversion of chemical energy into electrical energy.



Working Process of Fuel Cells

Types of Fuel Cells

Despite working similarly, there exist many varieties of fuel cells. Some of these types of fuel cells are discussed in this subsection.

The Polymer Electrolyte Membrane (PEM) Fuel Cell

- These cells are also known as proton exchange membrane fuel cells (or PEMFCs).
- The temperature range that these cells operate in is between 50°C to 100°C
- The electrolyte used in PEMFCs is a [polymer](#) which has the ability to conduct protons.
- A typical PEM fuel cell consists of bipolar plates, a catalyst, electrodes, and the polymer membrane.
- Despite having eco-friendly applications in transportation, PEMFCs can also be used for the stationary and portable generation of power.

Phosphoric Acid Fuel Cell

- These fuel cells involve the use of phosphoric acid as an electrolyte in order to channel the H^+
- The working temperatures of these cells lie in the range of 150°C – 200°C
- Electrons are forced to travel to the cathode via an external circuit because of the non-conductive nature of [phosphoric acid](#).
- Due to the acidic nature of the electrolyte, the components of these cells tend to corrode or oxidize over time.

Solid Acid Fuel Cell

- A solid acid material is used as the electrolyte in these fuel cells.
- The molecular structures of these solid acids are ordered at low temperatures.
- At higher temperatures, a phase transition can occur which leads to a huge increase in conductivity.
- Examples of solid acids include $CsHSO_4$ and CsH_2PO_4 ([cesium](#) hydrogen sulfate and cesium dihydrogen phosphate respectively)

Alkaline Fuel Cell

- This was the fuel cell which was used as the primary source of electricity in the Apollo space program.
- In these cells, an aqueous alkaline solution is used to saturate a porous matrix, which is in turn used to separate the [electrodes](#).
- The operating temperatures of these cells are quite low (approximately 90°C).
- These cells are highly efficient. They also produce heat and water along with electricity.

Solid Oxide Fuel Cell

- These cells involve the use of a solid oxide or a ceramic electrolyte (such as yttria-stabilized zirconia).
- These fuel cells are highly efficient and have a relatively low cost (theoretical efficiency can even approach 85%).
- The operating temperatures of these cells are very high (lower limit of 600°C, standard operating temperatures lie between 800 and 1000°C).
- Solid oxide fuel cells are limited to stationary applications due to their high operating temperatures.

Molten Carbonate Fuel Cell

- The electrolyte used in these cells is lithium potassium carbonate salt. This salt becomes liquid at high temperatures, enabling the movement of carbonate ions.
- Similar to SOFCs, these fuel cells also have a relatively high operating temperature of 650°C
- The anode and the cathode of this cell are vulnerable to corrosion due to the high operating temperature and the presence of the carbonate electrolyte.
- These cells can be powered by carbon-based fuels such as [natural gas](#) and biogas.

Applications of fuel cell

Fuel cell technology has a wide range of applications. Currently, heavy research is being conducted in order to manufacture a cost-efficient automobile which is powered by a fuel cell. A few applications of this technology are listed below.

- Fuel cell electric vehicles, or FCEVs, use clean fuels and are therefore more eco-friendly than internal combustion engine-based vehicles.
- They have been used to power many space expeditions including the Appolo space program.
- Generally, the byproducts produced from these cells are heat and water.
- The portability of some fuel cells is extremely useful in some military applications.
- These electrochemical cells can also be used to power several electronic devices.
- Fuel cells are also used as primary or backup sources of electricity in many remote areas.

Advantages:

More detailed information is available in the applications section, which offers information specific to each industry.

- High Efficiency- when utilizing co-generation, fuel cells can attain over 80% energy efficiency
- Good reliability- quality of power provided does not degrade over time.
- Noise- offers a much more silent and smooth alternative to conventional energy production.

- Environmentally beneficial- greatly reduces CO₂ and harmful pollutant emissions.
- Size reduction- fuel cells are significantly lighter and more compact

Disadvantages:

- Expensive to manufacture due the high cost of catalysts (platinum)
- Lack of infrastructure to support the distribution of hydrogen
- A lot of the currently available fuel cell technology is in the prototype stage and not yet validated.
- Hydrogen is expensive to produce and not widely available

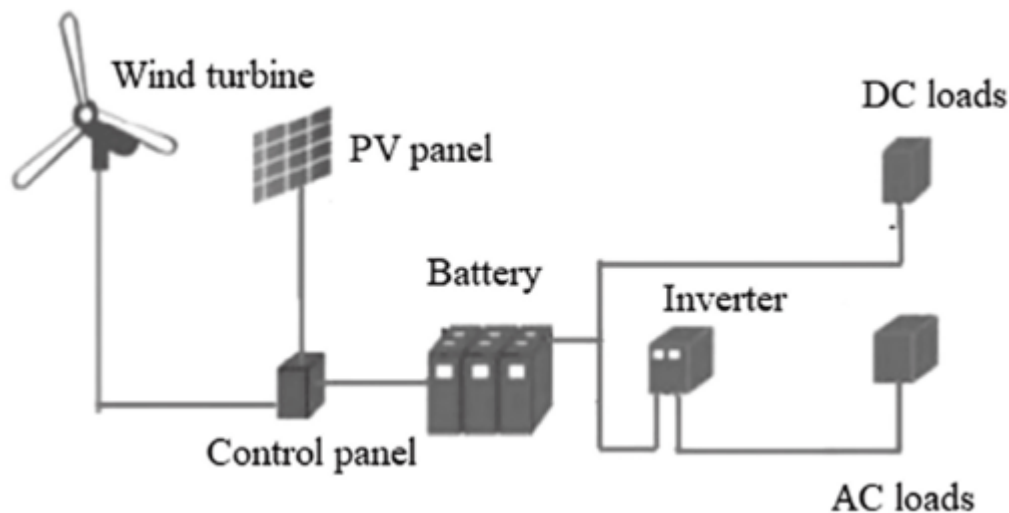
Classification of Hybrid Energy Systems

There are many possible configurations of hybrid energy systems, which operate differently under the influence of numerous climatic conditions. These hybrid energy systems are classified as:

- Hybrid wind-solar system
- Hybrid diesel-wind system
- Hybrid wind-hydropower system
- Hybrid fuel cell-solar system
- Hybrid solar-thermal system

Hybrid Wind-Solar System

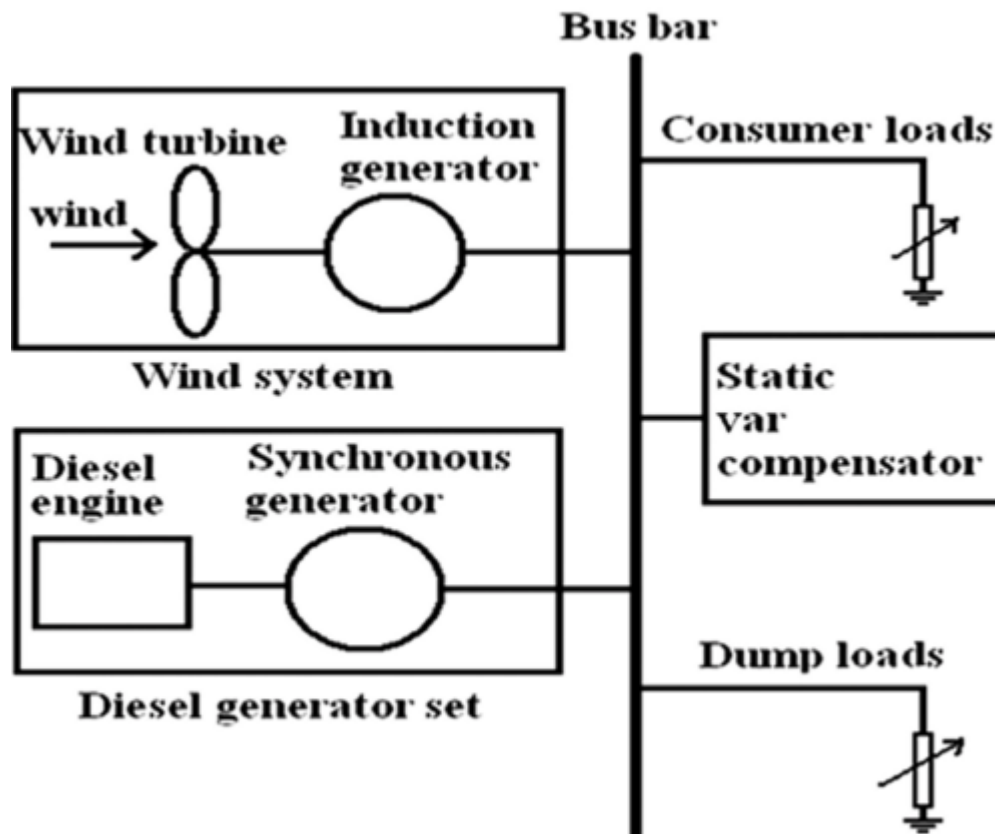
Hybrid systems are complex and many issues are associated with them but they have been developed considering the availability of and need for a particular type of land. Researchers simulating hybrid systems involve renewable energy sources, such as wind and solar, due to their abundance in nature and their interdependence, but both of these systems are intermittent in nature, and are unable to fulfill the load duration curve and to cater for the load uniformly. As a result, neither energy source can operate individually as neither alone will be able to support the capital costs incurred, whereas integrated systems lead to power quality issues as well as voltage sag and swell for a prolonged duration of time. Combined wind and solar systems can be used only at coastal regions or for a small population where the load is fixed and can be predicted in advance. A schematic of a typical hybrid solar-wind system is depicted in Figure.



There are various issues pertaining to hybrid solar-wind systems which need to be considered, namely solar irradiance, solar orientation, annual average wind speed, total output predicted, average temperature, and land suitability. Both systems need to cater for the load from end users and must be tested in both islanding mode and grid-connected mode, so that, should any element of the system ever fail, the secondary systems can fulfill the minimum requirements (base load), and the grid-connected mode should be available, as both systems are unpredictable. Grid codes must be evaluated for a specific region where hybrid systems are planned in consideration of energy requirements. Hybrid systems must follow grid code requirements, and operation should be in parallel, so that voltage stability is not affected, with extra energy being stored in batteries, to ameliorate economic aspects.

Hybrid Diesel-Wind System

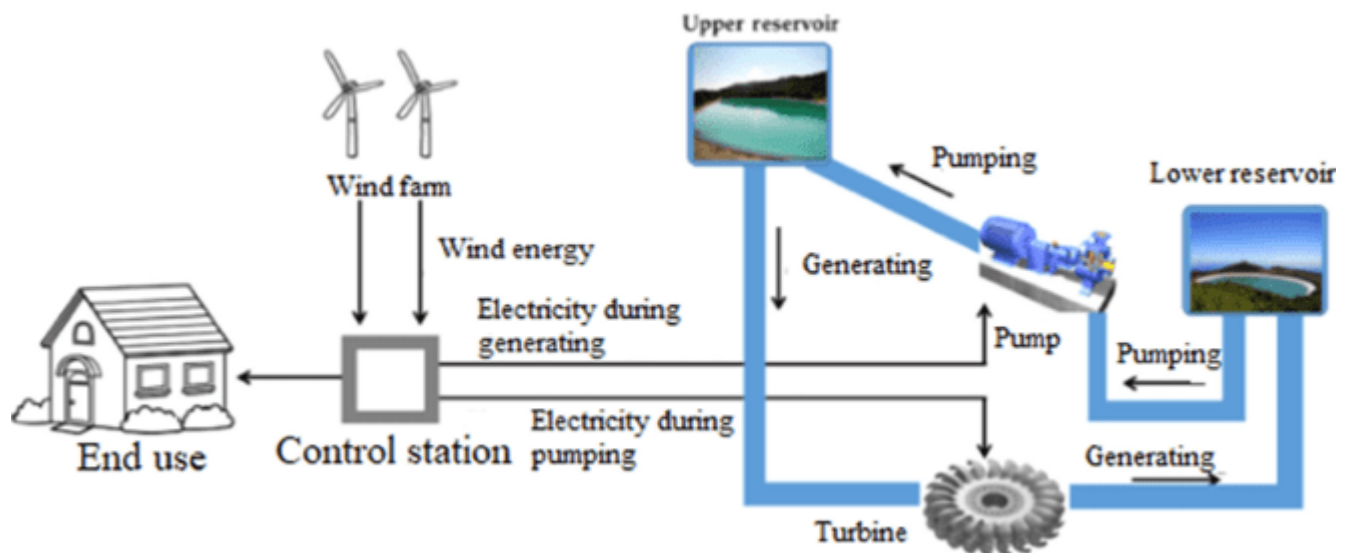
There are two diesel-wind strategies which can be followed: the first one is to operate a diesel engine continuously, and the second one is to operate the diesel engine at selected time intervals on a time scale of 4 out of 5 or on an intermediate basis, as required. Important components required are load, generators with a power electronic controller, a diesel engine, and a battery energy storage system. A schematic of a typical hybrid diesel-wind system is depicted in Figure . In a diesel-wind hybrid system at the same time scale, both components operate as peak power and the main objective is to use both systems economically, so that deliverables, in terms of output and efficiency, are cost effective, and optimization can be achieved with a minimal number of iterations. Such diesel-wind hybrid systems are used at remote locations and for small populations on an island or in remote places, where electrification is required in terms of security concerns and economic issues.



Schematic diagram of a typical hybrid diesel-wind system

Hybrid Wind-Hydropower System

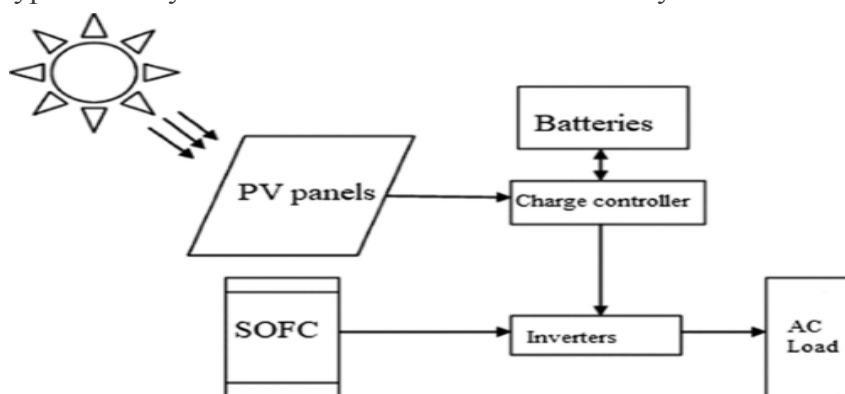
This kind of system is commonly used for generation of electricity on a larger scale. Such hybrid systems are very rare, as hydropower is limited by certain requirements, such as a water catchment area (dam and reservoir), whereas wind availability at a particular speed is another constraint, which can vary from place to place. Both systems (wind and hydropower) are location specific and are subjected to various constraints which cannot be overcome by including an alternative energy source. The most promising advantage of this kind of hybrid system involves a combination of a base power plant and a peak power plant, with the hydropower plant acting as the base power plant and the wind power plant behaving as the peak power plant, with the two systems able to complement one another. A pumped-storage plant can be implemented, in which both energy systems will operate in peak mode, but land constraints will still exist. A schematic of a typical hybrid wind-hydropower system is depicted in Figure.



Schematic diagram of a typical hybrid wind-hydropower system

Hybrid Fuel Cell-Solar System

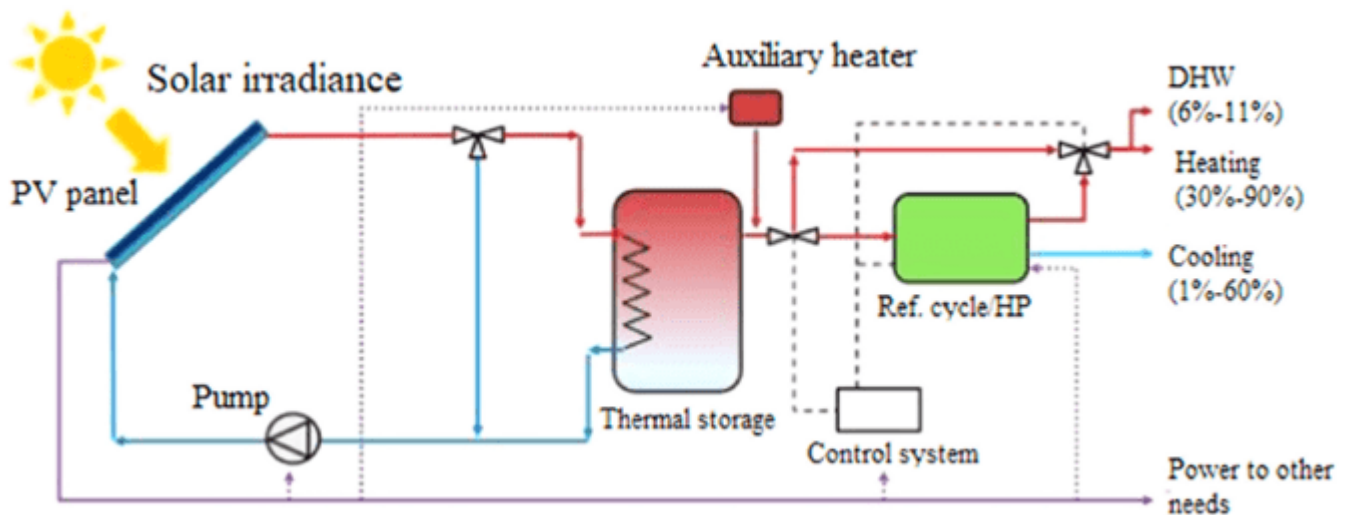
Considering a hybrid fuel cell-solar system, input power varies continuously with time, because sunlight irradiance changes continuously. This hybrid system consists of a solar photovoltaic (PV) cell, a proton-exchange membrane fuel cell, and power conditioning devices. The system must be designed in such a way that it performs continuously under ever-changing weather conditions. Electricity is produced by a PV cell to meet consumer demand. When there is any problem regarding generation due to low solar irradiance, the proton-exchange membrane fuel cell is used to maintain the reliability of the system. It is a hybrid system and both systems act as a catalyst to drive the other. One important feature of the fuel cell-solar system is its lower complexity, but it has a drawback of lower reliability indices. It also has a relatively low environmental impact. The power conditioning unit is a bidirectional power converter, which changes DC energy into AC energy; it also becomes a rectifier, changing AC power into DC power. Hence, the power conditioning unit behaves as the heart of the hybrid PV and fuel-cell system. This hybrid system reduces the usage of the fuel cell and improves the voltages of the entire system on a large scale. A schematic of a typical hybrid fuel cell-solar system is depicted in Figure



Schematic diagram of a typical hybrid fuel cell-solar system

Hybrid Solar-Thermal System

Another hybrid system can be operated by combining a solar PV and a thermal system. In this system, the performance of the entire system can be enhanced by variable levels of solar irradiance and the temperature of the plate. This provides both thermal efficiency and electrical efficiency. These efficiencies define the system performance under different climatic conditions. Optical concentration technologies are employed widely with the latest technologies and can be used in solar thermal systems for producing thermal energy storage for industrial application purposes. These kinds of system complement each other but a major drawback is the conversion technology, which is remote and limited, and cannot be accessed very easily by the end user. In addition, from the investor side, the technologies used are



Schematic diagram of a typical hybrid solar-thermal system

not user friendly. The popular concentrating solar thermal systems, such as parabolic trough collectors, linear Fresnel reflector systems, central receiver systems, and dish systems, are utilized in various applications [21]. A schematic diagram of a hybrid solar-thermal system is depicted in Figure 7.6.

Conclusion

Hybrid energy system installation is good for system performance under variable climatic conditions. It is also beneficial for remote domestic and industrial purposes. Because sometimes only one system is able to perform well, alternative sources of energy are needed to maintain continuity of electric power availability. Moreover, it has also been found that the electric power generation from hybrid energy is easy and safe for the environment. The operating systems have a longer lifespan than other conventional sources of available energy.

In this way, hybrid systems can provide more affordable solutions, with greater efficiency for power generation in future.