EE8703 - RENEWABLE ENERGY SYSTEMS

UNIT I RENEWABLE ENERGY (RE) SOURCES

Environmental consequences of fossil fuel use, Importance of renewable sources of energy, Sustainable Design and development, Types of RE sources, Limitations of RE sources, Present Indian and international energy scenario of conventional and RE sources.

Types of Energy Sources

1. ***Primary and secondary energy sources :***
   Primary energy resources are those found in nature. They include the fossil fuels (petroleum, natural gas, and coal), uranium, blowing wind and flowing water, biomass, and the radiant energy of the sun. Secondary energy comes from transforming primary energy, and includes things like gasoline and liquid fuels, refined biofuels, electricity, hydrogen, and heat.
2. ***Renewable and non-renewable energy or Non-Conventional and Conventional energy sources:***
   Renewable resources may be defined as resources that have the potential to be replaced over time by natural processes. The renewal process may be relatively quick, as with sunshine which comes on a daily basis.
   Nonrenewable resources may be defined as resources whose stock or reserves is limited or fixed. OR The renewal process may be very slow and may take hundreds or thousands of years. The available supply of nonrenewable resources may be replenished through recycling (e.g. recycling aluminum cans), but the overall supply remains relatively constant.

   Renewable resources include water, wind and solar etc. and nonrenewable resources include coal and natural gas etc.

Comparison of Conventional and Non-conventional Energy sources:

Conventional Sources of Energy	Non-conventional Sources of Energy
Conventional sources of Energy have been used since a long time	Non-Conventional sources of Energy are recently discovered sources of energy
They are common and widely used sources	They are relatively new and hence are not widely used. Example - Solar cells are still not widely used
Most of these sources cause pollution when used	Most of these sources do not cause pollution when used
They are non-renewable sources of energy	They are mostly renewable source of energy (except Nuclear Energy)
Example - Fossil Fuels like Coal, Petroleum, and Burning wood	**Example** - Solar Energy, Nuclear Energy, Geothermal Energy, Energy from the Oceans

Fossil fuels: Fossil fuels are buried flammable geologic deposits of organic substances such as dead plants, and animals that got deposited under several thousand feet of silt. These deposits decayed with the passage of time (Typically millions of years) and got converted to natural gas, coal, and petroleum due to the extreme heat and pressure inside the earth's crust. They are also known as non-renewable sources of energy as it takes a very long time for it to replenish.Fossil fuels contain high percentages of carbon and include petroleum, coal, and natural gas.

Coal : It is a hard, black coloured substance made up of carbon, hydrogen, nitrogen, oxygen, and sulphur.The major types of coal are- anthracite, bituminous and lignite. Anthracite has a higher carbon concentration and is the hardest type of coal. Lignite has a high concentration of oxygen and hydrogen but a low concentration of carbon. Bituminous is a moderate form of coal. Coal is processed industrially to obtain derivatives like coke, coal tar, and coal gas

Formation of coal : The process of formation of coal is known as carbonization. The dense forest present in the low-lying wetland got buried in the earth millions of years ago. Soil kept depositing over them and they got compressed. As they went deeper and deeper, they faced high temperature and pressure. As a result, the substances slowly got converted into coal.

Uses of Coal

1. Coal was used to produce steam in the railway engines initially.
2. It is used to cook food.
3. It is used to generate electricity in thermal plants.
4. It is used in industries as fuel.

Coal Mines in the world

- North Antelope Rochelle coal mine, US
- Haerwusu coal mine, China
- Hei Dai Gou coal mine, China
- Raspadskaya coal mine, Russia
- Moatize coal mine, Mozambique
- Black Thunder coal mine, US
- Peak Downs coal mine, Australia
- Mt Arthur coal mine, Australia
- Goonyella Riverside coal mine, Australia
- Saraji coal mine, Australia

Oil (liquid fossil fuel) :Oil is a liquid fossil fuel that is formed from the remains of micro-organisms. After millions of years the deposits end up in rock and sediment where oil is trapped in small spaces. It can be extracted by large drilling platforms. Oil is the most widely used fossil fuel. Crude oil consists of many different organic compounds which are transformed to products in a refining process.

Petroleum: It is a clear, oily liquid, usually green or black in colour. It has a very strange smell and is a mixture of petroleum gas, diesel, paraffin wax, petrol, lubricating oil, etc. It is also termed as “Black Gold” because of its wide range of uses in many industries.

Formation of petroleum: Dead animals and plants are deposited for millions of years. They got compressed by the layers of sand and clay. Their encounter with high temperature and pressure converts them into petroleum. The petroleum is separated from the crude oil by a series of processes in a refinery. This is known as petroleum refining.

Uses of Petroleum

1. It is used to power internal combustion engines in the form of petrol.
2. It is used in roofing, road pavements, and as a water repellent.
3. It is used in manufacturing detergents, plastics, fibers, polyethene, etc.

Natural Gas: It is a clean and non-toxic fossil fuel. It is colourless and odorless and can be easily transferred through pipelines. It is stored as compressed natural gas (CNG) under high pressure. It is less polluting and less expensive fossil fuel. Methane is the most important natural gas.

Formation of Natural Gas : Millions to hundreds of millions of years ago and over long periods of time, the remains of plants and animals (such as diatoms) built up in thick layers on the earth's surface and ocean floors, sometimes mixed with sand, silt, and calcium carbonate. Over time, these layers were buried under sand, silt, and rock. Pressure and heat changed some of this carbon and hydrogen-rich material into coal, some into oil (petroleum), and some into natural gas.

Sealed off in an oxygen-free environment and exposed to increasing amounts of heat and pressure, the organic matter undergo a thermal breakdown process that converted it into hydrocarbons. The lightest of these hydrocarbons exist in the gaseous state under normal conditions and are known collectively as natural gas. In its pure form, natural gas is a colorless, odorless gas composed primarily of methane

Uses of Natural gas

1. Compressed Natural Gas is used for generating power.
2. It is used as fuels in automobiles.
3. It can be used at homes for cooking.
4. It is used as a starting material in chemicals and fertilizers.

Advantages of Fossil Fuels

1. Fossil fuels can generate a large amount of electricity at a single location.
2. They can be found very easily.
3. They are cost effective.
4. Transportation of oil and gas can be done easily through pipelines.
5. They have become safer over time.
6. Despite being a finite resource, it is available in plenty.

Disadvantages of Fossil Fuels

1. Fossil fuels emit carbon dioxide when burnt which is a major greenhouse gas and the primary source of pollution. This has contributed to global warming.
2. They are a non-renewable resource, i.e., once used they cannot be replaced.
3. Combustion of fossil fuels makes the environment more acidic. This has led to unpredictable and negative changes in the environment.

4. Harvesting of fossil fuels also causes fatal diseases among the people. For eg., the coal miners often suffer from Black Lung Disease. The natural gas drillers are constantly exposed to chemicals and silica which is dangerous for their health.

Effects of fossil fuels on the environment

1.Carbon fuels such as wood, coal, petroleum release unburnt carbon particles in the environment. These particles are very dangerous pollutants and cause respiratory diseases for example asthma.

2. When fuels are incompletely burnt, they release carbon monoxide gas into the atmosphere. This gas is very dangerous as it is poisonous in nature. If we burn coal in a closed room, then the person sleeping in that room will be killed by the action of carbon monoxide.

3.The combustion of fossil fuels also releases a large amount of carbon dioxide into the atmosphere. Carbon dioxide is a greenhouse gas which is responsible for global warming. Global warming is a rise in the overall temperature of earth's surface. This leads to melting of polar caps and rise in the sea level and further results in flooding of coastal regions.

4.Burning of coal and diesel releases sulphur dioxide gas. This gas is extremely corrosive and suffocating in nature. Petrol gives off oxides of nitrogen. The oxides of sulfur and nitrogen get dissolved in rainwater and form acids. This is known as acid rain. This water is very harmful to plants, animals, and various monuments.

<u>Consequences of fossil fuel use</u>

Land degradation : Unearthing, processing, and moving underground oil, gas, and coal deposits take an enormous toll on our landscapes and ecosystems. The fossil fuel industry leases vast stretches of land for infrastructure such as wells, pipelines, access roads, as well as facilities for processing, waste storage, and waste disposal.

In the case of strip mining, entire swaths of terrain—including forests and whole mountaintops—are scraped and blasted away to expose underground coal or oil. Even after operations cease, the nutrient-leached land will never return to what it once was.As a result, critical wildlife habitat—land crucial for breeding and migration—ends up fragmented and destroyed. Even animals able to leave can end up suffering, as they're often forced into less-than-ideal habitat and must compete with existing wildlife for resources.

Water pollution: Coal, oil, and gas development pose countless threats to our waterways and groundwater. Coal mining operations wash acid runoff into streams, rivers, and lakes and dump vast quantities of unwanted rock and soil into streams. Oil spills and leaks during extraction or transport can pollute drinking water sources and endanger the entire freshwater or ocean ecosystems.

Fracking (injecting liquid at high pressure into subterranean rocks, boreholes, etc. so as to force open existing fissures and extract oil or gas) and its toxic fluids have also been found to contaminate drinking water. Drilling, fracking, and mining operations generate enormous volumes of wastewater, which can be laden with heavy metals, radioactive materials, and other pollutants. Industries store this waste in open-air pits or underground wells that can leak or overflow into waterways and contaminate aquifers with pollutants linked to cancer, birth defects, neurological damage, and much more.

Emissions: Fossil fuels emit harmful air pollutants long before they're burned, and we are exposed daily to toxic air pollution from active oil and gas wells and from transport and processing facilities.

These include benzene (linked to childhood leukemia and blood disorders) and formaldehyde (a cancer-causing chemical).

A booming fracking industry will bring that pollution to more backyards, despite mounting evidence of the practice's serious health impacts. Mining operations are no better, especially for the miners themselves, generating toxic airborne particulate matter. Strip mining—particularly in places such as Canada's boreal forest—can release giant carbon stores held naturally in the wild.

Burning Fossil Fuels and Global warming pollution: When we burn oil, coal, and gas, we don't just meet our energy needs—we drive the current global warming crisis as well. Fossil fuels produce large quantities of carbon dioxide when burned. Carbon emissions trap heat in the atmosphere and lead to climate change. Burning of fossil fuels, particularly for the power and transportation sectors, accounts for about three-quarters of our carbon emissions.

Other forms of air pollution: Fossil fuels emit more than just carbon dioxide when burned. Coal-fired power plants generate dangerous mercury emissions, sulphur dioxide emissions (which contribute to acid rain) and the vast majority of soot (particulate matter) in our air. Fossil fuel–powered cars, trucks, and boats are the main contributors of poisonous carbon monoxide and nitrogen oxide, which produces smog (and respiratory illnesses) on hot days.

Ocean acidification: When we burn oil, coal, and gas, we change the ocean's basic chemistry, making it more acidic. Our seas absorb as much as a quarter of all man-made carbon emissions. Since the start of the Industrial Revolution (and our coal-burning ways), the ocean has become 30 percent more acidic. As the acidity in our waters goes up, the amount of calcium carbonate—a substance used by oysters, lobsters, and countless other marine organisms to form shells—goes down. This can slow growth rates, weaken shells, and imperil entire food chains. Ocean acidification impacts coastal communities as well, which hits the industry badly and lose of thousands of jobs.

<u>Renewable Energy</u>

Renewable energy can be defined as the energy sources that are natural and continually replenished either at the same rate or faster than the rate at which they are being used up by humans more or less indefinitely such as the sun, wind, rain, tides, biomass and geothermal energy.

Green energy, alternative energy and sustainable energy are the other synonyms sometimes used to describe the renewable energy that is converted into either electricity, heat or mechanical power for use in homes or in industries by clean, harmless and non-polluting methods

<u>Importance of renewable sources of energy:</u>

Today, the world still heavily relies on fossil fuels and even continues subsidising them. Meanwhile, the pollution they cause – from climate-damaging greenhouse gases to health-endangering particles – has reached record levels.

Since 2011, renewable energy is growing faster than all other energy forms and this keeps growing.

1. All energy sources have an impact on our environment. Renewable energy is no exception to the rule, and each source has its own trade-offs.
2. The advantages of RE sources over the devastating impacts of fossil fuels are undeniable: from the reduction of water and land use, less air and water pollution, less wildlife and habitat loss, to no or lower greenhouse gas emissions. In addition, their local and decentralised character as well as technology development generate important benefits for the economy and people.

3. Renewables are on track to become a cheaper source of energy than fossil fuels, which is spurring a boom in clean energy development and jobs.
4. Higher levels of renewables can be integrated into our existing grid, though care must be taken to site and build renewable energy responsibly.

1. Renewable energy emits no or low greenhouse gases. That's good for the climate: The combustion of fossil fuels for energy results in a significant amount of greenhouse gas emissions that contribute to global warming. Most sources of renewable energy result in little to no emissions, even when considering the full life cycle of the technologies.

2. Renewable energy emits no or low air pollutants. That's better for our health: Worldwide increase in fossil fuel-based road transport, industrial activity, and power generation and open burning of waste in many cities contributes to elevated levels of air pollution. In many developing countries, the use of charcoal and fuelwood for heating and cooking also contributes to poor indoor air quality. Particles and other air pollutants from fossil fuels literally asphyxiate cities. "Instead of depleting precious resources and polluting the environment, renewable energy meets the objectives of a circular economy and is a strong motor for social and economic development"

3. Renewable energy comes with low costs. That's good for keeping energy prices at affordable levels: Geopolitical conflicts and confusions often come with increasing energy prices and limited access to resources. Since renewable energy is produced locally, it is less affected by geopolitical crisis or price spikes or sudden disruptions in the supply chain.

4. Renewable energy creates jobs. That's good for the local community: The largest part of renewable energy investments is spent on materials and workmanship to build and maintain the facilities, rather than on costly energy imports. Renewable energy investments are usually spent within the continent, frequently in the same country, and often in the same town. This means the money citizens pay on their energy bill stays home to create jobs and fuel the local economy.

5. Renewable energy makes the energy system resilient. That's important to prevent power shortages: Renewables make urban energy infrastructures more independent from remote sources and grids. Businesses and industry invest in renewable energy to avoid disruptions, including resilience to weather-related impacts of climate change.

6. Renewable energy is accessible to all. That's good for development: In many parts of the world, renewables represent the lowest-cost source of new power generation technology, and costs continue to decline. Especially for cities in the developing world, renewable energy is the only way to expand energy access to all inhabitants, particularly those living in urban slums and informal settlements and in suburban and peri-urban areas.

7.Renewable energy is secure. That's good for stability: Evolving energy markets and geopolitical uncertainty have moved energy security and energy infrastructure resilience to the forefront of many national energy strategies. Security of supply is a serious concern in energy markets worldwide, from the European Union and the United States to Egypt and India.

8.Key benefits of renewable energy for people and the planet: All energy sources have an impact on our environment. Renewable energy is no exception to the rule, and each source has its own trade-offs. However, the advantages over the devastating impacts of fossil fuels are undeniable: from the reduction of water and land use, less air and water pollution, less wildlife and habitat loss, to no or lower greenhouse gas emissions.In addition, their local and decentralised character as well as technology development generate important benefits for the economy and people.

9.Renewable energy emits no or low greenhouse gases. That's good for the climate: The combustion of fossil fuels for energy results in a significant amount of greenhouse gas emissions that contribute to global warming. Most sources of renewable energy result in little to no emissions, even when considering the full life cycle of the technologies.

10.Renewable energy emits no or low air pollutants. That's better for our health: Worldwide increase in fossil fuel-based road transport, industrial activity, and power generation and open burning of waste in many cities contributes to elevated levels of air pollution. In many developing countries, the use of charcoal and fuelwood for heating and cooking also contributes to poor indoor air quality. Particles and other air pollutants from fossil fuels literally asphyxiate cities.

"Instead of depleting precious resources and polluting the environment, renewable energy meets the objectives of a circular economy and is a strong motor for social and economic development"

11. Renewable energy comes with low costs. That's good for keeping energy prices at affordable levels: Geopolitical conflicts and confusions often come with increasing energy prices and limited access to resources. Since renewable energy is produced locally, it is less affected by geopolitical crisis or price spikes or sudden disruptions in the supply chain.

12.Renewable energy creates jobs. That's good for the local community.
The largest part of renewable energy investments is spent on materials and workmanship to build and maintain the facilities, rather than on costly energy imports. Renewable energy investments are usually spent within the continent, frequently in the same country, and often in the same town. This means the money citizens pay on their energy bill stays home to create jobs and fuel the local economy.

13. Renewable energy makes the energy system resilient. That's important to prevent power shortages: Renewables make urban energy infrastructures more independent from remote sources and grids. Businesses and industry invest in renewable energy to avoid disruptions, including resilience to weather-related impacts of climate change.

14. Renewable energy is accessible to all. That's good for development.
In many parts of the world, renewables represent the lowest-cost source of new power generation technology, and costs continue to decline. Especially for cities in the developing world, renewable energy is the only way to expand energy access to all inhabitants, particularly those living in urban slums and informal settlements and in suburban and peri-urban areas.

15. Renewable energy is secure. That's good for stability.
Evolving energy markets and geopolitical uncertainty have moved energy security and energy infrastructure resilience to the forefront of many national energy strategies. Security of supply is a serious concern in energy markets worldwide, from the European Union and the United States to Egypt and India.

Uses of renewable energy
Renewable energy can be used in all energy sectors: from power production and thermal comfort in buildings to industry and transport.

Thermal comfort in buildings (heating and cooling). Examples for the use of renewable energy in buildings are solar thermal water heaters, biomass boilers, heat pumps, and natural cooling. Reducing the energy demand of buildings and industry is key to transitioning to a renewables-based energy system. Therefore, an integrated policy approach to renewable energy and energy efficiency is fundamental.

Industrial heating and cooling processes, such as food processing and pulp and paper, can also be run on renewable energy. Hydrogen produced with renewables electricity can meet the needs of high-heat intensive industrial processes in the iron and steel and chemical industries.

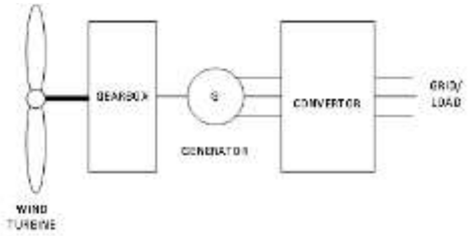
In transport, renewable energy can be used in the form of sustainable biofuels, high-percentage biofuel blends and drop-in biofuels. Renewable electricity can power the world's growing fleet of electric vehicles. Car batteries can be used as storage units so that the electricity can be used at a later time. Renewable electricity also can be used to produce electro-fuels, such as hydrogen to fuel long-haul transport, aviation and shipping. A focus on reducing overall fuel demand in the transport sector is critical and can be accomplished through policies that promote energy efficiency and conservation.
Worldwide, renewables already supplied 29% of electricity in 2020. Yet, outside of electricity, good news is still hard to come by. Uses of electricity (e.g., lighting and appliances) only represent 17% of the world's energy needs. About half of the energy is used for heating and cooling, one-third goes to the transport sector. With far lower shares of renewable energy, these two sectors are both lagging far behind in decarbonisation.

Types of Renewable Energy

1. Solar energy
2. Wind energy
3. Hydro power
4. Geo-thermal energy
5. Tidal energy
6. Fuel cell
7. Bio-mass

Wind Energy

Wind is a plentiful source of clean energy. Wind farms are an increasingly familiar sight with wind power making an ever-increasing contribution to the National Grid. To harness electricity from wind energy, turbines are used to drive generators which then feed electricity into the National Grid. Although domestic or 'off-grid' generation systems are available, not every property is suitable for a domestic wind turbine.
Wind energy is captured using a turbine and is converted into electric power using an electric alternator. In the wind power system, the transformation of kinetic energy in the wind into electrical energy takes place in two steps. Firstly, the wind's kinetic energy is converted into mechanical energy using a wind turbine and then this mechanical energy gets converted into electrical energy by means of generator.



<u>Environmental Impacts of Wind Power</u>

a) Land use

Wind turbines placed in flat areas typically use more land than those located in hilly areas.However, wind turbines are spaced approximately 5 to 10 rotor diameters apart. Thus, the turbines themselves and the surrounding infrastructure (including roads and transmission lines) occupy a large amount of the total area of a wind facility.Offshore wind facilities, which are currently not in operation, require larger amounts of space because the turbines and blades are bigger than their land-based counterparts. Depending on their location, such offshore installations may compete with a variety of other ocean activities, such as fishing, recreational activities, sand and gravel extraction, oil and gas extraction, navigation, and aquaculture.

b) Wildlife and Habitat

The bird and bat deaths from collisions with wind turbines.The National Wind Coordinating Committee concluded that these impacts are relatively low and do not pose a threat to species populations.

c) Public Health and Community

Sound and visual impact are the two main public health and community concerns associated with operating wind turbines. Most of the sound generated by wind turbines is aerodynamic, caused by the movement of turbine blades through the air. There is also mechanical sound generated by the turbine itself. Overall sound levels depend on turbine design and wind speed. Some people living close to wind facilities have complained about sound and vibration issues, but these issues do not adversely impact public health. However, these community concerns are important for wind turbine developers for siting turbines. Additionally, technological advances, such as minimizing blade surface imperfections and using sound-absorbent materials can reduce wind turbine noise. Under certain lighting conditions, wind turbines can create an effect known as shadow flicker. This annoyance can be minimized with careful siting, planting trees or installing window awnings.

d) Life-Cycle Global Warming Emissions

A global warming emission associated with life-cycle of wind turbine includes materials production, materials transportation, on-site construction and assembly, operation and maintenance, and decommissioning and dismantlement. Estimates of total global warming emissions depend on a number of factors, including wind speed, percent of time the wind is blowing, and the material composition of the wind turbine. Most estimates of wind turbine life-cycle global warming emissions are between 0.02 and 0.04 pounds of carbon dioxide equivalent per kilowatt-hour.

e) Water Use: There is no water impact associated with the operation of wind turbines. As in all manufacturing processes, some water is used to manufacture steel and cement for wind turbines.

Solar Energy

Sunlight is one of our planet's most abundant and freely available energy resources. The amount of solar energy that reaches the earth's surface in one hour is more than the planet's total energy requirements for a whole year. Although it sounds like a perfect renewable energy source, the amount of solar energy we can use varies according to the time of day and the season of the year as well as geographical location.

***Solar Photo Voltaic Systems*:** Solar cell is a thin silicon wafer of thickness 0.25mm and can have a round or square form. Solar panels absorb sunlight as a source of energy to generate electricity or heat. Photovoltaic(PV) are best method for generating electric power. Solar cells are used to convert energy from the sun into a flow of electrons by using semiconducting materials- exhibit the photovoltaic effect.

Photovoltaic Effect: Sunlight composed of photons or particles of solar energy, that contain various amounts of energy corresponding to the different wavelengths of the solar spectrum. The electrons present in the valence band absorb energy and being excited, jump to the conduction band and become free. It generates electrical energy.

Solar Thermal Systems

Solar thermal power plants are electricity generation plants that utilize energy from the Sun to heat a fluid to a high temperature. This fluid then transfers its heat to water, which then becomes superheated steam. This steam is then used to rotate turbines in a power plant, and mechanical energy is converted into electricity by a generator. This type of generation is essentially the same as electricity generation that uses fossil fuels, but produce steam using sunlight instead of combustion of fossil fuels. These systems use solar collectors to concentrate the Sun's rays on one point to achieve appropriately high temperatures. Solar thermal power generation systems use mirrors to collect sunlight and produce steam by solar heat to drive turbines for generating power.

Environmental Impacts of Solar Power

The scale of the system ranging from small, distributed roof top PV arrays to large utility-scale PV and CSP (concentrating solar thermal plants) projects also plays a significant role in the level of environmental impact.

a) Land Use: Depending on their location, larger utility-scale solar facilities can raise concerns about land degradation and habitat loss. A total land area requirement varies depending on the technology, the topography of the site, and the intensity of the solar resource. Estimates for utility-scale PV systems range from 3.5 to 10 acres per megawatt, However, land impacts from utility-scale solar systems can be minimized by siting them at lower-quality locations such as brownfields, abandoned mining land, or existing transportation and transmission corridors. Smaller scale solar PV arrays, which can be built on homes or commercial buildings, also have minimal land use impact. Unlike wind facilities, there is less opportunity for solar projects to share land with agricultural uses.

b) Water Use: Solar PV cells do not use water for generating electricity. However, as in all manufacturing processes, some water is used to manufacture solar PV components. Concentrating solar thermal plants (CSP), like all thermal electric plants, require water for cooling. Water use depends on the plant design, plant location, and the type of cooling system. CSP plants that use wet-recirculating technology with cooling towers withdraw between 600 and 650 gallons of water per megawatt-hour of electricity produced. CSP plants with once-through cooling technology have higher levels of water withdrawal, but lower total water consumption (because water is not lost as steam).

c) Hazardous Materials – The PV cell manufacturing process includes a number of hazardous materials, most of which are used to clean and purify the semiconductor surface. These chemicals include hydrochloric acid, sulfuric acid, nitric acid, hydrogen fluoride, and acetone. The amount and type of chemicals used depends on the type of cell, the amount of cleaning that is needed, and the size of silicon wafer.Workers also face risks associated with inhaling silicon dust. Hence, these chemicals and other manufacturing waste products are disposed properly. Thin-film PV cells contain a number of more toxic materials than those used in traditional silicon photovoltaic cells, including gallium arsenide, copper-indiumgallium-diselenide, and cadmium-tellurid. If not handled and disposed of properly, these materials could pose serious environmental or public health threats.However, manufacturers have a strong financial incentive to ensure that these highly valuable and often rare materials are recycled rather than thrown away

d) Life-Cycle Global Warming Emissions : A global warming emissions associated with life-cycle of the solar energy includes manufacturing, materials transportation, installation, maintenance, and decommissioning and dismantlement. Most estimates of life-cycle emissions for photovoltaic systems are between 0.07 and 0.18 pounds of carbon dioxide equivalent per kilowatt-hour.

Hydro power plant:

As a renewable energy resource, hydro power is one of the most commercially developed. By building a dam or barrier, a large reservoir can be used to create a controlled flow of water that will drive a turbine, generating electricity. This energy source can often be more reliable than solar or wind power (especially if it's tidal rather than river) and also allows electricity to be stored for use when demand reaches a peak. Like wind energy, in certain situations hydro can be more viable as a commercial energy source (dependant on type and compared to other sources of energy) but depending very much on the type of property, it can be used for domestic, 'off-grid' generation.

Hydroelectricity is the term referring to electricity generated by hydropower. The of electrical power produced through the use of the gravitational force of falling or flowing water.

First Hydro power plant: Fox river, Appleton, Wisconsin

Advantages:

- No Fuel charges
- Highly Reliable
- Maintenance and operation charges are very low
- Running cost of the plant is low
- Efficiency is high
- Takes few minutes to run and synchronize the plant
- Less supervising staff is required
- No fuel transportation problem
- No Ash problem
- No pollution since no smoke is produced
- Other than Power generation, plants are used for flood control and irrigation purposes

- Long life
- Number of operations are less compared to coal power plants
- Machines are robust and generally runs at low speeds at 300-400 rpm
- Cost of land is not a major problem since the hydro-electric stations are situated away from the developed areas

Disadvantages

- Initial cost of plant is very high
- Takes long time for the erection of such plants
- Such plants are usually located in hilly areas far away from the load center and as such they require long transmission lines to deliver power,
- Cost of transmission lines and the losses in them will be more
- Power generation depends on the quantity of water available which in turn depends on the natural phenomenon of rain. So plant will function satisfactorily only if the required quantity of water can be collected

Selection of site for Hydroelectric Powerplant

Factors to be considered for selection of site are,

1.Availability of water : Estimate should be made about the average quantity of water available throughout the year and also the maximum and minimum quantity of water available during the year. These details are necessary to,

a. Decide the capacity of the hydroelectric power plant
b. Setting up of peak load plants (steam, gas turbine, diesel etc.)
c. Provide adequate spillways or gate for relief during the flood period.

2.Water storage : Since there is wide variation in rainfall during the year, its necessary to store the water for continuous generation of power.

3.Water head : An increase in effective head, for a given output, reduces the quantity of water required to be supplied to the machine.

4.Accessibility of the site : Distance from load center : Will reduce the cost of erection and maintenance of transmission line

Environmental Impacts of Hydroelectric Power

Hydroelectric power includes both massive hydroelectric dams and small run-of-the-river plants.

a) Land Use :The size of the reservoir created by a hydroelectric project can vary widely, depending largely on the size of the hydroelectric generators and the topography of the land. Hydroelectric plants in flat areas tend to require much more land than those in hilly areas or canyons where deeper reservoirs can hold more volume of water in a smaller space.

Flooding land for a hydroelectric reservoir has an extreme environmental impact: it destroys forest, wildlife habitat, agricultural land, and scenic lands.

b) Wildlife Impacts :Dam or reservoirs are used for multiple purposes, such as agricultural irrigation, flood control, and recreation. so not all wildlife impacts associated with dams can be directly attributed to hydroelectric power.

Reservoir water is usually more stagnant than normal river water. As a result, the reservoir will have higher than normal amounts of sediments and nutrients, which can cultivate an excess of algae and other aquatic weeds. These weeds can crowd out other river animal and plant-life, and they must be controlled through manual harvesting or by introducing fish that eat these plants. In addition, water is lost through evaporation in dammed reservoirs at a much higher rate than in flowing rivers.

Reservoir water is typically low in dissolved oxygen and colder than normal river water. When this water is released, it could have negative impacts on downstream plants and animals. To mitigate these impacts, aerating turbines can be installed to increase dissolved oxygen and multi-level water intakes can help ensure that water released from the reservoir comes from all levels of the reservoir, rather than just the bottom (which is the coldest and has the lowest dissolved oxygen).

Life-cycle Global Warming Emissions

Global warming emissions are produced during the installation and dismantling of hydroelectric power plants. Such emissions vary greatly depending on the size of the reservoir and the nature of the land that was flooded by the reservoir. Small run-of-the-river plants emit between 0.01 and 0.03 pounds of carbon dioxide equivalent per kilowatt-hour. Life-cycle emissions from large-scale hydroelectric plants are also modest: approximately 0.06 pounds of carbon dioxide equivalent per kilowatt-hour

Ocean Energy: Energy can be harvested from the ocean by

a. Tapping energy in ocean currents
b. Using the ocean as a heat engine
c. Tidal energy
d. Wave energy

Energy from ocean currents

Ocean currents flow at a steady velocity.Place turbines in these currents that operate just like wind turbines.Water is more than 800 times denser than air, so for the same surface area, water moving 12 miles per hour exerts about the same amount of force as a constant 110 mph wind.

Disadv:

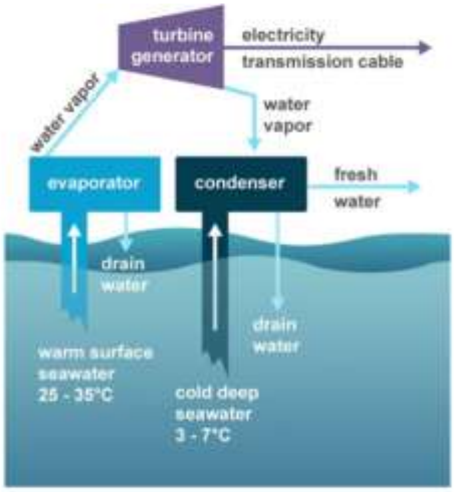
- Expensive proposition
- Upkeep could be expensive and complicated

Environmental concerns :

a. species protection (including fish and marine mammals) from injury from turning turbine blades.
b. Consideration of shipping routes and present recreational uses of location
c. Other considerations include risks from slowing the current flow by extracting energy.

Ocean as a heat engine (Thermal Energy Conversion-OTEC)

- There can be a 20° difference between ocean surface temps and the temp at 1000m .The surface acts as the heat source, the deeper cold water acts as a heat sink.
- Temperature differences are very steady
- Florida, Puerto Rico, Hawaii and other pacific islands are well suited to take advantage of this idea.
- It is Called OTEC (*Ocean Thermal Energy Conversion)*



Tidal Power

Tides or wave is periodic rise and fall of water level of the sea. They occur due to the attraction of sea water by moon.Tides contain large amount of potential energy which is used for power generation.When water is above the mean sea level, it is called flood tide and when water is below the mean sea level, it is called ebb tide.

Working of Tidal Power System

The ocean tides rise and fall and water can be stored during the rise period and can be discharged during fall. A dam is constructed separating the tidal basin from sea and difference in water level is obtained between the basin and sea. During high tide, water flows from sea in to the tidal basin through the water turbine, hence, turbine unit operate and generates power , as it is directly coupled to a generator. During low tide period, water flows from tidal basin to sea, as the water level in the basin is more than that of the tide in the sea. During this period also the flowing water rotates the turbine and generate power.

Environmental Issues of ocean energy:

1. Alters the flow of saltwater in and out of estuaries (Where tide meets the river), which changes the hydrology and salinity and possibly negatively affects the marine mammals that use the estuaries as their habitat
2. Some species lost their habitat due to the construction at estuaries, but other species colonized the abandoned space, which caused a shift in diversity.
3. Turbidity (the amount of matter in suspension in the water) decreases as a result of smaller volume of water being exchanged between the basin and the sea. This lets light from the Sun to penetrate the water further, improving conditions for the phytoplankton. The changes propagate up the food chain, causing a general change in the ecosystem.

4. If the turbines are moving slowly enough, such as low velocities of 25-50 rpm, fish kill is minimalized and silt and other nutrients are able to flow through the structures . Tidal fences block off channels, which makes it difficult for fish and wildlife to migrate through those channels. Larger marine mammals such as seals or dolphins can be protected from the turbines by fences or a sonar sensor auto-breaking system that automatically shuts the turbines down when marine mammals are detected
5. As a result of less water exchange with the sea, the average salinity inside the basin decreases, also affecting the ecosystem
6. Estuaries often have high volume of sediments moving through them, from the rivers to the sea. The introduction of a barrage into an estuary may result in sediment accumulation within the barrage, affecting the ecosystem and also the operation of the barrage.

Wave Energy

It is estimated that there is 2-3 million mW of energy in the waves breaking on the world coastlines, with energies derived ultimately form the wind. In Great Britain alone, almost twice the current electricity demand breaks on the countries coastlines every day.

As wind blows along the surface of a body of water, a surface wave develops. As the wind blows, pressure and friction forces perturb the equilibrium of the water surface.These forces transfer energy from the air to the water, forming waves.The water molecules actually move in circular motion.When a wave can no longer support its top, it collapses or breaks. Usually it happens when a wave reaches shallow water, such as near a coastline.

Geothermal Energy: Temperatures hotter than the sun's surface are continuously produced inside the earth by a slow decay of radioactive particles.People around the world may use geothermal energy to produce electricity and heat their homes by digging deep wells and pumping the heated water or steam to the surface

Uses and Goals

- Heat pumps – heat and cool building; melt snow from roads and sidewalks
- Direct use applications – heat water, pasteurize milk, food dehydration, gold mining
- Power plants – produce electricity

Geothermal Energy are found along major plate boundaries where earthquakes and volcanoes are concentrated (Geysers, Hot springs, Fumaroles (openings in the earth's surface that emit steam and volcanic gases), Geothermal reservoirs)

Hydrogen energy

Electricity generated from renewable sources could be used to produce hydrogen.Vehicles, computers, cell phones, home heating, and countless other applications could be powered. Basing an energy system on hydrogen could alleviate dependence on foreign fuels and help fight climate change. Government is funding for research into hydrogen and fuel cell technology to produce vehicles that run on hydrogen

Hydrogen Fuel Cell

A fuel cell is a device that converts chemical potential energy (energy stored in molecular bonds) into electrical energy. A PEM (Proton Exchange Membrane) cell uses hydrogen gas (H_2) and oxygen gas (O_2) as fuel.

The products of the reaction in the cell are water, electricity, and heat. This is a big improvement over internal combustion engines, coal burning power plants, and nuclear power plants, all of which produce harmful by-products. The development of fuel cells and hydrogen fuel shows promise to store energy in considerable quantities to produce clean, efficient electricity. A hydrogen economy would provide a clean, safe, and efficient energy system by using the world's simplest and most abundant element as fuel

Fuel cell

A fuel cell uses the chemical energy of hydrogen or another fuel to cleanly and efficiently produce electricity. If hydrogen is the fuel, electricity, water, and heat are the only products. Fuel cells are unique in terms of the variety of their potential applications; they can provide power for systems as large as a utility power station and as small as a laptop computer.

Significance of fuel cell with its working:

Fuel cells work like batteries, but they do not run down or need recharging. They produce electricity and heat as long as fuel is supplied. A fuel cell consists of two electrodes—a negative electrode (or anode) and a positive electrode (or cathode)—sandwiched around an electrolyte. A fuel, such as hydrogen, is fed to the anode, and air is fed to the cathode. In a hydrogen fuel cell, a catalyst at the anode separates hydrogen molecules into protons and electrons, which take different paths to the cathode. The electrons go through an external circuit, creating a flow of electricity. The protons migrate through the electrolyte to the cathode, where they unite with oxygen and the electrons to produce water and heat.

Parts of a fuel cell: Polymer electrolyte membrane (PEM) fuel cells are the current focus of research for fuel cell vehicle applications. PEM fuel cells are made from several layers of different materials. The main parts of a PEM fuel cell are described below. The heart of a PEM fuel cell is the membrane electrode assembly (MEA), which includes the membrane, the catalyst layers, and gas diffusion layers (GDLs). Hardware components used to incorporate an MEA into a fuel cell include gaskets, which provide a seal around the MEA to prevent leakage of gases, and bipolar plates, which are used to assemble individual PEM fuel cells into a fuel cell stack and provide channels for the gaseous fuel and air.

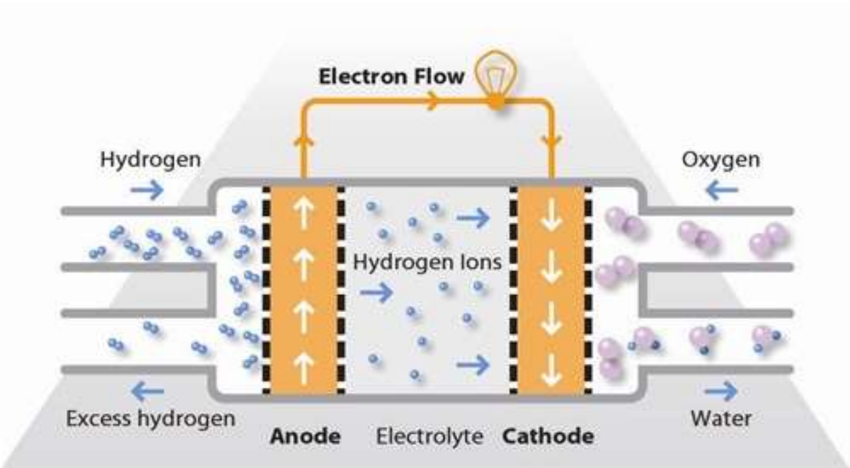


Diagram of a PEM fuel cell

PEM fuel cell is shown in fig above. The proton exchange membrane fuel cell (PEMFC) uses a water-based, acidic polymer membrane as its electrolyte, with platinum-based electrodes. PEMFC cells operate at relatively low temperatures (below 100 degrees Celsius) and can tailor electrical output to meet dynamic power requirements. Due to the relatively low temperatures and the use of precious metal-based electrodes, these cells must operate on pure hydrogen. PEMFC cells are currently the leading technology for light duty vehicles and materials handling vehicles, and to a lesser extent for stationary and other applications. The PEMFC fuel cell is also sometimes called a polymer electrolyte membrane fuel cell (also PEMFC).Hydrogen fuel is processed at the anode where electrons are separated from protons on the surface of a platinum-based catalyst. The protons pass through the membrane to the cathode side of the cell while the electrons travel in an external circuit, generating the electrical output of the cell. On the cathode side, another precious metal electrode combines the protons and electrons with oxygen to produce water, which is expelled as the only waste product; oxygen can be provided in a purified form, or extracted at the electrode directly from the air.

Biogas

Biogas technology: Generation of a combustible gas from anaerobic biomass digestion. A biogas plant can convert animal manure, green plants, waste from agro industry and slaughterhouses into combustible gas.

It is a mixture of: – Methane (CH_4) – Carbon dioxide (CO_2) – Hydrogen (H_2) – Hydrogen sulphide (H_2S).

The energy content of the gas depends mainly on its methane content. High methane content is therefore desirable. A certain amount of carbon dioxide and water vapour content is unavoidable, but Sulphur content must be minimized - particularly for use in engines**.**

Renewable energy has a sustainable development

Sustainable energy is the practice of using energy in a way that "meets the needs of the present without compromising the ability of future generations to meet their own needs.

Meeting the world's needs for electricity, heating, cooling, and power for transport in a sustainable way is widely considered to be one of the greatest challenges facing humanity in the 21st century. Worldwide, nearly a billion people lack access to electricity, and around 3 billion people rely on smoky fuels such as wood, charcoal or animal dung in order to cook. These and fossil fuels are a major contributor to air pollution, which causes an estimated 7 million deaths per year. Production and consumption of energy emits over 70% of human-caused greenhouse gas emissions.

Proposed pathways for limiting global warming to 1.5 °C describe rapid implementation of low-emission methods of producing electricity and a shift towards more use of electricity in sectors such as transport. The pathways also include measures to reduce energy consumption; and use of carbon-neutral fuels, such as hydrogen produced by renewable electricity or with carbon capture and storage. Achieving these goals will require government policies including carbon pricing, energy-specific policies, and phase-out of fossil fuel subsidies.

When referring to methods of producing energy, the term "sustainable energy" is often used interchangeably with the term "renewable energy". In general, renewable energy sources such as solar, wind, and hydroelectric energy are widely considered to be sustainable. However, particular renewable energy projects, such as the clearing of forests for the production of biofuels, can lead to similar or even worse environmental damage when compared to using fossil fuel energy. Nuclear power is a zero emission source and while its sustainability is debated, the European Union has chosen it to be the part of a low-carbon energy backbone by 2050.

Moderate amounts of wind and solar energy, which are intermittent energy sources, can be integrated into the electrical grid without additional infrastructure such as grid energy storage. These sources generated 7.5% of worldwide electricity in 2018, a share that has grown rapidly. As of 2019, costs of wind, solar, and batteries are projected to continue falling.

Present Indian and international energy scenario of conventional and RE sources.

India has made important progress towards meeting the United Nations Sustainable Development Goals, notably Goal 7 on delivering energy access. Both the energy and emission intensities of India's gross domestic product (GDP) have decreased by more than 20% over the past decade. This represents commendable progress even as total energy-related carbon dioxide (CO_2) emissions continue to rise. India's per capita emissions today are 1.6 tonnes of CO_2, well below the global average of 4.4 tonnes, while its share of global total CO_2 emissions is some 6.4%.

India is an active player at international fora in the fight against climate change. The country's Nationally Determined Contribution under the Paris Agreement sets out targets to reduce the emissions intensity of its economy and increase the share of non-fossil fuels in its power generation capacity while also creating an additional carbon sink by increasing forest and tree cover. Although the emissions intensity of India's GDP has decreased in line with targeted levels, progress towards a low-carbon electricity supply remains challenging.

India has taken significant steps to improve energy efficiency, which have avoided an additional 15% of annual energy demand and 300 million tonnes of CO_2 emissions over the period 2000‑18, according to IEA analysis. The major programmes target industry and business, relying on large-scale public procurement of efficient products such as LEDs and the use of tradable energy efficiency certificates. The government's LED programme has radically pushed down the price of the products in the global market and helped create local manufacturing jobs to meet the demand for energy-efficient lighting.

Based on current policies, India's energy demand could double by 2040, with electricity demand potentially tripling as a result of increased appliance ownership and cooling needs. Without significant improvements in energy efficiency, India will need to add massive amounts of power generation capacity to meet demand from the 1 billion air-conditioning units the country is expected to have by 2050. By raising the level of its energy efficiency ambition, India could save some USD 190 billion per year in energy imports by 2040 and avoid electricity generation of 875 terawatt hours per year, almost half of India's current annual power generation.

Recent IEA analysis shows that in 2018, India's investment in solar PV was greater than in all fossil fuel sources of electricity generation together. Large-scale auctions have contributed to swift renewable energy development at rapidly decreasing prices. By December 2019, India had deployed a total of 84 GW of grid-connected renewable electricity capacity. By comparison, India's total generating capacity reached 366 GW in 2019. India is making progress towards its target of 175 GW of renewables by 2022. In September 2019, it is announced that India's electricity mix would eventually include 450 GW of renewable energy capacity. Progress towards these targets will require a focus on unlocking the flexibility needed for effective system integration. This can potentially be achieved by improving the design of renewables auctions, with clear trajectories and criteria to reflect quality, location and system value, along with measures to foster grid expansion and demand-side response across India.

India has been addressing energy-related environmental pollution since the 1980s, including air, water, land and waste issues. Reducing the health impacts of air pollution is a key priority. Over the years, the government has been progressively strengthened rules to combat air pollution, and adopted the National Clean Air Programme (NCAP), which focuses on monitoring and enforcement. Real progress on the ground has so far been limited, with the deadline for the enforcement of stringent air pollution standards for thermal power plants pushed back from 2017 to 2021/22. However, the implementation of the NCAP is expected to help improve this issue.

India is particularly vulnerable to climate change impacts and is exposed to growing water stress, storms, floods and other extreme weather events. Adaptation and resilience of the energy system to these extreme climate conditions should be a high political priority. Furthermore, the energy sector is a large water user. As India's energy demand continues to grow, the government should ensure that energy planning takes into account the water–energy nexus, as well as future space cooling needs.

Present status of world energy scenario.

Renewable energy can be defined as the energy sources that are natural and continually replenished either at the same rate or faster than the rate at which they are being used up by humans more or less indefinitely such as the sun, wind, rain, tides, biomass and geothermal energy. Green energy, alternative energy and sustainable energy are the other synonyms sometimes used to describe the renewable energy that is converted into either electricity, heat or mechanical power for use in homes or in industries by clean, harmless and non-polluting methods. But it is important to understand the differences between the technologies used by each of the different sources to make the right choice for any particular application.

The crude oil crisis which began in 1971 and the continuously increasing prices for fossil fuels, has adversely affected the economic growth of developing countries. This woke up the world to look for the alternative and sustainable energy solutions. Therefore, energy security calls for using renewable energy resources.

With rapid economic growth, the demand for energy is increasing. Energy is by far the largest industry in the world. It is worth about US $ 7 trillion per year while the world's total GDP is about US $ 55 trillion. Thus, the energy industry is worth more than 10% of the entire world's economy. As reported by Renewable Energy World Magazine in their February 2, 2018 Issue, for the first time in history in 2017 in the 28 nation European Union, the power from renewables generated jointly by wind, solar and biomass was an all time high of 20.9% of all power, overtaking the power generated by coal which was down to 20.6%. Since 1980s, the government of India (and many other governments) has introduced myriad of incentives for the use and promotion of renewable energy sources.

Table: shows a comparison of renewable and conventional energy

Comparison of Renewable versus Conventional Energy

S.No.	Criteria	Renewable Energy	Conventional Energy
1	Availability	Can be used without any treatment	Needs to be extracted and treated through laborious and environmentally damaging processes
2	Quantity available	Continuously replenish-able resource	Dwindling reserves
3	Transportability	No need to transport, used where it is available	Needs to be transported from the site rendering it environmentally harmful
4	Green house gases (GHG)	Nil	Releases green house gases
5	Energy security	Minimises reliance on dwindling resources such as oil, coal and others	Energy security remains at risk due to more dependence on oil
6	Pollution	Completely pollution-free	Pollution occurs at various levels

India has made important progress towards meeting the United Nations Sustainable Development Goals, notably Goal 7 on delivering energy access. Both the energy and emission intensities of India's gross domestic product (GDP) have decreased by more than 20% over the past decade. This represents commendable progress even as total energy-related carbon dioxide (CO2) emissions continue to rise. India's per capita emissions today are 1.6 tonnes of CO2, well below the global average of 4.4 tonnes, while its share of global total CO2 emissions is some 6.4%.

India is an active player at international fora in the fight against climate change. The country's Nationally Determined Contribution under the Paris Agreement sets out targets to reduce the emissions intensity of its economy and increase the share of non-fossil fuels in its power generation capacity while also creating an additional carbon sink by increasing forest and tree cover. Although the emissions intensity of India's GDP has decreased in line with targeted levels, progress towards a low-carbon electricity supply remains challenging.

India has taken significant steps to improve energy efficiency, which have avoided an additional 15% of annual energy demand and 300 million tonnes of CO2 emissions over the period 2000‑18, according to IEA analysis. The major programmes target industry and business, relying on large-scale public procurement of efficient products such as LEDs and the use of tradable energy efficiency certificates. The government's LED programme has radically pushed down the price of the products in the global market and helped create local manufacturing jobs to meet the demand for energy-efficient lighting.

Based on current policies, India's energy demand could double by 2040, with electricity demand potentially tripling as a result of increased appliance ownership and cooling needs. Without significant improvements in energy efficiency, India will need to add massive amounts of power generation capacity to meet demand from the 1 billion air-conditioning units the country is expected to have by 2050. By raising the level of its energy efficiency ambition, India could save some USD 190 billion per year in energy imports by 2040 and avoid electricity generation of 875 terawatt hours per year, almost half of India's current annual power generation.

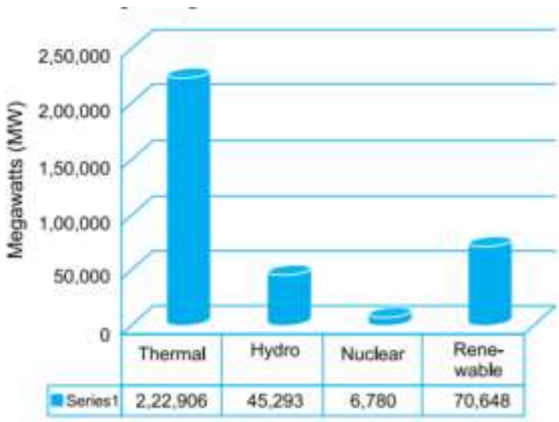
Recent IEA analysis shows that in 2018, India's investment in solar PV was greater than in all fossil fuel sources of electricity generation together. Large-scale auctions have contributed to swift renewable energy development at rapidly decreasing prices. By December 2019, India had deployed a total of 84 GW of grid-connected renewable electricity capacity. By comparison, India's total generating capacity reached 366 GW in 2019. India is making progress towards its target of 175 GW of renewables by 2022. In September 2019, it is announced that India's electricity mix would eventually include 450 GW of renewable energy capacity. Progress towards these targets will require a focus on unlocking the flexibility needed for effective system integration. This can potentially be achieved by improving the design of renewables auctions, with clear trajectories and criteria to reflect quality, location and system value, along with measures to foster grid expansion and demand-side response across India.

India has been addressing energy-related environmental pollution since the 1980s, including air, water, land and waste issues. Reducing the health impacts of air pollution is a key priority. Over the years, the government has been progressively strengthened rules to combat air pollution, and adopted the National Clean Air Programme (NCAP), which focuses on monitoring and enforcement. Real progress on the ground has so far been limited, with the deadline for the enforcement of stringent air pollution standards for thermal power plants pushed back from 2017 to 2021/22. However, the implementation of the NCAP is expected to help improve this issue.

India is particularly vulnerable to climate change impacts and is exposed to growing water stress, storms, floods and other extreme weather events. Adaptation and resilience of the energy system to these extreme climate conditions should be a high political priority. Furthermore, the energy sector is a large water user. As India's energy demand continues to grow, the government should ensure that energy planning takes into account the water–energy nexus, as well as future space cooling needs.

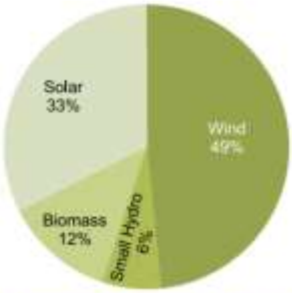
Energy planning issues aiming to bridge the gap between the energy demand and supply situation in India.

India is world's 3rd largest producer (3,44,690 MW) and 3rd largest electrical energy consumer as on September 2018. Massively expanding the large scale deployment of both centralised and distributed renewable energy including solar, wind, small hydro, biomass, and geothermal will ease the strain on the present transmission and distribution systems. As on September 2018 .India is having the 6th largest installed electric generation capacity of 3,44,002 MW. Of this total installed power, the contribution from thermal power plants is 2,22,906 MW (64.80%), large hydroelectric power plants is 45,293 MW (13.17%), nuclear power is 6,780 MW (1.97%) and that from all renewable sources put together is 70,648 MW (20.54%).



Installed Grid Connected Electrical Capacity in India (MW)

The grid connected renewable energy in India is (see Figure 1.2): 70,648 MW (on September 2018), wind power 34,294 MW (9.9%) small hydro—4,493 MW (1.3%), biomass—8,839 MW (2.6%), Solar PV—23,023 MW (6.7%). India plans to make a massive switch over from coal, oil, natural gas and nuclear power plants to renewable energy power plants, as MNRE has targeted to have an installed capacity of 1,00,000 MW of solar power and 60,000 MW of wind power by the year 2022. The large scale deployment of solar and wind power projects which represent a bright spot on India's economic future needs to be continued even at a quicker pace in order to effect the smooth transition from fossil fuels to renewable energy sources. In 1982, the foundation stone for harnessing renewable energy was laid in India by the establishment of the Department of Non-Conventional Energy Sources (DNES). In 1992 the DNES was converted into the Ministry of Non-Conventional Energy Sources (MNES) and later in 2006 it was re-christened as Ministry of New and Renewable Energy Sources (MNRE). In order to fully exploit the indigenous renewable energy sources at its doorstep, the MNRE has been addressing several challenges to remove the barriers that are holding back the development, by formulating suitable policies and setting up demonstration.



Overview of Grid Connected Renewable Energy Capacity in India (MW)

projects for various types of renewable energy power plants in various parts of India build up investor confidence and to promote research even in the private sector. Table depicts the presently available potential of the grid connected renewable sources in India

Potential of Grid Connected Renewable Energy in India

S.No.	Renewable Energy Source	Potential Capacity	Assumed PLF (%)
1	Wind power	1,00,000	25
2	Small hydro power	15,000	45
3	Bagasse power	5,000	60
4	Biomass power	16,881	60
5	Waste-to-power	5,000	60
6	Solar CSP-based power	2,00,000	35
7	Solar PV power	2,00,000	20
8	Geothermal power	10,000	80

The initial policy support for renewable energy began in 1993 when MNES issued guidelines for purchase of power prescribing the power purchase tariff of ` 2.25 kWh with annual escalation of 5% for the power generated from renewable energy sources. The renewable energy initiatives got a shot in the arm with the enactment of Indian Electricity Act 2003 and the State Electricity Regulatory Commissions (SERC), which states that every utility will have to mandatorily purchase the energy from the renewable energy sector. In 2011, the trading of renewable energy certificates (REC) started in India in line with the renewable purchase obligations (RPO) by various states of India. Under the National Action Plan for Climate Change (NAPCC), the government has set a goal for 15% of renewable energy (excluding the large hydroelectric power plants) and 15% of wind power by 2020 to promote renewable energy. India has reiterated its commitment by upscaling the renewable energy target to 175 GW capacity by 2022 to provide equitable sustainable development.

Table provides an overview of the capital cost for 1 kW of energy and generation cost of 1 kWh of electrical energy from various energy sources.

Energy Costs from Different Types of Energy Sources

S.No.	Energy Source	Capital Cost of 1 kW (Indian Rupees)	Generation Cost of 1 kWh (Indian Rupees)
1	Natural gas	27,500 to 82,500	2.16 to 3.38
2	Coal	1,04,500 to 3,19,000	1.08 to 2.16
3	Nuclear	2,47,500 to 4,12,500	15.66
4	Geothermal	1,40,400 to 1,89,400	5.4
5	Solar thermal	1,62,000 to 2,70,400	3.24 to 8.1
6	Solar photovoltaic	60,000 to 95,000	3.0
7	Wind	70,200 to 1,35,000	2.43 to 5.4
8	Biomass	Differs with technology	2.43 to 5.4
9	Tidal	Differs with technology	5.4
10	Wave	Differs with technology	6.48

Unit II

WIND ENERGY :

Power in the Wind – Types of Wind Power Plants (WPPs)–Components of WPPs-Working of WPPs- WPPs-Grid integration issues of WPPs.

History of wind power plants (WPP):

- As a rule of thumb, the capital cost of 1 MW of wind power project can be around ` 6 crores per MW from concept to commissioning. This gives a levelised cost of energy generation in the range of ` 2.00/kWh to ` 2.50/kWh taking into consideration the fiscal benefits and other incentives extended by the government of India. This explains the current wind rush in India by wind power developers as well as investors.
- GWEC has reported that wind farms generate power between 17 and 39 times as much power as they consume as compared to 16 times for nuclear plants and 11 times for coal plants.
- Today wind power plants (WPPs) produce electric power at competitive costs and contribute a large share of the power in many countries.
- Almost all WPPs start operating at wind speeds around 3 m/s and produce rated power output between 11 m/s to 15 m/s and continue to do so till the very high wind speed of 25 m/s (gale force) is achieved as such winds are rare.
- Although in a year, it typically generates around 15–30% (or more) of the theoretical rated output, the capacity factor is less than the conventional power plants.
- As a simple rule of thumb, a typical 1 MW WPP produces
- 2 GWh/acre on land and 3 GWh/acre offshore. With new WPPs of 80 m–100 m hub heights, these figures would be higher; 2.5 GWh on land and 4 GWh offshore. But as the wind is free, hence, no fuel costs; it is not logical to compare the efficiency of the WPP energy technologies with those fossil-based power plants.

Statistical data of WPP: India's position in WPP

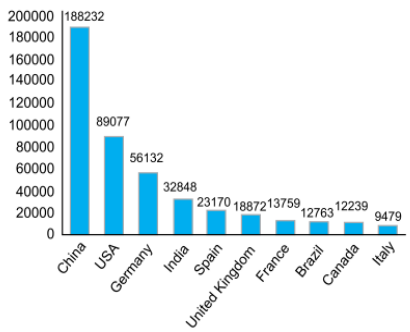


Figure 1.20 **Top Ten WPP Leading Countries (in MW):** Generally, India ranks 5th in the world, as on January 2018.

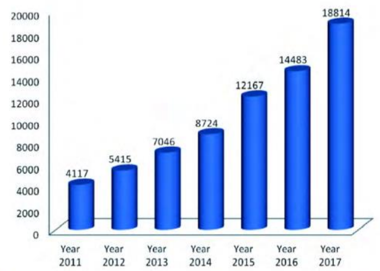


Figure 1.22 Growth of Global Installed Offshore Wind Power Installations in MW (2011 to 2017).
Courtesy: www.gwec.net.

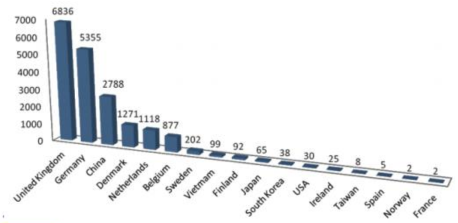


Figure 1.23 Distribution of Global Offshore Wind Power Installations in MW (As on February 2018).
Courtesy: www.gwec.net

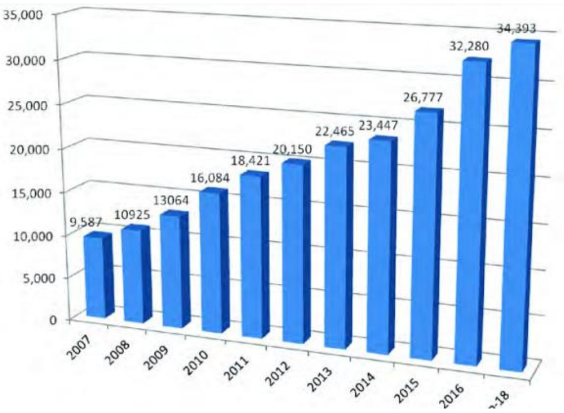
Wind energy companies

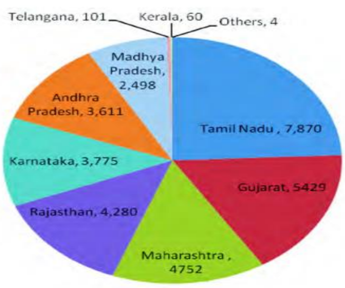
(iii) GE Wind — USA (Headquarter)
(iv) Goldwind — China (Headquarter)
(v) Enercon — Germany (Headquarter)
(vi) Nordex — Germany (Headquarter)
(vii) Nordex — Germany (Headquarter) (owned by USA)
(viii) United Power — China (Headquarter)
(ix) Envision — China (Headquarter)
(x) Suzlon — India (Headquarter)

Largest WPP:

- This largest cluster of WPPs in India is next to the largest cluster of WPPs at Altamont, Tehachapi and Palm Springs in California, USA. Today, Muppandal spanning several square kilometres in two districts of Tamil Nadu, is one of the permanent exhibition grounds at a single location in the world for a large variety of WPPs attracting not only the wind turbine specialists, but also tourists, researchers and everyone who is interested in them.

Cumulative Installed Growth of Wind Power in India in MW: As on March 2018.





Cumulative State Level Power Installations in India (MW): As on March 2018

1.10 STRENGTHS AND LIMITATIONS OF WIND POWER

Every resource has its strengths as well as limitations. Following are some of the main reasons of advocating wind power generation:

(i) Among all the renewable energy sources, wind power is the most matured technology competing with the conventional energy sources.
(ii) Wind power projects have the fastest payback period.
(iii) A wind power project has least investment in manpower.
(iv) The marketing risks are minimal, as the product is electrical energy.
(v) A permanent shield against everincreasing power prices. The cost per kWh reduces over a period of time contrary to the rising cost for conventional power.
(vi) The cheapest source of electrical energy (on a leveled cost over 20 years). The capital cost ranges between 5 crores/MW to 6 crores/MW depending upon the type of turbine, technology, size and location.
(vii) Least equity participation is required as well as low cost debt is easily available to wind energy projects.
(viii) A real fast track power project with the lowest gestation period and a modular concept. Capacity addition can be in modular form.

(ix) Operation and maintenance cost is very low.
(x) Fuel cost is zero.

Although wind power has the following limitations, the strengths discussed above outweigh them:

(i) The installation of WPPs depends on the availability of winds.
(ii) Wind is varying in nature and hence, cannot be used as a base load as large hydro and thermal power plants.
(iii) WPPs are subject to damage from hurricanes, typhoons and cyclones. However, this phenomenon is quite rare in India. Moreover, modern WPPs are generally built for survival wind speeds around 60 m/s.
(iv) Noise from the WPPs can be annoying to the neighbours in the vicinity. This problem is overcome as the WPPs are situated reasonably at a good distance from human habitation.

What is wind? Or Formation of wind:

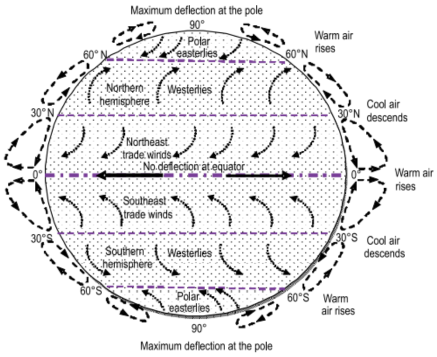
- Wind is the air in motion. The air is set in motion by the differences in temperature and air pressure due to solar radiation on the earth's surface.

- Air is a mixture of gas, solid and liquid particles. Cold air contains more air particles than warm air. Cold air is, therefore, heavier and sinks down through the atmosphere creating high pressure areas. Warm air rises through the atmosphere creating low pressure areas. This rising air, then, draws in cooler air from the surrounding as the air naturally flows from high pressure area to low pressure area and this movement is known as the wind

Types of wind:

- The earth is continuously rotating and the topography of the earth's surface upto an altitude of 100 m affects the flow of air in various ways. When viewed from the ground, the wind movement in the northern hemisphere is deflected to the right while in the southern hemisphere, it is deflected to the left. This apparent bending force (see Figure 2.3) is known as the Coriolis force [named after the French mathematician Gustave Gaspard Coriolis (1792–1843)]

Effect of Coriolis Force: Caused due to the earth’s rotation:



- The air movements toward the equator are called trade winds, that are characterised as warm, steady breezes that blow almost continuously.
- The trade winds, i.e., westerlies and easterlies flow around the world and cause many of the earth’s weather patterns. The westerlies (named from the direction from which they originate) are steady winds that generally blow between 30° and 60° latitude in both the northern and southern hemispheres. These are the winds that are good for wind power generation.
- Gravity pulls the air towards the earth’s surface. Close to the earth, the wind is influenced by friction against the surface. With increasing height from the surface of the earth, this friction gradually decreases and at a specific height, it is negligible.
- The geostrophic wind (see Figure) is a special case, in which the rising air reaches a condition of balance of two forces (pressure gradient force and Coriolis force) such that the wind flow becomes parallel to an isobar. This undisturbed wind is called the global wind or geostrophic wind.

Geostrophic wind:

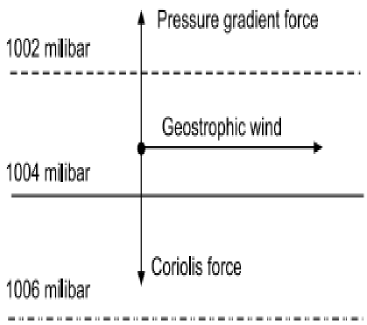


Figure 2.4 Geostrophic Wind: This is due to the balance between the Coriolis force and pressure gradient force.

The geostrophic wind is generally found at an altitude of 1000 m above the ground level and is not very much influenced by the surface of the earth.

Wind profiling and roughness:

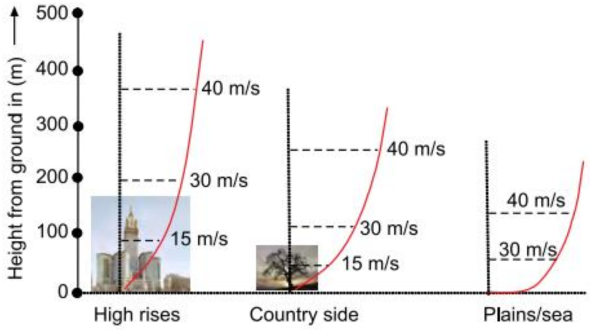


Figure 2.5 Wind Gradient: More the roughness, more will be the bend in the wind profile, affecting the hub height of the wind turbine.

- Roughness refers to the terrain and density of vegetation on the landscape. The terrain is classified into different roughness classes
- The roughness classes defined in the European Wind Atlas is on the basis of the roughness length in metres which is the height above the ground level, the value where the wind speed is theoretically zero. Sometimes, the expression roughness length is also used.
- This length has nothing to do with the length of the grass or the height of buildings. In fact, it is a mathematical factor used in the algorithms for calculations of how the terrain influences the wind speed.
- As a rule of the thumb, a WPP operating with wind speeds of 6.7 m/s at 70 m hub height could generate 20%–25% more if the hub is placed at 100 m instead of 50 m above ground level.

Table for roughness class:

Table 2.1 Roughness Classes and Roughness Lengths

Roughness Class	Roughness Length (m)	Energy Index (%)	Terrain, Obstacles and Buildings
0	0.0002	100	Open water, sea, lakes
0.5	0.0024	70	Completely open terrain such as airport runways
1	0.03	50	Sparse vegetation with no hedges, scattered buildings, soft rounded hills within 0 km to 3 km
1.5	0.05	45	Sparse vegetation with about 7 m–8 m tall hedges within a distance of 1200 m, few buildings
2	0.1	38	Sparse vegetation with about 7m–8m metre tall hedges within a distance of 500 m, few buildings
2.5	0.2	30	Sparse vegetation with about 7 m–8 m tall hedges within a distance of 250 m, few buildings
3	0.35	26	Some villages and small towns with 8 m high hedges, forests less than 250 m and very rough terrain
3.5	0.85	17	Large cities or high thick forest
4	1.65	12	Very large cities or very high thick forest

Wind shear:

The force of friction acts in the direction opposite to the wind movement. This change of wind speed and wind direction is called *wind shear* which is defined as the change in horizontal wind speed with the change in height. The wind blows more strongly higher above the ground than closer to it because of the friction of the earth's surface. The *wind shear exponent* (or *power law index*) α is to be determined for each site, as its magnitude is influenced by the site specific characteristics. It is given by:

$$\alpha = \frac{\log_{10}\left(\frac{v_2}{v_1}\right)}{\log_{10}\left(\frac{h_2}{h_1}\right)} \tag{2.1}$$

where,

α = Wind shear exponent or power law index
v_2 = Wind speed at height h_2
v_1 = Wind speed at height h_1

A power law model used for height projection of long term wind is given by

$$\frac{v_2}{v_1} = \left(\frac{h_2}{h_1}\right)^{\alpha} \tag{2.2}$$

The value of α depends on the roughness of the terrain given as follows:

α = 0.1 for roughness class 0 (still water or plain sand)
α = 0.15 for roughness class 1 (open plain)
α = 0.2 for roughness class 2 (countryside with farms)
α = 0.3 for roughness class 3 (villages and low forest)

- When the air moves parallel to the ground, it is called laminar wind flow which is best suited for generating steady electrical power. When this laminar flow is disturbed, it is termed as turbulence.
- **Turbulence Intensity (TI)** is a measure of the strength of the turbulence of the wind compared to its underlying average speed.

$$\mathrm{TI} = \frac{\sigma}{\overline{v}} \tag{2.3}$$

where,

σ = Standard deviation (SD) of the wind speed
$\overline{v}$ = Mean wind speed.

If TI is less than 0.1, it indicates low level turbulence.

If it is from 0.1 to 0.25, it represents moderate level. If TI is greater than 0.25, it is said to be a high level.

problem:

Calculate the turbulence intensity for the mean wind speed of 6.5 m/s with a standard deviation of 2.96 m/s.

Solution:

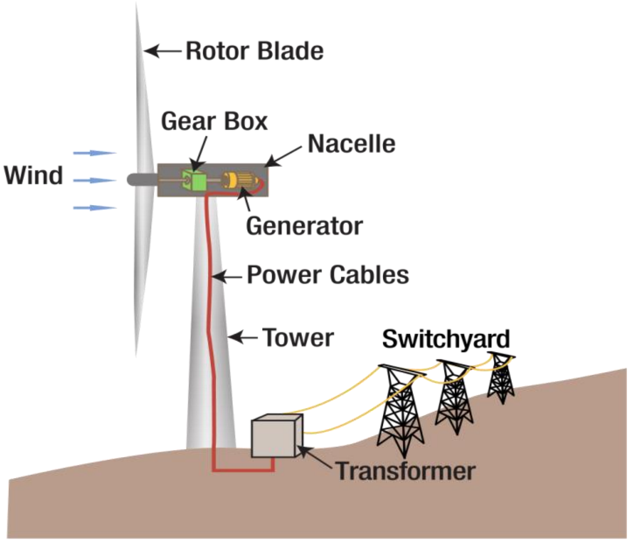
Using Eq. (2.3)

i.e., $$TI = \frac{\sigma}{\bar{v}}$$

$$TI = \frac{2.98}{6.5} = 0.46$$

This means that the wind flow has a high level of turbulence.

Wind turbine model (WPP):



Power in the Wind:

Wind of velocity v blowing through a disc area (wind turbine rotor) is considered as the swept area A for a distance d. Since moving air is not a solid mass but a fluid, therefore, m = ρAd.

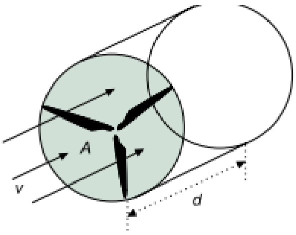


fig: Wind with a velocity blowing through a disc area 'A'

The air density also affects the power produced. The air density varies as a function of pressure and temperature in compliance with perfect gas law. Since pressure and temperature vary according to the altitude of the installation site, their combination affects the air density which can be derived from the simplified relation (valid up to 6000 m altitude) given below:

$$\rho = \rho_0 - 1.194 \times 10^{-4} \times H \tag{2.5}$$

where,

ρ_0 = Standard density (1.225) at sea level

H = Height of the installation site above sea level (m).

But when a volume of air passes through an area A per unit time, d becomes 1, then,

$$m = \rho A$$

However, when mass flow rate of air through A is with velocity v, then

$$m = \rho A v \tag{2.6}$$

Therefore, total power contained in the wind flowing through the swept area A will be:

$$\begin{aligned} P_{\text{total}} &= 1/2 \text{ (Mass flow rate) } v^2 \\ &= 1/2(\rho A v) v^2 \\ P_{\text{total}} &= 1/2(\rho A v^3) \end{aligned} \tag{2.7}$$

Unit of $P = (\text{kg/m}^3).(\text{m}^2).(\text{m}^3/\text{s}^3) = \text{kg m/s}^2 \text{ m/s} = \text{N m/s} = \text{Watt}$

Problem 2.3:

Calculate the total wind power in an area where the average wind speed is 6 m/s, using a WPP with a 60 m rotor diameter. Assume air temperature is 25°C with a density of 1.225 kg/m³.

Problem: 2.4

In Example 2.3, if the wind speed v = 4 m/s and 8 m/s, determine the difference in the power output from the wind turbine.

solution: eg 2.3

Solution:

$$\begin{aligned} P_{\text{total}} &= 1/2\ \rho A v^3 \\ &= 1/2\ \rho(\pi R^2) v^3 \\ &= 1/2 \times 1.225(\pi 30^2)\ 6^3 \text{ W} \\ &= \frac{1/2 \times 1.225(\pi 30^2)6^3}{1000} \text{ kW} \\ &= 373.88 \text{ kW or } 374 \text{ kW} \end{aligned}$$

Solution 2.4:

Solution:

$$P_{\text{total}} = 1/2\ \rho A v^3 = 1/2(1.225 \times 3.14 \times (30)^2 \times 4^3) \approx 110 \text{ kW}$$

For wind speed v = 8 m/s, using Eq. (2.7),

$$P_{\text{total}} = 1/2(1.225 \times 8^3) = 0.625 \times 3.14 \times (30)^2 \times 8^3 = 886 \text{ kW}$$

- Wind power plant:

  Nowadays, the wind turbines have power ratings ranging from a mere 300 W to a stupendous 7.5 MW capacity. Each large WPP functions as a mini (or micro) power station continuously far in excess of the designed technical life time of 20 years as an automatically controlled conventional electrical generator with low maintenance.

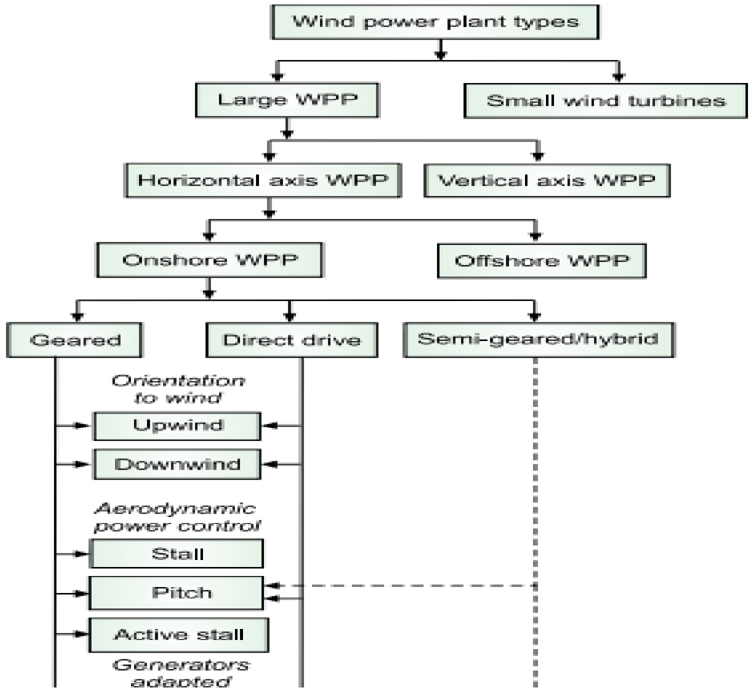
  Based on the type of axis adapted, today, there are two broad families of wind turbines in the world—**horizontal axis wind turbines (HAWTs) and vertical axis wind turbines (VAWTs**).

  VAWT:

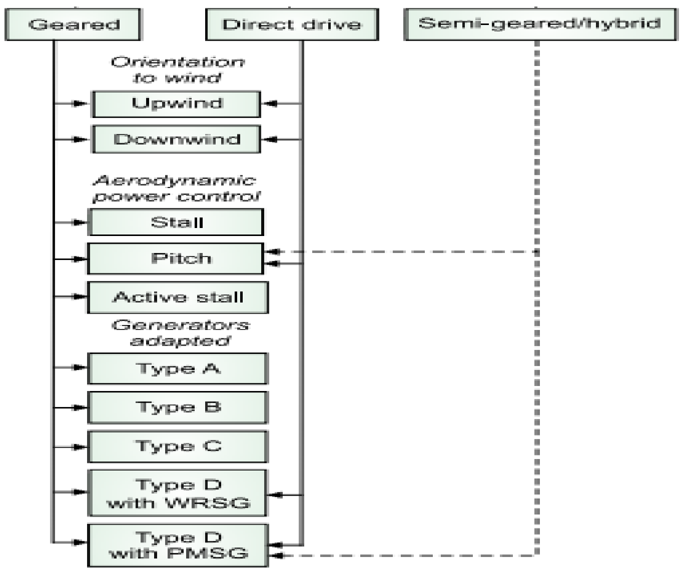
- Although VAWTs have some merits, yet because of their serious limitations, large capacity VAWT market did not survive.
- The large Darrieus type VAWT (see Fig)with egg-beater shaped rotors suffered from a number of serious technical problems such as metal fatigue related failures of the curved rotor blades and others which caused the large VAWTs to disappear from the mainstream commercial market, although the small VAWTs and their variations prevail in the market.

  Darrieus type VAWT:

Classification of WPP:



(contd—from geared)



WECS – WIND ENERGY CONVERSION SYSTEM:

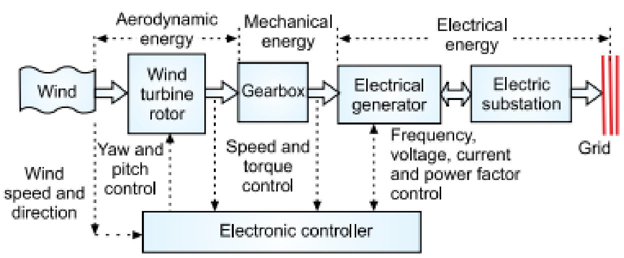


Figure 3.3 **Wind Energy Conversion in Wind Power Plant:** The wind turbine rotor rotates at slow speed which is stepped up to high speed by the gearbox. The high speed shaft turns the electrical generator to produce electric power which is fed to the electric substation and transmitted through the electric grid to the place of use.

WECS – WORKING:

- (i) No sooner is the cut-in wind speed detected by the anemometer which may be around 3 m/s and the exact direction of the blowing wind sensed by the digital wind vane , the nacelle is turned (or yawed) to face the wind direction and the rotation of the wind turbine rotor is initiated.
- Based on the various inputs received from the sensors to the microcomputer, the electronic controller automatically performs the aerodynamic, electric and various controls for the healthy working of the WPP.
- (ii) The wind flowing over the wind turbine rotor blades produces a torque on the main shaft connected to the gearbox and/or electric generator.
- (iii) If it is a geared wind turbine, the rotation per minute of the slow speed main shaft is increased by a step-up gearbox to match the rotation per minute of the high speed electrical generator.
- (iv)The high speed shaft from the rear of the gearbox connects to the rotor of an induction generator (or synchronous generator) to produce electric power
- For a direct-drive or semi-geared/hybrid wind turbine, the slow speed main shaft directly turns the rotor of a synchronous generator to produce electric power.
- (v) The electric power (produced at 690 V AC under the control of an electronic controller) goes through the circuit breakers in the substation to be stepped up to an intermediate voltage by the electrical transformer.
- (vi) The electric power from the transformer is then delivered to the wind farm electric substation by cable or overhead conductors where it is again stepped up to the electric grid voltage level for onward transmission.

Table 3.1 Wind Turbine Classes

Wind class	Type of wind	Wind speed (m/s)	Type of turbulence	Turbulence (%)	Extreme 50 year gust (m/s)
I a	High wind	10.0	Higher turbulence	18	70
I b	High wind	10.0	Lower turbulence	16	70
II a	Medium wind	8.5	Higher turbulence	18	59.5
II b	Medium wind	8.5	Lower turbulence	16	59.5
III a	Low wind	7.5	Higher turbulence	18	52.5
III b	Low wind	7.5	Lower turbulence	16	52.5

Components of WPP:

- Rotor • Nacelle • Tower • Electric substation • Foundation.

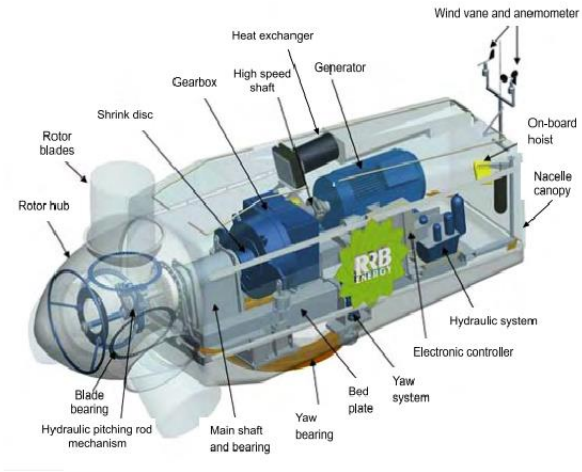


Fig: Components of WPP

Rotor:

- A wind turbine rotor (see Figure) consists of a hub with aerodynamically shaped two or three blades attached to the nacelle.
- The hub also holds the tip brake control (in case of stall controlled wind turbine) or pitching system for aerodynamic control of the wind turbine. It is made of either welded steel, cast steel or spheroidal graphite iron castings which have better acoustic damping than the normal steel. To render them light and tough enough, the rotor blades are hollow and made of light weight glass fibre reinforced plastic (GRP) or the more modern material of carbon fibre reinforced plastic (CRP) painted with light colours.

Wind turbine blade –figure

3.5 **Large Wind Turbine Rotor Blade:** This 600 kW blade is ready to be despatched to the wind farm for installation. The people near the blade depict the sheer size.

NACELLE:

- The function of the nacelle (see Figure) is to hold together all the components of the WPP.
- Under normal operating conditions, the nacelle of an upwind WPP always faces the upstream wind direction. The nacelle cover (also called canopy) is the outer covering to protect all the parts inside the nacelle from the sun and rain. It is made of GRP or thin steel

a) Main shaft:

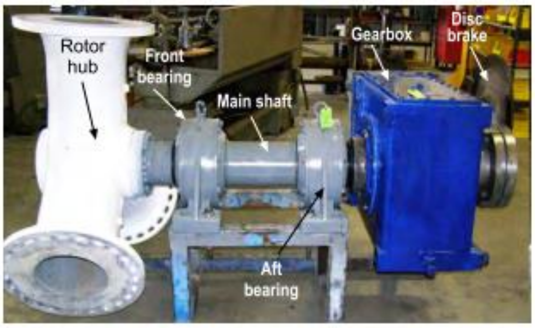


Figure 3.6 **Main Shaft:** Main shaft and drive train of a 110 kW geared WPP. *Picture by author.*

- In the geared WPP, the major function of the main shaft (see Figure), also referred as the slow speed shaft, is to optimally transfer the torque from wind turbine rotor to the gearbox and/or electrical generator.
- It is relatively long and supported by roller bearings and/or shrink discs on both the ends.
- The main shaft of forged steel is generally centre-bored to reduce its weight and at the same time, to allow the hydraulic/electric power circuits and pitch system components to pass through for the blade pitching systems situated in the hub

<u>(b) Gearbox:</u>

- The large WPPs run at a low speed in the range of 10 RPM to 20 RPM depending on the rotor diameter. Hence, many WPPs mounted with high speed generators require a gearbox to step up the speed to match the electric generator speed.
- If the synchronous speed of the electrical generator is 1500 RPM and if the rated WPP rotor speed (for the most probable wind speed at a particular windy site) is taken as 30 RPM, then a gearbox ratio of approximately 50:1 will be necessary
- Following types of gearboxes have been used in WPPs:
- • Parallel axis gearbox using spur and helical gears
- • Planetary or epicyclic gearbox
- • Combination of the above two types
- • Hydrodynamic gearbox
- The planet gears are mounted on the rotating planet carrier. A typical three-stage planetary gearbox has two planetary stages and one helical stage and is generally used in a typical large geared WPP.
- Two-stage planetary gearbox is typically used in hybrid (semi-geared) WPP .
- Due to the wind turbulence, the gearbox suffers tremendous stress and even a small defect in any one interlinked component can bring the WPP to a complete halt, rendering it the most high maintenance oriented part.

- Planetary gearboxes have higher power densities than the parallel axis gears offering a multitude of gearing options and a large change in RPM within a small volume.
- The limitation of planetary gearbox is the need for highly complex designs and the general inaccessibility of important parts and high loads on the shaft bearings. Cooling of the gearbox is done by the gearbox oil which is again cooled by a heat exchanger

(c) Couplings:

- The basic function of the coupling is to transmit the torque.
- To couple the shafts, gearboxes, generators and other parts, different types of couplings are used by the WPP manufacturers: • Flange couplings • Shrink fit couplings • Fluid couplings.

(d) High Speed Shaft:

- The high speed shaft is only applicable to the geared WPPs and not to the directdrive WPPs. The high speed shaft (see Figures) connects the rear of the gearbox to the electrial generator shaft.

(e) DISC BRAKE:

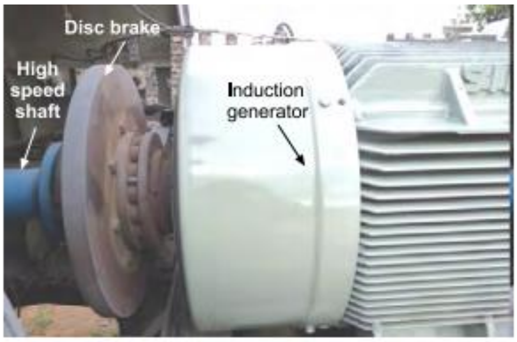


Figure 3.7 **Disc Brake:** The disc brake is generally mounted on the high speed shaft. *Picture by author.*

- Although, the primary braking of large wind turbines is always aerodynamic most of the wind turbines additionally have a disc brake that is activated to fully stop the wind turbine rotor after it has been slowed down to around 1 RPM by the primary aerodynamic braking.
- The disc brake is a friction device of hardened alloy mounted with a brake calliper, brake pads, spring loaded activator and hydraulic circuits.
- It is generally mounted on the high speed shaft nearer to the gearbox. Depending on the sensor inputs, the signals from the electronic controller activate the brake callipers to apply the brake pads on to the disc to completely halt the rotation of the wind turbine, usually at the time of maintenance.
- If in any case, the aerodynamic brake fails, the disc brake is also designed to stop the wind turbine with full torque as well.

(f) Hydraulic System:

- To operate the disc brakes (or tip brakes of stall wind turbines or blade pitching, if hydraulically operated) and other functions, a hydraulic system is mounted generally Wind Power Technology on the mainframe of the nacelle .
- The hydraulic system consists of an oil sump, electric motor, closed loop hydraulic circuits, relevant sensors and all these are controlled by the electronic controller.

(g) Electric Generator:

- The electric generator is the last link in the geared WPP power train, that is, the main shaft, gearbox, couplings and high speed shaft.
- Unlike other components of the drive train, the mechanical stress is relatively low on the generator.
- It is rotated by the high speed shaft (or directly by the main shaft in the case of directdrive wind turbines) to convert the mechanical energy into electrical energy.
- Depending on the design and control strategy adopted, different WPP manufacturers use different types of electrical generators. It could be a squirrel cage induction generator (), wound rotor induction generator, doubly fed induction generator, wound rotor synchronous generator or permanent magnet synchronous generator.

(h) Cooling Systems:

- Considerable amount of heat is generated continuously in a WPP nacelle, mainly from the electrical generators, gearbox, yaw gears and the hydraulic unit.
- The cooling of the gearbox is done by the lubrication oil inside the gearbox which is again cooled by a heat exchanger
- The heat exchanger mounted on the nacelle canopy pushes out the heated air to the outside atmosphere.
- The electric generator can be cooled in two ways—either by air or liquid. Lower capacities WPPs usually employ air cooled generators while the higher capacity ones generally adopt liquid systems. The air flow needed for air-cooled ones is produced by a fan located on one end of the generator axis

(i) Electronic Controller:
It is the electronic controller (which is responsible for rendering the WPP to be intelligent and fully unmanned.
It regularly analyses the signals from all the WPP sensors, especially the power output several times in a second.
Every WPP has two electronic controllers—the nacelle electronic controller (see Figure) mounted on the mainframe of the nacelle and tower bottom electronic controller.
Both are almost identical, and can monitor and control the entire WPP operations simultaneously and independently. This is done for redundancy, that is, if one of them fails for any reason, the other will still continue to function and keep the WPP operating.
Moreover, the maintenance personnel can monitor and control the WPP from the tower bottom itself without climbing to the top of the tower.

(j) Sensors in WPPs:

- (i) Wind vane: Sensing the wind direction is of prime importance as the wind turbine has to be turned (yawed) in a particular direction.
- (ii) Anemometer: The wind speed is continuously measured by the anemometer to decide various modes of operation of the WPP. This comes in various types, however, the cup type is the most popular, but of late the modern ultrasonic ammeter is also becoming popular.
- (iii) Pitch angle sensor: This measures the blade pitch angle for pitch-regulated WPPs.
- (iv) Wind turbine rotor speed sensor: This optical speed sensor keeps track of the rotation per minute of the slow speed shaft.
- (v) Electric generator rotor speed sensor: This continuously monitors the speed of the electric generator.
- (vi) Sensors for hydraulically activated tip brakes: This is for stall regulated WPPs.
- (vii) Pressure drop sensor: This monitors the pressure in the hydraulic circuits of the hydraulic system.
- (viii) Disc brake pad sensor: One of the most replaced components during maintenance checks are the brake pads which get worn out due to the frequent operation of the disc brake and its wearing out is monitored by the brake pad sensor.
- (ix) Temperature sensors: There are temperature sensors in various locations of the WPP nacelle to measure the ambient temperature outside the nacelle, inside nacelle, main bearings, gearbox oil, generator winding, hydraulic fluid, etc. They are even duplicated at crucial places for redundancy.
- (x) Vibration sensors: These are for the WPP nacelle and the tower structure to avoid their collapse.
- (xi) Oil level sensors: These sensors are found wherever there are oil filled enclosures such as the gearbox and other components.
- (xii) Electrical parameter measurement sensors: These are used to measure various parameters such as voltage, current, power, frequency and others. (xiii) Automatic shut down sensor: In the event of grid failure, this is necessary to avoid islanding

K) Electric Hoist:

- Almost all modern large WPPs have an electric service hoist (see Figure) at the rear end of the nacelle on the mainframe to lift up maintenance related heavy material from the ground level. The hoisting capacity may range between 500 kg to 1 ton or more

Nacelle Electric Hoist: The electric hoist is almost a mandatory item in the WPP to lift up maintenance related material from the ground level.

fig: electric hoist

TOWER:

- The main function of a tower is to hold the nacelle high above the ground safely so that the rotor blades get a relatively non-turbulent laminar wind flow which is usually available at greater heights. Larger WPPs are usually mounted on tower heights ranging from 50 m to 127 m above the ground level.
- The tower also ensures that the blades do not touch the ground and also transfers the useless thrust loads effectively to the foundation.
- Following are the major types of towers that are used by the wind industry: • Lattice towers assembled from angle iron members.
- • Steel conical tubular towers.
- • Guyed towers are generally used for lower capacity WPPs where guy wires (or stay wires) are used to hold the tubular or lattice type tower in vertical position and also to tilt it down for maintenance.
- • Concrete tower is built of concrete with steel reinforcements.
- • Hybrid tower is partly built of concrete tubular section at lower base and the upper portion of steel tubular sections.

Types of tower: figures

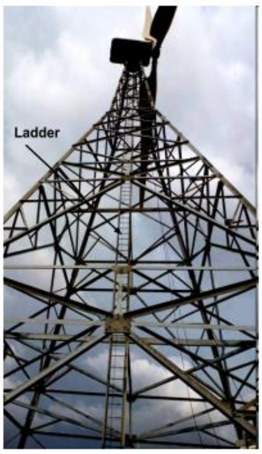


Figure 3.10 **Lattice Tower Ladder.** *Picture by author.*

Figure 3.11 **Tubular Tower Bottom:** In a tubular tower, no separate building is required for the electric panel and transformer.

- <u>(a) Electric Control Panel</u>

  Every WPP has an electric panel at the bottom of the tower. If it is a tubular tower, this will be housed inside the tower bottom (see Figure 3.11). The power and control cables, which are brought down from the nacelle top, are terminated in the electric control panel at the bottom of the tower consisting of power electronic devices, relays, electrical contractors and measuring and recording instruments.
- <u>(b) Tower Bottom Electronic Controller</u> : The tower bottom electronic controller is a replica of the nacelle electronic controller and is generally housed adjacent to the electric panel.
- The microcomputer housed in electronic controllers, continuously stores the enormous amount of data collected from the various sensors, checks the status and controls numerous switches, actuators, hydraulic pumps, valves, and electric motors of the WPP

- <u>(c) Tower Climb Systems:</u>

  To reach the nacelle for maintenance purposes, the maintenance crew enter the tower door to climb the tower ladder in every tubular and lattice tower. At regular intervals along the ladder, resting platforms are provided inside the tower, for the maintenance crew as they climb up for service and maintenance.

  <u>ELECTRIC SUBSTATION:</u>
- Most of the WPPs produce power at 690 V AC. Some larger WPPs such as the direct-drive ones use a higher generator voltage, around 3 kV but this is not high enough for economical direct interconnection to the grid.
- Invariably, all WPPs have an electric substation consisting of a pad-mounted transformer connected to transmission network through a medium voltage collector network. A power transformer is used to interface with the transmission grid.

Figure 3.14 Electric Substation.

- (a) Transformer:
- Generally, the power produced by a typical WPP is of 690 V AC and hence, cannot be directly fed to the grid. Therefore, it is necessary to have a transformer (to step up to medium voltage) with protective circuit breakers, protection relays and associated switchgear located at the tower base of each WPP
- In most of the WPPs, the electric power cables from the nacelle top are dropped down to the electric transformer at the bottom of the tower where the voltage is stepped up to a higher voltage of 11 kV or 33 kV/66 kV. Most of the times in India, whether it is a lattice type or tubular type tower, the transformer is mounted on a raised masonry platform
- (b) Electric Switchgear
- Most of the associated electric switchgear like circuit breakers, isolators, other interconnecting devices and the associated electrical poles are installed inside the fenced enclosure adjacent to the tower (see Figure 3.14). From safety point of view, the entire WPP installation and substation is well earthed. Fire extinguishers are also provided inside the switch room/switchyard at the bottom of the tower
- The foundation of a WPP performs two basic functions. Firstly, it has to bear the dead load weight of the WPP and the tower to keep it upright without any sinkage during the whole technical lifetime of 20 years.

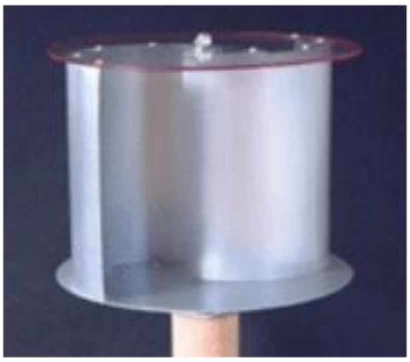
- Secondly, due to the major cantilever dynamic loads produced as result of the wind thrust and other forces, it has to prevent the wind turbine from tipping over. Whether it is the tubular tower foundation or the lattice tower foundation, the average depth of the foundation approximately ranges from 3.5 m to 4.5 m depending on the soil condition and the capacity of WPP.

<u>Wind Energy Conversion- forces and performance parameters:</u>

- * Rotation principle *Forces on a rotor blade * Factors affecting performance of rotor *.Thrust and torque on rotor *. Power curve * Lift-based VAWT
  <u>Rotation principle:</u>
  There are two major methods for converting the kinetic energy of the wind into mechanical work.
  Drag principle • Lift principle.

- <u>Drag Principle:</u>
- The least efficient principle of rotating the wind turbine rotor is by the drag principle. 'Drag' is the force experienced by an object that is in line with the flow of any fluid such as the air stream. Drag force is developed by obstructing the flowing wind and creating a turbulence.
- Drag devices are simple wind machines that use flat or curved blades to catch the wind in the enclosed area to turn the rotor. Drag force depends on exposing a flat or curved area on one side of a rotor to the wind while shielding the other—the resulting differential drag force turns the rotor
- Savonius wind turbine (see Fig) is another example which works on the drag principle. The Savonius rotor consists of two or more curved interlocking plates grouped around a central shaft between two end caps. It works on the principle of drag. Such turbines are more popular in the small wind turbine category.

  Drag Principle: The force of the wind impinges on the concave surfaces on the vertical axis to drag them along to rotate and the electrical generator coupled to it generates power.
  Figure: savonius wind turbine



A pure drag force D can be found by calculating the power P captured by a body with surface area A, moving with a velocity v due to the impinging of the wind stream of undisturbed wind velocity v_o.

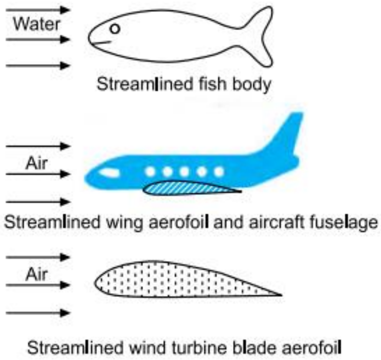
$$P = Dv_r \tag{4.1}$$

where,
v_r = Relative velocity given by $v_o - v$.

<u>Lift Principle:</u>

- The modern electricity producing large WPPs work on the principle of 'lift'. The lift principle is applicable to streamlined objects (see Figure).
- Objects designed to minimise the drag forces are called as streamlined because the lines that flow around them follow smooth, stream-like lines such as the shape of a fish, aircraft fuselage and wing sections of aircrafts, helicopters and the wind turbine blade ;aerofoil

- Figure: lift principle



igure 4.2 Fluid Flow Streamlined Objects.

<u>The performance of a WPP also depends on the following wind speed values:</u>

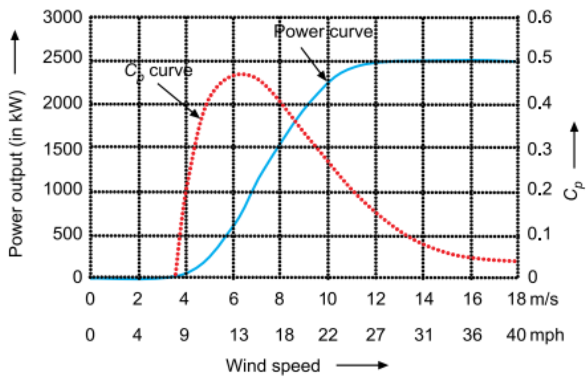
- • Start-up speed: With this wind speed, the rotor just starts to rotate and the electric generator generates a voltage increases when the wind speed rises.
- • Cut-in speed: At this wind speed, the voltage which is high enough for the WPPs to be connected to the grid. It ranges between 2 m/s–4 m/s.
- • Rated speed: It is the wind speed at which the rated power is reached and its range is between 10 m/s–14 m/s.
- • Cut-off speed: It is the wind speed beyond which the rotor is stopped to save the WPP from possible damage. It ranges between 20 m/s–25 m/s.
- • Survival speed: It is the wind speed which the WPP withstands without getting damaged in the worst storm which may occur on the installation site during the design lifetime (50 year recurrence period). It ranges between 55 m/s–65 m/s.

<u>FACTORS AFFECTING PERFORMANCE OF ROTOR:</u>

- (i) Aerodynamic efficiency Cp (ii) Tip speed (iii) Tip speed ratio (TSR) l (iv) Solidity s (v) Blade count (vi) Blade twist (vii) Blade taper (viii) Wake losses and aerofoil pressure distribution (ix) Yaw error.

<u>Aerodynamic efficiency Cp:</u>

- The aerodynamic efficiency Cp (also known as power coefficient) of a WPP is the instantaneous efficiency of the conversion of the wind energy into mechanical energy at the shaft.
- Albert Betz, a scientist from Gottingen, Germany proved that the entire energy in the wind cannot be harnessed. Betz showed that 1/3 of the retardation of the wind speed happens just in front of the WPP rotor and 1/3 just behind the WPP rotor after the wind has passed through the rotor blades.
- Efficiency curve:



- re 4.8 Typical Efficiency Curve and Power Curve of a 2500 kW WPP.

- The undisturbed wind speed vo is reduced to vo (1 – a) when it passes through the gaps in the rotor blades and to ---
- v (1 – 2a) when it covers some distance behind it (the retardation starts about one rotor diameter in front of the WPP and reaches its minimum about one diameter behind it).
- The unit ‘a’ is called the interference factor. If this factor is 0.5, the wind speed behind the rotor will be reduced to zero, i.e., 0 < a < 0.5.

Power efficiency:

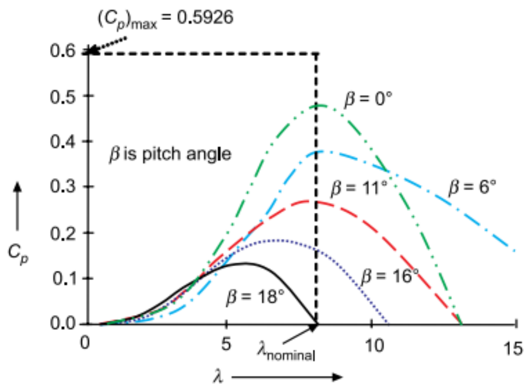


Figure 4.9 Wind Turbine Rotor Power Efficiency versus TSR.

- The theoretical maximum share of the power in the undisturbed wind that can be utilised is 16/27 and corresponds to 59.3% (≈ 0.593) called the Betz limit.
- This share of the power in the wind that can be harnessed by the rotor is called the power coefficient Cp.
- The power coefficient Cp is dependent on blade pitch angle (beta) and TSR (lambda) (see Figure) and represented as Cp–lambda curve of a WPP and it, varies for different types of aerofoils.

Cp:

$$C_p = \frac{\text{Actual power extracted by the rotor}}{\text{Total power available in the wind}}$$

$$C_p = \frac{P_{\text{actual}}}{P_{\text{total}}}$$

i.e.,
$$P_{\text{actual}} = C_p P_{\text{total}} \tag{4.10}$$

Hence, the actual power that a WPP can attain is expressed as:

$$P_{\text{actual}} = C_p \, 1/2 \, \rho A v^3 \tag{4.11}$$

where,

C_p = Power coefficient
ρ = Air density
A = Swept area
v = Wind speed.

But practically, C_p is still lower, due to the following causes:

- Rotation of the wake behind the rotor
- Finite number of blades
- Non-zero aerodynamic drag.

Problem:

A WPP of 80 m rotor diameter is rotating at a particular windy site with the average wind speed of 6 m/s at a power coefficient of 0.4. Assuming the air temperature as 25°C with a density of 1.225 kg/m^3, calculate the (a) total power available in the wind, (b) maximum power density, (c) actual power density, and (d) power output from the WPP.

Solution:

(a) Power density of air $P_{\text{total}} = 1/2 \, \rho v^3$

$$= 1/2 \times 1.225 \times 6^3$$

$$= 132.3 \text{ W/m}^2$$

(b) Maximum possible power density is limited by the Betz limit of 0.593.

$\therefore$
$$P_{\max} = 0.593 \times P_{\text{total}}$$

$$= 0.593 \times 132.3 = 78.45 \text{ W/m}^2$$

(c) Actual power density is decided by the efficiency of the blades, i.e., 40%.

$\therefore$
$$P_{\text{actual}} = 78.45 \times 0.4$$

$$= 31.38 \text{ W/m}^2$$

(d) Power output from the WPP = $P_{\text{actual}} \times$ Swept area

$$= 31.38 \times \frac{\pi D^2}{4}$$

$$= 31.38 \times 4024 \text{ W}$$

$$= 157653/1000 \text{ kW}$$

$$= 157.653 \text{ kW}$$

Tip Speed:

- Wind turbine rotors rotate between 8 RPM (for multimegawatt WPPs) to 25 RPM (for submegawatt WPPs).
- When the wind turbine blades rotate, the speed at the blade tip is higher than the speed at the middle of the blade and also at the blade root near the hub, where it becomes zero or near zero.
- The blade tip of modern WPPs can have a speed about 10 times faster than the wind speed, i.e., a wind speed of 5 m/s that rotates a WPP rotor can have a tip speed of even 50 m/s. This may seem impossible, but it is what that happens.
- The force of a wind turbine blade tip is quite large during rotation as compared to the force when the blade is stationary.
- This large difference in force is due to the high wind speed at the blade tip (say, 60 m/s) during the rotation which is many times greater than the average wind speed (say, 9 m/s) at stationary position.
- The tip speed inreases with the length of the blade. If a 40 m WPP has a blade tip speed of 60 m/s, the speed at the middle of the blade will be only 30 m/s

There is also a relation between tip speed V_{tip}, RPM and the radius of the rotors. Tip speed is calculated by the formula:

$$v_{tip} = \frac{2\pi RN}{60} \text{ m/s} \tag{4.12}$$

where,

R = Radius of the wind turbine rotor
N = RPM of the wind turbine rotor.

<u>Problems:</u>

a.A 1.2 MW direct-drive variable speed WPP rated at 12.8 m/s wind speed has a rotor diameter of 62 m and a speed range of 10 RPM to 20 RPM. Find the range of its tip speed ratio.

b.A WPP has a rotor diameter of 80 m. The RPM is 15 and the wind speed is 8 m/s. The power coefficient is 0.4. Assuming the air density as 1.225 kg/m3 , find the torque coefficient CT. Also, determine the torque available at the rotor shaft.

Solutions for (a) and (b):

Solution:

The angular speed ω for 10 RPM to 20 RPM = $2\pi N/60$.

It will range from $(2\pi \times 10)/60$ to $(2\pi \times 20)/60$ rad/s

$= 1.46$ to 2.09 rad/s

Rotor tip speed $v = \omega R$

It will range from 1.46×31 to 2.09×31 m/s.

$= 45.26$ to 64.89 m/s

TSR λ range $= (\omega R)/v_0$.

It will range from 45.26/12 to 64.89/12

$= 3.77$ to 5.40

Solution:

$$\omega = \frac{2\pi N}{60} = \frac{2 \times 3.14 \times 15}{60} = 1.57 \text{ rad/s}$$

Tip speed $v = \omega.R = 1.57 \times 40 = 62.8$ m/s

$$\lambda = \frac{v}{v_o} = \frac{62.8}{8} = 7.85$$

$$\lambda = \frac{C_p}{C_T} \text{ where, } C_T \text{ is the torque coefficient}$$

$$\therefore \quad C_T = \frac{C_p}{\lambda} = \frac{0.4}{7.85} = 0.050$$

The torque developed at the shaft is given by $T = 1/2\,\rho A v^2 R\, C_T$

Swept area $A = \pi R^2 = 40^2 = 1600 \text{ m}^2$

$$\therefore \quad T = 0.5 \times 1.225 \times 1600 \times 8^2 \times 40 \times 0.05 = 1{,}25{,}440 \text{ Nm}$$

Maximum torque $T_{max} = T/C_T = 1{,}25{,}440/0.050 = 25{,}08{,}800$ Nm

Solidity (s):

4.4.4 Solidity

Solidity (σ) is a term to describe the proportion of a WPP rotor's swept area that is filled with solid blades. *Solidity* is defined as the ratio of the total blade area to the total swept disc area.

$$\text{Solidity } \sigma = \frac{\text{Projected blade area}}{\text{Total swept area}}$$

As the solidity increases, the TSR for maximum power coefficient C_p gets reduced. Even the *lift coefficient* affects the solidity. Higher the lift coefficient, smaller will be the chord. When the rotor planform (projected) blade area is $3a$ (see Figure 4.11) and total swept area is A, then:

$$\sigma = \frac{na}{2\pi R} \tag{4.14}$$

where,

n = Number of blades
a = Projected area of single blade
R = Radius of wind turbine rotor.

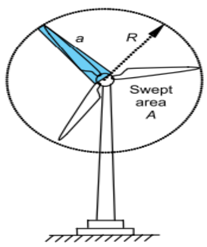


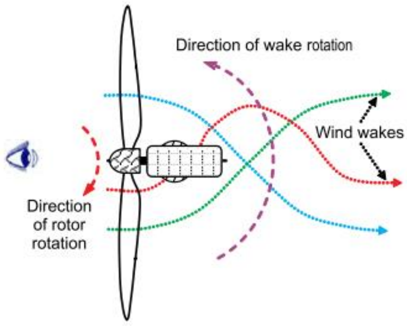
Figure 4.11 **Solidity:** As solidity increases, lift and drag forces increase and the efficiency decreases. Hence, the solidity of modern WPPs is less than 0.10.

Other parameters:

- Blade Count
- Blade Twist
- Blade Taper
- Wake Losses and Aerofoil Pressure Distribution

- Yaw Error

<u>Wake Losses and Aerofoil Pressure Distribution:</u>



- The lift force on the wind turbine blades generates a torque that has an equal and opposite effect on the flowing wind, tending to push it around tangentially in the opposite direction. The result is that the air on the leeside of the WPP has swirl or wake.
- Depending on the wind direction, the WPP has to be yawed so that the wind always perpendicularly impinges on the blades. If this is not perpendicular, then it is called a yaw error.
-

<u>Thrust and torque force :</u>

4.5 THRUST AND TORQUE ON ROTOR

The WPP extracts wind energy causing a difference in the momentum between the upstream and downstream air flow (see Figure 4.18) and gives rise to two forces—the *torque force* that turns the blades (connected to the shaft) and the *thrust force* that tries to tip the tower.

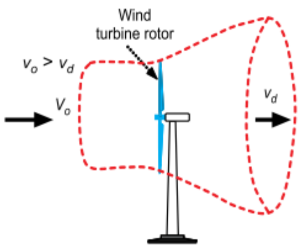


Figure 4.18 **Wind Stream Tube:** Shape of wind stream tube due to wind turbine rotor. Here, v_o represents undisturbed upstream wind and v_d represents disturbed downstream wind.

Thrust force:

where,
v_o = Undisturbed wind velocity in front of wind turbine rotor
v_d = Downstream wind velocity at the back of the rotor after energy extraction
A = Swept area
D = Rotor diameter.

It is known that for maximum output, v_d = 1/3 v_o

$$\therefore \quad (F_{\text{thrust}})_{\max} = \frac{\pi}{8} D^2 \rho \left(v_o^2 - \frac{1}{9} v_o^2 \right) = \frac{\pi}{8} D^2 \rho \frac{8}{9} v_o^2 = \frac{\pi}{9} D^2 \rho v_o^2 \quad (4.16)$$

Thrust is necessary for torque. While developing a torque in the wind turbine rotor blades, they generate more downwind force that exerts far greater stress on the tower. The thrust force applied in the rotor axis direction exerts a load on the tower and foundation.

The thrust force F_{thrust} (see Figure 4.18) must be equal to the loss of momentum of the air stream v_d.

i.e.,

$$F_{\text{thrust}} = \frac{1}{2} \rho A (v_o^2 - v_d^2)$$

$$= \frac{1}{2} \rho \frac{\pi}{4} D^2 (v_o^2 - v_d^2)$$

$$= \frac{\pi}{8} D^2 \rho (v_o^2 - v_d^2) \tag{4.15}$$

where,

v_o = Undisturbed wind velocity in front of wind turbine rotor
v_d = Downstream wind velocity at the back of the rotor after energy extraction
A = Swept area
D = Rotor diameter.

It is known that for maximum output, $v_d = 1/3\ v_o$

$\therefore$

$$(F_{\text{thrust}})_{\max} = \frac{\pi}{8} D^2 \rho \left(v_o^2 - \frac{1}{9} v_o^2 \right)$$

$$= \frac{\pi}{8} D^2 \rho \frac{8}{9} v_o^2$$

$$= \frac{\pi}{9} D^2 \rho v_o^2 \tag{4.16}$$

Torque:

Torque is necessary for wind energy extraction. The physical size of any electric generator is governed by the torque, as it is required to absorb. If the wind imparts a torque T_{aero} on the blades, then the blades must be imparting a torque on the wind. The actual rotor torque T_{aero} would occur when the circumferential force F_{torque} (see Figure 4.6) acts on the rotor blade at radius R.

i.e.,

$$T_{\text{aero}} = F_{\text{torque}} R \tag{4.17}$$

Maximum theoretical torque $T_{\max}$ would occur if the circumferential force F_{torque} acts at the tip of the rotor blade. But practically, the wind turbine rotor produces a torque which is only a fraction of this value.

The ratio of the actual torque T_{aero} developed by the rotor to the maximum theoretical torque $T_{\max}$ is termed as the *torque coefficient* C_T given by

$$C_T = \frac{T_{\text{aero}}}{T_{\max}} \tag{4.18}$$

$\therefore$

$$T_{\text{aero}} = C_T T_{\max} \tag{4.19}$$

When a WPP shaft is turned at an angular speed ω, the actual power P_{actual} developed by a WPP is the product of the rotor torque T_{aero} (in Newton metre per radian or watts) and angular speed ω (in radians per second).

$$P_{\text{actual}} = T_{\text{aero}}\ \omega \tag{4.20}$$

It is known that out of the total power available in the wind, the actual power extracted by the wind turbine rotor is given by the following equation:

$$P_{\text{actual}} = C_p P_{\text{total}} \tag{4.21}$$

Substituting the value of P_{actual} and T_{aero} in Eq. (4.20), it becomes

$$C_p P_{\text{total}} = C_T T_{\max} \omega \tag{4.22}$$

It is known that:

$$T_{\max} = \frac{P_{\text{total}}}{v_o} R \tag{4.23}$$

Now, substituting the value of $T_{\max}$ in Eq. (4.22), it becomes:

$$C_p P_{\text{total}} = C_T \frac{P_{\text{total}}}{v_o} R\omega$$

$$\therefore \quad C_p = \frac{\omega C_T R}{v_o}$$

$$\therefore \quad \frac{C_p}{C_T} = \frac{\omega R}{v_o}$$

But it has been proved that:

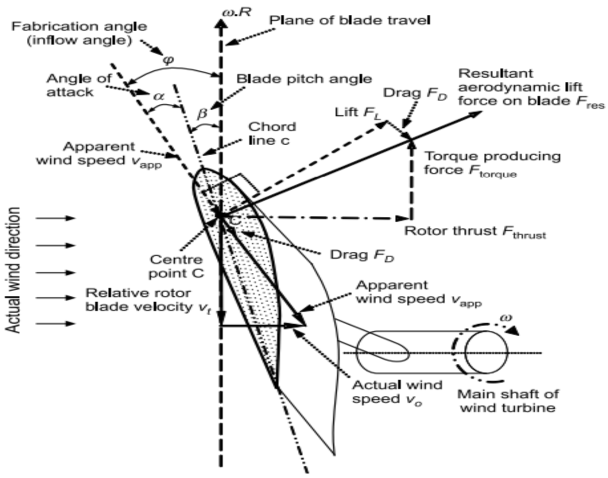
$$\lambda = \frac{\omega R}{v_o}$$

$$\therefore \quad \frac{C_p}{C_T} = \lambda \tag{4.24}$$

i.e., when the value of C_p is maximum, i.e., 0.593, as per Betz criterion, then:

$$(C_T)_{\max} = \frac{(C_p)_{\max}}{\lambda} \tag{4.25}$$

Forces on a rotating wind turbine blade:



$$v_{\text{app}} = \sqrt{v_o^2 + v_t^2} = \sqrt{v_o^2 + (\omega R)^2}$$

$$F_{\text{torque}} = F_L \sin\ \varphi - F_D \cos\ \varphi$$

$$F_{\text{thrust}} = F_L \cos\ \varphi + F_D \sin\ \varphi$$

$$F_L = 1/2\ \rho A v^2\ C_L \qquad (4.5)$$

where,

F_L = Lift force (in newton)
ρ = Air density (in kilogramme per metre cube)
A = Aerofoil plan area [i.e. Chord × Span of blade (in metre square)]
v = Wind speed (in metre per second)
C_L = Lift coefficient (a dimensionless number).

Typical value of C_L is equal to 0.8. It could range from 0.8 to 1.25. The lift coefficient C_L can also be known from tables of aerofoil data. It should be noted that the lift coefficient is not a constant, but varies with the angle of attack α.

The drag force F_D that is perpendicular to lift force is given by the *drag equation*:

$$F_D = 1/2\ \rho A v^2\ C_D \qquad (4.6)$$

where,

C_D = Drag coefficient (a dimensionless number).

$$E = \frac{C_L}{C_D}$$

An aerodynamic *pitching moment* about an axis perpendicular to the aerofoil section, described by the pitching coefficient C_M is given by:

$$C_M = \frac{\text{Pitching moment}}{\text{Dynamic moment}}$$

i.e.,

$$C_M = \frac{M}{1/2 \rho\, A\, L\, v^2} \qquad (4.8)$$

where,

C_M = Pitching coefficient (a dimensionless number)
M = Pitching moment
L = Lift.

Another factor that affects the lift and drag forces is the Reynolds number R_e which is the ratio between the gravitational force and the viscous force given by:

$$R_e = \frac{vC}{\gamma} \qquad (4.9)$$

where,

v = Wind velocity
C = Chord length
γ = Kinematic velocity of fluid (for air at 20°C, the value is 15×10^{-6} m/s).

Wind turbine aerodynamics:

- Every wind power plant (WPP) is fully unmanned and its operation and control is performed by a microcomputer with custom-designed software. It can be said that there is a three-fold purpose in the control of small and large WPPs:
- • Speed regulation—to restrict the noise levels whereby the tip speeds of WPPs are limited to ~120 m/s.
- • Load mitigation—to ensure that the torque of the WPP is under control to operate safely by limiting the various forces.
- • Power regulation—to get as much energy as possible out of a WPP.

Aerodynamic power regulation:

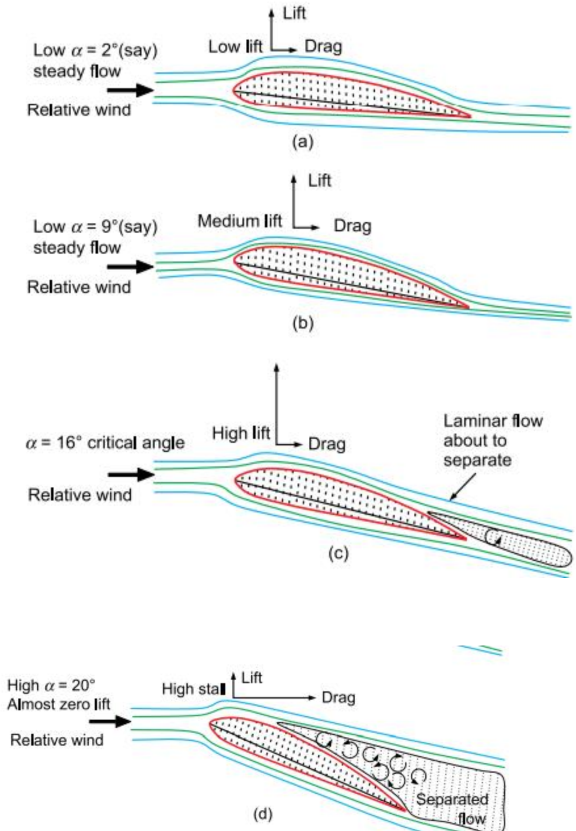
5.2 AERODYNAMIC POWER REGULATION

The power regulation of WPPs is done by aerodynamic, electric and electronic control. The following aerodynamic control methods are popularly being adapted by the manufacturers to regulate the power of large wind turbine rotors, although other types of aerodynamic control are still under experimentation and research:

- **Stall-control** (It is also called *stall-regulated*): In this, the stall profiled rotor blades are mounted at a fixed angle on the hub.
- **Active-stall control** (It is also called *active-stall regulated*): In this, the stall profiled rotor blades are pivotable for few angles in the longitudinal axis.
- **Pitch-control** (It is also called *pitch-regulated*): In this, the rotor blades are almost infinitely pivotable in the opposite direction to the active-stall blades from 0° to 90° in longitudinal axis.

STALL CONTROLLED WPP:

Typical stall angle:



(a) At an angle of attack, say 2°, the air flow is laminar. The lift force is greater than the drag force and the rotor produces some power, (b) At a greater angle of attack, say 9°, the air flow continues to be laminar and the rotor produces more power, (c) At critical angle, stall action gradually sets in but lift force is the highest, and (d) At this angle, drag force is greater than the lift force and the blade rotation stops.

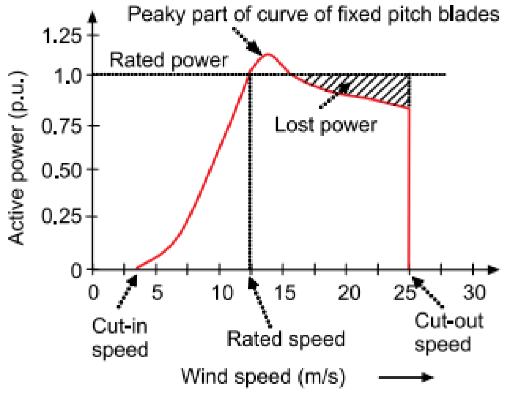


Figure 5.2 **Stall Controlled WPP Peaky Power Curve:** The stall phenomenon slowly sets in much earlier than the cut-out speed. Here, it is around 16 m/s and the shaded area depicts the lost power at higher wind speeds even before the cut-out speed is reached.

VORTEX GENERATORS:

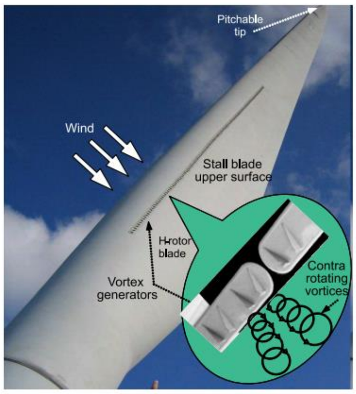


Figure 5.3 **Vortex Generators on a Stall Blade:** Small panes about 1 cm in length are mounted on the upper surface of blade, alternatively inclined towards left and right.

- The design requirements of stall regulation have led to new aerofoil developments and also the use of devices such as vortex generators, (see Figure) stall strips, fences and gurney flaps for fine tuning rotor blade performance.
- Vortex generators are small panes (usually about 1 cm in length) that are mounted on the blade upper surface alternatively inclined towards left and right opposite to each other at a certain angle that causes counter-current eddies in the air flow.
- Large stall controlled WPP manufacturers, therefore, use vortex generators to fine-tune the stall properties for a flat-topped power curve (as desired) and thereby, not to overload the electric generator.
- When the wind speed starts increasing beyond the rated wind speed and if the stalling action sets in along the entire length of the blade at the same moment, the rotating motion may become jerky, which is not desirable at all.
- By using vortex generators beginning from the root on the upper surface of the blade, the aerodynamics of the blade controlled stalling action occurs. The vortex generators initiate a small turbulent air flow on the blade surface, much before the full stall action. Different segments of the blade surface at different times and the jerky stall motion is eliminated.

- These vortex generators are fixed in a form called stall strip

FEATURES OF STALL CONTROLLED WPP:

(i) Based on the simplest wind turbine technology.
(ii) Since the power is always controlled aerodynamically, it produces less fluctuating power output, as compared to that produced by a pitch regulated WPP.
(iii) Responds much more quickly to gusts than the pitch regulated WPPs (where mechanical pitch adjustments require a finite response time to effect it).
(iv) Cheapest among all types of WPPs.
(v) Time-tested WPP for its reliability and robustness.

There are many demerits as well which are given below:

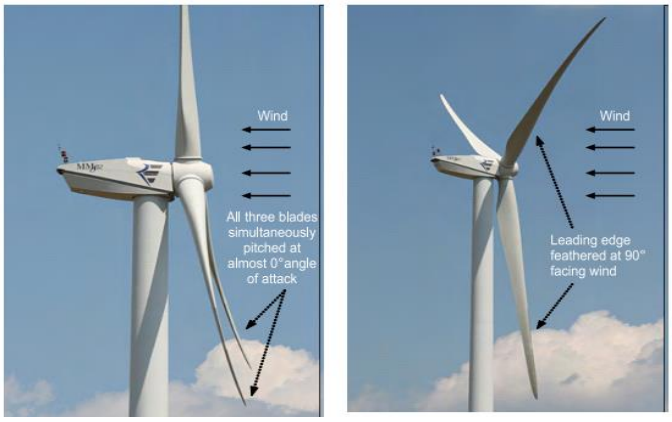
(i) The main demerit of the passive stall regulated constant speed WPP is that it does not have the possibility of active electric power control, except when using mechanical brakes on the main shaft or when connecting and disconnecting the electrical generator from the grid.
(ii) Limited control of reactive power makes it more difficult to control network voltages.
(iii) During network disturbances (such as a sudden fault in the network), such a WPP is likely to aggravate the situation.
(iv) It is not self-starting.
(v) It is suited for relatively stronger grids.
(vi) The power of the electric generator must be overdimensioned so that it does not lose synchronism during wind gusts.
(vii) The blade aerofoil (which is quite complex) may not be exactly matched with the wind resource characteristics at that particular site. Hence, it may not produce optimal electric power even in the best windy conditions.
(viii) Being rigidly attached to the hub, to withstand the high aerodynamic loads, the strength and the stiffness of the rotor blades must be relatively higher than the pitch regulated WPPs.
(ix) If the atmospheric conditions change, the power prediction may not match the specifications of the stall controlled WPPs leading to deviations even to the order of 10%.
(x) The aerodynamic properties of the blade aerofoil get altered due to corrosion of the blades and insect deposits disturbing the streamlining effect, which calls for the periodic cleaning of stall blades.
(xi) It has a lower efficiency at lower wind speeds.
(xii) Stall control is not preferred much for megawatt capacity WPP as the pitchable tip become unwieldy and other associated problems for activating them with ease.

PITCH CONTROLLED WPP:

- The angle that the blade chord makes with the rotor disc is the pitch angle.
- Pitch control can be undertaken to reduce as well as to increase the angle of attack to modify the lift and drag values to regulate the power harnessed from the wind.

  PI controller for pitch control:

- Conventionally, blade pitch is often controlled by a simple proportional integral (PI)-based collective blade pitch controller which receives its input signal from the error in electrical generator speed.
- The microprocessor (or microcomputer)-based electronic controller checks the various parameters received from the sensors of the operating WPP several times per second.
- The microcomputer adjusts the pitch of the blades to a few degrees to maintain the rotor blades at an optimum angle in order to maximise the output power for all wind speeds



Pitch controlled WPP: (a) Operating pitch controlled WPP. Based on the wind speed, 2.5 MW blades are continuously pitched at optimum angles to maximise the harnessing of energy. (b) 2.5 MW wind turbine is in stopped position with the leading edge of the blade facing the wind at 90° to the wind.
Courtesy: www.thewindpower.net

Pitch controlled curve:

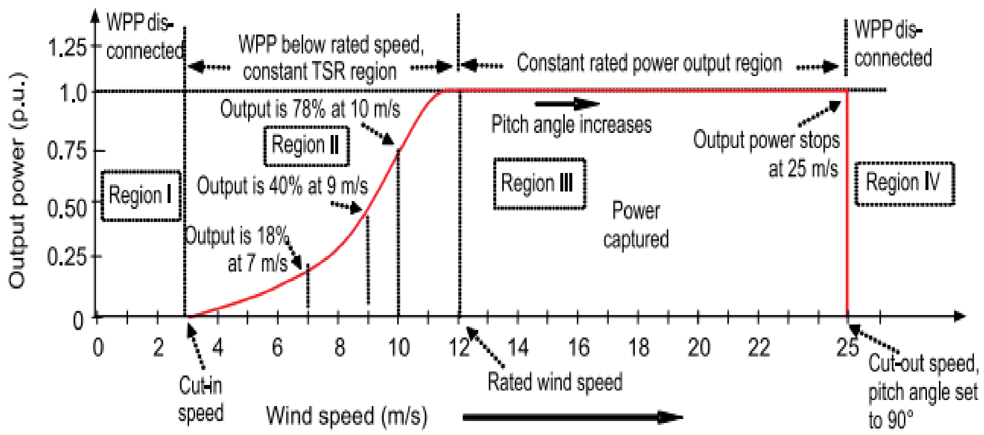


Figure 5.5 **Pitch Controlled WPP Power Curve:** Unlike the peaky power curve of the stall controlled WPP, the power curve of pitch control WPP is flat-topped due to the pitching action of the blades resulting in lesser stresses on the various mechanical and electrical components.

Features of pitch controlled WPP:

• It is compact, simple in construction and requires little maintenance. • The need to transfer thermal energy from working fluid to another fluid is eliminated as air is used directly as working fluid. • Corrosion is completely eliminated. • Leakage of air from the duct is less severe. • Possibility of freezing of working fluid is also eliminated. • The pressure inside the collector does not become very high. Major disadvantage of air collector are: • Large amount of fluid is to be handled due to low density. As a result the electrical power required to blow the air through the system can be significant if the pressure drop is not kept within prescribed limits. • Heat transfer between absorber plate and air is poor. • There is less storage of thermal energy due to low heat capacity.

However, there are some limitations as well:

(i) For the same rating, the extra energy that can be obtained practically is only about 2%–4% as compared to the stall WPP.

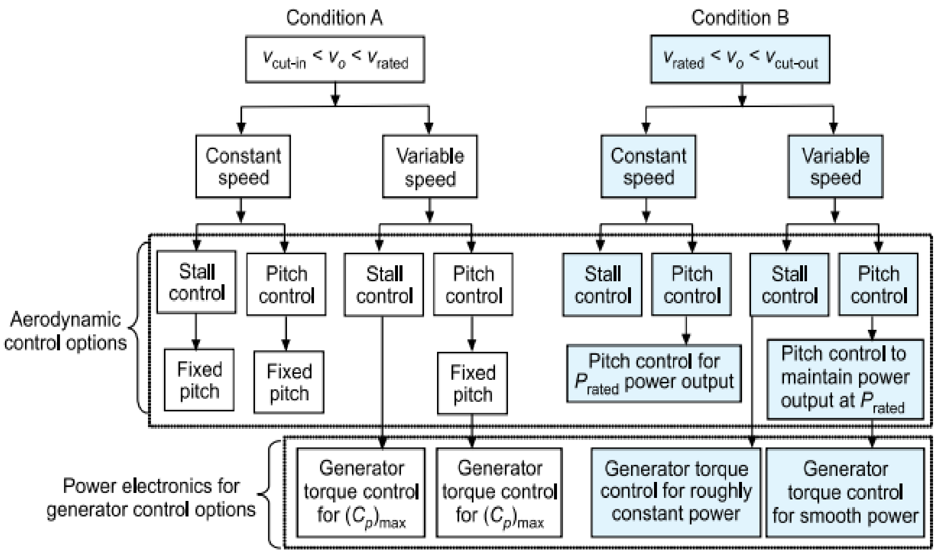
(ii) Main limitation is that during high wind speeds, even small wind speed variations result in large variations in power output to which the pitch mechanism is not fast enough to respond. To limit the power excursions especially during the gusts, the pitch changing has to act rapidly, say 6°/s to 7°/s or even better.

(iii) Fatigue loading is also higher than that of the stall WPPs due to the rate of change of the lift coefficient.

(iv) Hub of pitch controlled WPP is more sophisticated, as it has to hold the pitch bearing and pitching mechanisms.

<u>Wind power control strategies:</u>

- Constant speed WPP
- Variable speed WPP



(a) (b)

6.5 CONSTANT SPEED AND VARIABLE SPEED WPPs

The prime mover of the WPP is moving air, i.e., the wind cannot be controlled and it fluctuates randomly. Therefore, electrical generating systems of WPPs are different from the generators used in conventional power plants. Based on the electric generators used, WPPs are broadly categorised as constant and variable speed WPPs.

Based on the type of control, constant speed WPPs can further be classified as follows:

- Type A constant speed WPP with a speed variation of 1% to 2% from the synchronous speed.
- Type B narrow range variable speed WPP having a range of 0% to 10% speed variation from the synchronous speed.

Constant and variable speed curves:

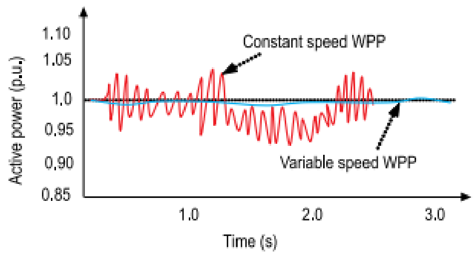
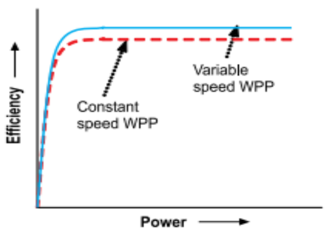


Figure 6.9 **Typical Power Variations of Constant and Variable Speed WPP:** Wind speed fluctuations have a bearing on the stresses of the mechanical components.



gure 6.10 **Efficiencies of Constant and Variable Speed WPP:** Although the efficiencies may not be substantial, but annually, it does make a difference.

Variable speed WPP:

- • Due to varying wind speeds, the fluctuations from the wind turbine rotor are directly translated as torque pulsations onto the gearbox which may accelerate the failure rate.
- • The constant speed WPPs cannot operate at maximum efficiency (they work suboptimally) except at the wind speeds corresponding to its designed TSR. Constant speed WPPs are around 10% less efficient than the variable speed WPPs.

• There are difficulties in the control of both active and reactive electric power.

- The major benefits of variable speed WPPs are as follows:

- • They can be connected to the grid even at lower wind speeds. They speed up in proportion to the increased wind speed and thereby, enable increased energy capture even below the rated power.
- • Variable speed capability above the rated power (even over quite a small speed range) can substantially relieve loads, ease pitch system duty and greatly reduce output power variability.

Different classes of variable speed WPPs based on the type of control are:

- • Type-C limited range variable speed WPP with a range of –30% to +40% speed variation from the synchronous speed.
- • Type-D wide range variable speed WPP with a range of about 2.5 times the rated speed

Constant speed WPP:

- Till the beginning of 1990s, the squirrel cage induction generators (SCIG) were the ones in all constant speed WPPs that were connected through a gearbox to the wind turbine rotor and running at constant speed determined by the grid frequency, the gear ratio of the gearbox as well as by the number of poles of the electric generator.
- The rotors of these generators prevented from turning much faster than the synchronous RPM, even if there was a slight change in the RPM caused by generator slip of the order of 1%–2%. In other words, the SCIG is electrically locked to the grid to which its stator is directly connected. Therefore, for all practical purposes, they are called constant speed WPPs.
- An increase in wind speed does not affect the speed of the SCIG greatly, Wind Power Control Strategies l 147 up to a certain limit. However, it affects the electromagnetic torque which varies with the increase in load angle d and hence, there is an increase in the electrical power generated and fed into the grid upto the designed upper limit of the SCIG. Beyond this upper limit, the SCIG does not remain locked with the grid, but runs out of synchronism and comes to a halt.

Variable speed - slight change in speed;

- the wound rotor induction generator (WRIG) was also used in WPPs. It also work on the same principle as SCIG but because of the external resistors, a slightly more variable speed range could be obtained and hence a little more increase in the power output.

Characteristic curve of WPP:

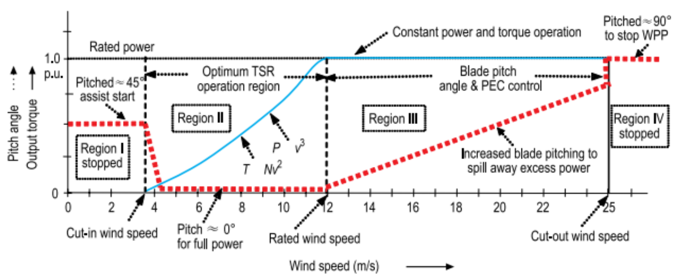


Figure 6.11 Torque, Speed and Pitch Angle Characteristics for Maximum Power from a WPP.

Type A WPP:

amount of time.

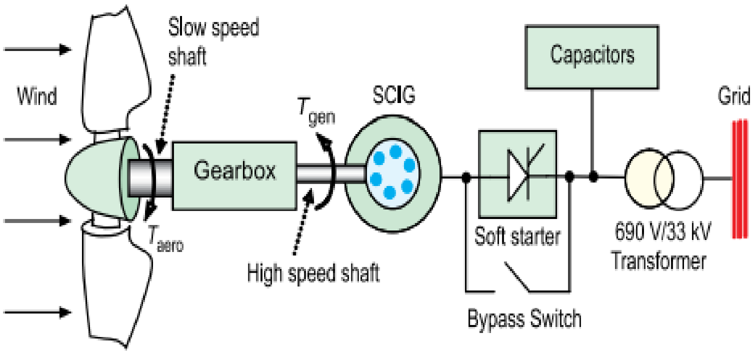


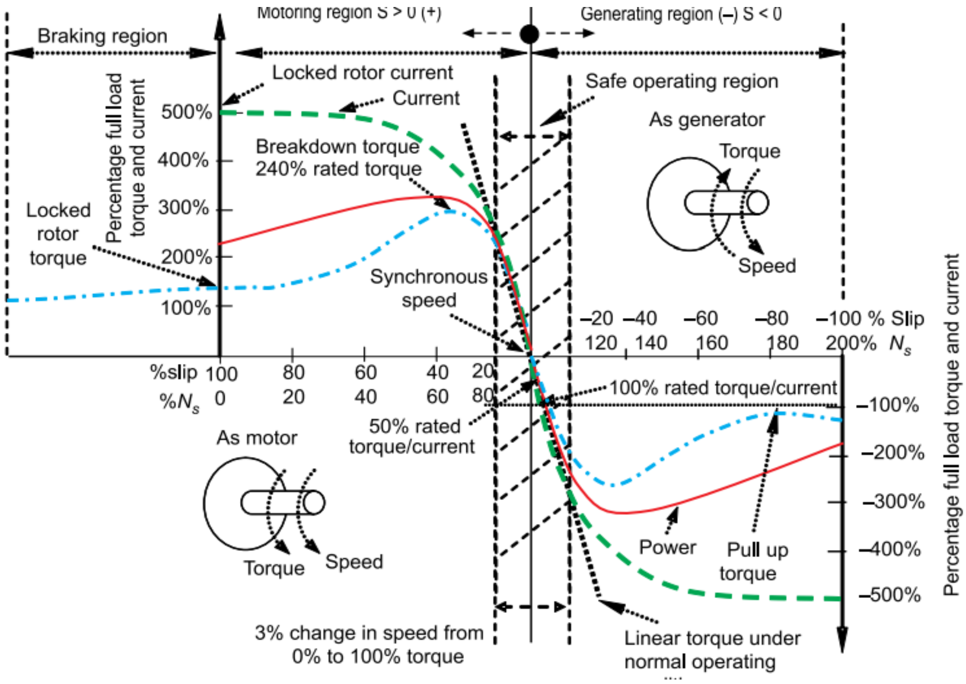
Figure 7.1 **Type-A WPP:** Stator of the SCIG is directly connected to the electrical grid through a soft starter. Capacitor banks are used for power factor correction.

- Since decades, Type-A WPP (see Figure) with the SCIG has been the workhorse of the wind power industry, as it has an inherent torque–speed curve that fits the WPP application quite naturally.
- Although, the over speed variations in SCIG are very small (1% to 2%), its mechanical simplicity, robust construction and relatively lower cost have made it quite popular in the wind industry for a considerable amount of time.
- An interesting mechanical property of Type-A WPP is that whenever the torque varies, the speed of the SCIG increases or decreases only a little, thereby resulting in less tear and wear of the gearbox (lower peak torque).
- This is the most important reason for using induction generator rather than a synchronous generator in a WPP

Working:

- Type-A WPP can either be a fixed blade stall controlled rotor or it could be a pitch controlled rotor. In either case, the rotors are connected to a slow speed (ranging from 15 RPM to 25 RPM) main shaft of a gearbox to step up the speed to around 1500 RPM.
- When the wind interacts with the rotor blades, it produces an aerodynamic torque Taero (see Figure) on the low speed, high torque shaft. This torque is transferred through the gearbox to step up the speed to match the generator rotor shaft. The high speed generator shaft torque Tgen reacts with aerodynamic torque Taero which must be equal and opposite for the constant speed machine to accelerate or decelerate

SCIG torque speed and power characteristics:



Type B WPP:

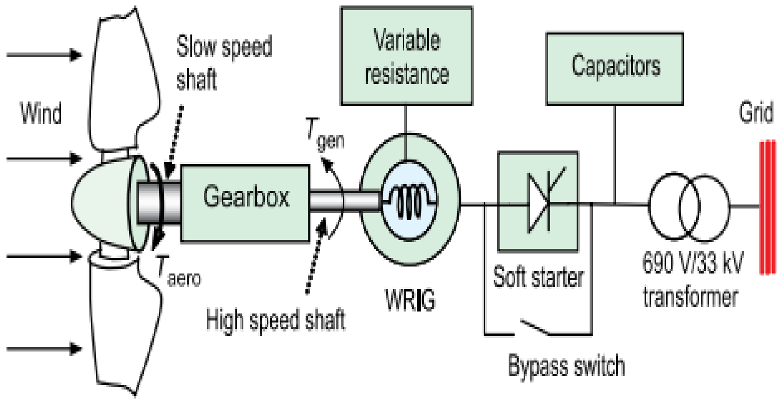


Figure 7.13 **Type-B WPP with WRIG:** The stator is directly connected to the grid. The copper windings of the rotor are connected to the external variable resistors.

Type-B WPP is a relatively cheaper solution than the Type-C WPP to harness more energy from the varying wind speeds. For the first time, *Weier* (from Germany) developed the Type-B WPP mounted with wound rotor induction generator (WRIG) that operates in a narrow range speed variation (upto 10%–16% above the synchronous speed). It overcomes many of the disadvantages of the Type-A WPP mounted with SCIG. The mechanical construction of the WRIG stator is similar to that of the SCIG. However, the rotor circuit has copper windings that are not shorted by the end rings, but are star connected to the external variable resistors (see Figure 7.13) through slip rings and brushes. The resistors lower the voltage to the required value by dropping some of the supply voltage across it. Modern Type-B WPP has done away with slip rings by mounting rotating variable resistors and the optically controlled (so-called opti-slip or flexi-slip) control circuitry is mounted on the generator rotor shaft itself whereby, the heat that is generated in the resistors is dissipated. For every 1% increase in slip, extra 1% losses occur.

Type C:

- Type-C WPP operates within a range of –30% to +40% of its rated speed and hence, is considered as a limited range variable speed WPP.
- The doubly-fed induction generator (DFIG) in type-C WPPs combines the advantages (e.g. robustness) of an induction generator as well as the variable speed feature of the synchronous generator.
- It is basically an induction generator with three-phase stator winding that is directly connected to the electrical grid

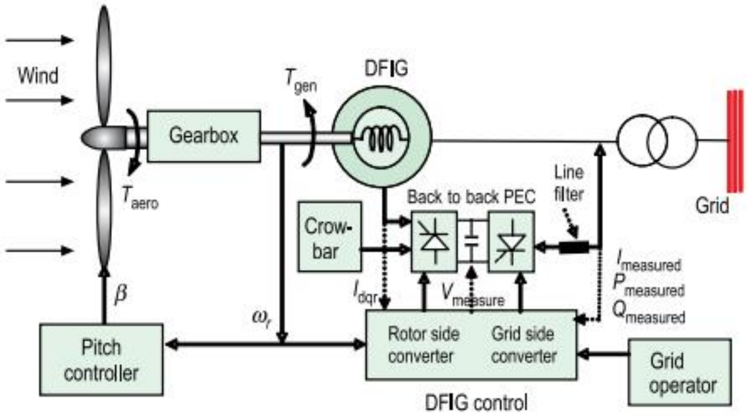


Figure 8.2 **Type-C WPP Working Principle:** The DFIG is controlled by a back-to-back PEC. The coordinated operation of the pitch controller and the DFIG variable speed operation is possible and the active and reactive power can be controlled.

- The three-phase wound rotor is connected to the grid through a PEC with the help of slip rings and brushes. This is a back-to-back partially rated (30%) PEC that feeds the grid so that the mechanical rotor speed and the electrical rotor frequency are decoupled and the stator and rotor frequencies can be matched, independent of the mechanical rotor speed.
- Almost all the Type-C WPPs are of Type-C1 category, as they have blades which can be fully feathered. Type-C WPPs fulfil the grid code requirements and DFIG is one of the control technologies for WPPs that minimises the peak voltage values, flicker and harmonics, thus easing the connection licensing issues for grid connection.
- issues for grid connection. The back-to-back PEC usually consists of a pulse with modulated (PWM) converter.
- Due to the bidirectional power flow ability of the PEC, the DFIG may operate as a generator or motor both subsynchronously (0 < slip < 1) and supersynchronously (slip < 0). By directing the slip power of the rotor circuit through the PEC, the WPP can be operated with limited range variable speed.
- Type-C WPP has to prevent overspeeding which is done by the coordinated action of the pitch control and PEC. The use of the partial scale PEC for the Type-C WPP is an attractive concept from an economical point of view

- The DFIG is still characteristically an induction generator. However, since both the stator and rotor windings are connected to the grid and participate in the energy conversion process, they are termed as doubly-fed.
- Unlike the WRIG in Type-B WPP where the rotor power is dissipated as heat energy in the passive resistors, in Type-C WPP, the slip power in the DFIG rotor circuit is recovered, treated, transformed and sent onwards to the grid through a partial scale (one-third of the rated power) back-to-back PEC.
- The DFIG supplies the grid with two-third of the rated power through the stator directly connected and one-third through the rotor connected to the PEC. It is possible to control the reactive power production and allow voltage regulation and magnetisation of the machine by the rotor, regardless of the grid voltage.

Torque-speed char of DFIG:

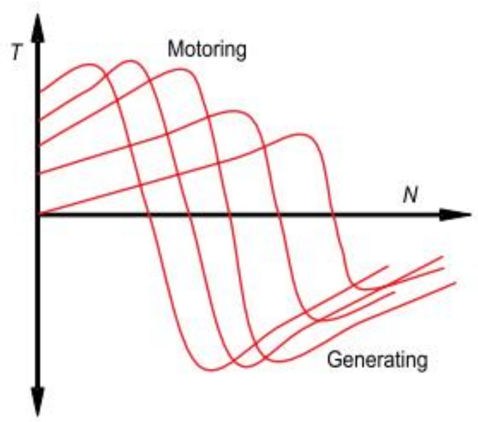


Figure 8.3 Torque–Speed Characteristics of DFIG: For every change in frequency, there will be a separate torque–speed characteristic.

Type C WPP- subsynchronous:

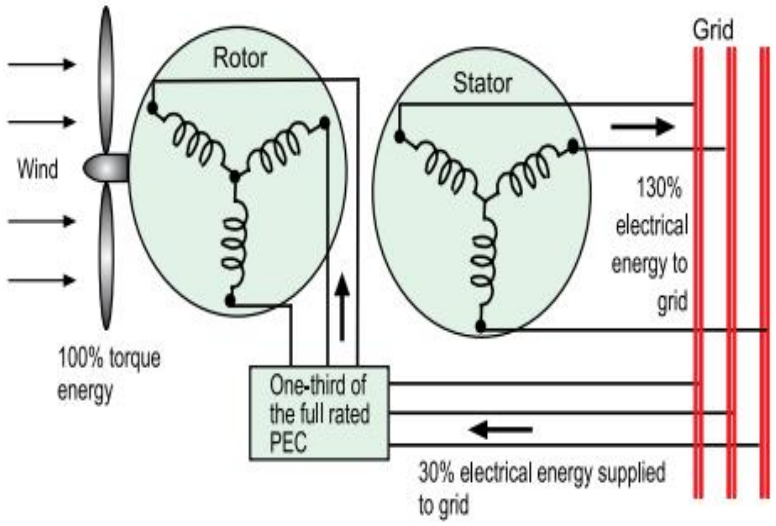


Figure 8.4 Type-C WPP Subsynchronous Speed Operation: Here the stator appears to be supplying 130% of power to the grid. Note that the generator rotor has borrowed 30%, leaving the line with 100% for the theoretical lossless DFIG.

Type C – super syn:

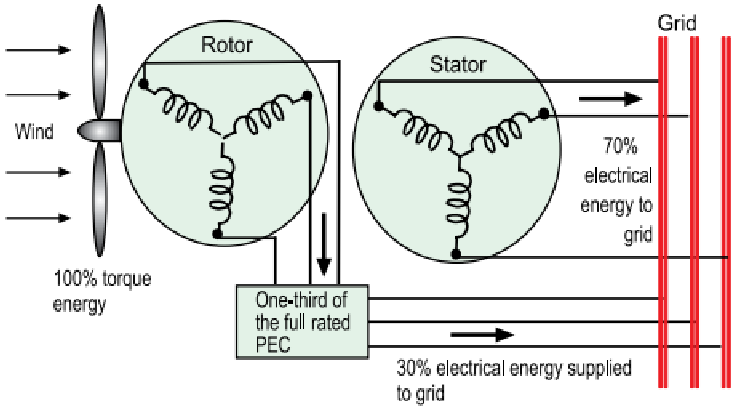


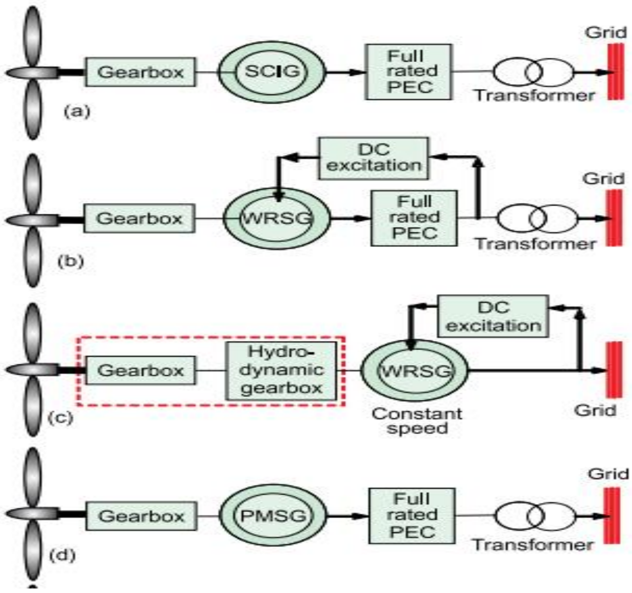
Figure 8.5 **Type-C WPP Supersynchronous Speed Operation:** Unlike the WRIG where 30% of the energy is wasted as heat in the rotor circuit, in DFIG, this slip power is fed to the grid through the PEC.

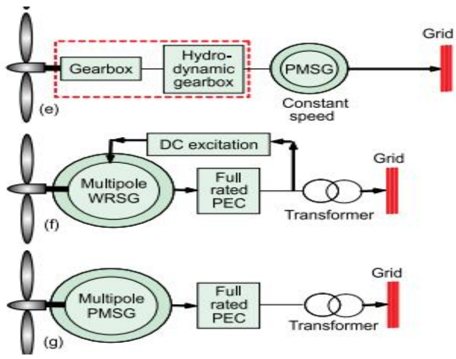
TYPE-D WPP:

- The greatest asset of type-D WPPs is that they can operate over a wide range of wind speeds, about 2.5 times the rated wind speed.
- Their output power from the stator terminals of the electric generators are either grid compatible due to the hydrodynamic gearbox arrangement

Types of type D WPP:

- (i) Type-D geared WPP with variable speed SCIG and full rated PEC. (ii) Type-D geared WPP with variable speed WRSG and full rated PEC. (iii) Type-D hydro dynamically geared WPP with constant speed WRSG. (iv) Type-D geared WPP with variable speed PMSG and full rated PEC. (v) Type-D hydro dynamically geared WPP and constant speed PMSG. (vi) Type-D direct-drive WPP with variable speed WRSG and full rated PEC. (vii) Type-D direct-drive WPP with variable speed PMSG and full rated PEC. (viii) Type-D hybrid (semi-geared) WPP with variable speed PMSG and full rated PEC.
- Type D types:



- 

<u>Full Rated PEC in Type-D WPP:</u>

- Unlike the one-third of the full power rated PEC of DFIG, the full power from the stator of the generator of a type-D WPP is fed into the full power rated VSI-based back-to-back PEC operating in the four-quadrant mode, allowing maximum speed variability and grid compatibility.
- The PEC in type-D WPPs that carry the full power has following three primary functions:
- • PEC, as an energy buffer for the WPP rotor side, prevents the power fluctuations caused by the gusty wind energy from reaching the electric generator.
- • It prevents disturbances from the grid side from reaching the generator.
- • It controls the magnetisation of the generator and to avoid problems keeps it synchronous with the grid frequency.

<u>TYPE-D GEARED WPP WITH VARIABLE SPEED SCIG</u>:

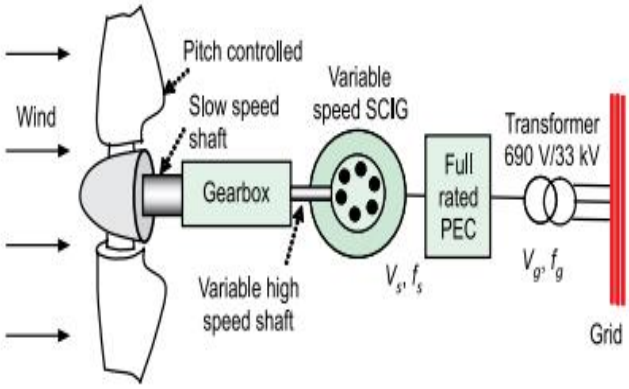


Figure 8.9 **Type-D Geared WPP with Variable Speed SCIG:** Since this WPP has SCIG, it is more rugged. The full rated PEC treats the variable voltage and variable frequency output power to render it grid compatible.

Type D geared WPP:

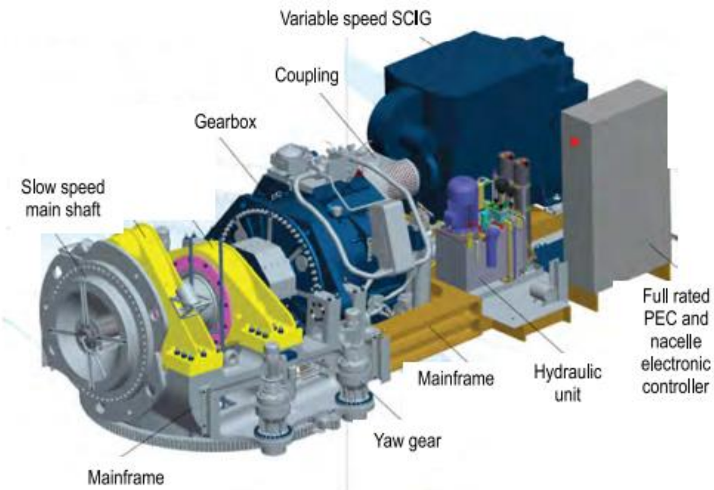


Figure 8.10 **Type-D Geared WPP with Wide Range Variable Speed SCIG–1800 kW.**
Courtesy: www.rrbenergy.com

v/f control – type D:

- Decreasing the frequency of the current fed to the SCIG decreases the reactance XL, thereby increasing the stator current. This may cause the stator magnetic circuit to saturate with disastrous results.
- For speed control, the supply voltage must increase in step with the frequency, otherwise the flux in the machine deviates from the desired optimum operating point. In other words, if the flux density B is to be constant, the volts/hertz (V/f) must also be constant.
- In practice, the voltage across SCIG needs to be decreased when the frequency is decreased. This is also called the flux weakening region. However, the voltage also needs to be increased to overcome increasing reactance XL to keep the current upto a normal value and maintain the torque. This is known as V/f control, the principle on which wide range variable speed SCIGs are designed to operate

Scalar and vector control:

- The speed control of SCIG can be achieved through scalar control (which generally adapts relatively simpler and lower cost methods to control only voltage and frequency without feedback) or
- the vector control where the flux and torque producing components of the stator current are measured or estimated on a realtime basis to enhance the torque–speed curve. This control also allows the power factor of the grid to be controlled independently

v/f characteristics :

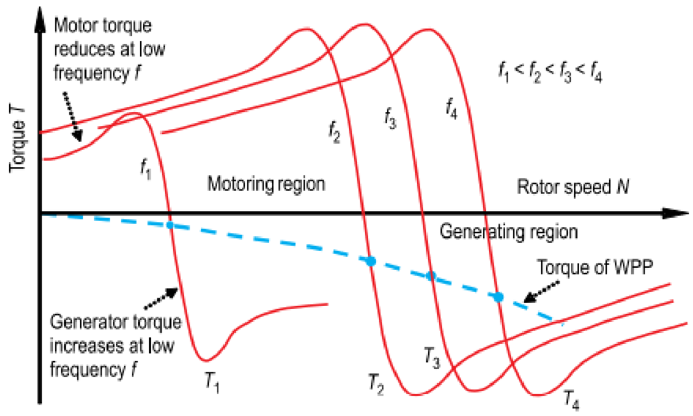


Figure 8.12 **Typical Variable SCIG Torque–Speed Characteristics for Constant *V/f* Operation:** By keeping the *V/f* constant in a SCIG, the machine can be run at wide range variable speed, even if the RPM keeps on changing (hence the frequency) due to the changing wind speeds.

Grid integrated issues:

- THE ELECTRIC GRID:

An electric grid network basically consists of following three sections :

• Interconnection network • Transmission network • Distribution network.

Electric grid network:

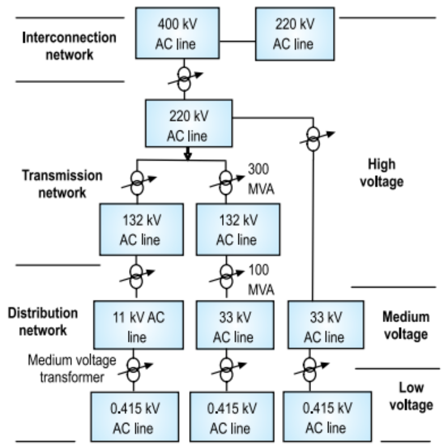


Figure 10.1 **Typical Electric Grid Network:** Generally, the electric distribution networks are in rural areas where the WPPs are connected. Therefore integrating WPPs into the electric network has to be taken due care.

Electric grid model:

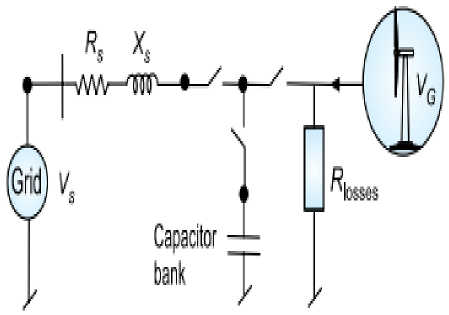


Figure 10.2 Simplified Electric Grid Model with WPP: Equivalent voltage source V_s is in series R_s and X_s of a power system, (resistance representing losses).

<u>WPP in the grid:</u>

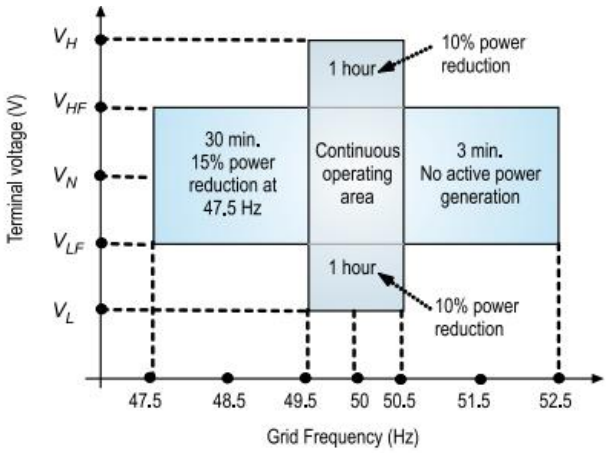


Figure 10.3 Typical Voltage and Frequency Dimensioning for WPPs.

<u>Requirements of Grid Connected WPP:</u>

- Feed-in quality
- Grid support
- Transmission

<u>WPP Grid Connections:</u>

- • Direct grid connection of WPP
- • Indirect grid connection of WPP
- • Direct grid connection of wind farm
- • Meshed grid connection of wind farm.

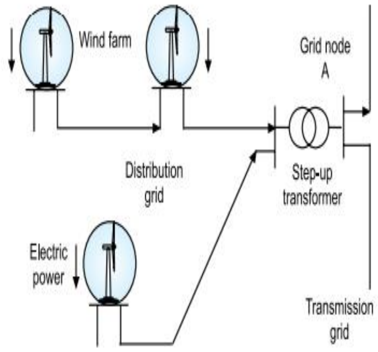


Figure 10.4 **Wind Farm Direct Grid Connection:** All the WPPs in the wind farm feed the electric power through one node via transformer into the transmission line.

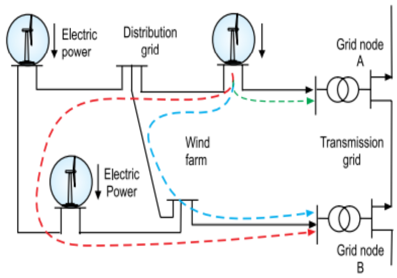
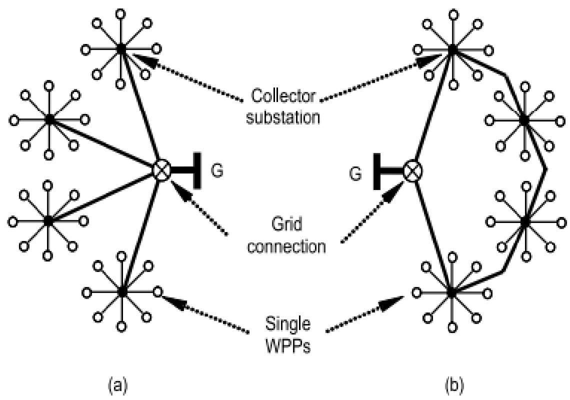
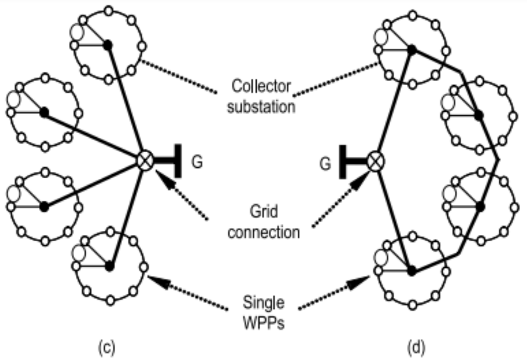


Figure 10.5 **Wind Farm Meshed Grid Connection:** A decrease in power output of a wind farm has not only an effect on the power flow via the transformer to grid node A, which should be controlled, but also on the power flow via the transformer to grid node B.

<u>Grid Connection Topologies:</u>

- • Nested radial network
- • Radial on ring network
- • Ring on radial network
- • Nested ring network





Grid issues:

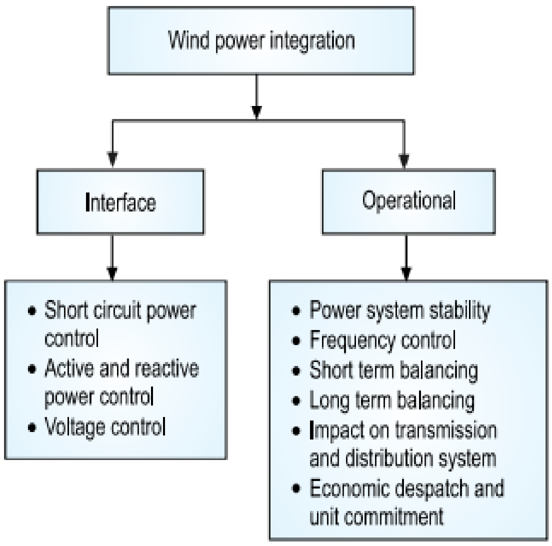


Figure 10.8 Wind Power Integration Issues: Since the wind speed varies and the WPPs are usually located in the electrical distribution network, these integration issues need to be addressed when connecting them to the network.

INTERFACE ISSUES:

The major factors related to interface issues include the following:

• Short circuit power control • Active and reactive power control • Voltage control.

To enhance interface issues, the transmission capacity of the network could be enhanced in several ways: • Add transformers to the existing substations to enable a higher load feed and in some cases, to evacuate higher generated power. • Upgrade the transmission infrastructure, e.g. operate a line at higher voltage (within its design limits), tighten the conductors and reinforce the towers to increase the transmission capacity. • Improve the distribution of power flows among different parallel paths by installing new facilities in grid substations such as series reactors, phase shifting transformers or devices to increase voltage support such as shunt reactive and FACTS devices. • Improve the utilisation of existing infrastructure, e.g. by replacing line conductors with high temperature conductors or add a second circuit on an existing line (within the design limit of the towers). • Replace the existing infrastructure with those of a higher transmission capacity, e.g. replacing an existing 220 kV line with a 400 kV double circuit

Short Circuit Power Control:

An electrical fault (or simply called fault) in an electric power system can be defined as a short circuit somewhere in the system. Short circuit power is one of the indicators that indicates the capacity of the WPP/wind farm production (or consumption) which can be connected at the PCC of the grid network. The usual practice is that installed capacity of the connected object (here WPP/wind farm) should be about 10% of the short circuit power. If the short circuit power is high, then the voltage variation due to changes in power production/consumption at the connection point are low and vice versa. During and after faults in the system, the behaviour of WPPs is different from that of the conventional power plants which use synchronous generators that are able to continue to operate even during severe voltage transients produced by transmission system faults. If a large number of WPPs are tripped because of a fault, the negative effects of that fault could be magnified. This may, in turn, affect the transmission capacity in areas with significant amount of wind power, as a sequence of contingencies would have to be considered in the security assessment instead of only one contingency

Reactive Power Control:

In a power system, reactive power is produced in capacitive components (e.g. capacitors, cables) and consumed in inductive components (e.g. transformers, motors, fluorescent tubes). Reactive power is a concept associated with oscillating exchange of energy stored in the capacitive and inductive components of a power system. Reactive power causes a phase shift between them and adds geometrically to the active power. The grid operator expects individual and collective WPPs/wind farms to behave like any other conventional power plant to maintain the power system stability. Figure 10.9 shows a lagging power factor. The notation lagging refers to production of reactive power and leading refers to absorption of reactive power. In generator sign convention, the current lags the voltage when reactive and active current are positive. Wind farms are required to have sufficient reactive power compensation to be neutral in reactive power at any operating point. If the active power is less than rated, wind farms must be able to supply the same MVArs as under full load.

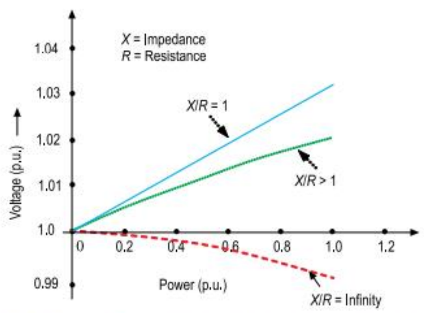


Figure 10.9 Typical Wind Power Characteristics for Lagging and Leading Power Factor.

Although reactive power causes additional loading, for steady state conditions, reactive power produced should be equal to reactive power consumed. Depending on the output and defined margins, at the PCC, the exchange of reactive power should be more or less zero. WPPs with reactive power control capability may have a characteristic (see Figure 10.10), where the reactive power within ±0.95 power factor is available over almost the entire operating range of the WPP, as indicated by the dashed line and hashed portion. It can be seen the reactive power capability reduces with generation level down to zero when the WPP does not produce active power. The dot–

dash line is indicative of the reactive capability of a conventional synchronous generator where the limitation arises only due to stator current limits. Reactive active power oscillates between the energy storage elements like capacitors and inductors in the grid networks

Voltage Control:

The voltage is a local variable which means that its value is location dependent. The voltage at a given location depends on the grid parameters, viz. reactance, capacitance and current. Generally, the voltage increases at the PCC of the wind farm and on the feeder to which the wind farm is connected. Voltage control means the task of keeping the node voltages in the grid within the required limits and preventing any deviation from the nominal value within the specified limits. Voltage control is necessary due to line impedances. High consumption and low power production renders the voltage to low levels. High production and low consumption render the voltage to the levels higher than the set limits. Hence, voltages on the transmission system are controlled through a combination of generator excitation systems, tap-changers in the transformer, static reactive devices and FACTS devices which combine power electronics and control techniques with capacitors, inductors and transformers. If cables and overhead lines do not have susceptance and impedance, the voltage anywhere in the grid is equal to that at the generator terminals and the voltage control is not necessary due to line impedances. Since every large WPP/wind farm is also a power station, the functions of the voltage control are as follows: • Maintain constant voltage at POI/PCC. • Maintain stable distribution of reactive power over other WPPs. • Prevent high voltages in case of loss of load. • In short circuit situations, increase the grid stability by increasing the excitation of Type-C and Type-D WPPs and thereby the synchronism of the grid.

The two conventional approaches to voltage control in distribution networks are by • Tap changing of the transformers. • Shunt capacitors or reactors (that generate or consume reactive power). Voltage control depends on the WPP type connected to the grid. • Extra devices are needed in case of constant speed Type-A and Type-B WPPs. • Reactive power is dependent on PEC current limit and rotor current of DFIGs of Type-C WPP. • Reactive power is dependent on PEC current limit in Type-D variable speed WPPs.

OPERATIONAL ISSUES :

As electrical energy cannot be stored, i.e., whatever amount of energy is required at that very moment, it has to be fed into the grid to be taken out and consumed. The day-to-day operation of the WPPs and the electrical power supply into the network have raised some operational problems, as it is distributed generation (DG) source.

Since the prime mover (wind) of the WPPs is uncontrollable, it leads to the following operational issues which need to be addressed: • Power system stability • Frequency control • Short term balancing • Long term balancing • Transmission and distribution system impacts • Economic despatch of power and unit commitment.

Power System Stability :

Power system stability is dependent on how it responds to the dynamic performance of the various phenomena on the grid network. WPPs can affect transmission and distribution systems by altering the designed power flow or causing large voltage fluctuations. It could also be due to a contingency (i.e., n–1 contingency or more) such as loss of a transmission line or large transformer or generating unit that causes a portion of the remaining transmission system to be operated near its steady state stability limit which can be below its thermal limit for long transmission distances. Power transmission in a power system is limited by the thermal stability of the conductors and at the same time, by the voltage stability of the power system. Usually, for long transmission lines (> 100 km long) voltage stability limits are reached before the thermal limits. However, with greater penetration of WPPs, along with the thermal and voltage stability limits, grid operators want wind project developers to undertake simulation studies for steady state stability, dynamic stability and the transient stability limits of the power system due to the connection of their WPPs into the network.

Frequency Control:

As the integration of wind power progresses, growing concerns on the frequency control have been raised and discussed around the world. The frequency of an electrical power system is determined by the equilibrium between the power demand and the power produced minus the losses. If generation exceeds consumption, the frequency rises and if consumption exceeds generation, the frequency falls. Pproduced = Pdemanded + Plosses (10.3) Any imbalance between the left hand side and right hand side of Eq. (10.3) causes a frequency drift. Therefore, electrical frequency is an indicator of balance between the supply and the demand of power requirement in an interconnected electric power system. In electric power systems, the balance between the generation and the consumption must be maintained continuously (see Figure 10.13). Surplus generated power leads to frequency increase (i.e. > 50 Hz) and if the generated power is short of demand, it leads to frequency decrease (i.e., < 50 Hz). The frequency drift continues till the Eq. (10.3) is not fulfilled and a steady state condition is reached. Therefore, power plants constantly monitor the frequency.

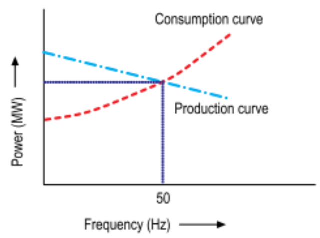


Figure 10.13 Demand Production Curve: If power demand is constant and the power generation increases, then frequency will increase and vice versa.

Maintaining a constant system frequency is vital for grid security. Hence, any event that causes frequency changes must be quickly corrected. The frequency has to be kept within strict limits to avoid system degradation, usually ±1% for normal operation. If the frequency deviates beyond 2%, automatic disconnection is necessary to arrest the slide and avoid collapse. Though power system frequency deviations are not uncommon, but due to the adherence to reliability standards and practices, often, the disturbed system does settle down to a stable operating point after specified period. However, situations do occur when the mismatch between the load and the generation become significant, leading to the tripping of very large generating plants or an entire power station or the loss of a major transmission line. When system frequency is suppressed (i.e., demand is greater than generation), every available generator has to be sustained, i.e., it is not desirable to lose generation due to all too tight operating limits. When system frequency rises beyond nominal, power output from the generators should be reduced rather than their disconnection. No sooner does the grid frequency starts to drift, the power plants slightly change the generated power to stop the frequency drift. This strategy is called the frequency control. However, this control is only feasible when the unbalance between the generation and the load is relatively small. For large unbalances, the control range of the power plants are not large enough to restore the balance. This situation is then taken care by switching on new power plants (or switching off some loads) or by stopping some power plants according to the need. When comparing the frequency operating ranges, the stiffness of the grid has also to be borne in mind. As compared to large systems, smaller power systems are more prone to deviate from the nominal frequency in case of unbalance between the load and the generated power.

Types of Frequency Control:

Increasing the electrical load in the power system tends to brake the generators, tending the frequency to fall. The frequency control of the system then increases the torque on some of the generators until equilibrium is restored and the frequency becomes 50 Hz again. The aim of frequency control is to maintain the balance between the load and the generation within a control area.

Frequency control is generally based on three control actions: • Primary frequency control • Secondary frequency control • Tertiary frequency control. There is always a chance for imbalance due to the changes in load and generation. Therefore, primary and secondary frequency controls operate continuously to maintain the power system stability.

Short Term Balancing :

Balancing is dependent on power system frequency. For power balance to be maintained in a power system, the frequency requires to be continuously stabilised. 306 l Wind Power Technology Typically, an AC grid network is said to be stable when the voltage variation is 90% to 105% and the frequency variation is between 49 Hz to 50 Hz. Short term balancing of WPPs capabilities are determined by the output power controllability (when the output power needs to be changed quickly but in small amounts). Usually, low frequency occurs more often than the high frequency. Although short term balancing may be possible, in some cases, in the strictest sense, prima facie the WPPs are not suitable for both types of balancing (as the wind speed is not exactly predictable). Therefore, as long as there are cheaper means available to keep the power system balanced, WPPs will probably not contribute to the system balancing. Variable speeds WPPs have much more short term balancing capabilities than constant speed WPPs.

When frequency goes high, depending on the degree of controllability and ratings of WPPs in a wind farm short term balancing can be achieved by: • Switching off the WPPs one by one • Increasing the pitch angle of the WPPs so that lesser energy is extracted from the wind to cancel out the power fluctuations on the grid.

Long Term Balancing:

The variability of the wind in the longer term (from fifteen minutes and may be for several hours) tends to complicate the despatch of the power from the remaining conventional power plants that supply to the load because it causes the demand curve to be matched by these units (which is equal to the system load minus the wind power generation) to be far less smooth than would be the case without wind power. Long term balancing for WPPs is difficult because it is determined by the actual availability of output power which depends on the wind. In fact, if the wind power penetration becomes higher (typically more than 5%), long term balancing is more complicated because if there is no wind at the predicted time, all the WPPs will stop producing power that can affect large regions. Therefore, for long term balancing, load flow studies and transient stability analysis are to be done thoroughly using relevant computer software which should include load forecast, coverage of demand, probable network availability, programmed maintenance of generators and transmission assets.

Transmission and Distribution System Impacts:

The day-to-day operation of the power system in high level of wind power penetration is a challenging experience. The grid operators must balance the generation without breaching system constraints and maintain the quality of supply to the consumers while operating the system economically. The variability of the wind, on timescales of seconds to hours makes these tasks more difficult. If these variations are big and quick, there will be corresponding changes in the magnitudes and directions of the power flows from the WPPs and from the conventional generators providing regulating and operating reserve services in the other parts of the system. Unless these variations are addressed quickly, the voltages on the grid will vary and if the variations are large enough, the limits may get infringed, which is not desired by the grid operators. A large proportion of WPPs are generally embedded in the local distribution network. Therefore, connection of large WPPs or wind farms to the distribution system introduces some additional complexity to the connection arrangement owing to the radial nature of most distribution feeders. The individual wind farms can be transferred across the grid network, as they outgrow the capacity of the local distribution network. However, for a fault on a distribution system where a circuit breaker connecting the distribution feeder to the transmission grid opens, it is important to note that the wind farm trips offline to prevent creating an islanded network. To cover both instances the wind farm needs to provide both voltage ride through capability and also anti-islanding protection. Sometimes, it may be difficult to meet both of these objectives satisfactorily.

Economic Despatch and Unit Commitment:

The power demand continually changes, requiring generation to be monitored, scheduled and despatched. Unit (power plant) commitment is the scheduling of specific power plants to meet expected electrical energy demand on a day-to-day basis. Some generators require several hours to get started and synchronised to the grid while in many cases, the shutdown process of the conventional power generators is also lengthy and units may require several hours of cooling prior to restarting. This timescale is called unit commitment, and it can range from several hours to several days, depending on the specific generator characteristics and operational practice. System operators have the information on schedules for production, consumption and interconnector usage. If the output from a WPP is accurately predicted one to two days in advance, then the grid operators can more easily determine the units that would need to be committed. The lack of an accurate forecast adds further uncertainty to the commitment decision. The result is that the optimised unit commitment is complicated due to the variable output of the WPPs. Units are committed to the schedule based on the generation maintenance schedules, generator start-up and shutdown costs, minimum fuel burn requirements and seasonal availability of intermittent resources such as hydro and wind. This schedule is usually made at least 24 hours in advance.

Another problem is that as the output powers from the WPPs follow long term wind speed fluctuations, the remaining conventional generators face complicated demand patterns. As the conventional generators are already connected to the grid, they have not only to cope with the normal load variations but also with the differences resulting from the variability of the WPP output power and this is aggravated especially when there is a simultaneous wind speed decrease and load increase. This heavily affects the despatch of the conventional power producing units and the required reserve margins.

Unit III

Solar Radiation, Radiation Measurement, Solar Thermal Power Plant, Central Receiver Power Plants, Solar Ponds.- Thermal Energy storage system with PCM- Solar Photovoltaic systems : Basic Principle of SPV conversion – Types of PV Systems- Types of Solar Cells, Photovoltaic cell concepts: Cell, module, array ,PV Module I-V Characteristics, Efficiency & Quality of the Cell, series and parallel connections, maximum power point tracking, Applications.

Introduction:

- The sun radiates energy uniformly in all directions in the form of electromagnetic waves.
- When absorbed by a body, it increases its temperature. It provides the energy needed to sustain life in our solar system.
- It is a clean, inexhaustible, abundantly and universally available renewable energy source.

  Major drawbacks of solar energy are:

  it is a dilute form of energy, which is available intermittently, uncertainly and not steadily and continuously. However, it is more predictable than wind energy.
- Also peak solar insolation (incident solar radiation) often coincides with peak daytime demand;
- it can be well matched to commercial power needs.
- The output of sun is 2.8 × 1023kW. The energy reaching the earth is 1.5 × 1018kWh/year.

  Solar energy can be utilized directly in two ways:

  (i) by collecting the radiant heat and using it in a thermal system or (ii) by collecting and converting it directly to electrical energy using Photovoltaic system. The former is referred to as 'Solar Thermal' and the later as 'Solar Photovoltaic' (SPV) system.

  Sun-earth relationship:

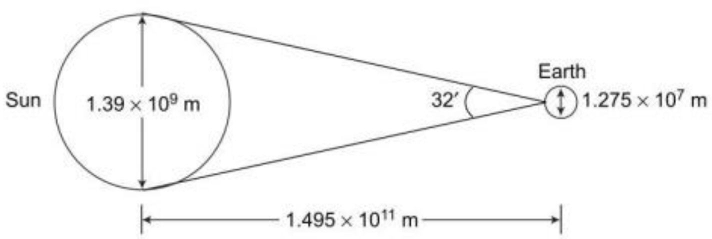


Figure 4.1 Sun–earth relationship

SUN, EARTH RADIATION SPECTRUM:

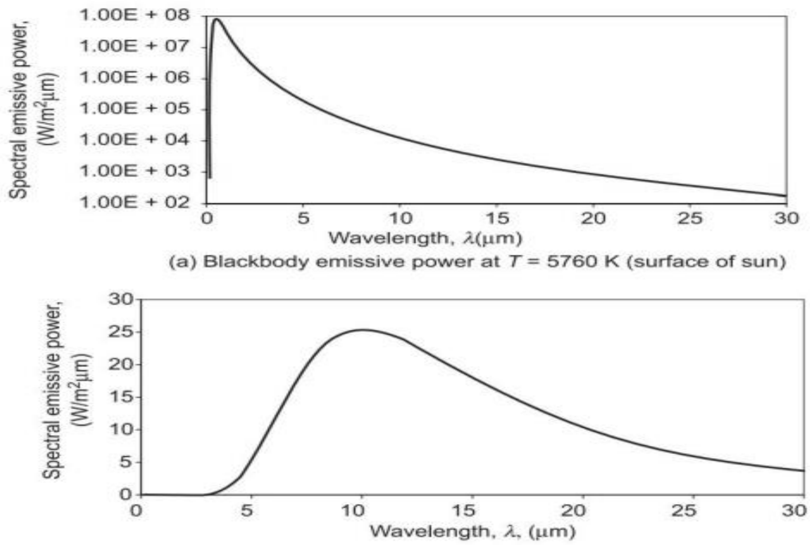
The wavelength distribution of radiation emitted by a black body is given by Planck's law:

$$W_\lambda = \frac{C_1 \lambda^{-5}}{\exp(C_2/\lambda T) - 1} \quad (\text{W/m}^2\text{-unit wavelength}) \qquad (4.1)$$

where, C_1 and C_2 are often called Planck's first and second radiation constants respectively. Their suggested values are $C_1 = 3.74 \times 10^{-16}$ Wm^2, and $C_2 = 0.01439$ mK. λ is the wavelength in m and T is temperature in Kelvin. Total energy emitted by the black body at temperature T is obtained by integrating W_λ over the wavelengths.

Using this formula the power density distribution of solar radiation at the surface of the sun considering the surface temperature to be 5760 K can be calculated. Also the same for the earth surface can be found out assuming the average earth temperature to be 288 K (15 °C). The comparison of these radiations from the sun and the earth

Power density spectrum:



(a) Blackbody emissive power at T = 5760 K (surface of sun)

(b) Blackbody emissive power at T = 288 K (surface of earth)

Solar constant (Isc):

- A useful term, Solar Constant, Isc is defined as the energy received from the sun per unit time, on a unit area of surface perpendicular to the direction of propagation of the radiation, at the earth's mean distance from the sun.

- The World Radiation Center (WRC) has adopted a value of solar constant as 1367 W/m2 (1.940 cal/cm2 min, 432Btu/ft2 hr or 4.921 MJ/m2 hr). This has been accepted universally as a standard value of solar constant.

EXTRATERRESTRIAL AND TERRESTRIAL RADIATIONS:

- The intensity of solar radiation keeps on attenuating as it propagates away from the surface of the sun, though the wavelengths remain unchanged.

- Solar radiation incident on the outer atmosphere of the earth is known as Extraterrestrial Radiation, Iext.

$$I_{ext} = I_{sc}\,[1 + 0.033 \cos(360\,n/365)]\ \mathrm{W/m^2}. \qquad (4.2)$$

where, n is the day of the year starting from January 1.

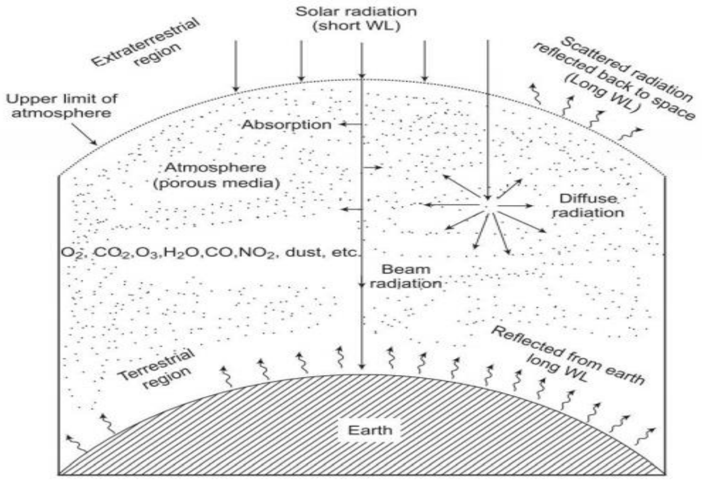


Figure 4.3 Propagation of solar radiation through atmosphere

- Solar radiation that reaches earth surface after passing through the earth's atmosphere is known as Terrestrial Radiation.

- The terrestrial radiation expressed as energy per unit time per unit area (i.e. W/m2) is known as Solar Irradiation. The term Solar Insolation (incident solar radiation) is defined as solar radiation energy received on a given surface area in a given time (in J/m2 or kWh/m2).

<u>Spectral radiation, extra and terrestrial radiation:</u>

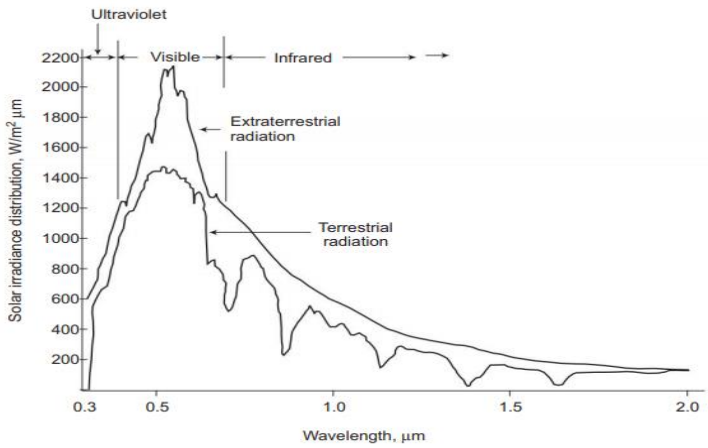


Figure 4.4 Special solar irradiation, extraterrestrial and terrestrials

<u>MEASUREMENT OF SOLAR RADIATION:</u>

- Solar radiation data are measured mainly by following instruments: (i) Pyranometer: A pyranometer is designed to measure global radiation, usually on a horizontal surface but can also be used on an inclined surface. When shaded from beam radiation by using a shading ring, it measures diffuse radiation only.

- (ii) Pyrheliometer: An instrument that measures beam radiation by using a long and narrow tube to collect only beam radiation from the sun at normal incidence.
- (iii) A sunshine recorder measures the sunshine hours in a day.

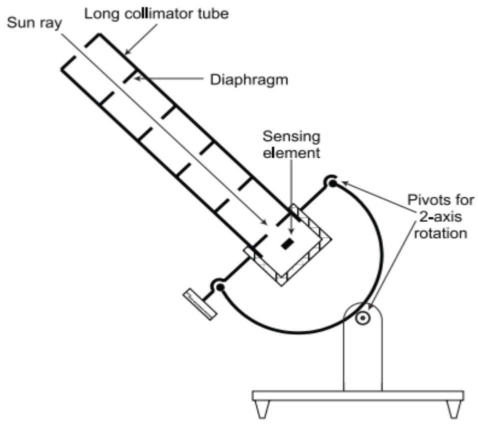
Pyranometer:

Figure 4.6 Pyranometer (*Courtesy:* Eppley Laboratory)

Figure 4.7 A pyranometer with shadow band (*Courtesy:* Eppley Laboratory)

- A precision pyranometer is designed to respond to radiation of all wavelengths and hence measures accurately the total power in the incident spectrum.
- It contains a thermopile whose sensitive surface consists of circular, blackened, hot junctions, exposed to the sun and cold junctions are completely shaded.
- The temperature difference between the hot and cold junctions is the function of radiation falling on the sensitive surface. The sensing element is covered by two concentric hemispherical glass domes to shield it from wind and rain. This also reduces the convection currents.
- A radiation shield surrounding the outer dome and coplanar with the sensing element, prevents direct solar radiation from heating the base of the instrument.
- The instrument has a voltage output of approximately 9 µV/W/m2 and has an output impedance of 650 W.
- A precision spectral pyranometer (model: PSP) of Eppley laboratory is shown in Fig. 4.6.
- The pyranometer, when provided with a shadow band (or occulting disc) to prevent beam radiation from reaching the sensing element, measures the diffuse radiation only. Such an arrangement of shadow bandstand (model: SBS) is shown in Fig. 4.7

Pyroheliometer;



- The normal incidence pyranometer, shown in Fig. , uses a long collimator tube to collect beam radiation whose field of view is limited to a solid angle of 5.5° (generally) by appropriate diaphragms inside the tube.
- The inside of the tube is blackened to absorb any radiation incident at angles outside the collection solid angle. At the base of the tube a wire wound thermopile having a sensitivity of approximately 8 mV/W/m2 and an output impedance of approximately 200 W is provided.
- The tube is sealed with dry air to eliminate absorption of beam radiation within the tube by water vapor. A tracker is needed if continuous readings are desired.

Sunshine recorder:

- The bowl and glass sphere is arranged in such a way that sun's rays are focused sharply at a spot on a card held in a groove in the bowl.
- The card is prepared from special paper bearing a time scale. As the sun moves, the focused bright sunshine burns a path along this paper.
- The length of the trace thus obtained on the paper is the measure of the duration of the bright sunshine. Three overlapping pairs of grooves are provided in the spherical segment to take care of the different seasons of the year.

Solar Thermal Systems:

- Solar power has low density per unit area (1 kW/sq. m. to 0.1 kW/sq. m.). Hence it is to be collected by covering large ground area by solar thermal collectors.
- Solar thermal collector essentially forms the first unit in a solar thermal system. It absorbs solar energy as heat and then transfers it to heat transport fluid efficiently. The heat transport fluid delivers this heat to thermal storage tank / boiler / heat exchanger, etc., to be utilized in the subsequent stages of the system.

Solar collectors – types:

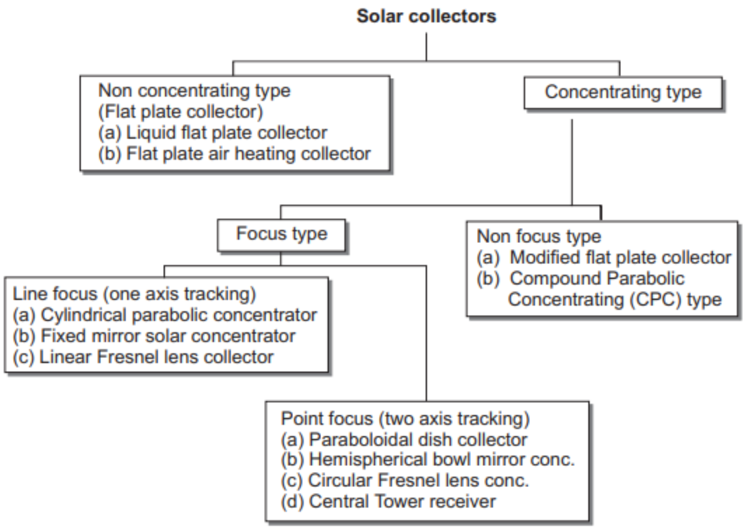


Figure 5.1 Types of solar collectors

Unit 4

Introduction:

Plant matter created by the process of photosynthesis is called biomass (or) all organic materials such as plants, trees and crops are potential sources of energy and are collectively called biomass. The term biomass is also generally understood to include human waste, and organic fractions of sewage sludge, industrial effluents and household wastes. The biomass sources are highly dispersed and bulky and contain large amounts of water (50 to 90%). Thus, it is not economical to transport them over long distances, and conversion into usable energy must takes place close to source, which is limited to particular regions.

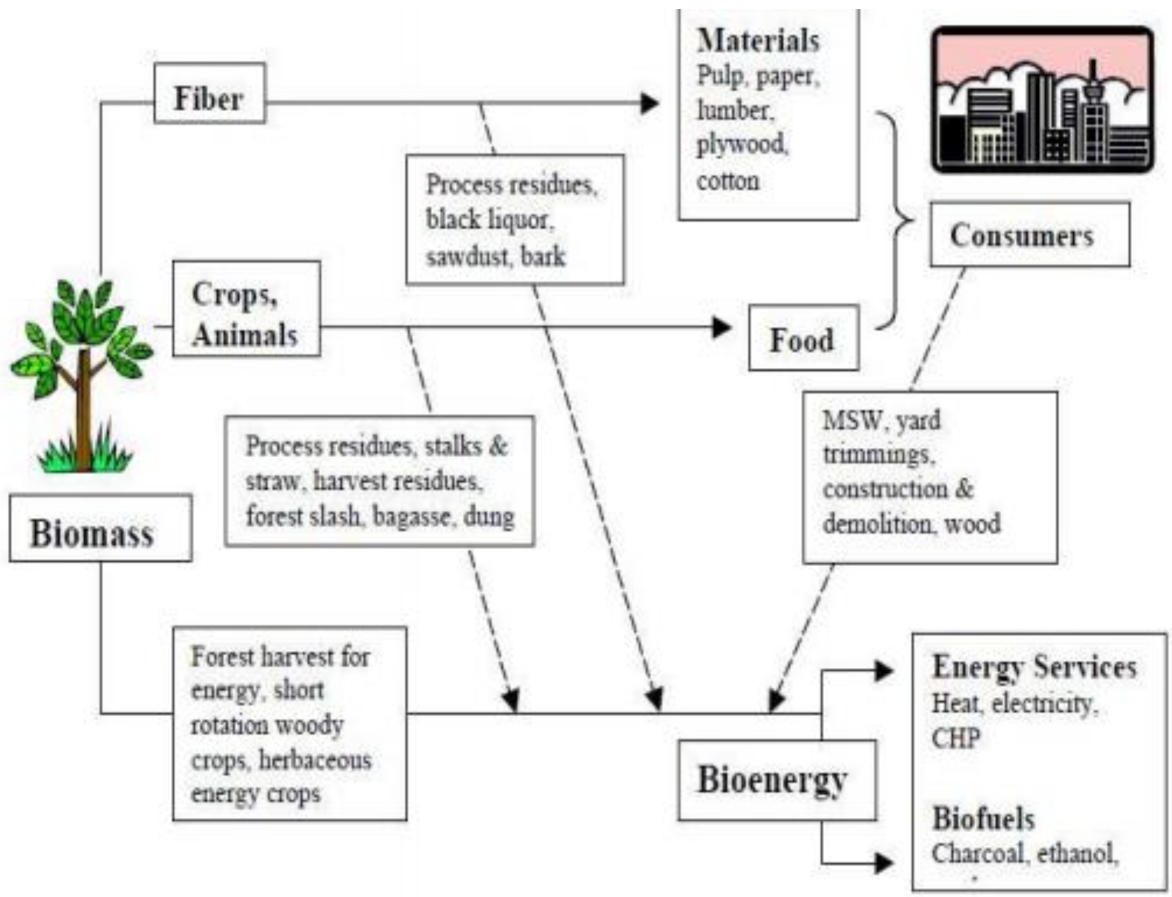


Fig. 4.1 Schematic diagram of utilization of biomass

Biomass resources:

Biomass resources that are available on a renewable basis and are used either directly as a fuel or converted to another form or energy product are commonly referred to as “feedstocks.”

BIOMASS FEEDSTOCKS

Biomass feedstocks include dedicated energy crops, agricultural crop residues, forestry residues, algae, wood processing residues, municipal waste, and wet waste (crop wastes, forest residues, purpose-grown grasses, woody energy crops, algae, industrial wastes, sorted municipal solid waste [MSW], urban wood waste, and food waste).

DEDICATED ENERGY CROPS

Dedicated energy crops are non-food crops that can be grown on marginal land (land not suitable for traditional crops like corn and soybeans) specifically to provide biomass. These break down into two general categories: herbaceous and woody. Herbaceous energy crops are perennial (plants that live for more than 2 years) grasses that are harvested annually after taking 2 to 3 years to reach full productivity. These include switchgrass, miscanthus, bamboo, sweet sorghum, tall fescue, kochia, wheatgrass, and others. Short-rotation woody crops are fast-growing hardwood trees that are harvested within 5 to 8 years of planting. These include hybrid poplar, hybrid willow, silver maple, eastern cottonwood, green ash, black walnut, sweetgum, and sycamore. Many of these species can help improve water and soil quality, improve wildlife habitat relative to annual crops, diversify sources of income, and improve overall farm productivity.

AGRICULTURAL CROP RESIDUE

There are many opportunities to leverage agricultural resources on existing lands without interfering with the production of food, feed, fiber, or forest products. Agricultural crop residues, which include the stalks and leaves, are abundant, diverse, and widely distributed across the United States. Examples include corn stover (stalks, leaves, husks, and cobs), wheat straw, oat straw, barley straw, sorghum stubble, and rice straw. The sale of these residues to a local biorefinery also represents an opportunity for farmers to generate additional income.

FORESTRY RESIDUES

Forest biomass feedstocks fall into one of two categories: forest residues left after logging timber (including limbs, tops, and culled trees and tree components that would be otherwise unmerchantable) or whole-tree biomass harvested explicitly for biomass. Dead, diseased, poorly formed, and other unmerchantable trees are often left in the woods following timber harvest. This woody debris can be collected for use in bioenergy, while leaving enough behind to provide habitat and maintain proper nutrient and hydrologic features. There are also opportunities to make use of excess biomass on millions of acres of forests. Harvesting excessive woody biomass can reduce the risk of fire and pests, as well as aid in forest restoration, productivity, vitality, and resilience. This biomass could be harvested for bioenergy without negatively impacting the health and stability of forest ecological structure and function.

ALGAE

Algae as feedstocks for bioenergy refers to a diverse group of highly productive organisms that include microalgae, macroalgae (seaweed), and cyanobacteria (formerly called “blue-green algae”). Many use sunlight and nutrients to create biomass, which contains key components—including lipids, proteins, and carbohydrates— that can be converted and upgraded to a variety of biofuels and products. Depending on the strain, algae can grow by using fresh, saline, or brackish water from surface water sources, groundwater, or seawater. Additionally, they can grow in water from second-use sources, such as treated industrial wastewater; municipal, agricultural, or aquaculture wastewater; or produced water generated from oil and gas drilling operations.

WOOD PROCESSING RESIDUES

Wood processing yields byproducts and waste streams that are collectively called wood processing residues and have significant energy potential. For example, the processing of wood for products or pulp produces unused sawdust, bark, branches, and leaves/needles. These residues can then be converted into biofuels or bioproducts. Because these residues are already collected at the point of processing, they can be convenient and relatively inexpensive sources of biomass for energy.

SORTED MUNICIPAL WASTE

MSW resources include mixed commercial and residential garbage, such as yard trimmings, paper and paperboard, plastics, rubber, leather, textiles, and food wastes. MSW for bioenergy also represents an opportunity to reduce residential and commercial waste by diverting significant volumes from landfills to the refinery.

WET WASTE

Wet waste feedstocks include commercial, institutional, and residential food wastes (particularly those currently disposed of in landfills); organic-rich biosolids (i.e., treated sewage sludge from municipal wastewater); manure slurries from concentrated livestock operations; organic wastes from industrial operations; and biogas (the gaseous product of the decomposition of organic matter in the absence of oxygen) derived from any of the above feedstock streams. Transforming these “waste streams” into energy can help create additional revenue for rural economies and solve waste-disposal problems

Energy from biomass:

People have used biomass energy—energy from living things—since the earliest “cave men” first made wood fires for cooking or keeping warm.

Biomass is organic, meaning it is made of material that comes from living organisms, such as plants and animals. The most common biomass materials used for energy are plants, wood, and waste. These are called biomass feedstocks. Biomass energy can also be a non-renewable energy source.

Biomass contains energy first derived from the sun: Plants absorb the sun’s energy through photosynthesis, and convert carbon dioxide and water into nutrients (carbohydrates).

The energy from these organisms can be transformed into usable energy through direct and indirect means. Biomass can be burned to create heat (direct), converted into electricity (direct), or processed into biofuel (indirect).

Thermal Conversion

Biomass can be burned by thermal conversion and used for energy. Thermal conversion involves heating the biomass feedstock in order to burn, dehydrate, or stabilize it. The most familiar biomass feedstocks for thermal conversion are raw materials such as municipal solid waste (MSW) and scraps from paper or lumber mills.

Different types of energy are created through direct firing, co-firing, pyrolysis, gasification, and anaerobic decomposition.

Before biomass can be burned, however, it must be dried. This chemical process is called torrefaction. During torrefaction, biomass is heated to about 200° to 320° Celsius (390° to 610° Fahrenheit). The biomass dries out so completely that it loses the ability to absorb moisture, or rot. It loses about 20% of its original mass, but retains 90% of its energy. The lost energy and mass can be used to fuel the torrefaction process.

During torrefaction, biomass becomes a dry, blackened material. It is then compressed into briquettes. Biomass briquettes are very hydrophobic, meaning they repel water. This makes it possible to store them in moist areas. The briquettes have high energy density and are easy to burn during direct or co-firing.

Direct Firing and Co-Firing

Most briquettes are burned directly. The steam produced during the firing process powers a turbine, which turns a generator and produces electricity. This electricity can be used for manufacturing or to heat buildings.

Biomass can also be co-fired, or burned with a fossil fuel. Biomass is most often co-fired in coal plants. Co-firing eliminates the need for new factories for processing biomass. Co-firing also eases the demand for coal. This reduces the amount of carbon dioxide and other greenhouse gases released by burning fossil fuels.

Pyrolysis

Pyrolysis is a related method of heating biomass. During pyrolysis, biomass is heated to 200° to 300° C (390° to 570° F) without the presence of oxygen. This keeps it from combusting and causes the biomass to be chemically altered.

Pyrolysis produces a dark liquid called pyrolysis oil, a synthetic gas called syngas, and a solid residue called biochar. All of these components can be used for energy.

Pyrolysis oil, sometimes called bio-oil or biocrude, is a type of tar. It can be combusted to generate electricity and is also used as a component in other fuels and plastics. Scientists and engineers are studying pyrolysis oil as a possible alternative to petroleum.

Syngas can be converted into fuel (such as synthetic natural gas). It can also be converted into methane and used as a replacement for natural gas.

Biochar is a type of charcoal. Biochar is a carbon-rich solid that is particularly useful in agriculture. Biochar enriches soil and prevents it from leaching pesticides and other nutrients into runoff. Biochar is also an excellent carbon sink. Carbon sinks are reservoirs for carbon-containing chemicals, including greenhouse gases.

Gasification

Biomass can also be directly converted to energy through gasification. During the gasification process, a biomass feedstock (usually MSW) is heated to more than 700° C (1,300° F) with a controlled amount of oxygen. The molecules break down, and produce syngas and slag.

Syngas is a combination of hydrogen and carbon monoxide. During gasification, syngas is cleaned of sulfur, particulates, mercury, and other pollutants. The clean syngas can be combusted for heat or electricity, or processed into transportation biofuels, chemicals, and fertilizers.

Slag forms as a glassy, molten liquid. It can be used to make shingles, cement, or asphalt.

Industrial gasification plants are being built all over the world. Asia and Australia are constructing and operating the most plants, although one of the largest gasification plants in the world is currently under construction in Stockton-on-Tees, England. This plant will eventually be able to convert more than 350,000 tons of MSW into enough energy to power 50,000 homes.

Anaerobic Decomposition

Anaerobic decomposition is the process where microorganisms, usually bacteria, break down material in the absense of oxygen. Anaerobic decomposition is an important process in landfills, where biomass is crushed and compressed, creating an anaerobic (or oxygen-poor) environment.

In an anaerobic environment, biomass decays and produces methane, which is a valuable energy source. This methane can replace fossil fuels.

In addition to landfills, anaerobic decomposition can also be implemented on ranches and livestock farms. Manure and other animal waste can be converted to sustainably meet the energy needs of the farm.

Biofuel

Biomass is the only renewable energy source that can be converted into liquid biofuels such as ethanol and biodiesel. Biofuel is used to power vehicles, and is being produced by gasification in countries such as Sweden, Austria, and the United States.

Ethanol is made by fermenting biomass that is high in carbohydrates, such as sugar cane, wheat, or corn. Biodiesel is made from combining ethanol with animal fat, recycled cooking fat, or vegetable oil.

Biofuels do not operate as efficiently as gasoline. However, they can be blended with gasoline to efficiently power vehicles and machinery, and do not release the emissions associated with fossil fuels.

Ethanol requires acres of farmland to grow biocrops (usually corn). About 1,515 liters (400 gallons) of ethanol is produced by an acre of corn. But this acreage is then unavailable for growing crops for food or other uses. Growing enough corn for ethanol also creates a strain on the environment because of the lack of variation in planting, and the high use of pesticides.

Ethanol has become a popular substitute for wood in residential fireplaces. When it is burned, it gives off heat in the form of flames, and water vapor instead of smoke.

Biochar

Biochar, produced during pyrolysis, is valuable in agricultural and environmental use.

When biomass rots or burns (naturally or by human activity), it releases high amounts of methane and carbon dioxide into the atmosphere. However, when biomass is charred, it sequesters, or stores, its carbon content. When biochar is added back to the soil, it can continue to absorb carbon and form large underground stores of sequestered carbon—carbon sinks—that can lead to negative carbon emissions and healthier soil.

Biochar also helps enrich the soil. It is porous. When added back to the soil, biochar absorbs and retains water and nutrients.

Biochar is used in Brazil's Amazon rain forest in a process called slash-and-char. Slash-and-char agriculture replaces slash-and-burn, which temporarily increases the soil nutrients but causes it to lose 97% of its carbon content. During slash-and-char, the charred plants (biochar) are returned to the soil, and the soil retains 50% of its carbon. This enhances the soil and leads to significantly higher plant growth.

Black Liquor

When wood is processed into paper, it produces a high-energy, toxic substance called black liquor. Until the 1930s, black liquor from paper mills was considered a waste product and dumped into nearby water sources.

However, black liquor retains more than 50% of the wood's biomass energy. With the invention of the recovery boiler in the 1930s, black liquor could be recycled and used to power the mill. In the U.S., paper mills use nearly all their black liquor to run their mills, and the forest industry is one of the most energy-efficient in the nation as a result.

More recently, Sweden has experimented in gasifying black liquor to produce syngas, which can then be used to generate electricity.

Hydrogen Fuel Cells

Biomass is rich in hydrogen, which can be chemically extracted and used to generate power and to fuel vehicles. Stationary fuel cells are used to generate electricity in remote locations, such as spacecraft and wilderness areas. Yosemite National Park in the U.S. state of California, for example, uses hydrogen fuel cells to provide electricity and hot water to its administration building.

Hydrogen fuel cells may hold even more potential as an alternative energy source for vehicles. The U.S. Department of Energy estimates that biomass has the potential to produce 40 million tons of hydrogen per year. This would be enough to fuel 150 million vehicles.

Currently, hydrogen fuel cells are used to power buses, forklifts, boats, and submarines, and are being tested on airplanes and other vehicles.

However, there is a debate as to whether this technology will become sustainable or economically possible. The energy that it takes to isolate, compress, package, and transport the hydrogen does not leave a high quantity of energy for practical use.

Biomass and the Environment

Biomass is an integral part of Earth's carbon cycle. The carbon cycle is the process by which carbon is exchanged between all layers of the Earth: atmosphere, hydrosphere, biosphere, and lithosphere.

The carbon cycle takes many forms. Carbon helps regulate the amount of sunlight that enters Earth's atmosphere. It is exchanged through photosynthesis, decomposition, respiration, and human activity. Carbon that is absorbed by soil as an organism decomposes, for example, may be recycled as a plant releases carbon-based nutrients into the biosphere through photosynthesis. Under the right conditions, the decomposing organism may become peat, coal, or petroleum before being extracted through natural or human activity.

Between periods of exchange, carbon is sequestered, or stored. The carbon in fossil fuels has been sequestered for millions of years. When fossil fuels are extracted and burned for energy, their sequestered carbon is released into the atmosphere. Fossil fuels do not re-absorb carbon.

In contrast to fossil fuels, biomass comes from recently living organisms. The carbon in biomass can continue to be exchanged in the carbon cycle.

In order to effectively allow Earth to continue the carbon cycle process, however, biomass materials such as plants and forests have to be sustainably farmed. It takes decades for trees and plants such as switchgrass to re-absorb and sequester carbon. Uprooting or disturbing the soil can be extremely disruptive to the process. A steady and varied supply of trees, crops, and other plants is vital for maintaining a healthy environment.

Algal Fuel

Algae is a unique organism that has enormous potential as a source of biomass energy. Algae, whose most familiar form is seaweed, produces energy through photosynthesis at a much quicker rate than any other biofuel feedstock—up to 30 times faster than food crops!

Algae can be grown in ocean water, so it does not deplete freshwater resources. It also does not require soil, and therefore does not reduce arable land that could potentially grow food crops. Although algae releases carbon dioxide when it is burned, it can be farmed and replenished as a living organism. As it is replenished, it releases oxygen, and absorbs pollutants and carbon emissions.

Algae takes up much less space than other biofuel crops. The U.S. Department of Energy estimates that it would only take approximately 38,850 square kilometers

(15,000 square miles, an area less than half the size of the U.S. state of Maine) to grow enough algae to replace all petroleum-fueled energy needs in the United States.

Algae contains oils that can be converted to a biofuel. At the Aquaflow Bionomic Corporation in New Zealand, for example, algae is processed with heat and pressure. This creates a "green crude," which has similar properties to crude oil, and can be used as a biofuel.

Algae's growth, photosynthesis, and energy production increases when carbon dioxide is bubbled through it. Algae is an excellent filter that absorbs carbon emissions. Bioenergy Ventures, a Scottish firm, has developed a system in which carbon emissions from a whiskey distillery are funneled to an algae pool. The algae flourishes with the additional carbon dioxide. When the algae die (after about a week) they are collected, and their lipids (oils) are converted into biofuel or fish food.

Algae has enormous potential as an alternative energy source. However, processing it into usable forms is expensive. Although it is estimated to yield 10 to 100 times more fuel than other biofuel crops, in 2010 it cost $5,000 a ton. The cost will likely come down, but it is currently out of reach for most developing economies.

People and Biomass

Advantages
Biomass is a clean, renewable energy source. Its initial energy comes from the sun, and plants or algae biomass can regrow in a relatively short amount of time. Trees, crops, and municipal solid waste are consistently available and can be managed sustainably.

If trees and crops are sustainably farmed, they can offset carbon emissions when they absorb carbon dioxide through respiration. In some bioenergy processes, the amount of carbon that is re-absorbed even exceeds the carbon emissions that are released during fuel processing or usage.

Many biomass feedstocks, such as switchgrass, can be harvested on marginal lands or pastures, where they do not compete with food crops.

Unlike other renewable energy sources, such as wind or solar, biomass energy is stored within the organism, and can be harvested when it is needed.

Disadvantages

If biomass feedstocks are not replenished as quickly as they are used, they can become non-renewable. A forest, for instance, can take hundreds of years to re-establish itself. This is still a much, much shorter time period than a fossil fuel such as peat. It can take 900 years for just a meter (3 feet) of peat to replenish itself.

Most biomass requires arable land to develop. This means that land used for biofuel crops such as corn and soybeans are unavailable to grow food or provide natural habitats.

Forested areas that have matured for decades (so-called “old-growth forests”) are able to sequester more carbon than newly planted areas. Therefore, if forested areas are not sustainably cut, re-planted, and given time to grow and sequester carbon, the advantages of using the wood for fuel are not offset by the trees’ regrowth.

Most biomass plants require fossil fuels to be economically efficient. An enormous plant under construction near Port Talbot, Wales, for instance, will require fossil fuels imported from North America, offsetting some of the sustainability of the enterprise.

Biomass has a lower “energy density” than fossil fuels. As much as 50% of biomass is water, which is lost in the energy conversion process. Scientists and engineers estimate that it is not economically efficient to transport biomass more than 160 kilometers (100 miles) from where it is processed. However, converting biomass into pellets (as opposed to wood chips or larger briquettes) can increase the fuel’s energy density and make it more advantageous to ship.

Burning biomass releases carbon monoxide, carbon dioxide, nitrogen oxides, and other pollutants and particulates. If these pollutants are not captured and recycled, burning biomass can create smog and even exceed the number of pollutants released by fossil fuels.

Biomass Conversion:

Biomass can either be utilized directly as a fuel, or can be converted into liquid or gaseous fuels, which can also be as feedstock for industries. Most biomass in dry state can be burned directly to produce heat, steam or electricity. On the other hand biological conversion technologies utilize natural anaerobic decay processes to produce high quality fuels from biomass. Various possible conversion technologies for getting different products from biomass is broadly classified into three groupsviz. (i) thermo-chemical conversion, (ii) bio-chemical conversion and (iii) oil extraction.

Thermo-chemical conversion includes processes like combustion, gasification and pyrolysis. Combustion refers to the conversion of biomass to heat and power by directly burning it, as occurs in boilers. Gasification is the process of converting solid biomass with a limited quantity of air into producer gas, while pyrolysis is the thermal decomposition of biomass in the absence of oxygen. The products of pyrolysis are charcoal, condensable liquid and gaseous products.

Combustion, gasification and pyrolysis are all thermochemical processes to convert biomass into energy. In all of them, the biomass is heated to evaporate water and then to cause pyrolysis to occur and to produce volatiles.

Thermal conversion processes for biomass involve some or all of the following processes:

Pyrolysis: Biomass +heat charcoal , gas and oil

Gasification: Biomass +limited oxygen fuel gas

Combustion: Biomass +stoichiometric O2 hot combustion products

Combustion:

Combustion is a process whereby the total or partial oxidation of carbon and hydrogen converts the chemical energy of biomass into heat. This complex chemical reaction can be briefly described as follows: Burning fuel = Products from reaction + heat During the combustion process, organic matter decomposes in phases, i.e. drying, pyrolysis/gasification, ignition of volatile substances and charcoal combustion. Generally speaking, these phases correspond to two reaction times: release of volatile substances and respective combustion, followed by charcoal combustion.

Wood, agricultural residues, wood pulping liquor, municipal solid waste (MSW) and refuse derived fuel are examples of feed stocks for combustion. Combustion requires high temperatures for ignition, sufficient turbulence to mix all of the components with the oxidant, and time to complete all of the oxidation reactions. The moisture content of the feedstock should be low and pre-drying may be necessary in some cases. Biomass combustion starts by heating and drying the feedstock. After all of the moisture has been removed, temperature rises for pyrolysis to occur in the absence of oxygen. The major products are hydrogen, CO, CO2, CH4 and other hydrocarbons. In the end, char and volatile gases are formed and they continue to react independently. The volatile gases need oxygen in order to achieve a complete flame combustion. Mostly CO2 and H2O result from complete combustion. When combusting biomass in a furnace, hot gases are released. They contain about 85% of the fuel‟s potential energy. The heat can be used either directly or indirectly through a heat exchanger, in the form of hot air or water. Boiler used for biomass combusting transfers the produced heat into steam. The steam can be used for producing electricity, mechanical energy or heat.

Gasification:

Gasification is a process whereby organic matter decomposes through thermal reactions, in the presence of stoichiometric amounts of oxidising agents. The process generates a combustible gas mix, essentially composed of carbon monoxide, hydrogen, carbon dioxide, methane, steam and, though in smaller proportions, other heavier hydrocarbons and tars. The process is aimed at converting the energy potential of a solid fuel into a gas product, whose energy content has the form of chemical energy with the capacity to generate work. Gasification is carried out in two steps. First, the biomass is heated to around 600 degrees. The volatile components, such as hydrocarbon gases, hydrogen, CO, CO2, H2O and tar, vaporize by various reactions. The remaining by-products are char and ash. For this first endothermic step, oxygen is not required. In the second step, char is gasified by reactions with oxygen, steam and hydrogen in high temperatures. The endothermic reactions require heat, which is applied by combusting some of the unburned char. Main products of gasification are synthesis gas, char and tars. The content depends on the feedstock, oxidizing agent and the conditions of the process. The gas mainly consists of CO, CO4, H2O, CH4 and other hydrocarbons.

The synthesis gas can be utilized for heating or electricity production. It can also be used for the production of ethanol, diesel and chemical feed stocks.

Pyrolysis:

In pyrolysis, biomass is heated in the absence of air. The process results liquid, solid and gaseous fractions, mainly gases, bio-oil and char. The gases and the bio-oil are from the volatile fraction of biomass, while the char is mostly the fixed carbon component. In the first step, temperature is increased to start the primary pyrolysis reactions. As a result, volatiles are released and char is formed. Finally, after various reactions, pyrolysis gas is formed. The main product of slow pyrolysis, a thousands of years old process, is char or charcoal. In slow pyrolysis biomass is heated to around 500 degrees for 5 to 30min.Fast pyrolysis results mainly in bio-oil. The biomass is heated in the absence of oxygen and the residence time is 0, 5 to 5s. Vapours, aerosols and char are generated through decomposition. After cooling, bio-oil is formed. The remaining non condensable gases can be used as a source of energy for the pyrolysis reactor. Calculated by weight, fast pyrolysis results in 60%-75% liquid bio-oil, 15%-25% solid char, and 10%-20% non-condensable gases.

Gasifiers:

Gasification of wood and other agricultural cellulosic residues was a common practice at the beginning of this century to produce low calorie fuel gas. Gasifiers can be suitably used for thermal decomposition of a wide range of feed materials from forestry products, agricultural residues, and aquatic biomass to municipal solid wastes.

However, some important points which should be taken into consideration while undertaking any biomass gasification system:

- A gasifier itself is of little use. It is used either to generate a combustible gas to provide heat or to generate a fuel gas which can be used in an internal combustion engine as a petroleum oil substitute.

- Some of the gaseous, liquid and solid products of combustion are not only harmful to engines and burners, but also to human beings. That is why these gases are not used as cooking gas.

• A gasifier must have an effective gas cleaning train if the gas is to be used for internal combustion engines. A maximum limit of 5-15 mg solids and tar per kg of gas may be allowed for the use of the gas in an internal combustion engine.

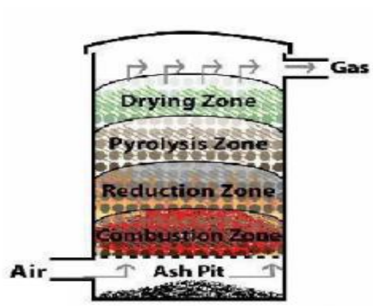
• A gasification system may not be of much advantage to generate a combustible gas, as far as fossil fuel savings, economies and ease of operation are concerned.

Types of Gasifiers :

`Gasifiers are generally classified on the basis of the physical conditions of the feed stocks in the reactors. The gasifiers may be grouped into the following types: (a) Dense phase reactors (b) Lean phase reactors (a) Dense phase reactors In dense phase reactors, the feedstock fills most of the space in the reactor. They are common, available in different designs depending upon the operating conditions, and are of three types: downdraft, updraft, and cross-draft.

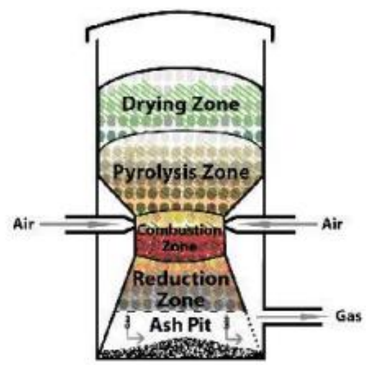
i) Downdraft or co-current gasifiers:

The downdraft (also known as co-current) gasifier is the most common type of gasifier. In downdraft gasifiers, the pyrolysis zone is above the combustion zone and the reduction zone is below the combustion zone. Fuel is fed from the top. The flow of air and gas is downwards (hence the name) through the combustion and reduction zones. The term co-current is used because air moves in the same direction as that of fuel, downwards. A downdraft gasifier is so designed that tar, which is produced in the pyrolysis zone, travels through the combustion zone, where it is broken down or burnt. As a result, the mixture of gases in the exit stream is relatively clean. The position of the combustion zone is thus a critical element in the downdraft gasifier, its main advantage being that it produces gas with low tar content, which is suitable for gas engines.



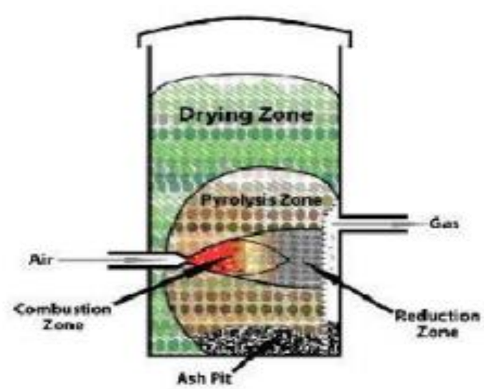
Downdraft or co-current gasifiers

ii) Updraft or counter-current gasifier In updraft gasifiers (also known as counter-current), air enters from below the grate and flows upwards, whereas the fuel flows downwards. An updraft gasifier has distinctly defined zones for partial combustion, reduction, pyrolysis, and drying. The gas produced in the reduction zone leaves the gasifier reactor together with the products of pyrolysis from the pyrolysis zone and steam from the drying zone. The resulting combustible producer gas is rich in hydrocarbons (tars) and, therefore, has a higher calorific value, which makes updraft gasifiers more suitable where heat is needed, for example in industrial furnaces. The producer gas needs to be thoroughly cleaned if it is to be used for generating electricity.



Up-draft gasifier

iii) Cross-draft gasifier In a cross-draft gasifier, air enters from one side of the gasifier reactor and leaves from the other. Cross-draft gasifiers have a few distinct advantages such as compact construction and low cleaning requirements. Also, cross-draft gasifiers do not need a grate; the ash falls to the bottom and does not come in the way of normal operation.



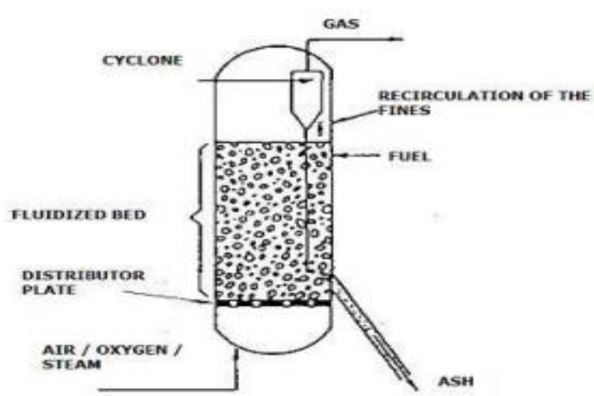
Cross-draft gasifier

b) Lean phase reactors:

Lean phase gasifiers lack separate zones for different reactions. All reactions – drying,combustion, pyrolysis, and reduction – occur in one large reactor chamber. Lean phase reactors are mostly of two types, fluidized bed gasifiers and entrained-flow gasifiers.

i) Fluidized bed gasifiers:

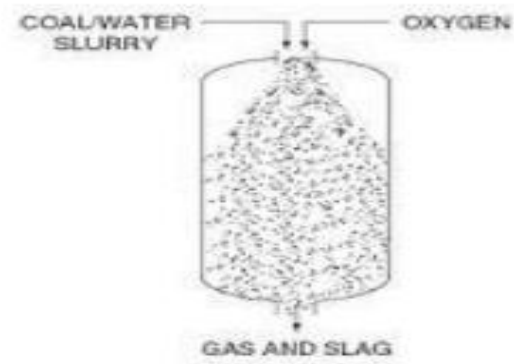
In fluidized bed gasifiers, the biomass is brought into an inert bed of fluidized material (e.g. sand, char, etc.). The fuel is fed into the fluidized system either above-bed or directly into the bed, depending upon the size and density of the fuel and how it is affected by the bed velocities. During normal operation, the bed media is maintained at a temperature between 550 °C and 1000 °C. When the fuel is introduced under such temperature conditions, its drying and pyrolyzing reactions proceed rapidly, driving off all gaseous portions of the fuel at relatively low temperatures. The remaining char is oxidized within the bed to provide the heat source for the drying and devolatilizing reactions to continue. Fluidized bed gasifiers are better than dense phase reactors in that they produce more heat in short time due to the abrasion phenomenon between inert bed material and biomass, giving a uniformly high (800–1000 ºC) bed temperature. A fluidized bed gasifier works as a hot bed of sand particles agitated constantly by air. Air is distributed through nozzles located at the bottom of the bed.



Fluidized bed gasifiers

ii) Entrained-flow gasifiers In entrained-flow gasifiers, fuel and air are introduced from the top of the reactor, and fuel is carried by the air in the reactor. The operating temperatures are 1200–1600 °C and the pressure is 20–80 bar.

Entrained-flow gasifiers can be used for any type of fuel so long as it is dry (low moisture) and has low ash content. Due to the short residence time (0.5–4.0 seconds), high temperatures are required for such gasifiers. The advantage of entrained-flow gasifiers is that the gas contains very little tar.



Entrained-flow gasifiers

Producer gas applications:The producer gas obtained can be used either to produce heat or to generate electricity.

Thermal applications: Producer gas can also be burnt directly in open air, much like Liquid Petroleum Gas (LPG), and therefore can be used for cooking, boiling water, producing steam, and drying food and other materials.

- Dryer: The hot gas after combustion can be mixed with the right quantity of secondary air to lower its temperature to the desired level for use in dryers in the industries such as tea drying, cardamom drying etc.
- Kilns: Firing of tiles, pottery articles, limestone and refractories, where temperatures of 800–950 °C are required.
- Boilers: Producer gas can be used as fuel in boilers to produce steam or hot water.

Power applications: Producer gas can be used for generating motive power to run either dual-fuel engines (which run on a mixture of gas and diesel, with gas replacement of up to 85% of diesel) or engines that run on producer gas alone (100% diesel replacement).

In general, the fuel-to electricity efficiency of gasification is much higher than that of direct combustion: The conversion efficiency of gasification is 35%–45% whereas that of combustion is only 10%– 20%. Generated electricity can be fed into the grid or can be used for farm operations, irrigation, chilling or cold storage, and other commercial and industrial applications.

Conditions and requirements for implementation:

Biomass gasifier needs uniform-sized and dry fuel for smooth and trouble-free operation. Most gasifier systems are designed either for woody biomass (or dense briquettes made from loose biomass) or for loose, pulverized biomass.

Woody biomass:

- Pieces smaller than 5–10 cm (2–4 inches) in any dimension, depending on design
- Bulk density of wood or briquettes: less than 250–300 kg/m3

Loose biomass:

- Pulverized biomass, depending on design
- Moisture content up to 15%–25%, depending on gasifier design
- Ash content below 5% preferred; with a maximum limit of 20%
- Bulk density of loose biomass is less than 150 kg/m3

Briquetting:

It is the process of compaction of residues into a product of higher density than the original raw materials. It is also known as densification. The handling characteristics of material for packaging, transportation and storage are also improved. If produced at low cost and made conveniently accessible to consumers, briquettes could serve as compliments to firewood and charcoal for domestic cooking and agro-industrial operations, thereby reducing the high demand for both. Besides, briquettes have advantages over fuel wood in terms of greater heat intensity, cleaningness, convenience in use and relatively smaller space requirement for storage. The briquettes are normally cylindrical or rectangular in shape.

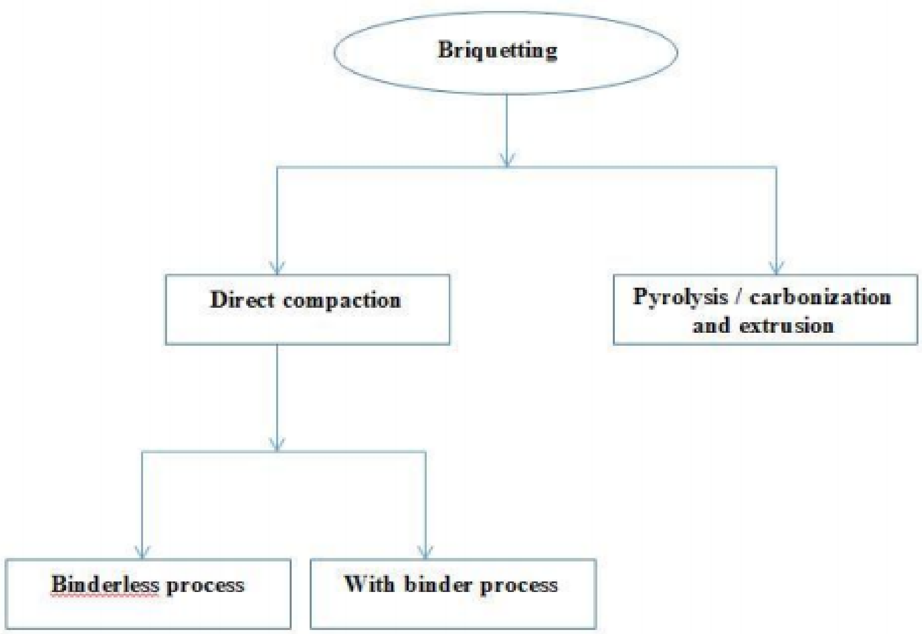
Types of Briquetting:

On the basis of compaction, the briquetting technologies can be divided into: High pressure compaction, medium pressure compaction with a heating device and low pressure compaction with a binder.

At present, there are two high-pressure technologies: Piston press and screw extrusion machines used for briquetting. The briquetting produced by a piston press are completely solid, while screw press briquettes have a concentric hole, which gives better combustion characteristics due to a larger specific area. The screw press briquettes are also homogenous and do not disintegrate easily. Having a high combustion rate, these can substitute for coal in most applications and in boilers. Briquettes can be produced with a density of 1200 Kg/m3 from loose biomass of bulk density 100 to 200 Kg/m3 . A higher density gives the briquette a higher heat value (KJ/Kg), and makes the briquettes burn more slowly as compared to the raw materials from which the briquettes are made.

Process of briquetting:

Briquetting is a technological method of compressing and densifying the bulky raw material, thereby reducing its volume-weight ratio and making it usable for various purposes. The vital requirement of briquette formation from woody biomass is the destruction of the elasticity of the wood, which could be done either by previous heat treatment or by a high pressure or by a combination of both. There are two processes of briquetting biomass, namely direct compaction and compaction after pyrolysis or carbonization as mentioned below:



Process of briquetting

a)Direct compaction:

There are two technologies for the manufacture of briquettes by directly compacting the biomass without previous heat treatment.

(i) Binderless process :The process involves two steps

- Semi-fluidizing the biomass: Biomass is semi-fluidized through the application of high pressure in the range of 1200 – 2000 kg/cm2 , at which conditioned biomass gets heated to a temperature of about 182°C and the lignin present in biomass begins to flow and act as binder, provides mechanical support and repels water.
- Extracting the densified material: The semi-fluidized biomass is densified through electrically operated briquetting machines available in the range of 100-300 kg/h, the cost of such briquetting units depend upon its capacity and is in between Rs. 3 lakh to 20 lakhs.

(ii) With binder process: In this process, the biomass requires addition of some external binding materials like molasses, dung slurry, lignasulphonate, sodium silicate etc. The briquetting machines operate at lower pressure range of 500-1000 kg/cm2 and are powered by electricity. Such machines are available in the capacity range of 100 to 400 kg/h.

b)Pyrolysis / carbonization and extrusion: The elasticity of biomass could be destroyed by previous heat treatment of the biomass. Pyrolysis is the process of destructive distillation of organic materials heated at slow rate at about 270°C in the absence or minimum presence of oxygen. During process of pyrolysis, solid char, liquid tar and combustible gases besides organic liquids are produced. The nature and quantum of these products depend on various factors such as composition of biomass, residence time in kiln and temperature. During the pyrolysis, the fibre content of biomass is broken, which later facilitates in briquetting of produced charcoal. The charcoal is briquetted through extrusion or compaction process.

Briquettes:

Fuel briquettes are essentially a compressed block of organic waste materials used for domestic cooking and heating. The final end product of briquetting process is known as a briquette. Briquettes are made from raw materials that are compacted into a mould. Briquette could be made of different shapes and sizes depending on the mould. The appearance, burning characteristics of briquettes depend on the type of feedstock and the level of compactness and the mould used. But in general, briquettes have better physical properties and combustion rate than the initial waste. Production of briquette charcoal helps to ease the pressure on the forest reserve, there by solving the deforestation problem.

Applications of Briquettes:

Briquettes have many numerous uses which include both domestic and small industrial cottage applications. They are often used as a development intervention to replace firewood, charcoal, or other solid fuels. This is because with the current fuel shortage and ever rising prices, consumers are looking for affordable alternative fuels and briquettes fill this gap for:

- Cooking and water heating in households
- Heating productive processes such as tobacco curing, fruits, tea drying, poultry rearing etc.
- Firing ceramics and clay wares such as improved cook stoves, pottery, bricks etc.
- Fuel for gasifiers to generate electricity
- Powering boilers to generate steam.

Advantages of Briquetting Process:

- The process helps to solve the problem of loose waste / residues of agricultural forestry and agro-industrial processing so as to check environmental pollution.
- The process increases the net calorific value per unit volume.
- The fuel produced is uniform in size and quality. No toxic gas and sulphur emission, even no odour during combustion.
- Densified product is easy to transport and store. Bulk density of briquettes (1000 kg /m3) is higher than agro-wastes (50 kg /m3).
- Fire risk in loose storage of biomass is minimized.

- The process produces high quality fuel with very low ash content (2-5 %) compared to 30-40% in case of coal.

- The briquettes are easy to burn, as briquettes have lower ignition temperature compared to coal.

- It produces gas during burning which accelerates burning efficiencies and inhales Co2 and releases oxygen to the atmosphere

Limitations of Briquetting Process:

- Briquettes can only be used as solid fuels. They have no application as liquid fuel such as the one being used in internal combustion engines.

- The second major problem identified with the briquetting process is the life of the screw, where dies screw is used. Usually the screw wears out within 3-4 hours and becomes unusable.

- Repairing of the screw causes interruption in the work and also one screw cannot be repaired more than 10 times Therefore, the cost of screw and its repair are one of the major barriers to further dissemination of briquetting technology.

- Briquettes cannot withstand direct contact with water, so a covered storage facility is required. The maximum attainable temperature is 1000oC due to their low carbon content. However, this temperature is more than adequate for cooking purpose, but may not be sufficient for industrial applications.

- The burning capacity per unit volume is low compared to coal, so a larger storage area is required.

Types of densification processes:

- Briquetting: Where biomass is compacted between rollers with cavities producing eggshaped briquettes (product 1-4 cm size).

- Pelleting: Where biomass is forced through the holes in a die-plate by pressure rolls (product 0.5- 1 cm size).

- Cutting: A modified form of pelleting (product 2 -5 cm size).

- Extruding: Where biomass is forced through the holes using a screw (2 -10 cm dia).

• Rolling / Compressing: Where biomass is wrapped round a rotating shaft which produces a high density roll or log (Where biomass is forced through the holes in a die-plate by pressure rolls (product 10 -18 cm dia).

Biofuel:

It is a generic description given to all type of fuel produced from biomass, that is, material derived from recently living organisms. This is the scientific name given to any plant or animal substance that is combustible, thus releasing off energy which can be then used for a number of purposes, including for producing motion (such as the movement of a piston in an internal combustion engine) and heating liquids (such as water in a boiler).

Types of biofuels:

Biofuels can range from solid, liquid and gaseous products, and their application is as varied as that of the petroleum products they replace. Biofuels can be used in almost all applications where petroleum products are used. Only in the aviation industry is their used still very limited, almost inexistent, however recent studies and experimental flights might in the future lead to a breakthrough and a wider use similar to that experienced in the road transport sector. The following is a list of the main biofuels available and a brief description of their use.

Solid biofuels:

Examples of solid biofuels are probably the most common to understand as their use has been present for as long as man has discovered fire. The main examples are wood and charcoalwhich are used for everyday use in heating and cooking.

Liquid biofuels:

Liquid biofuels Liquid biofuels, as their name suggests, are fuels derived from biomass and processed to produce a combustible liquid fuel. There are two main categories:

• Alcohol fuels - these include ethanol and methanol

• Vegetable oils - derived from plant seeds, such as sunflower, sesame, linseed

Bioethanol

Ethanol fuels basically an alcohol fuel produced by the use of enzymes and microorganisms through the process of fermentation of starches and sugar. It can be used as a fuel, mainly as a biofuel alternative to petrol, and is widely used in cars in Brazil, where sugar cane is used as the base material. Ethanol with less than 1% water called anhydrous ethanolcan be blended with petrol in varying quantities. Currently, all sparkignited petrol engines can operate with mixtures of up to 5% bioethanol (E5), however certain engine manufacturers do not discourage and actually suggest higher blends of bioethanol to be used.

The substitution of ethanol for gasoline in passenger cars and light vehicles in Brazil is one of the largest biomass-to-energy programmes in existence today. Engines that run strictly on gasoline are no longer available in the country, having been replaced by neat ethanol engines and by gasohol engines that burn a mixture of 78 per cent gasoline and 22 per cent ethanol by volume. Technological advances, including more efficient production and processing of sugarcane, are responsible for the availability and low price of ethanol. The transition to ethanol fuel has reduced Brazil‟s dependence on foreign oil (thus lowering its import export ratio), created significant employment opportunities and greatly enhanced urban air quality. In addition, because sugarcane-derived ethanol is a renewable resource (the cane is replanted at the same rate it is harvested), the combustion of ethanol adds virtually no net carbon dioxide to the atmosphere and so helps reduce the threat of global warming.

Methanol:

It is produced by a process of chemical conversion. It can be produced from any biomass with moisture content of less than 60%; potential feed stocks include forest and agricultural residues, wood and various energy crops. As with ethanol it can either be blended with gasoline to improve the octane rating of the fuel or used in its neat form. Both ethanol and methanol are often preferred fuels for racing cars.

Vegetable oils: A further method of extracting energy from biomass is the production of vegetable oils as a fuel known as biodiesel. The process of oil extraction is carried out the same way as for extraction of edible oil from plants. There are many crops grown in rural areas of the developing world which are suitable for oil production – sunflower, coconut, cotton seed, palm, rapeseed, soy bean, peanut, hemp and more. Sunflower oil, for example, has an energy content about 85% that of diesel fuel.

There are two well-established technologies for oil extraction:

- The simple screw press, which is a device for physically extracting the oil from the plant - this technology is well suited to small-scale production of oil as fuel or as foodstuff in rural areas. The press can be motorised or hand-operated.

- Solvent extraction is a chemical process which requires large, sophisticated equipment. This method is more efficient - that is, it extracts a greater percentage of the oil from the plant - but is less suited to rural applications. The oil, as well as being used for lighting and heating, can be used as a fuel in internal combustion engines. Biodiesel production is not complex and can be done on a small scale. The vegetable oil is converted to a useable fuel by adding ethanol or methanol alcohol along with a catalyst to improve the reaction. Small amounts of potassium hydroxide or sodium hydroxide (commonly called lye or caustic soda, which is used in soap making) are used as the catalyst material. Glycerine separates out as the reaction takes place and sinks to the bottom of the container. This removes the component that gums up the engine so that a standard diesel engine can be used. The glycerine can be used as a degreasing soap or refined to make other products.

Gaseous biofuels:

Biogas is a renewable fuel, which is produced by the breaking down of organic matter by a process of microbiological activity. Basically this means that rotting municipal waste, food waste or sewage (both human and animal) is turned into gas by means of „anaerobic conversion‟ in a digester.Biogas contains methane, which in itself is a fuel and can be recovered from industrial anaerobic digesters, mechanical biological treatment systems and engineered landfills. In engineered landfills, the collected landfill gas can be used to produce electricity and heat.

Biodiesel:

It is an alternative fuel similar to conventional or „fossil‟ diesel. Its primary advantages are that it is one of the most renewable fuels currently available and it is also non-toxic and biodegradable. It can also be used directly in most diesel engines without requiring extensive engine modifications. Biodiesel can be produced from straight vegetable oil, animal oil/fats, tallow and waste cooking oil. The largest possible source of suitable oil comes from oil crops such as rapeseed, palm or soybean. Most biodiesel produced at present is produced from waste vegetable oil sourced from restaurants, chip shops, industrial food producers such as Birdseye etc. Though oil straight from the agricultural industry represents the greatest potential source it is not being produced commercially simply because the raw oil is too expensive. After the cost of converting it to biodiesel has been added on it is simply too expensive to compete with fossil diesel. Waste vegetable oil can often be sourced for free or sourced already treated for a small price. (The waste oil must be treated before conversion to biodiesel to remove impurities). The result is Biodiesel produced from waste vegetable oil can compete with fossil diesel.

Significance of biodiesel:

- It is a processed fuel resulting from the biological sources and it is equivalent to petrodiesel
- Biodiesel acts as a safe alternative fuel for substituting traditional petroleum diesel. It is a clean burning fuel with high lubricity
- It is produced from renewable sources acts like petroleum diesel but produces significantly less air pollution
- It is bio-degradable and very safe for the environment
- Biodiesel production can be achieved in different methods. Biodiesel is a mono alkyl ester of fatty acids produced from both edible and non edible vegetable oils or animal fat and various other bio fuels such as methanol, ethanol etc.

Advantages of biodiesel:

- Biodiesel can be produced from renewable, domestic resources
- It is energy efficient (The total fossil fuel energy efficiency of biodiesel is 320% vs. 83% for petroleum diesel)
- Can be used directly in most diesel engine applications
- Can reduce global warming and tailpipe emissions (-41%)
- It is nontoxic and biodegradable

• It is a good solvent and may clean out fuel line and tank sediments (this may result in fuel filter clogging during initial use.

Limitations of biodiesel:

• Biodiesel contains approximately 8% less energy per gallon

• It has a higher cloud and pour point (will freeze at a higher temp) than conventional diesel

• It is not compatible with some hose and gasket materials, which may cause them to soften, degrade, and rupture.

• Biodiesel is not compatible with some metals and plastics

• It may increase nitrogen oxide emissions

Biogas:

Most organic materials undergo a natural anaerobic digestion in the presence of moisture and absence of oxygen and produce biogas.The biogas so obtained is a mixture of methane (CH_4): 55-65% and Carbon dioxide (CO_2) : 30-40%. The biogas contains traces of H_2, H_2S and N_2. The calorific value of biogas ranges from 5000 to 5500 Kcal/Kg (18.8 to 26.4 MJ /m^3).

Digestion is biological process that occurs in the absence of oxygen and in the presence of anaerobic organisms at temperatures (35-70ºC) and atmospheric pressure. The container in which, this process takes place is known as digester.

Types of biogas plants: Biogas plants basically are two types

Floating dome type:

o The floating-drum plant with a cylindrical digester (KVIC model)

Fixed dome type

o The fixed-dome plant with a brick reinforced, moulded dome (Janata model)

o The fixed-dome plant with a hemisphere digester (Deenbandhu model)

Floating dome type: Floating-drum plants consist of an underground digester and a moving gas-holder. The gasholder floats either directly on the fermentation slurry or in a water jacket of its own. The gas is collected in the gas drum, which rises or moves down, according to the amount of gas stored. The gas drum is prevented from tilting by a guiding frame. If the drum floats in a water jacket, it cannot get stuck, even in substrate with high solid content.

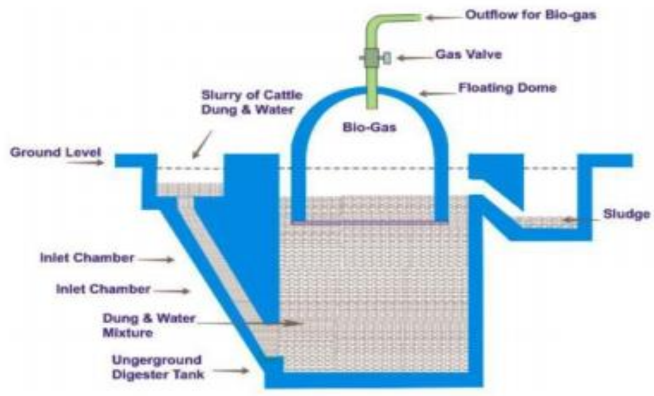


Fig 3.1 Floating dome type plant

Drum:-In the past, floating-drum plants were mainly built in India. A floating-drum plant consists of a cylindrical or dome-shaped digester and a moving, floating gas-holder, or drum. The gas-holder floats either directly in the fermenting slurry or in a separate water jacket. The drum in which the biogas collects has an internal and/or external guide frame that provides stability and keeps the drum upright. If biogas is produced, the drum moves up, if gas is consumed, the gas-holder sinks back.

Size:-Floating-drum plants are used chiefly for digesting animal and human feces on a continuous feed mode of operation, i.e. with daily input. They are used most frequently by smallto middle-sized farms (digester size: 5-15m3) or in institutions and larger agro-industrial estates (digester size: 20-100m3).

KVIC type biogas plant:

This mainly consists of a digester or pit for fermentation and a floating drum for the collection of gas. Digester is 3.5-6.5 m in depth and 1.2 to 1.6 m in diameter. There is a partition wall in the center, which divides the digester vertically and submerges in the slurry when it is full. The digester is connected to the inlet and outlet by two pipes. Through the inlet, the dung is mixed with water (4:5) and loaded into the digester. The fermented material will flow out through outlet pipe. The outlet is generally connected to a compost pit. The gas generation takes place slowly and in two stages. In the first stage, the complex, organic substances contained in the waste are acted upon by a certain kind of bacteria, called acid formers and broken up into small-chain simple acids. In the second stage, these acids are acted upon by another kind of bacteria, called methane formers and produce methane and carbon dioxide.

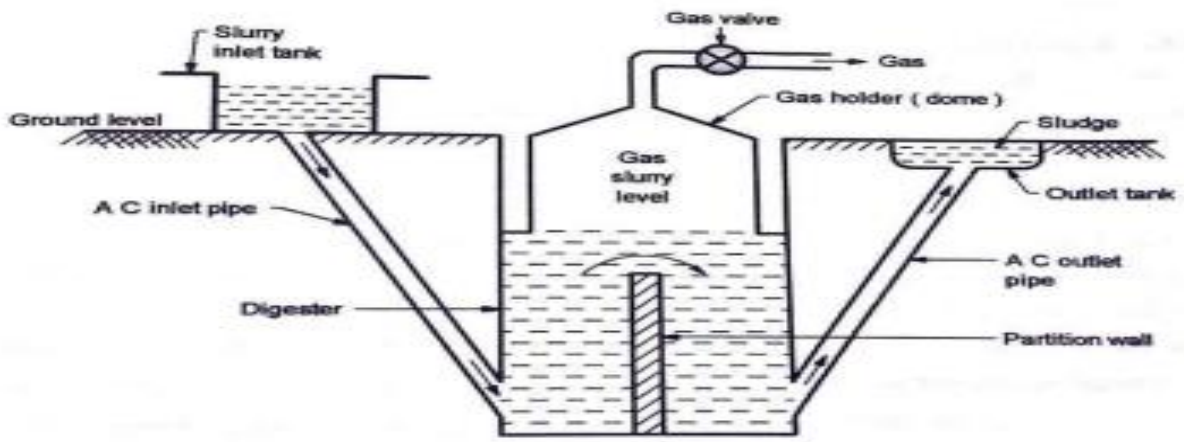


Fig 3.2 KVIC model biogas plant

Gas holder :-The gas holder is a drum constructed of mild steel sheets. This is cylindrical in shape with concave. The top is supported radically with angular iron. The holder fits into the digester like a stopper. It sinks into the slurry due to its own weight and rests upon the ring constructed for this purpose. When gas is generated the holder rises and floats freely on the surface of slurry. A central guide pipe is provided to prevent the holder from tilting. The holder also acts as a seal for the gas. The gas pressure varies between 7 and 9 cm of water column. Under shallow water table conditions, the adopted diameter of digester is more and depth is reduced. The cost of drum is about 40% of total cost of plant. It requires periodical maintenance. The unit cost of KVIC model with a capacity of 2 m3 /day costs approximately Rs.14, 000.

Advantages :

- Simple, easily understood operation
- Volume of stored gas is directly visible
- The gas pressure is constant, determined by the weight of the gas holder

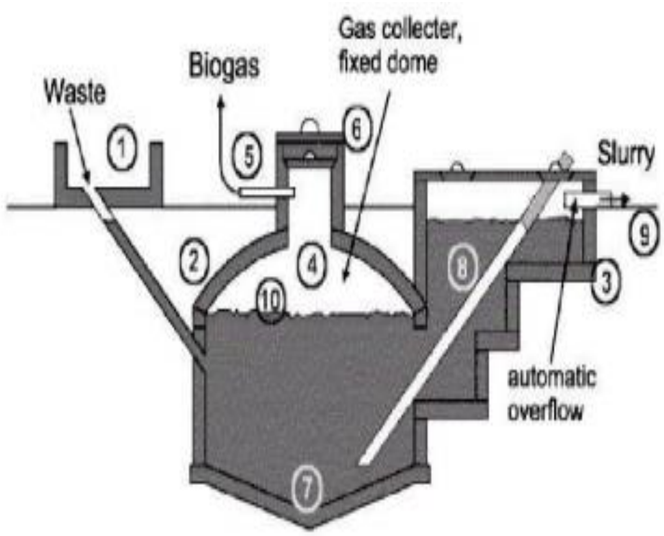
- The construction is relatively easy, construction mistakes do not lead to major problems in operation and gas yield.

Disadvantages:

- High material costs of the steel drum
- Susceptibility of steel parts to corrosion floating drum plants have a shorter life span than fixed-dome plants
- Regular maintenance costs for the painting of the drum

Fixed-dome type plants:

A fixed-dome plant consists of a digester with a fixed, non-movable gas holder, which sits on top of the digester. When gas production starts, the slurry is displaced into the compensation tank. Gas pressure increases with the volume of gas stored and the height difference between the slurry level in the digester and the slurry level in the compensation tank.



1 Mixing tank with inlet pipe and sand trap.

2 Digester

3 Compensation and removal tank

4 Gasholder

5 Gaspipe

6 Entry hatch, with gastight seal

7 Accumulation of thick sludge.

8 Outlet pipe

9 Reference level

10 Supernatant scum, broken up by varying level

a) Function - A fixed-dome plant comprises of a closed, dome-shaped digester with an immovable, rigid gas-holder and a displacement pit, also named 'compensation tank'. The gas is stored in the upper part of the digester. When gas production commences, the slurry is displaced into the compensating tank. Gas pressure increases with the volume of gas stored, i.e. with the height difference between the two slurry levels. If there is little gas in the gas-holder, the gas pressure is low.

b) Digester - The digesters of fixed-dome plants are usually masonry structures, structures of cement and ferro-cementexist. Main parameters for the choice of material are:

o Technical suitability (stability, gas- and liquid tightness)

o Cost-effectiveness

o Availability in the region and transport costs

o Availability of local skills for working with the particular building material.

Fixed dome plants produce just as much gas as floating-drum plants, if they are gas-tight. However, utilization of the gas is less effective as the gas pressure fluctuates substantially. Burners and other simple appliances cannot be set in an optimal way. If the gas is required at constant pressure (e.g., for engines), a gas pressure regulator or a floating gas-holder is necessary.

c) Gas Holder - The top part of a fixed-dome plant (the gas space) must be gas-tight. Concrete, masonry and cement rendering are not gas-tight. The gas space must therefore be painted with a gas-tight layer (e.g. 'Water-proofer', Latex or synthetic paints). A possibility to reduce the risk of cracking of the gas-holder consists in the construction of a weak-ring in the masonry of the digester. This "ring" is a flexible joint between the lower (water-proof) and the upper (gas-proof) part of the hemispherical structure. It prevents cracks that develop due to the hydrostatic pressure in the lower parts to move into the upper parts of the gas-holder.

Advantages:

Low initial costs and long useful lifespan

• No moving or rusting parts involved

• Basic design is compact, saves space and is well insulated

• Construction creates local employment.

• The underground construction saves space and protects the digester from temperature changes

Disadvantages

Masonry gas-holders require special sealants and high technical skills for gas-tight construction

• Gas leaks occur quite frequently; fluctuating gas pressure complicates gas utilization

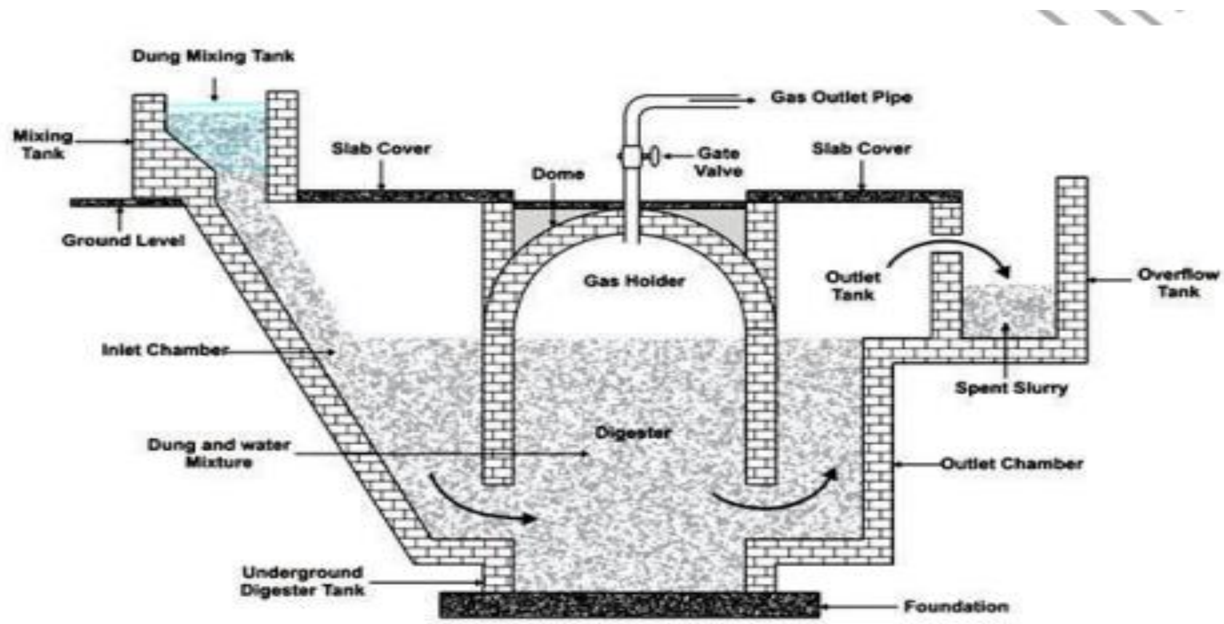
• Amount of gas produced is not immediately visible, plant operation not readily understandable

• Fixed dome plants need exact planning of levels; excavation can be difficult and expensive in bedrock.

Types of Fixed Dome Plants:

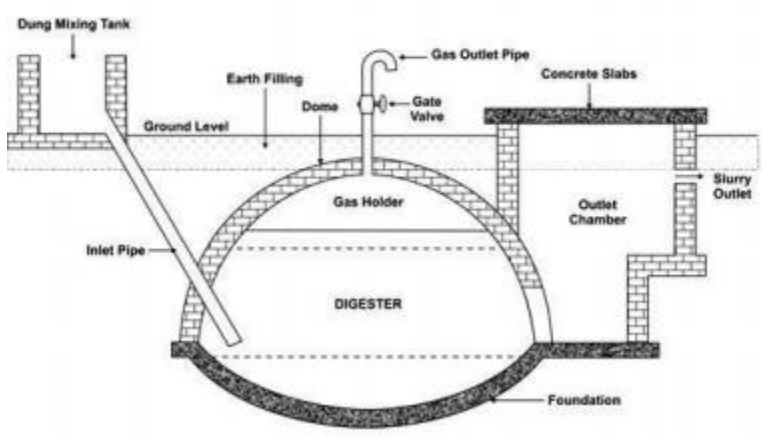
Janata model:

The design of this plant is of Chinese origin but it has been introduced under the name "Janata biogas plant" by Gobar Gas Research Station, Ajitmal in view of its reduced cost. This is a plant where no steel is used, there is no moving part in it and maintenance cost is low. The plant can be constructed by village mason taking some pre-explained precautions and using all the indigenously available building materials. Good quality of bricks and cement should be used to avoid the afterward structural problems like cracking of the dome and leakage of gas.



Janata model

Deenbandhu Model



Deenbandhu model biogas plant was developed by AFPRO (Action for Food Production, New Delhi) in 1984. The world Deenbandhu is meant as the friend of the poor. This plant is designed on the principle that the surface area of biogas plants is reduced (minimized) to reduce their installation cost without sacrificing the efficiency of the plant. The design consists of segments of two spheres of different diameters, joined at their bases. The structure thus formed act as the digester as fermentation chamber as well as the gas storage chamber. The higher compressive strength of the brick masonry and concrete makes it preferable to go in for a structure which could always be kept under compression. A spherical structure loaded from the convex side will be under compression and therefore, the internal load will not have any residual effect on the structure. The digester is connected with the inlet pipe and the outlet tank. The upper part above the normal slurry level of the outlet tank is designed to accommodate the slurry to be displaced out of the digester with the generation and accumulation of biogas and is called outlet displacement chamber. The size of these plants is recommended up to 6 m3 per day.

i. Principle:

Gasification is a process whereby organic matter decomposes through thermal reactions, in the presence of stoichiometric amounts of oxidizing agents. The process generates a combustible gas mix, essentially composed of carbon monoxide, hydrogen, carbon dioxide, methane, steam and, though in smaller proportions, other heavier hydrocarbons and tars. The process is aimed at converting the energy potential of a solid fuel into a gas product, whose energy content has the form of chemical energy with the capacity to generate work. Gasification is carried out in two steps. First, the biomass is heated to around 600 degrees. The volatile components, such as hydrocarbon gases, hydrogen, CO, CO2, H2O and tar, vaporize by various reactions. The remaining by-products are char and ash. For this first endothermic step, oxygen is not required. In the second step, char is gasified by reactions with oxygen, steam and hydrogen in high temperatures. The endothermic reactions require heat, which is applied by combusting some of the unburned char. Main products of gasification are synthesis gas, char and tars. The content depends on the feedstock, oxidizing agent and the conditions of the process. The gas mainly consists of CO, CO4, H2O, CH4 and other hydrocarbons. The synthesis gas can be utilized for heating or electricity production. It can also be used for the production of ethanol, diesel and chemical feed stock.

ii. Chemical Composition:

The composition of biogas varies depending upon the origin of the anaerobic digestion process. Landfill gas typically has methane concentrations around 50%. Advanced waste treatment technologies can produce biogas with 55-75% CH4.

Component	Content [%]
Methane, CH_4	50-75
Carbon dioxide, CO_2	25-50
Nitrogen, N_2	0-10
Hydrogen, H_2	0-1
Hydrogen sulphide, H_2S	0-3
Oxygen, O_2	0-2

Like those of any pure gas, the characteristic properties of biogas are pressure and temperature-dependent.

iii. Applications of Gas:

- Heating and cooling. In the commercial and residential sectors, gas is mainly used for space heating and cooling, water heating, and cooking.
- Power generation -Power plants can use gas to generate electricity.
- Transport Applications
- Oil ,Gas using in Pipeline Industry
- Natural Gas as a Vehicle Fuel

iv. Biogas Plant Construction: The biogas plant is a brick and cement structure. The feed material is mixed with water in the influent collecting tank The fermentation slurry flows through the inlet into the digester. The bacteria from the fermentation slurry are intended to produce biogas in the digester. For this purpose, they need time. Time to multiply and to spread throughout the slurry. The digester must be designed in a way that only fully digested slurry can leave it. The bacteria are distributed in the slurry by stirring (with a stick or stirring facilities). The fully digested slurry leaves the digester through the outlet into the slurry storage. The biogas is collected and stored until the time of consumption in the gasholder. The gas pipe carries the biogas to the place where it is consumed by gas appliances. Condensation collecting in the gas pipe is removed by a water trap. Depending on the available building material and type of plant under construction, different variants of the individual components are possible. The following (optional) components of a biogas plant can also play an important role and are described separately: Heating systems, pumps, weak ring.

Influent collecting tank:

Fresh substrate is usually gathered in an influent collecting tank prior to being fed into the digester. Depending on the type of system, the tank should hold one to two days' substrate. An influent collecting tank can also be used to homogenize the various substrates and to set up the required consistency, e.g. by adding water to dilute the mixture of vegetable solids (straw, grass, etc.), or by adding more solids in order to increase the bio-mass. The fibrous material is raked off the surface, if necessary, and any stones or sand settling at the bottom are cleaned out after the slurry is admitted to the digester. The desired degree of homogenization and solids content can be achieved with the aid of an agitator, pump or chopper. A rock or wooden plug can be used to close off the inlet pipe during the mixing process.

Inlet and Outlet

The inlet (feed) and outlet (discharge) pipes lead straight into the digester at a steep angle. For liquid substrate, the pipe diameter should be 10-15 cm, while fibrous substrate requires a diameter of 20-30 cm. The inlet and the outlet pipe mostly consist of plastic or concrete.

Digesters:

The digesters consist of the digestion tank as such, which is thermally insulated, plus a heating system, mixer systems and discharge systems for sediments and the spent substrate. Choosing a right biogas digester is a very important while constructing a biogas plant. From the standpoint of fluid dynamics and structural strength, an egg-shaped vessel is about the best possible solution. This type of construction, however, is comparatively expensive, therefore, its use is usually restricted to large-scale sewage treatment plants. The Chinese fixed-dome designs are of similar shape, but less expensive. The hemispherical CAMARTEC design is optimized in structural strength, but does not make optimal use of the excavation required.

Simplified versions of such digester designs include cylinders with conical covers and bottoms. They are much easier to build and are sometimes available on the market as prefabricated units. Their disadvantage lies in their less favorable surface-volume ratio. The cylinder should have a height equal to its diameter. Prone cylinders have become quite popular on farms, since they are frequently the more favorable solution for small-scale biomethanation. Cuboid digesters are often employed in batch-fed systems used primarily for fermenting solid material, so that fluid dynamics are of little interest.

Bio gas piping:

At least 60% of all non-functional biogas units are attributable to defect gas piping. Utmost care has to be taken, therefore, for proper installation. For the sake of standardization, it is advisable to select a single size for all pipes, valves and accessories. The requirements for biogas piping, valves and accessories are essentially the same as for other gas installations. However, biogas is 100% saturated with water vapor and contains hydrogen-sulfide. Consequently, no piping, valves or accessories that contain any amounts of ferrous metals may be used for biogas piping, because they would be destroyed by corrosion within a short time. The gas lines may consist of standard galvanized steel pipes. Also, suitable (and inexpensive) is plastic tubing made of rigid PVC or rigid PE. Flexible gas pipes laid in the open must be UV-resistant.

Water traps:

Due to temperature changes, the moisture-saturated biogas will form inevitably condensation water in the piping system. Ideally, the piping system should be laid out in a way that allows a free flow of condensation water back into the digester. If depressions in the piping system cannot be avoided, one or several water traps have to be installed at the lowest point of the depressions. Inclination should not be less than 1%. One has to decide then, if an 'automatic' trap or a manually operated trap is more suitable. Automatic traps have the advantage that emptying - which is easily forgotten - is not necessary. But if they dry up or blow empty, they may cause heavy and extended gas losses. In addition, they are not easily understood. Manual traps are simple and easy to understand, but if they are not emptied regularly, the accumulated condensation water will eventually block the piping system. Both kinds of traps have to be installed in a solid chamber, covered by a lid to prevent an eventual filling up by soil

Valves:

To the extent possible, ball valves or cock valves suitable for gas installations should be used as shutoff and isolating elements. The most reliable valves are chrome-plated ball valves. Gate valves of the type normally used for water pipes are not suitable. Any water valves exceptionally used must first be checked for gas-tightness. They have to be greased regularly. A U-tube pressure gauge is quick and easy to make and can normally be expected to meet the requirements of a biogas plant.

The main gas valve has to be installed close to the biogas digester. Sealed T-joints should be connected before and after the main valve. With these T-joints it is possible to test the digester and the piping system separately for their gas-tightness. Ball valves as shutoff devices should be installed at all gas appliances. With shutoff valves, cleaning and maintenance work can be carried out without closing the main gas valve.

Gas Analysis Equipment

Sensors:

Sensors in the gas space must satisfy explosion protection requirements and should be resistant to corrosion and high levels of moisture.

- Infrared sensors
- Thermal conductivity sensors

The sensors used to measure the temperature should be installed at various heights so that stratification and inadequate mixing can be detected. Care should also be taken that the sensors are not installed in dead zones or too close to the temperature stabilization equipment. Resistance sensors (e.g. PT 1000 or PT 100) or thermocouples are suitable for measuring the temperature.

- Electrochemical sensors
- Paramagnetic sensors
- Inductive and capacitive sensors

Power generation from solid waste:

1. Municipal Solid Waste: Municipal solid waste (MSW) is generated from households, offices, hotels, shops, schools and other institutions. The major components are food waste, paper, plastic, rags, metal and glass, although demolition and construction debris are often included in collected waste, as are small quantities of hazardous waste, such as electric light bulbs, batteries, automotive parts and discarded medicines and chemicals.

Generation rates for MSW vary from city to city and from season to season and have a strong correlation with levels of economic development and activity. High-income countries (such as Australia, Japan, Hong Kong, China, Republic of Korea, and Singapore) produce between 1.1 and 5.0 kg/capita/ day; middle-income countries (such as Indonesia, Malaysia and Thailand) generate between 0.52 and 1.0 kg/capita/day, whilst low-income countries (such as Bangladesh, India, Viet Nam and Myanmar) have generation rates of between 0.45 and 0.89 kg/capita/ day.

The composition of municipal solid waste varies significantly across the region with some middle- and low-income countries generating waste containing over 70 per cent organic content, with a corresponding moisture content in excess of 50 per cent. Differences in the characterization and reporting of waste types also differ with some municipal authorities including construction and demolition waste and industrial waste as part of the municipal waste stream. Some inter-urban differences relate to climate and fuel use. The cities where heating is needed in winter such as Beijing, Shanghai, Seoul and Tokyo and where coal is the main source of energy, have much greater amount of ash in the waste in those cold months. The basic infrastructure brings other variations in cities and towns (such as Calcutta, Dhaka, and Hanoi) with unpaved or poorly paved streets that have large amounts of dust and dirt from street sweeping. There are big differences in amounts of organic waste among cities according to the number of trees and shrubs in public places. Large and bulky waste items such as abandoned motorcars, furniture and packaging are found in the higher income economies such as Brunei Darussalam, Japan, Republic of Korea and Singapore, but not in low-income countries such as Bangladesh, Cambodia, Myanmar, Nepal, Sri Lanka and Viet Nam.

2. Industrial Solid Waste: Industrial solid waste in the Asian and Pacific Region, as elsewhere, encompasses a wide range of materials of varying environmental toxicity. Typically this range would include paper, packaging materials, waste from food processing, oils, solvents, resins, paints and sludges, glass, ceramics, stones, metals, plastics, rubber, leather, wood, cloth, straw, abrasives, etc. As with municipal solid waste, the absence of a regularly up-dated and systematic database on industrial solid waste ensures that the exact rates of generation are largely unknown. Industrial solid waste generation varies, not only between countries at different stages of development but also between developing countries (see Figure 8.4). In People's Republic of China, for example, the generation ratio of municipal to industrial solid waste is one to three. In Bangladesh, Sri Lanka and Pakistan, however, this ratio is much less. In high-income, developed countries, such as Australia and Japan, the ratio is one to eight. However, based on an average ratio for the region, the industrial solid waste generation in the region is equivalent to 1900 million tons per annum. This amount is expected to increase substantially and at the current growth rates, it is estimated that it will double in less than 20 years. As the existing industrial solid waste collection, processing and disposal systems of many countries are grossly inadequate, such incremental growth will pose very serious challenges.

3. Agricultural Waste and Residues: Expanding agricultural production has naturally resulted in increased quantities of livestock waste, agricultural crop residues and agro-industrial by-products. Table 8.3 provides an estimate of annual production of agricultural waste and residues in some selected countries in the region (ESCAP 1997); the implications of liquid and slurry waste for receiving inland and coastal waters is examined in Chapter 4. Among the countries in the Asian and Pacific Region, People's Republic of China produces the largest quantities of agriculture waste and crop residues followed by India. In People's Republic of China, some 587 million tonnes of residues are generated annually from the production of rice, corn and wheat alone. Figure illustrates the proportions of waste that Malaysia generates from the production of rice, palm oil, rubber, coconut and forest products (ESCAP 1997). In Myanmar, crop waste and residues amount to some 4 million tonnes per year (of which more than half constitutes rice husk), whilst annual animal waste production is about 28 million tonnes with more than 80 per cent of this coming from cattle husbandry.

Biomass Cogeneration Systems:

1. **Cogeneration:** The cogeneration is a combined production of heat and electricity, suitable for fossil fuel or biofuel (biomass) combustion systems. Cogeneration is the best solution for energy saving and environmental preservation. Cogeneration is a well-advanced technology that has existed for more than a century. At the end of the 19th century several manufacturing plants adopted this technology. Cogeneration requires a heat exchanger to absorb and recover exhaust heat . Biomass cogeneration is considered an effective alternative to reduce greenhouse gas emissions due to their low CO2 emission. Many researches have been conducted in recent years to improve the economic and environmental efficiency and effectiveness of biomass cogeneration systems. Biomass cogeneration systems are becoming increasingly popular. Several cogeneration technology and systems have been developed in recent years, some of which are suitable for large power plants and other for medium power and micro-cogeneration.
2. **Steam Cycle:** The operating principle is in line with the classic Clausius-Rankin process . High temperature, high pressure steam generated in the boiler and then enters the steam turbine. In the steam turbine, the thermal energy of the steam is converted into mechanical work. The low-pressure steam leaving the turbine enters the condenser housing and condenses on the condenser tubes. The condensate is transported by the water supply system to the boiler, where it is reused in a new cycle .

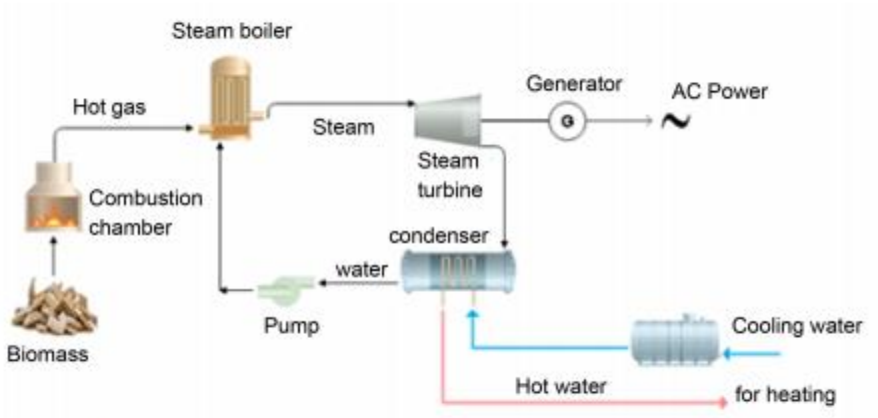


Figure Principle of operation of a steam turbine biomass cogeneration plant.

The process of producing electricity and heat from steam includes the following components: a biomass combustion system (combustion chamber), a steam system (boiler plus distribution systems), a steam turbine, an electricity generator and the heat distribution system for heating from the condenser. At present, electricity and heat generation in biomass power plants with a steam cycle remains the most developed technology, adapted to high temperatures and high power; however, this technology is not suitable for cogeneration systems with a power of less than 100 kW compared to its low electrical efficiency and high investment costs.

Biomass cogeneration plants generally use grid combustion systems with a thermal combustion capacity of 20 to 30 MW. In the case where chemically untreated wood biomass is used, the steam temperature reaches 540˚C. The achievable annual electrical efficiency depends on the steam parameters (temperature and pressure) and the temperature level required for the heating process. Annual electricity efficiencies generally range from 18% to 30% for biomass cogeneration plants between 2 and 25 MW.

Advantages of the use of steam cycle:

• The use of water as a heat transfer fluid has great advantages, such as its high availability, non-toxic, non-flammable, chemical stability, low viscosity (less friction losses);

• Thermal efficiency greater than 30%;

• Low pump consumption.

3. **Organic Rankin Cycle (ORC)**:

Since the 1980s, the ORC market has grown exponentially. ORC applications have generated a lot of economic and environmental interest, because of which much work has been done on ORC systems and working fluids that can be found in the literature.

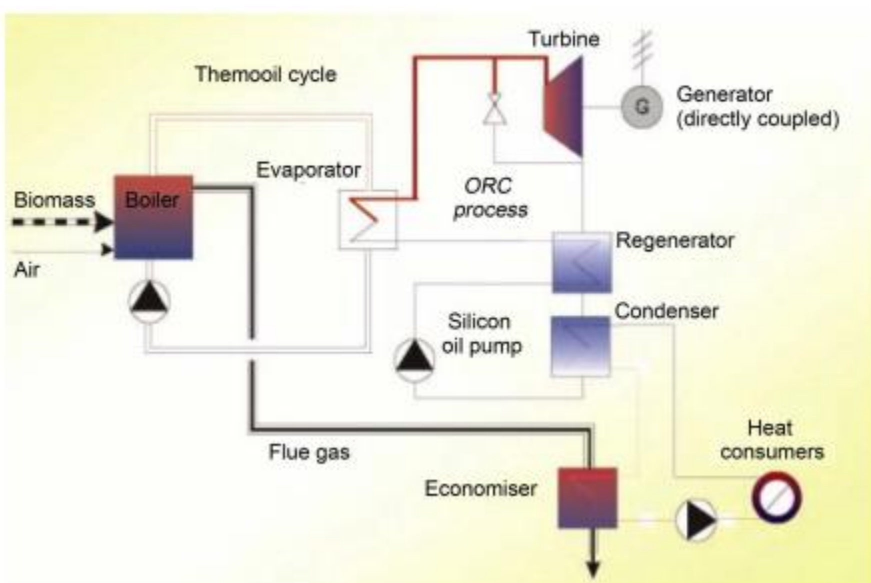


Figure Schematic of Rankine's organic cycle

ORC technology has reached a very high degree of maturity for biomass applications; it only requires a sufficient source of heat. The ORC system can be integrated into any industrial facility equipped with a low temperature heating system to recover waste energy in the form of heat and convert it into electricity. Electricity produced by biomass ORC systems is considered carbon neutral, thus improving a company's environmental profile and promoting the transformation of the forest sector towards the use of more environmentally friendly energy sources.

Instead of water, the Rankine organic cycle uses an organic fluid with favorable thermodynamic properties as a heat transfer fluid. The evaporation temperature of organic fluids is lower than the evaporation temperature of water, which results in higher efficiency in cogeneration installations with an ORC cycle. The ORC has two circuits, one for thermal oil and the other for organic fluid. The heat released by the combustion of biomass is transmitted through an oil cycle by an exchanger to the organic fluid, which evaporates at high temperature and high pressure. The ORC system consists of four main components, namely a pump, an evaporator, a turbine and a condenser. The superheated organic steam is expanded in a turbine and then condensed in a condenser and returned to the circulation pump to start a new cycle. The condenser can act as a heat exchanger for sending heat remotely at low temperatures. The condensed organic liquid is pumped through the regenerator to the evaporator. ORC technology is suitable for medium power . Heat is generally supplied at a temperature of about 300˚C and condensation occurs at about 90˚C. There are more than 50 biomass cogeneration plants that have adopted CRO technology with a capacity greater than 5 MWe and have approved the technical and economic feasibility of this technology on a medium scale (200 - 2000 kW). The thermal efficiency of ORCs at high temperatures does not exceed 24% . The organic fluids used in these systems are dry and do not require overheating, they are not corrosive or erosive; they evaporate at low and medium temperatures. When temperatures exceed 500˚C, the organic liquid degrades and turns into small particles.

Advantages of ORC installations are:

• Long service life due to the characteristics of the working fluid;

• Less complex installation with a high efficiency cycle;

• More economical than a water steam turbine in terms of investment and maintenance costs;

• The isentropic efficiency of a turbine varies with its power scale and design;

• No water treatment system is required;

• The system pressure is low, which makes the installation safer;

• No need for fluid control;

• Efficient solution for low temperature installations.

Geothermal Energy

Geothermal energy is the thermal energy generated and stored in the Earth. Thermal energy is the energy that determines the temperature of matter. The geo thermal energy of the Earth's crust originates from the original formation of the planet and from radioactive decay of materials.

- **Geothermal energy—geo (earth) + thermal (heat)—is heat energy from the earth.**
- Geothermal resources are reservoirs of hot water that exist at varying temperatures and depths below the Earth's surface.
- Mile-or-more-deep wells can be drilled into underground reservoirs to tap steam and very hot water that can be brought to the surface for use in a variety of applications, including electricity generation, direct use, and heating and cooling.
- In the United States, most geothermal reservoirs are located in the western states.

Use of geothermal energy

People can capture geothermal energy through:

- **Geothermal power plants,** which use heat from deep inside the Earth to generate steam to make electricity.
- **Geothermal heat pumps,** which tap into heat close to the Earth's surface to heat water or provide heat for buildings.

Some applications of geothermal energy use the earth's temperatures near the surface, while others require drilling miles into the earth. There are three main types of geothermal energy systems:

- Direct use and district heating systems
- Geothermal power plants
- Geothermal heat pumps

Direct use and district heating systems

- Direct use and district heating systems use hot water from springs or reservoirs located near the surface of the earth.
- Ancient Roman, Chinese, and Native American cultures used hot mineral springs for bathing, cooking, and heating.
- Today, many hot springs are still used for bathing, and many people believe the hot, mineral-rich waters have health benefits.
- Geothermal energy is also used to directly heat individual buildings and to heat multiple buildings with district heating systems.
- Hot water near the earth's surface is piped into buildings for heat.
- A district heating system provides heat for most of the buildings in Reykjavik, Iceland.

Industrial applications of geothermal energy include food dehydration (drying), gold mining, and milk pasteurizing.

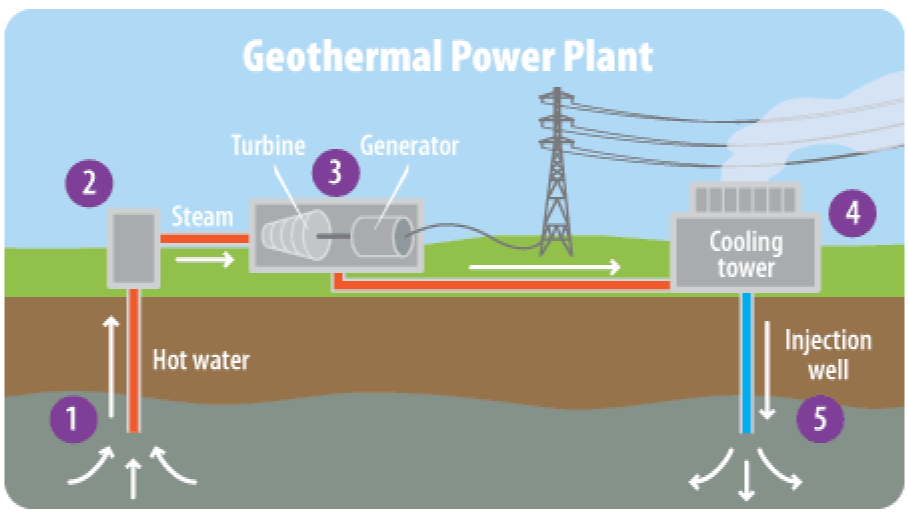
Geothermal electricity generation

- Geothermal electricity generation requires water or steam at high temperatures (300° to 700°F).
- Geothermal power plants are generally built where geothermal reservoirs are located, within a mile or two of the earth's surface.
- The United States leads the world in the amount of geothermal electricity generation.
- In 2019, there were geothermal power plants in seven states, which produced about 16 billion kilowatthours (kWh), equal to 0.4% of total U.S. utility-scale electricity generation.

- Indonesia was the second-largest geothermal electricity producer after the United States, at 12.8 billion kWh of electricity, which was equal to about 5% of Indonesia's total electricity generation.
- Kenya was the ninth-largest geothermal electricity producer at about 4.8 billion kWh, but it had the largest share of its total electricity generation from geothermal energy at about 47%.

Geothermal Power Plants

At a geothermal power plant, wells are drilled 1 or 2 miles deep into the Earth to pump steam or hot water to the surface. You're most likely to find one of these power plants in an area that has a lot of hot springs, geysers, or volcanic activity, because these are places where the Earth is particularly hot just below the surface.



How does it works:

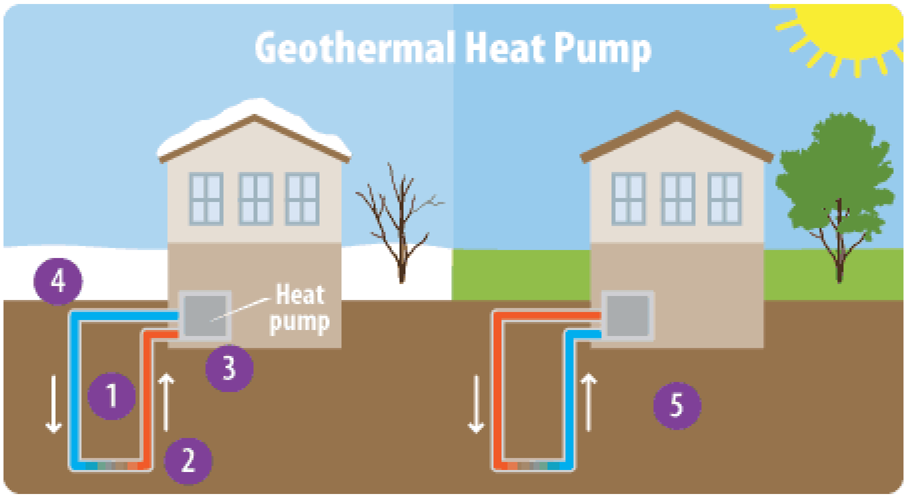
- Hot water is pumped from deep underground through a well under high pressure.
- When the water reaches the surface, the pressure is dropped, which causes the water to turn into steam.
- The steam spins a turbine, which is connected to a generator that produces electricity.
- The steam cools off in a cooling tower and condenses back to water.

- The cooled water is pumped back into the Earth to begin the process again.

Geothermal Heat Pumps

Not all geothermal energy comes from power plants. Geothermal heat pumps can do all sorts of things—from heating and cooling homes to warming swimming pools. These systems transfer heat by pumping water or a refrigerant (a special type of fluid) through pipes just below the Earth's surface, where the temperature is a constant 50 to 60°F. During the winter, the water or refrigerant absorbs warmth from the Earth, and the pump brings this heat to the building above. In the summer, some heat pumps can run in reverse and help cool buildings.

- Geothermal heat pumps transfer heat from the ground (or water) into buildings during the winter and reverse the process in the summer.
- Geothermal heat pumps (GHPs) take advantage of the relatively stable moderate temperature conditions that occur within the first 300 metres (1,000 feet) of the surface to heat buildings in the winter and cool them in the summer.
- In that part of the lithosphere, rocks and groundwater occur at temperatures between 5 and 30 °C (41 and 86 °F).
- At shallower depths, where most GHPs are found, such as within 6 metres (about 20 feet) of Earth’s surface, the temperature of the ground maintains a near-constant temperature of 10 to 16 °C (50 to 60 °F).
- Consequently, that heat can be used to help warm buildings during the colder months of the year when the air temperature falls below that of the ground.
- Similarly, during the warmer months of the year, warm air can be drawn from a building and circulated underground, where it loses much of its heat and is returned.



How does it work:

- Water or a refrigerant move through a loop of pipes.
- When the weather is cold, the water or refrigerant heats up as it travels through the part of the loop that's buried underground.
- Once it gets back above ground, the warmed water or refrigerant transfers heat into the building.
- The water or refrigerant cools down after its heat is transferred. It is pumped back underground where it heats up once more, starting the process again.
- On a hot day, the system can run in reverse. The water or refrigerant cools the building and then is pumped underground where extra heat is transferred to the ground around the pipes.
- A GHP system is made up of a heat exchanger (a loop of pipes buried in the ground) and a pump.
- The heat exchanger transfers heat energy between the ground and air at the surface by means of a fluid that circulates through the pipes; the fluid used is often water or a combination of water and antifreeze.

- During warmer months, heat from warm air is transferred to the heat exchanger and into the fluid.
- As it moves through the pipes, the heat is dispersed to the rocks, soil, and groundwater.
- The pump is reversed during the colder months. Heat energy stored in the relatively warm ground raises the temperature of the fluid.
- The fluid then transfers this energy to the heat pump, which warms the air inside the building.

Advantages:

- GHPs have several advantages over more conventional heating and air-conditioning systems.
- They are very efficient, using 25–50 percent less electricity than comparable conventional heating and cooling systems, and they produce less pollution.
- The reduction in energy use associated with GHPs can translate into as much as a 44 percent decrease in greenhouse gas emissions compared with air-source heat pumps (which transfer heat between indoor and outdoor air).
- In addition, when compared with electric resistance heating systems (which convert electricity to heat) coupled with standard air-conditioning systems, GHPs can produce up to 72 percent less greenhouse gas emissions.

BENEFITS OF GEOTHERMAL ENERGY

- **Renewable**—Through proper reservoir management, the rate of energy extraction can be balanced with a reservoir's natural heat recharge rate.
- **Baseload**—Geothermal power plants produce electricity consistently, running 24 hours per day / 7 days per week, regardless of weather conditions.
- **Domestic**—Geothermal resources can be harnessed for power production without importing fuel.
- **Small Footprint**—Geothermal power plants are compact; using less land per GWh (404 m^2) than coal (3642 m^2) wind (1335 m^2) or solar PV with center station (3237 m^2).*

- **Clean**—Modern closed-loop geothermal power plants emit no greenhouse gasses; life cycle GHG emissions (50 g CO_2 eq/kWhe) are four times less than solar PV, and six to 20 times lower than natural gas. Geothermal power plants consume less water on average over the lifetime energy output than the most conventional generation technologies.

Hydroelectric power:

- Hydroelectric energy, also called hydroelectric power or hydroelectricity, is a form of energy that harnesses the power of water in motion—such as water flowing over a waterfall—to generate electricity.
- People have used this force for millennia.
- Over two thousand years ago, people in Greece used flowing water to turn the wheel of their mill to ground wheat into flour.

HYDROTHERMAL RESOURCES

- A geothermal resource requires fluid, heat, and permeability to generate electricity.
- Conventional hydrothermal resources contain all three components naturally.
- These geothermal systems can occur in widely diverse geologic settings, sometimes without clear surface manifestations of the underlying resource.
- The lack of ability to accurately predict temperature and permeability at depth from the surface is a major cause of exploration risk.
- Additionally, subsurface characterization and imaging are critical for the efficient utilization of all types of geothermal resources, including low temperature and coproduced, permeable sedimentary and enhanced geothermal systems.
- The Geothermal Technologies Office is also focused on reducing the operations and maintenance (O&M) costs of hydrothermal systems.

  How Does Hydroelectric Energy Work?

- Most hydroelectric power plants have a reservoir of water, a gate or valve to control how much water flows out of the reservoir, and an outlet or place where the water ends up after flowing downward.

- Water gains potential energy just before it spills over the top of a dam or flows down a hill.
- The potential energy is converted into kinetic energy as water flows downhill.
- The water can be used to turn the blades of a turbine to generate electricity, which is distributed to the power plant's customers.

classification of hydropower schemes:

A mass of water moving down a height difference contains energy which can be harvested using some waterwheel or turbine. The moving water drives the waterwheel and this rotation either drives machinery directly (e.g. mill, pump, hammer, thresher) or is coupled with a generator which produces electric power. Hydro power is probably the first form of automated power production which is not human / animal driven. Moving a grind stone for milling first, developed into the driving of an electrical generator. Next to steam it was for long the main power source for electricity. Its continual availability does not require any power storage (unlike wind / solar power). It is mainly mechanical hardware. This makes it relative easy to understand and repair-/maintainable. In smaller units its environmental impact becomes neglect-able.

Classification of hydropower:

By size

Hydropower installations can be classified by size of power output, although the power output is only an approximate diversion between different classes. There is no international consensus for setting the size threshold between small and large hydropower.

For the United Nations Industrial Development Organization (UNIDO) and the European Small Hydropower Association (ESHA) and the International Association for Small Hydro (IASH) a capacity of up to 10 MW total is becoming the generally accepted norm for small hydropower plants (SHP). In China, it can refer to capacities of up to 25 MW, in India up to 15 MW and in Sweden small means up to 1.5 MW, in Canada 'small' can refer to upper limit capacities of between 20 and 25 MW, and in the United States 'small' can mean 30 MW.

The German Federal Ministry for Environment, Nature Conservation and Nuclear Safety mentioned that a SHP is <1 MW, everything above is a large hydro electric plant and usually comes along with a large dam. The International Commission on Large Dams (ICOLD) defines a large dam as a dam with a height of 15 m or more from the foundation. If dams are between 5-15 m high and have a reservoir volume of more than 3 million m3, they are also classified as large dams. Using this definition, there are over 45 000 large dams around the world.

Small hydro can be further subdivided into mini, micro and pico:

▪ Mini (MH)	< 1 MW	grid connected	special know how required
▪ Micro	< 100 kW	partially grid con.	professional know how required
▪ Pico (PH)	< 10 kW	island grids	small series units produced locally; professional equipment available
▪ Family (FH)	< ~1 kW	single households/clusters	often locally handmade solutions; professional equipment available

There is no binding definition how mini hydro power output is to be classified. Rules for communication avoiding misunderstandings: Generally the terms can be used "downwards compatible". Pico- is also Mini- but not visa versa. Specific terms (Pico, Family) should be used only if they are required to indicate specifics. The spectrum needs higher diversification as smaller it becomes as there are certain differences in technique, usage, applicability and the grade of of ability to replicate them.

Large hydropower developments involve large dams and huge water storage reservoirs. They are typically grid connected supplying large grids. Preference for large hydro is on the decline due to the high investment costs, long payback periods and huge environmental impacts (losses of arable land, forced migration, diseases and damage to biodiversity). Many social and environmental impacts are related to the impoundment and existence of a reservoir, and therefore are greater for 'large hydro' plants with reservoir.

Small hydropower stations are typically run-of-the-river. They combine the advantages of hydropower with those of decentralized power generation, without the disadvantages of large scale installations. Advantages include: low distribution costs, no/low environmental costs as with large hydro, low maintenance and local implementation and management. Power generated with small hydro station can be used for agro-processing, local lighting, water pumps and small business.

The constructions and integration into local environments of Small Hydro Power (SHP) schemes typically takes less time and effort compared to large hydropower plants. For this reason, the deployment of SHPs is increasing in many parts of the world, especially in remote areas where other energy sources are not viable or are not economically attractive.

However, larger facilities will tend to have lower costs on a USD/kW basis due to economies of scale, even if that tendency will only hold on average. Moreover, one large-scale hydropower project of 2,000 MW located in a remote area of one river basin might have fewer negative impacts than the cumulative impacts of four hundred 5 MW hydropower projects in many river basins.

By Facility

Hydropower plants can be classified in three categories according to operation and type of flow:[3]

1. Run-of-river (RoR), Small and micro hydropower utilizes water that runs of a river and avoids big environmental impacts.
2. Storage (reservoir)
3. Pumped storage hydro power plants (HPPs) work as energy buffer and do not produce net energy.
4. In-stream Hydropower Schemes use a rivers natural elevation drop without to dam a river.

Run-of-River Hydropower Plant (RoR)

- RoR plant produce energy from the available flow and the natural elevation drop of a river
- It is suitable for rivers that have at least a minimum flow all year round.
- The water to powers the turbine is diverted and channeled into a penstock and then returned to the river
- RoR plants usually have no or only small storage, allowing for some adaptations to the demand profile.
- As bigger the storage capacity is as higher the environmental impacts are
- Power generation is dictated by local river flow conditions and thus depends on precipitation and runoff and may have substantial daily, monthly or seasonal variations

Hydropower Plant with Reservoir

- Hydropower projects with a reservoir (storage hydropower) store water behind a dam for times when river flow is low
- Therefore power generation is more stable and less variable than for RoR plants

- The generating stations are located at the dam toe or further downstream, connected to the reservoir through tunnels or pipelines
- Type and design of reservoirs are decided by the landscape and in many parts of the world are inundated river valleys where the reservoir is an artificial lake
- Reservoir hydropower plants can have major environmental and social impacts due to the flooding of land for the reservoir

Pump Storage Hydropower Plant

- Pumped storage plants are not energy sources, instead they are storage devices
- Water is pumped from a lower reservoir into an upper reservoir, usually during off-peak hours, while flow is reversed to generate electricity during the daily peak load period or at other times of need
- Although the losses of the pumping process make such a plant a net energy consumer, the plant provides large-scale energy storage system benefits
- Pumped storage is the largest capacity form of grid energy storage now readily available worldwide

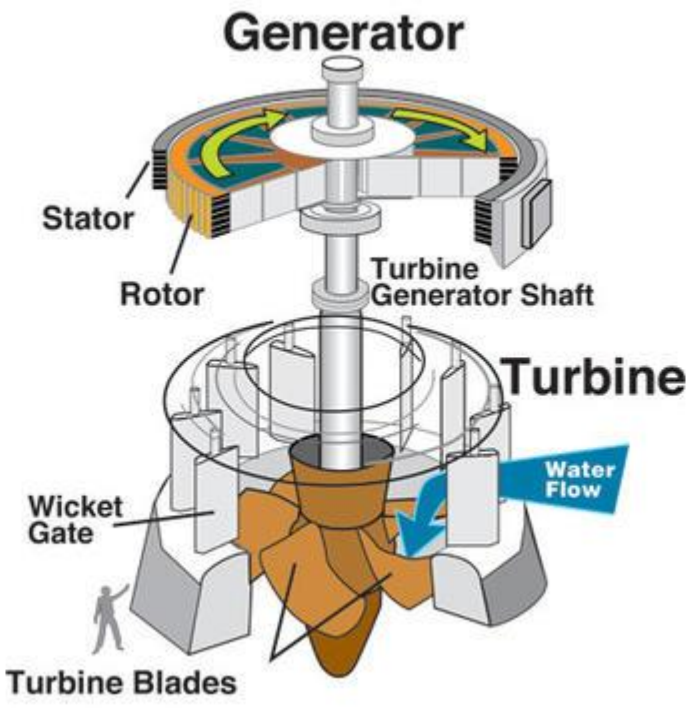
In-stream Hydropower Scheme

- Basically in-stream Hydropower functions like a RoR scheme, but the turbine is mostly built within the dam in the riverbed. Usually the river flow is not diverted.
- To optimize existing weirs, barrages, canals or falls, small turbines or hydrokinetic turbines can be installed
- At rivers close to the sea the technologies may operate bi-directional (tidal)

Turbine:

A turbine and generator produce the electricity

As to how this generator works, the Corps of Engineers explains it this way: ***"A hydraulic turbine converts the energy of flowing water into mechanical energy. A hydroelectric generator converts this mechanical energy into electricity. The operation of a generator is based on the principles discovered by Faraday. He found that when a magnet is moved past a conductor, it causes electricity to flow. In a large generator, electromagnets are made by circulating direct current through loops of wire wound around stacks of magnetic steel laminations. These are called field poles, and are mounted on the perimeter of the rotor. The rotor is attached to the turbine shaft, and rotates at a fixed speed. When the rotor turns, it causes the field poles (the electromagnets) to move past the conductors mounted in the stator. This, in turn, causes electricity to flow and a voltage to develop at the generator output terminals."***



Different types of water turbines:

There are two main types of hydro turbines: impulse and reaction. The type of hydropower turbine selected for a project is based on the height of standing water—referred to as "head"—and the flow, or volume of water, at the site. Other deciding factors include how deep the turbine must be set, efficiency, and cost.

IMPULSE TURBINE

The impulse turbine generally uses the velocity of the water to move the runner and discharges to atmospheric pressure. The water stream hits each bucket on the runner. There is no suction on the down side of the turbine, and the water flows out the bottom of the turbine housing after hitting the runner. An impulse turbine is generally suitable for high head, low flow applications.

Pelton

A pelton wheel has one or more free jets discharging water into an aerated space and impinging on the buckets of a runner. Draft tubes are not required for impulse turbine since the runner must be located above the maximum tailwater to permit operation at atmospheric pressure.

A Turgo Wheel is a variation on the Pelton and is made exclusively by Gilkes in England. The Turgo runner is a cast wheel whose shape generally resembles a fan blade that is closed on the outer edges. The water stream is applied on one side, goes across the blades and exits on the other side.

Cross-Flow

A cross-flow turbine is drum-shaped and uses an elongated, rectangular-section nozzle directed against curved vanes on a cylindrically shaped runner. It resembles a "squirrel cage" blower. The cross-flow turbine allows the water to flow through the blades twice. The first pass is when the water flows from the outside of the blades to the inside; the second pass is from the inside back out. A guide vane at the entrance to the turbine directs the flow to a limited portion of the runner. The cross-flow was developed to accommodate larger water flows and lower heads than the Pelton.

REACTION TURBINE

A reaction turbine develops power from the combined action of pressure and moving water. The runner is placed directly in the water stream flowing over the blades rather than striking each individually. Reaction turbines are generally used for sites with lower head and higher flows than compared with the impulse turbines.

Propeller

A propeller turbine generally has a runner with three to six blades in which the water contacts all of the blades constantly. Picture a boat propeller running in a pipe. Through the pipe, the pressure is constant; if it isn't, the runner would be out of balance. The pitch of the blades may be fixed or adjustable. The major components besides the runner are a scroll case, wicket gates, and a draft tube. There are several different types of propeller turbines:

BULB TURBINE

The turbine and generator is a sealed unit placed directly in the water stream.

STRAFLO

The generator is attached directly to the perimeter of the turbine.

TUBE TURBINE

The penstock bends just before or after the runner, allowing a straight line connection to the generator.

KAPLAN

Both the blades and the wicket gates are adjustable, allowing for a wider range of operation.

Francis

A Francis turbine has a runner with fixed buckets (vanes), usually nine or more. Water is introduced just above the runner and all around it and then falls through, causing it to spin. Besides the runner, the other major components are the scroll case, wicket gates, and draft tube.

Kinetic

Kinetic energy turbines, also called free-flow turbines, generate electricity from the kinetic energy present in flowing water rather than the potential energy from the head. The systems may operate in rivers, man-made channels, tidal waters, or ocean currents. Kinetic systems utilize the water stream's natural pathway. They do not require the diversion of water through manmade channels, riverbeds, or pipes, although they might have applications in such conduits. Kinetic systems do not require large civil works; however, they can use existing structures such as bridges, tailraces and channels.

Design and application:

Turbine selection is based on the available water head, and less so on the available flow rate. In general, impulse turbines are used for high head sites, and reaction turbines are used for low head sites. Kaplan turbines with adjustable blade pitch are well-adapted to wide ranges of flow or head conditions, since their peak efficiency can be achieved over a wide range of flow conditions.

Small turbines (mostly under 10 MW) may have horizontal shafts, and even fairly large bulb-type turbines up to 100 MW or so may be horizontal. Very large Francis and Kaplan machines usually have vertical shafts because this makes best use of the available head, and makes installation of a generator more economical. Pelton wheels may be either vertical or horizontal shaft machines because the size of the machine is so much less than the available head. Some impulse turbines use multiple jets per runner to balance shaft thrust. This also allows for the use of a smaller turbine runner, which can decrease costs and mechanical losses.

Essential components of hydroelectric powerplant:

The essential components of hydroelectric powerplant are

1. Forebay and Intake Structures:

As the name suggests forebay is an enlarged body of water in front of intake. The reservoir acts as forebay when penstock takes water directly from it. When canal leads water to the turbines the section of the canal in front of turbines is enlarged to create forebay. The forebay temporarily stores water for supplying the same to the turbines. The water cannot be allowed to pass as it comes in the reservoir or the canal. At intake gates are provided with hoist to control the entry of water. In front of the gates trash racks are provided to prevent debris, trees, etc., from entering into the penstock. Rakes are also provided to clean the trash racks at intervals.

2. Head Race or Intake Conduits: The pressure conduit does not follow the ground contours and any gradient is given to suit the site conditions. The velocity of water in the power conduit is also higher than in the open channel. Up to about 60 metres head the velocity may range between 2.5 to 3 0 m/sec.

For higher heads the velocity may be still higher. Sometimes it is convenient or economical to adopt open channel partly or wholly as the main conduit. The head race canal may lead water to the turbines or to the penstocks and is usually adopted in low-head installations where head losses are relatively important. The advantage of an open channel is that it could be used for irrigation or navigation purposes.

3. Surge Tank:

A surge tank is a storage reservoir fitted at some opening made on a long pipe line or penstock to receive the rejected flow when the pipe line is suddenly closed by a valve fitted at its steep end. A surge tank, therefore, relieves the pipe line of excessive pressure produced due to its closing, thus eliminating the positive water hammer effect.

It is done by admitting in the surge tank a large mass of water which otherwise would have flown out of the pipe line, but returns to the tank due to closure of pipe end. It also serves the purpose of supplying suddenly an additional flow whenever required by the hydraulic prime movers at any instant. The surge tank is mostly employed in a water power plant or in a large pumping plant to control the pressure variations resulting from rapid changes in the flow.

They carry water to the turbines from the reservoir. The choice of open channel or a pressure conduit (Penstock) depends upon site conditions. The pressure conduit may be in the form of a flared intake passage in the body of the dam or it may be a long conduit of steel or concrete or sometimes a tunnel extending for few kilometers between the reservoir and the power house.

In the case of water power plant, when there is sudden reduction of load on the turbine it becomes necessary for the governor to close the turbine gates for adjusting the flow of water in order to keep the speed of the turbine constant. However, the water is already on its way to the turbine.

When the turbine gates are closed, the moving water has to go back. A surge tank would then act as a receptacle to store the rejected water and thus avoids water hammer On the other hand when there is an immediate demand on the turbine tor more power the governor re-opens the gates in proportion to the increased load, thus, making it necessary to supply more water.

For a long pipe it takes a considerable time before the entire mass of water can be accelerated. The surge tank which is generally located near the turbine will meet the suddenly increased demand of water till such time the velocity in the upper portion of the line acquires a new value.

Functions of Surge Tank:

The surge tank thus serves the following purposes:

i. Control of pressure variations resulting from rapid changes in pipe line flow, thus eliminating water hammer effect.

ii. Regulation of flow in power and pumping plants by providing necessary accelerating or retarding head.

4. Turbines and Generators:

Turbine converts hydraulic energy into mechanical energy. The mechanical energy developed by a turbine is used in running an electric generator. It is directly coupled to the shaft of the turbine. The generator develops electric power. A turbine consists of a wheel called runner. The runner is provided with specially designed blades or buckets. The water possessing large hydraulic energy strikes the blades and the runner rotates.

Water turbines may be classified under two types, namely:

i. Impulse or velocity turbines, and

i. Reaction or pressure turbines.

Impulse Turbine:

In the impulse turbine, all the available potential energy or head is converted into kinetic energy or velocity head by passing the water through a contracting nozzle or by guide vanes before it strikes the buckets. The wheel revolves free in air and water is in contact with only a part of wheel at a time. The pressure of water all along is atmospheric.

In order to prevent splashing and to guide the water discharged from the buckets to the tail race, a casing is provided. An impulse turbine is essentially a low-speed wheel and is used for relatively high heads. Pelton wheel, Turgo impulse wheel and Girard turbine, are some types of impulse turbine. In the Pelton wheel water strikes the runner tangentially.

Reaction Turbine:

In a reaction turbine, only part of the available potential energy is converted into velocity head, at the entrance to the runner. The balance portion remains as a pressure head. The pressure at the inlet of the turbine is much higher than the pressure at the outlet.

It varies throughout the passage of water through the turbine. Mostly the power is developed by the difference in pressure acting on front and back of runner blades. Only small part of power comes from the dynamic action of velocity. Since the water is under pressure, the entire flow from head race to tail race takes place in a closed system.

Francis and Kaplan turbines are two important types of reaction turbines. In Francis turbine there is inward radial flow of water. In modern Francis turbine the flow enters radially inward but leaves in parallel direction to shaft at centre. It is called mixed flow.

In Girard, propeller and Kaplan turbines the flow is axial or parallel to the axis of the turbine shaft. Selection of a suitable type of turbine depends primarily upon the available head and the quantity of waste required.

The turbines may be classified as follows with reference to type of power plant:

- Low head turbine (less than 30 m);
- Medium head turbine (30 to 160 m);
- High head turbine (up to and over 1000 m);

Low head turbines are Propeller turbine and Kaplan turbine. These turbines use large quantity of water. Medium head turbines are modern Francis turbines. Impulse turbines are high head turbines. These turbines require relatively less quantity of water.

5. Power House:

The purpose of the power house is to support and house the hydraulic and electrical equipment.

The power house is readily divided into two parts as follows:

i. The substructure to support the equipment and to provide the necessary water-ways.

ii. The superstructure or building to house and protect the equipment.

Substructure:

The substructure may form an integral part of the dam and intake structure. In other cases the substructure may be remote from the dam, the dam intake and power house being entirely separate structures. The substructure is built exclusively of concrete and is enforced with steel where necessary.

Super-Structure:

The generating room, the main portion of the power house, contains the main units and their accessories, and usually there is a power or hand operated overhead crane which spans the width of the power house. The switch board and operating stand are usually near the middle of the station, either at floor level or, for better visibility, on the second floor or at a level above the main floor.

Usually an auxiliary bay or section of the power house will be required upstream from the main units for the switches, bus connections, and outgoing lines. If transformers are located inside the station, these will also be in the auxiliary bay, commonly at floor level and shut off the main floor by steel doors or shutters.

A travelling crane is an important part of the power house equipment. In fixing the elevation of the crane rail above the floor, it is essential that sufficient headroom is provided for lifting and carrying along any of the various machine parts.

6. Tail Race and Draft Tube

The channel into which the turbine discharges in case of impulse wheel and through draft tube in case of reaction turbine is called a tail race. The suction pipe or draft tube is nothing but an airtight tube fitted to all reaction turbines on the outlet side. It extends from the discharge end of the turbine runner to about 0.5 metres below the surface of the tail water level. The straight draft tube is generally given a flare of 4 to 6 degrees to gradually reduce the velocity of water.

The suction action of the water in this tube has same effect on the runner as an equivalent head so that the turbine develops the same power as if it were placed at the surface of the tail water. The tail race of the impulse wheel is commonly an approximately rectangular passage, running from a point under the wheel to a point outside the power house foundations where it enters the exit channel or the river. Because of the small discharge of the impulse wheel, as well as higher allowable velocity, the tail race passage is much smaller than that of the reaction turbine.

In case of the reaction turbine the width of the tail race channel under the power house depends upon the unit spacing and thickness of piers and walls between the unit bays. The depth of the tail race channel depends upon the velocity which is generally taken to be about 1 metre per second. Where the power house is close to the river, the tail race may be the river itself. In other case a tail race channel of some length may be provided to join the turbine pit with the river.

Advantages to Hydroelectric Power:

- Fuel is not burned so there is minimal pollution
- Water to run the power plant is provided free by nature

- Hydropower plays a major role in reducing greenhouse gas emissions
- Relatively low operations and maintenance costs
- The technology is reliable and proven over time
- It's renewable - rainfall renews the water in the reservoir, so the fuel is almost always there

Disadvantages:

- High investment costs
- Hydrology dependent (precipitation)
- In some cases, inundation of land and wildlife habitat
- In some cases, loss or modification of fish habitat
- Fish entrainment or passage restriction
- In some cases, changes in reservoir and stream water quality
- In some cases, displacement of local populations

Hydropower and the Environment:

- Hydropower is nonpolluting, but does have environmental impacts
- Hydropower does not pollute the water or the air. However, hydropower facilities can have large environmental impacts by changing the environment and affecting land use, homes, and natural habitats in the dam area.
- Most hydroelectric power plants have a dam and a reservoir. These structures may obstruct fish migration and affect their populations. Operating a hydroelectric power plant may also change the water temperature and the river's flow. These changes may harm native plants and animals in the river and on land. Reservoirs may cover people's homes, important natural areas, agricultural land, and archaeological sites. So, building dams can require relocating people. Methane, a strong greenhouse gas, may also form in some reservoirs and be emitted to the atmosphere.

Unit 5

OTHER ENERGY SOURCES

Tidal energy:

Introduction:

Tidal energy is produced by the surge of ocean waters during the rise and fall of tides. Tidal energy is a renewable source of energy.

During the 20th century, engineers developed ways to use tidal movement to generate electricity in areas where there is a significant tidal range—the difference in area between high tide and low tide. All methods use special generators to convert tidal energy into electricity.

Tidal energy production is still in its infancy. The amount of power produced so far has been small. There are very few commercial-sized tidal power plants operating in the world. The first was located in La Rance, France. The largest facility is the Sihwa Lake Tidal Power Station in South Korea. The United States has no tidal plants and only a few sites where tidal energy could be produced at a reasonable price. China, France, England, Canada, and Russia have much more potential to use this type of energy.

In the United States, there are legal concerns about underwater land ownership and environmental impact. Investors are not enthusiastic about tidal energy because there is not a strong guarantee that it will make money or benefit consumers. Engineers are working to improve the technology of tidal energy generators to increase the amount of energy they produce, to decrease their impact on the environment, and to find a way to earn a profit for energy companies.

Principle

Tidal power is taken from the Earth's oceanic tides. Tidal forces are periodic variations in gravitational attraction exerted by celestial bodies. These forces create corresponding motions or currents in the world's oceans. Due to the strong attraction to the oceans, a bulge in the water level is created, causing a temporary increase in sea level. As the Earth rotates, this bulge of ocean water meets the shallow water adjacent to the shoreline and creates a tide. This occurrence takes place in an unfailing manner, due to the consistent pattern of the moon's orbit around the earth. The magnitude and character of this motion reflects the changing positions of the Moon and Sun relative to the Earth, the effects of Earth's rotation, and local geography of the seafloor and coastlines.

Tidal power is the only technology that draws on energy inherent in the orbital characteristics of the Earth–Moon system, and to a lesser extent in the Earth–Sun system. Other natural energies exploited by human technology originate directly or indirectly with the Sun, including fossil fuel, conventional hydroelectric, wind, biofuel, wave and solar energy. Nuclear energy makes use of Earth's mineral deposits of fissionable elements, while geothermal power utilizes the Earth's internal heat, which comes from a combination of residual heat from planetary accretion (about 20%) and heat produced through radioactive decay (80%).

A tidal generator converts the energy of tidal flows into electricity. Greater tidal variation and higher tidal current velocities can dramatically increase the potential of a site for tidal electricity generation.

Because the Earth's tides are ultimately due to gravitational interaction with the Moon and Sun and the Earth's rotation, tidal power is practically inexhaustible and classified as a renewable energy resource. Movement of tides causes a loss of mechanical energy in the Earth-Moon system: this is a result of pumping of water through natural restrictions around coastlines and consequent viscous dissipation at the seabed and in turbulence. This loss of energy has caused the rotation of the Earth to slow in the 4.5 billion years since its formation. During the last 620 million years the period of rotation of the earth (length of a day) has increased from 21.9 hours to 24 hours; in this period the Earth has lost 17% of its rotational energy. While tidal power will take additional energy from the system, the effect is negligible and would only be noticed over millions of years.

Tidal Energy Generators

There are currently three different ways to get tidal energy: tidal streams, barrages, and tidal lagoons.

For most tidal energy generators, turbines are placed in tidal streams. A tidal stream is a fast-flowing body of water created by tides. A turbine is a machine that takes energy from a flow of fluid. That fluid can be air (wind) or liquid (water). Because water is much more dense than air, tidal energy is more powerful than wind energy. Unlike wind, tides are predictable and stable. Where tidal generators are used, they produce a steady, reliable stream of electricity.

Placing turbines in tidal streams is complex, because the machines are large and disrupt the tide they are trying to harness. The environmental impact could be severe, depending on the size of the turbine and the site of the tidal stream. Turbines are most effective in shallow water. This produces more energy and allows ships to navigate around the turbines. A tidal generator's turbine blades also turn slowly, which helps marine life avoid getting caught in the system.

The world's first tidal power station was constructed in 2007 at Strangford Lough in Northern Ireland. The turbines are placed in a narrow strait between the Strangford

Lough inlet and the Irish Sea. The tide can move at 4 meters (13 feet) per second across the strait.

Barrage

Another type of tidal energy generator uses a large dam called a barrage. With a barrage, water can spill over the top or through turbines in the dam because the dam is low. Barrages can be constructed across tidal rivers, bays, and estuaries.

Turbines inside the barrage harness the power of tides the same way a river dam harnesses the power of a river. The barrage gates are open as the tide rises. At high tide, the barrage gates close, creating a pool, or tidal lagoon. The water is then released through the barrage's turbines, creating energy at a rate that can be controlled by engineers.

The environmental impact of a barrage system can be quite significant. The land in the tidal range is completely disrupted. The change in water level in the tidal lagoon might harm plant and animal life. The salinity inside the tidal lagoon lowers, which changes the organisms that are able to live there. As with dams across rivers, fish are blocked into or out of the tidal lagoon. Turbines move quickly in barrages, and marine animals can be caught in the blades. With their food source limited, birds might find different places to migrate.

A barrage is a much more expensive tidal energy generator than a single turbine. Although there are no fuel costs, barrages involve more construction and more machines. Unlike single turbines, barrages also require constant supervision to adjust power output.

The tidal power plant at the Rance River estuary in Brittany, France, uses a barrage. It was built in 1966 and is still functioning. The plant uses two sources of energy: tidal energy from the English Channel and river current energy from the Rance River. The barrage has led to an increased level of silt in the habitat. Native aquatic plants suffocate in silt, and a flatfish called plaice is now extinct in the area. Other organisms, such as cuttlefish, a relative of squids, now thrive in the Rance estuary. Cuttlefish prefer cloudy, silty ecosystems.

Tidal Lagoon

The final type of tidal energy generator involves the construction of tidal lagoons. A tidal lagoon is a body of ocean water that is partly enclosed by a natural or manmade barrier. Tidal lagoons might also be estuaries and have freshwater emptying into them.

A tidal energy generator using tidal lagoons would function much like a barrage. Unlike barrages, however, tidal lagoons can be constructed along the natural coastline. A tidal lagoon power plant could also generate continuous power. The turbines work as the lagoon is filling and emptying.

The environmental impact of tidal lagoons is minimal. The lagoons can be constructed with natural materials like rock. They would appear as a low breakwater (sea wall) at low tide, and be submerged at high tide. Animals could swim around the structure, and smaller organisms could swim inside it. Large predators like sharks would not be able to penetrate the lagoon, so smaller fish would probably thrive. Birds would likely flock to the area.

But the energy output from generators using tidal lagoons is likely to be low. There are no functioning examples yet. China is constructing a tidal lagoon power plant at the Yalu River, near its border with North Korea. A private company is also planning a small tidal lagoon power plant in Swansea Bay, Wales.

DTP

Dynamic tidal power (DTP) is one of the newest proposals to harness the power of tides. Using DTP, enormous dams (as long as 50 kilometers (31 miles)) would extend straight from the shore into the open ocean.

Issues and challenges

Environmental concerns

Tidal power can have effects on marine life. The turbines can accidentally kill swimming sea life with the rotating blades, although projects such as the one in Strangford feature a safety mechanism that turns off the turbine when marine animals approach. However, this feature causes a major loss in energy because of the amount of marine life that passes through the turbines. Some fish may no longer utilize the area if threatened with a constant rotating or noise-making object. Marine life is a huge factor when placing tidal power energy generators in the water and precautions are made to ensure that as many marine animals as possible will not be affected by it. The Tethys database provides access to scientific literature and general information on the potential environmental effects of tidal energy. In terms of Global Warming Potential (i.e. carbon footprint), the impact of tidal power generation technologies ranges between 15 and 37 gCO_2-eq/kWhe, with a median value of 23.8 gCO_2-eq/kWhe. This is in-line with the impact of other renewables like wind and solar power, and significantly better than fossil-based technologies.

Tidal turbines

The main environmental concern with tidal energy is associated with blade strike and entanglement of marine organisms as high-speed water increases the risk of organisms being pushed near or through these devices. As with all offshore renewable energies, there is also a concern about how the creation of electromagnetic fields and acoustic outputs may affect marine organisms. Because these devices are in the water, the acoustic output can be greater than those created with offshore wind energy. Depending on the frequency and amplitude of sound generated by the tidal energy devices, this acoustic output can have varying effects on marine mammals (particularly those who echolocate to communicate and navigate in the marine environment, such as dolphins and whales). Tidal energy removal can also cause environmental concerns such as degrading far-field water quality and disrupting sediment processes. Depending on the size of the project, these effects can range from small traces of sediment building up near the tidal device to severely affecting nearshore ecosystems and processes.

Tidal barrage

Installing a barrage may change the shoreline within the bay or estuary, affecting a large ecosystem that depends on tidal flats. Inhibiting the flow of water in and out of the bay, there may also be less flushing of the bay or estuary, causing additional turbidity (suspended solids) and less saltwater, which may result in the death of fish that act as a vital food source to birds and mammals. Migrating fish may also be unable to access breeding streams, and may attempt to pass through the turbines. The same acoustic concerns apply to tidal barrages. Decreasing shipping accessibility can become a socio-economic issue, though locks can be added to allow slow passage. However, the barrage may improve the local economy by increasing land access as a bridge. Calmer waters may also allow better recreation in the bay or estuary.[54] In August 2004, a humpback whale swam through the open sluice gate of the Annapolis Royal Generating Station at slack tide, ending up trapped for several days before eventually finding its way out to the Annapolis Basin.

Tidal lagoon

Environmentally, the main concerns are blade strike on fish attempting to enter the lagoon, the acoustic output from turbines, and changes in sedimentation processes. However, all these effects are localized and do not affect the entire estuary or bay.

Corrosion

Saltwater causes corrosion in metal parts. It can be difficult to maintain tidal stream generators due to their size and depth in the water. The use of corrosion-resistant materials such as stainless steels, high-nickel alloys, copper-nickel alloys, nickel-copper alloys and titanium can greatly reduce, or eliminate corrosion damage.

Mechanical fluids, such as lubricants, can leak out, which may be harmful to the marine life nearby. Proper maintenance can minimize the number of harmful chemicals that may enter the environment.

Fouling

The biological events that happen when placing any structure in an area of high tidal currents and high biological productivity in the ocean will ensure that the structure becomes an ideal substrate for the growth of marine organisms. In the references of the

Tidal Current Project at Race Rocks in British Columbia, this is documented. Also see this page and Several structural materials and coatings were tested by the Lester Pearson College divers to assist Clean Current in reducing fouling on the turbine and other underwater infrastructure.

Cost

Tidal Energy has an expensive initial cost which may be one of the reasons tidal energy is not a popular source of renewable energy. It is important to realize that the methods for generating electricity from tidal energy are relatively new technology. It is projected that tidal power will be commercially profitable within 2020[needs update] with better technology and larger scales. Tidal Energy is however still very early in the research process and the ability to reduce the price of tidal energy can be an option. The cost-effectiveness depends on each site tidal generators are being placed. To figure out the cost-effectiveness they use the Gilbert ratio, which is the length of the barrage in metres to the annual energy production in kilowatt hours.

Due to tidal energy reliability, the expensive upfront cost of these generators will slowly be paid off. Due to the success of a greatly simplified design, the orthogonal turbine offers considerable cost savings. As a result, the production period of each generating unit is reduced, lower metal consumption is needed and technical efficiency is greater. Scientific research has the capability to have a renewable resource like tidal energy that is affordable as well as profitable.

Advantages of tidal energy

1. Renewable
Tidal energy is a renewable source of energy, which means the energy doesn't deplete as it is used.

So, as you are harnessing energy from the changing tides, you don't decrease the amount of energy the tides can produce in the future. The gravitational pull from the sun and the moon, which controls the tides, won't cease to exist anytime soon.

2. Zero-carbon emissions
In addition to being a renewable energy source, tidal power stations do not emit greenhouse gasses during electricity generation.

Because greenhouse gas emissions are one of the leading causes of climate change, finding zero-emission energy sources is more important than ever.

3. Predictable
Tidal currents are highly predictable. Low and high tides follow well-known cycles, making it easier to know when power will be produced throughout the day.

It also makes it easy to know how much power will be produced by turbines, since the power of the tides and currents can be forecasted accurately.

4. High power output
Tidal power plants are able to produce high amounts of electricity. One of the main reasons for this is because water is so dense - almost 800 times more dense than air.

This means that a tidal turbine will produce substantially more energy than a wind turbine of the same size.

Plus, even when water is moving at low speeds, the density of water allows it to power a turbine. So, tidal turbines have the potential to produce large amounts of electricity even if the conditions of the water aren't ideal.

Disadvantages of tidal energy

1. Limited installation sites
In order for a tidal power plant to be built, the potential installation site must meet very specific requirements. First, they need to be located on a coastline, which limits potential station sites to coastal states.

There are additional requirements a potential site must meet. For example, tidal power stations need to be built in places where the difference in height between high and low tide is significant enough to power turbines.

This limits where the power stations can be installed, making it difficult for tidal power to be implemented widely.

2. Expensive
One of the biggest drawbacks to tidal power is the high upfront costs. Tidal energy turbines need to be much sturdier than wind turbines, because of the high density of water. The cost of constructing a tidal power generation plant varies depending on what type of technology they use.

Most of the tidal power plants that are currently in operation are made of tidal barrages, which are essentially low-walled dams. The construction of a tidal barrage is extremely expensive, since a whole concrete structure - plus turbines - needs to be put in place.

The cost barrier is one of the main reasons why tidal power has been slow to be adopted.

3. Environmental effects
Just because tidal energy is renewable doesn't mean it is completely environmentally friendly. The construction of tidal energy power stations can have a substantial impact on the surrounding ecosystem.

Tidal turbines have the same issue that wind turbines face with birds - marine life collisions. As turbines spin, fish and other sea life could swim into the blades leading to serious injury or death. Tidal turbines also create low level noise beneath the surface of the water that negatively impacts marine mammals, like seals.

Tidal barrages have an even larger impact on the local environment. Not only do they cause the same problems that turbines do on their own, they also have a similar impact that dams have. Tidal barrages prevent the migration of fish, and cause flooding of surrounding areas that forever changes the landscape.

4. Energy demand
While tidal power does have predictable power generation, it doesn't have constant power production. We can know exactly when the tidal power plant will generate electricity, but that electrical generation might not match up with the demand for energy.

For example, if high tide is at noon, the tidal electricity will be produced around noon. Peak energy demand is usually in the morning and the evenings, with the lowest energy demand in the middle of the day.

So, the tidal power plant will produce all of this electricity, but it won't be needed. So, tidal power would realistically need to be paired with battery storage to make the most out of the energy it produces.

The future of tidal power
Tidal power has huge potential, especially as new technologies, like dynamic tidal power, continue to be developed.

Currently, there are less than ten tidal power stations in operation globally. The two most popular tidal power plants, Rance Tidal Power Station and Sihwa Lake Tidal Power Station, produce enough tidal energy to power 94,507 homes in the United States for an entire year. Not only is that a substantial amount of power, the power produced is predictable, and carbone-free.

However, tidal power plants can have a substantial impact on the surrounding ecosystem, high upfront costs, and there are limited suitable sites for them. Hopefully, as technology continues to improve, we will be able to take advantage of the energy stored within the tides.

WAVE ENERGY

Wave energy (or wave power) is the transport and capture of energy by ocean surface waves. The energy captured is then used for all different kinds of useful work, including electricity generation, water desalination, and pumping of water. Wave energy is also a type of renewable energy and is the largest estimated global resource form of ocean energy.

Technology

There are multiple different technologies used for Wave energy. There are five main types of technology used including; Absorbers, Attenuators, Oscillation water columns, overtopping and Inverted- Pendulum device.

- Abosorbers extract energy from the rise and fall of the waves with a buoy. Once the energy is extracted it is then converted to electrical energy with a linear or rotary generator.
- Attenuators capture energy by being placed perpendicular to the length of the wave, this causes the attenuator to contentiously flex where segments are connected. This connection is then connected to hydraulic pumps which convert the energy
- Oscillation Water Columns (OWC) is a partially submerged enclosed structure. the upper part of the structure, above the water, is filled with air and incoming waves are funneled into the bottom part of the structure. When these waves come through the structure it causes the water column to rise and fall with the wave which causes the air in the top structure to pressurize and depressurize. this in turn pushes and pulls air through a connected air turbine at the top of the structure, converting the energy.
- Overtopping has a wave lift over a barrier which fills a reservoir with the water and is then drained through a hydro turbine. This technology is very similar to a conventional hydropower dam.
- Inverted-Pendulum device uses the motion of waves to move a hinged paddle back and forth. The motion of the paddle drives hydraulic pumps which drives electrical generators.

Pros of Wave Energy:

- Wave energy has a lot of potential. Oceans cover 71% of the Earth, so it's very accessible.
- Wave energy also has many different positive aspects. First, the energy is green. Harnessing wave energy doesn't emit any harmful gases, and it can easily replace energies that do, such as using fossil fuels.
- Second, the energy is renewable. Ultimately, the energy is caused by heat which is emitted from the Sun, and this energy will not be disappearing any time soon.
- Third, there is an incredible potential in wave energy.xFor every meter of wave along the shore, the energy density is between 30 kW and 40 kW. The Electric Power Research Institute (EPRI) analyzed the potential, and for the U.S. alone, there is a potential of about 2,640 TWh/y along the continental shelf edge.

- Fourth, wave energy is reliable. Solar always needs the Sun, and wind energy always needs the wind to work. Since waves are essentially always in motion and are never interrupted, it's a reliable source compared to others.

Cons of wave energy:

- Wave energy effects the environment. As with wind farms being an eye-sore, wave energy could cause conflicts with appearance of oceans, which in turn could conflict with tourism and local acceptance.
- It is also currently unclear on how harvesting wave energy affects marine life. Because of these, installations on the coast and land facilities are held to higher restriction on size and location for wave energy farms.
- Wave energy also has issues in terms of cost. It still is in the early stages of development, so costs of wave power are still fairly high compared to other forms of technology.
- Wave energy devices also require regular maintenance which isn't cheap either.

Wave energy technologies:

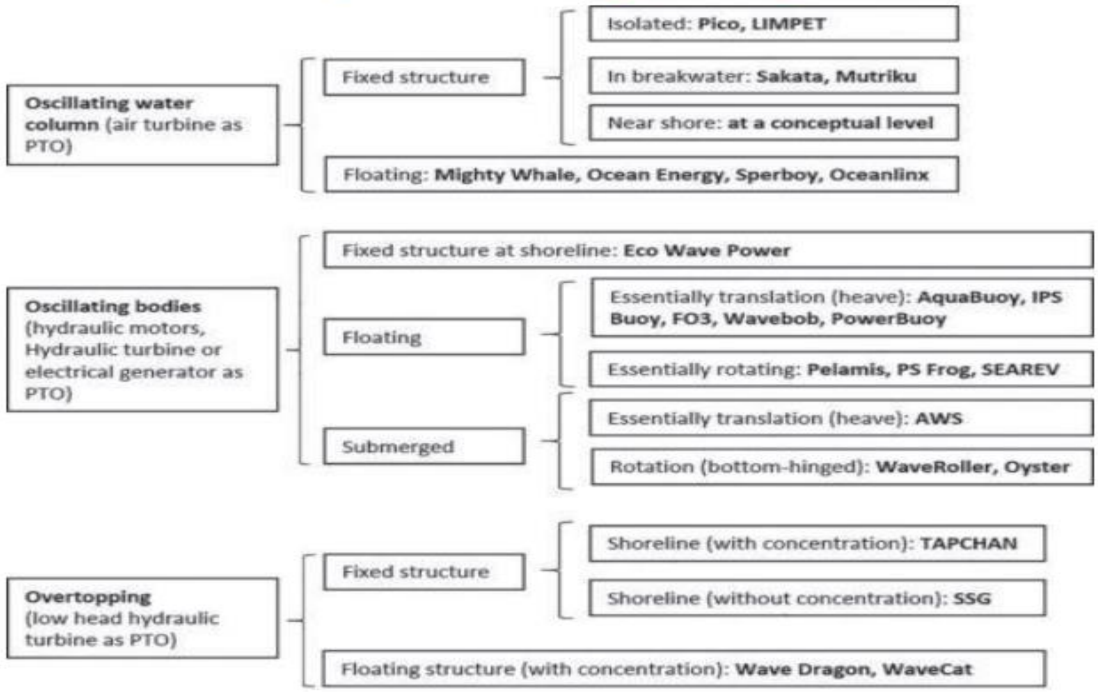
Wave energy technologies consist of a number of components:

1) the structure and prime mover that captures the energy of the wave,

- 2) foundation or mooring keeping the structure and prime mover in place,
- 3) the power take-off (PTO) system by which mechanical energy is converted into electrical energy, and

4) the control systems to safeguard and optimise performance in operating conditions.

Figure : Wave energy technologies



Oscillating Water Columns:

- Oscillating Water Columns are conversion devices with a semi-submerged chamber, keeping a trapped air pocket above a column of water.
- Waves cause the column to act like a piston, moving up and down and thereby forcing the air out of the chamber and back into it.
- This continuous movement generates a reversing stream of high-velocity air, which is channeled through rotor blades driving an air turbine-generator group to produce electricity.
- Waves contain essentially three motions.

• A horizontal front/back motion (the “surge”) that can be extracted with technologies using a “roll rotation”;

• A horizontal side to side motion (the “sway”) that can be extracted with technologies using a “pitch rotation”;

• A vertical (up and down) motion (the “heave”) that can be extracted with technologies using a “yaw rotation” or “translation”.

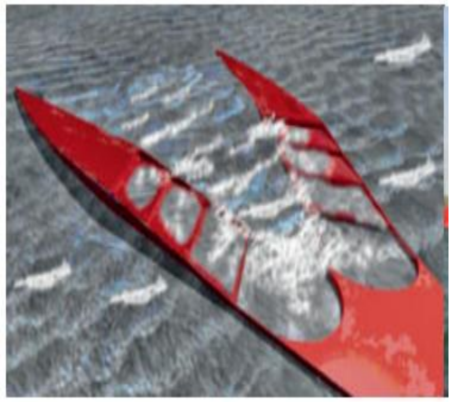
The main advantages of these systems are their simplicity (essentially there are no moving parts other than the air turbine) and the fact that they are usually reliable. Conversely, the performance level is not high, although there are new control strategies and turbine concepts under development, which are notably increasing the power performance.

Oscillating Body Converters:

- Oscillating Body Converters are either floating (usually) or submerged (sometimes fixed to the bottom).
- They exploit the more powerful wave regimes that normally occur in deep waters where the depth is greater than 40 metres (m).
- In general, they are more complex than OWCs, particularly with regards to their PTO systems.
- In fact, the many different concepts and ways to transform the oscillating movement into electricity has given rise to various PTO systems, e.g., hydraulic generators with linear hydraulic actuators, linear electric generators, piston pumps, etc.
- The advantages of oscillating body converters include their size and versatility since most of them are floating devices. A distinct technology has yet to emerge and more research, to increase the PTO performance and avoid certain issues with the mooring systems, needs to be undertaken.

Overtopping converters:

- Overtopping converters (or terminators) consist of a floating or bottom fixed water reservoir structure, and also usually reflecting arms, which ensure that as waves arrive, they spill over the top of a ramp structure and are restrained in the reservoir of the device.
- The potential energy, due to the height of collected water above the sea surface, is transformed into electricity using conventional low head hydro turbines
- The main advantage of this system is the simple concept – it stores water and when there is enough, lets it pass through a turbine. Key downsides include the low head (in the order of 1-2 m) and the vast dimensions of a full scale overtopping device



Power take-off (PTO) systems:

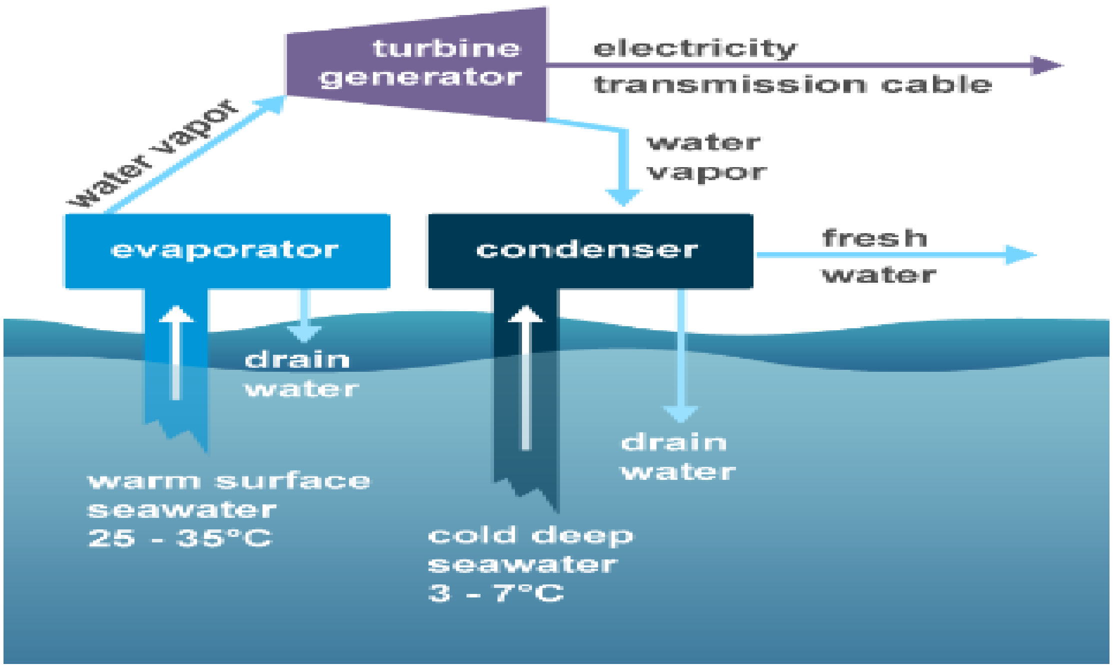
- There are a number of different PTO systems that can be used to convert the wave energy into electricity: turbines, hydraulic systems, electrical linear generators as well as full mechanical systems.
- OWCs use air turbines (pneumatic systems) to convert the wave motion into electricity, whilst oscillating bodies and overtopping converters predominantly use a variety of hydraulic PTO systems or turbines.
- PTO systems have to be adapted to be used in WECs, as the energy flow provided by wave energy is random and highly variable per wave, per day, and per season.
- As a consequence, air turbines can only reach efficiencies of 50-60%, while hydraulic turbines can reach efficiencies from 70-90%. Furthermore, high-pressure oil hydraulic motors are being explored that include gas accumulator systems capable of storing energy over a few wave periods, smoothing out the irregularities provided by wave energy.
- Other technological advances in PTO systems include multistage rotor turbines, and adjustable inlet guide vanes to increase the efficiency of the systems (Falcao, 2010).
- Of the current WECs concepts developed so far, 42% use hydraulic systems, 30% direct-drive systems (mostly linear generators), 11% hydraulic turbines, and 11% pneumatic systems (IRENA, 2014).

Difference between tidal and wave energy

Tidal Energy	Wave Energy
Harnessed from the rise and fall of sea levels	Harnessed from waves moving along the surface of the ocean
Caused by the gravitational pull of the moon and sun on the Earth	Caused by wind
Intensity is affected by location and position of the Earth	Intensity is affected by wind strength
	Often referred to as wave power
Types of tidal energy include kinetic and potential energy	Types of wave energy include kinetic energy
Harnessed using barrages, dams, tidal fences and tidal turbines	Harnessed using offshore and onshore systems
More reliable since it is based on the gravitational pull of the moon and sun	Less reliable since it is based on the effect of the strength of the wind on the surface of the water
Discontinuous source of energy that is generated for about 6 – 12 hours at a time	Continuous source of energy
Can disrupt migrating routes of birds and boating pathways and result in large amounts of fish kill	Effect on surrounding environments, ecosystems and communities are low
High construction costs but low maintenance costs	Extremely high start-up costs to design and develop the technology required

Ocean thermal energy conversion:

- Ocean thermal energy conversion (OTEC) is a process or technology for producing energy by harnessing the temperature differences (thermal gradients) between ocean surface waters and deep ocean waters.
- Ocean Thermal Energy Conversion (OTEC) systems use a temperature difference (of at least 77° Fahrenheit) to power a turbine to produce electricity.
- Warm surface water is pumped through an evaporator containing a working fluid. The vaporized fluid drives a turbine/generator.
- The vaporized fluid is turned back to a liquid in a condenser cooled with cold ocean water pumped from deeper in the ocean.
- OTEC systems using seawater as the working fluid can use the condensed water to produce desalinated water.



Ocean thermal energy conversion system

- The United States became involved in OTEC research in 1974 with the establishment of the Natural Energy Laboratory of Hawaii Authority. The laboratory is one of the world's leading test facilities for OTEC technology.
- The laboratory operated a 250 kilowatt (kW) demonstration OTEC plant for six years in the 1990s.
- The United States Navy supported the development of a 105 kW demonstration OTEC plant at the laboratory site. This facility became operational in 2015 and supplies electricity to the local electricity grid.
- Other larger OTEC systems are in development or planned in several countries, mostly to supply electricity and desalinated water for island communities.
- The Ocean Energy Research Center (OERC) is an essential tool for the development and testing of candidate OTEC heat exchangers.
- Heat Exchangers will be the single most expensive component in a commercial offshore OTEC plant and thus optimizing their cost, longevity and performance are critical for OTEC's economic success.
- The operating conditions of OTEC heat exchangers are unique, and an optimal design has yet to be developed.
- The OERC enables OTEC engineers to rapidly design, build, and test OTEC heat exchangers on an operational land-based OTEC plant, providing the feedback that is necessary for optimization.
- Makai uses a unique OTEC plant analysis software to design heat exchangers which accounts for lifespan, performance (heat transfer and pumping efficiencies), and cost (fabrication and effect on platform), to enable true optimization.
- Makai is in the process of scaling up a design for a low-cost, compact, corrosion-resistant design that could revolutionize OTEC heat exchangers.

- In addition, Makai provides objective performance testing services to other OTEC engineering firms for multiple heat exchangers simultaneously.

Power cycle types

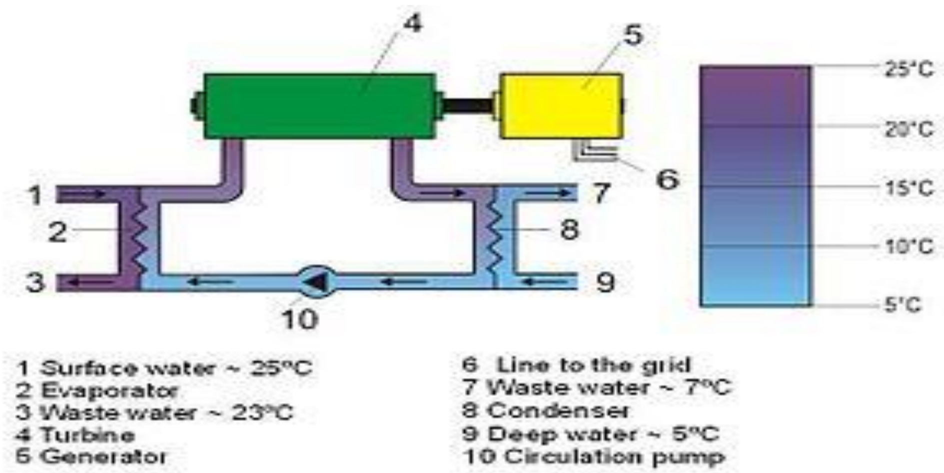
Cold seawater is an integral part of each of the three types of OTEC systems: closed-cycle, open-cycle, and hybrid. To operate, the cold seawater must be brought to the surface. The primary approaches are active pumping and desalination. Desalinating seawater near the sea floor lowers its density, which causes it to rise to the surface.

The alternative to costly pipes to bring condensing cold water to the surface is to pump vaporized low boiling point fluid into the depths to be condensed, thus reducing pumping volumes and reducing technical and environmental problems and lowering costs.

Closed

Closed-cycle systems use fluid with a low boiling point, such as ammonia (having a boiling point around -33 °C at atmospheric pressure), to power a turbine to generate electricity. Warm surface seawater is pumped through a heat exchanger to vaporize the fluid. The expanding vapor turns the turbo-generator. Cold water, pumped through a second heat exchanger, condenses the vapor into a liquid, which is then recycled through the system.

In 1979, the Natural Energy Laboratory and several private-sector partners developed the "mini OTEC" experiment, which achieved the first successful at-sea production of net electrical power from closed-cycle OTEC. The mini OTEC vessel was moored 1.5 miles (2.4 km) off the Hawaiian coast and produced enough net electricity to illuminate the ship's light bulbs and run its computers and television.

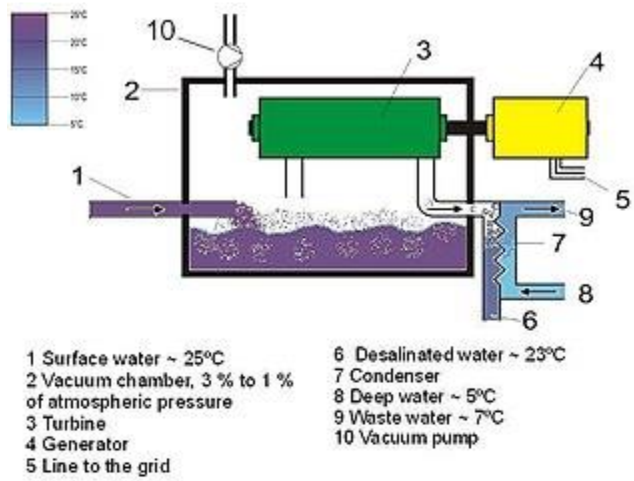


Open

Open-cycle OTEC uses warm surface water directly to make electricity. The warm seawater is first pumped into a low-pressure container, which causes it to boil. In some schemes, the expanding vapor drives a low-pressure turbine attached to an electrical generator. The vapor, which has left its salt and other contaminants in the low-pressure container, is pure fresh water. It is condensed into a liquid by exposure to cold temperatures from deep-ocean water. This method produces desalinized fresh water, suitable for drinking water, irrigation or aquaculture.

In other schemes, the rising vapor is used in a gas lift technique of lifting water to significant heights. Depending on the embodiment, such vapor lift pump techniques generate power from a hydroelectric turbine either before or after the pump is used.

In 1984, the Solar Energy Research Institute (now known as the National Renewable Energy Laboratory) developed a vertical-spout evaporator to convert warm seawater into low-pressure steam for open-cycle plants. Conversion efficiencies were as high as 97% for seawater-to-steam conversion (overall steam production would only be a few percent of the incoming water). In May 1993, an open-cycle OTEC plant at Keahole Point, Hawaii, produced close to 80 kW of electricity during a net power-producing experiment. This broke the record of 40 kW set by a Japanese system in 1982.



Hybrid

A hybrid cycle combines the features of the closed- and open-cycle systems. In a hybrid, warm seawater enters a vacuum chamber and is flash-evaporated, similar to the open-cycle evaporation process. The steam vaporizes the ammonia working fluid of a closed-cycle loop on the other side of an ammonia vaporizer. The vaporized fluid then drives a turbine to produce electricity. The steam condenses within the heat exchanger and provides desalinated water (see heat pipe).

Working fluids

A popular choice of working fluid is ammonia, which has superior transport properties, easy availability, and low cost. Ammonia, however, is toxic and flammable. Fluorinated carbons such as CFCs and HCFCs are not toxic or flammable, but they contribute to ozone layer depletion. Hydrocarbons too are good candidates, but they are highly flammable; in addition, this would create competition for use of them directly as fuels. The power plant size is dependent upon the vapor pressure of the working fluid. With increasing vapor pressure, the size of the turbine and heat exchangers decreases while the wall thickness of the pipe and heat exchangers increase to endure high pressure especially on the evaporator side.

Environmental impact

Carbon dioxide dissolved in deep cold and high pressure layers is brought up to the surface and released as the water warms.[citation needed]

Mixing of deep ocean water with shallower water brings up nutrients and makes them available to shallow water life. This may be an advantage for aquaculture of commercially important species, but may also unbalance the ecological system around the power plant.[citation needed]

OTEC plants use very large flows of warm surface seawater and cold deep seawater to generate constant renewable power. The deep seawater is oxygen deficient and generally 20-40 times more nutrient rich (in nitrate and nitrite) than shallow seawater. When these plumes are mixed, they are slightly denser than the ambient seawater. Though no large scale physical environmental testing of OTEC has been done, computer models have been developed to simulate the effect of OTEC plants.

Hydrodynamic modeling

In 2010, a computer model was developed to simulate the physical oceanographic effects of one or several 100 megawatt OTEC plant(s). The model suggests that OTEC plants can be configured such that the plant can conduct continuous operations, with resulting temperature and nutrient variations that are within naturally occurring levels. Studies to date suggest that by discharging the OTEC flows downwards at a depth below 70 meters, the dilution is adequate and nutrient enrichment is small enough so that 100-megawatt OTEC plants could be operated in a sustainable manner on a continuous basis.

Biological modeling

The nutrients from an OTEC discharge could potentially cause increased biological activity if they accumulate in large quantities in the photic zone. In 2011 a biological component was added to the hydrodynamic computer model to simulate the biological response to plumes from 100 megawatt OTEC plants. In all cases modeled (discharge at 70 meters depth or more), no unnatural variations occurs in the upper 40 meters of the ocean's surface. The picoplankton response in the 110 - 70 meter depth layer is approximately a 10-25% increase, which is well within naturally occurring variability. The nanoplankton response is negligible. The enhanced productivity of diatoms (microplankton) is small. The subtle phytoplankton increase of the baseline OTEC plant suggests that higher-order biochemical effects will be very small.

Hydrogen Production and Storage:

Introduction:

Hydrogen might be the most abundant element on earth but it can be found rarely in its pure form.

Practically, this fact means that in order to produce hydrogen, it needs to be extracted from its compound.Of course, this extraction process needs energy but hydrogen can be produced or extracted using virtually any primary source of energy, be it fossil or renewable. Characteristically, hydrogen can be produced using diverse resources including fossil fuels, such as natural gas and coal, biomass, non-food crops, nuclear energy and renewable energy sources, such as wind, solar, geothermal, and hydroelectric power to split water. This diversity of potential supply sources is the most important reason why hydrogen is such a promising energy carrier.

Although most of the world’s hydrogen production today is being produced through a more CO2 intensive process called Steam Methane Reforming (SMR), hydrogen can also

be produced through a process that makes use of renewable electricity, leading to the production of "green" or CO_2 neutral hydrogen.
The current (new methods are being researched every day) most notable production pathways are the following:

Electrolysis and high temperature Electrolysis

Method: Electrolysis
In short: Process where water (H_2O) is split into hydrogen (H_2) and oxygen (O_2) gas with energy input and heat in the case of high temperature Electrolysis.
In Practice: An electric current splits water into its constituent parts. If renewable energy is used, the gas has a zero-carbon footprint, and is known as green hydrogen.

Steam Methane Reforming:

Method: Reforming - most notably Reforming of natural gas but also biogas
In short: The primary ways in which natural gas, mostly methane, is converted to hydrogen involve reaction with either steam (steam reforming or steam methane reforming SMR when methane is used), oxygen (partial oxidation), or both in sequence (autothermal reforming)
In practice: Steam reforming: Pure water vapour is used as the oxidant. The reaction requires the introduction of heat ("endothermic").

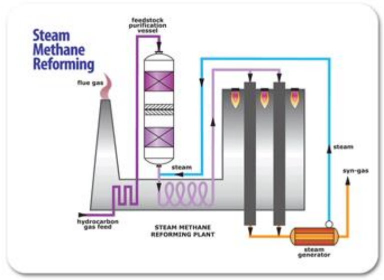
- Partial oxidation: Oxygen or air is used in this method. The process releases heat ("exothermic").
- Autothermal reforming: This process is a combination of steam reforming and partial oxidation and operates with a mixture of air and water vapour. The ratio of the two oxidants is adjusted so that no heat needs to be introduced or discharged ("isothermal").

Hydrogen as a By-Product or Industrial Residual Hydrogen

Method: Hydrogen from other industrial processes that create hydrogen as a by-product
In Short: Electrochemical processes, such as the industrial production of caustic soda and chlorine produce hydrogen as a waste product.
In Practice: Producing chlorine and caustic soda comes down to passing an electric current through brine (a solution of salt – sodium chloride – in water). The brine dissociates and recombines through exchange of electrons (delivered by the current) into gaseous chlorine, dissolved caustic soda1 and hydrogen. By the nature of the chemical reaction, chlorine, caustic soda and hydrogen are always manufactured in a fixed ratio: 1.1 tonne of caustic and 0.03 tonne of hydrogen per tonne of chlorine.

Reforming

Steam methane reforming (SMR):



As already described above, currently, most of the hydrogen produced today, is being produced through the CO2 intensive process called Steam Methane Reforming.

High-temperature steam (700°C–1,000°C) is used to produce hydrogen from a methane source, such as natural gas. In steam-methane reforming, methane reacts with steam under 3–25 bar pressure (1 bar = 14.5 psi) in the presence of a catalyst to produce hydrogen, carbon monoxide, and a relatively small amount of carbon dioxide. Steam reforming is endothermic—that is, heat must be supplied to the process for the reaction to proceed.

Subsequently, in what is called the "water-gas shift reaction," the carbon monoxide and steam are reacted using a catalyst to produce carbon dioxide and more hydrogen. In a final process step called "pressure-swing adsorption," carbon dioxide and other impurities are removed from the gas stream, leaving essentially pure hydrogen. Steam reforming can also be used to produce hydrogen from other fuels, such as ethanol, propane, or even gasoline.

For chemists:

Steam-methane reforming reaction

$CH_4 + H_2O$ (+ heat) $\rightarrow CO + 3H_2$

Water-gas shift reaction

$CO + H_2O \rightarrow CO_2 + H_2$ (+ small amount of heat)

Partial Oxidation

In partial oxidation, the methane and other hydrocarbons in natural gas react with a limited amount of oxygen (typically from air) that is not enough to completely oxidize the hydrocarbons to carbon dioxide and water. With less than the stoichiometric amount of oxygen available, the reaction products contain primarily hydrogen and carbon monoxide (and nitrogen, if the reaction is carried out with air rather than pure oxygen), and a relatively small amount of carbon dioxide and other compounds. Subsequently, in a water-gas shift reaction, the carbon monoxide reacts with water to form carbon dioxide and more hydrogen.

Partial oxidation is an exothermic process—it gives off heat. The process is, typically, much faster than steam reforming and requires a smaller reactor vessel. As can be seen in chemical reactions of partial oxidation, this process initially produces less hydrogen per unit of the input fuel than is obtained by steam reforming of the same fuel.

For chemists:

Partial oxidation of methane reaction

$CH_4 + ½O_2 \rightarrow CO + 2H_2$ (+ heat)

Water-gas shift reaction

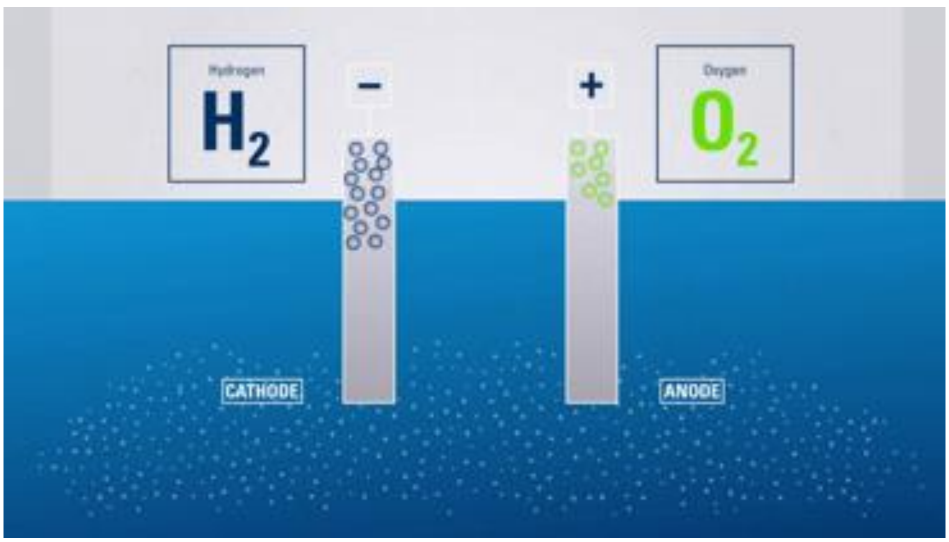
$CO + H_2O \rightarrow CO_2 + H_2$ (+ small amount of heat)

Source: energy.gov

Steam methane reforming (SMR) for biogas

The process of SMR can also be utilized for the production of hydrogen from biogas.

Electrolysis



Despite the fact that hydrogen can be produced in numerous ways, the most interesting but also promising part is the production of hydrogen through electrolysis of water.

In this process, the electrolysis breaks down water into hydrogen and oxygen by using electricity. If the electricity used, springs from renewable energy sources like wind or solar and the hydrogen produced is used in a fuel cell, then the entire energy process would create no net emissions. In this case, we would be talking about “green hydrogen”.

The electrolyser consists of a DC source and two noblemetal-coated electrodes, which are separated by an electrolyte. The electrolyte or ionic conductor can be a liquid, for example conductive caustic potash solution (potassium hydroxide, KOH) for alkaline electrolysis.
In an alkaline electrolyser the cathode (negative pole) loses electrons to the aqueous solution.

The water is dissociated, leading to the formation of hydrogen (H2) and hydroxide ions (OH –) The charge carriers move in the electrolyte towards the anode. At the anode (positive pole) the electrons are absorbed by the negative OH – anions. The OH – anions are oxidised to form water and oxygen. Oxygen rises at the anode. A membrane prevents the product gases H2 and O2 from mixing but allows the passage of OH – ions. Electrolysers consist of individual cells and central system units (balance of plant). By combining electrolytic cells and stacks, hydrogen production can be adapted to individual needs.

Electrolysers are differentiated by the electrolyte materials and the temperature at which they are operated: low-temperature electrolysis (LTE), including alkaline electrolysis (AE), proton exchange membrane (PEM) electrolysis and anion exchange membrane (AEM) electrolysis (also known as alkaline PEM), and high-temperature electrolysis (HTE). The latter group most notably includes solid oxide electrolysis (SOE), but this is still at an advanced R&D stage and products are not yet commercially available. Once it reaches market maturity, its advantages are expected to include increased conversion efficiency and the possibility of producing a synthesis gas directly from steam and CO 2 , for use in various applications such as synthetic liquid fuels (E4tech 2014, IEA 2015b).

High temperature electrolysis is particularly interesting when there is a source of heat next to the electrolyser (as it is often the case in industrial plants or) is more efficient economically than traditional room-temperature electrolysis. Indeed some of the energy is supplied as heat, which is either free or cheaper than electricity, and also because the electrolysis reaction is more efficient at higher temperatures. The choice of a given electrolysis technology depends on the use needs and the local context.

Hydrogen is like electricity in the sense that its use does not generate any emission. Its carbon footprint is related to its production mode. In the case of hydrogen produced by electrolysis, its carbon footprint of hydrogen is directly related with the source of electricity. Hydrogen produced from carbon free renewable or nuclear electricity is therefore carbon free. Hydrogen produced with the grid mix has the same carbon intensity as the grid mix.

Hydrogen as a by-product

As explained above hydrogen is produced by separating from its compound.

If the production of hydrogen can be the first objective of the separation process, it can also be that the separation process aims first at producing another molecule and produces hydrogen as a by-product.

Producing chlorine and caustic soda comes down to passing an electric current through brine (a solution of salt – sodium chloride – in water). The brine dissociates and recombines through exchange of electrons (delivered by the current) into gaseous chlorine, dissolved caustic soda and hydrogen. By the nature of the chemical reaction, chlorine, caustic soda and hydrogen are always manufactured in a fixed ratio: 1.1 ton of caustic and 0.03 ton of hydrogen per ton of chlorine.

A number of studies have sought to quantify the amount of industrial residual hydrogen available. The EU project "Roads 2 HyCom" (Maisonnier et al. 2007) produced among other results a map showing hydrogen production sites in Europe. In this map the hydrogen sources were broken down into three categories: the "merchant" category supplies hydrogen to other industrial customers, while the "captive" category retains hydrogen on site for its own use. Only "by-product" hydrogen has no further use within the process or on site; only this category can be made available for other applications, such as fuel cell electric vehicles.

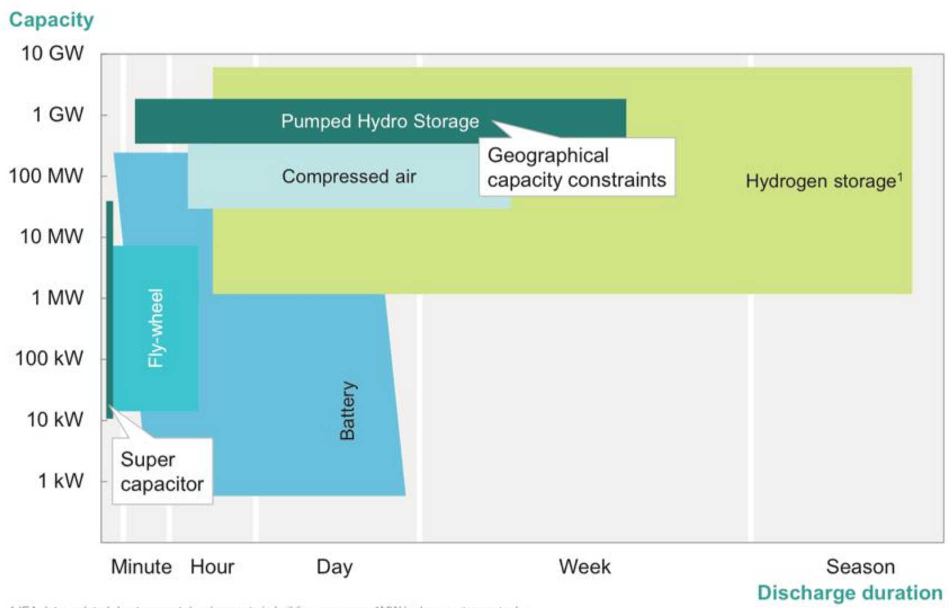
Hydrogen as a by-product is an interesting and cheap source of hydrogen to initiate the deployment of hydrogen applications in the area where it is produced. Not surprisingly regions with high quantities of hydrogen as a byproduct are among the most advanced in their hydrogen deployment strategy.

Hydrogen storage :

Batteries are not suitable in storing large amounts of electricity over time. A major advantage of hydrogen is that it can be produced from (surplus) renewable energies, and unlike electricity it can also be stored in large amounts for extended periods of time. For that reason, hydrogen produced on an industrial scale could play an important part in the energy transition.

However, hydrogen can complement batteries in the transport sector. The optimal energy storage system for vehicles lies in hydrogen and battery systems. The hydrogen system would provide the bulk energy storage, while a relatively small energy capacity battery would allow regenerative braking, meet peak power demands, and generally buffer the fuel cell against load changes to extend its lifetime. This complementary use of hydrogen and battery storage is precisely the arrangement employed by Honda in its FCX Clarity hydrogen car that is now available commercially in limited numbers.

Alongside other demand and supply measures, energy storage can play an important part in improved system integration. Short-term electricity storage in batteries for small plants is developing dynamically, however, longer-term storage of larger surplus amounts of electricity requires new types of storage, such as chemical storage in the form of hydrogen.



1 IEA data updated due to recent developments in building numerous 1MW hydrogen storage tanks

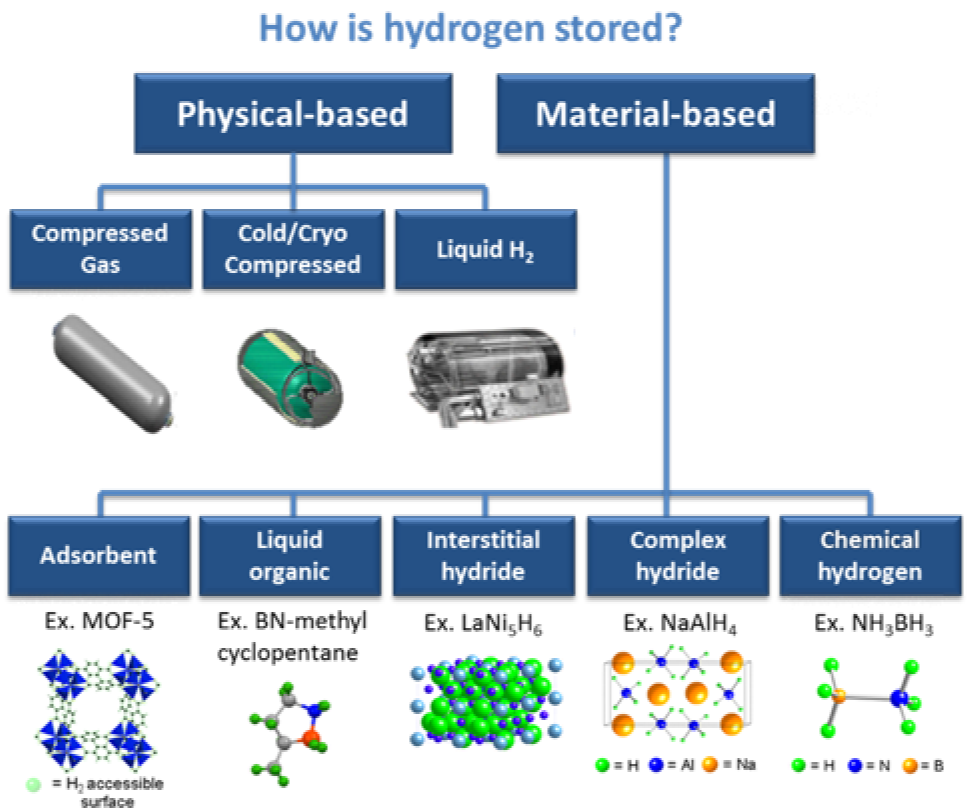
Source: IEA Energy Technology Roadmap Hydrogen and Fuel Cells, JRC Scientific and Policy Report 2013

Hydrogen can be obtained by electrolysis from electricity produced with surplus renewables. If there is a corresponding energy demand, the hydrogen can fulfil it directly. However, it can also be stored in bulk tanks as pressurised gas and retrieved when supplies are low.

Hydrogen can be utilized several ways as an energy carrier, such as feeding it in small amounts into the natural gas network, converting it to CH4 and introduce the obtained methane into the natural gas network, or the stored hydrogen can be directly converted back into electricity via fuel cells.

Hydrogen as an energy carrier has by far the highest gravimetric energy density. The mass-based energy density of hydrogen is thus almost three times higher than that of liquid hydrocarbons, however, the volumetric energy density of hydrogen is comparatively low. Therefore, for practical handling purposes, the density of hydrogen must be increased significantly for storage purposes.

The most important hydrogen storage methods, which have been tried and tested over lengthy periods of time, include physical storage methods based on either compression or cooling or a combination of the two (hybrid storage). In addition, a large number of other new hydrogen storage technologies are being pursued or investigated. These technologies can be grouped together under the name materials-based storage technologies. These can include solids, liquids or surfaces.



Liquefied hydrogen

As well as storing gaseous hydrogen under pressure, it is also possible to store cryogenic hydrogen in the liquid state. Liquid hydrogen (LH2) is in demand today in applications requiring high levels of purity, such as in the chip industry for example. As an energy carrier, LH2 has a higher energy density than gaseous hydrogen, but it requires liquefaction at –253 °C, which involves a complex technical plant and an extra economic cost. When storing liquid hydrogen, the tanks and storage facilities have to be insulated in order to keep in check the evaporation that occurs if heat is carried over into the stored content, due to conduction, radiation or convection. Tanks for LH2 are used today primarily in space travel.

Cold- and cryo-compressed hydrogen

In addition to separate compression or cooling, the two storage methods can be combined. The cooled hydrogen is then compressed, which results in a further development of hydrogen storage for mobility purposes. The first field installations are already in operation. The advantage of cold or cryogenic compression is a higher energy density in comparison to compressed hydrogen. However, cooling requires an additional energy input.

Currently it takes in the region of 9 to 12 % of the final energy made available in the form of H2 to compress hydrogen from 1 to 350 or 700 bar. By contrast, the energy input for liquefaction (cooling) is much higher, currently around 30 %. The energy input is subject to large spreads, depending on the method, quantity and external conditions. Work is currently in progress to find more economic methods with a significantly lower energy input.

Materials-based H2 storage

An alternative to physical storage methods is provided by hydrogen storage in solids and liquids and on surfaces. Most of these storage methods are still in development, however. Moreover, the storage densities that have been achieved are still not adequate, the cost and time involved in charging and discharging hydrogen are too high, and/or the process costs are too expensive. Materials-based hydrogen storage media can be divided into three classes: first, hydride storage systems; second, liquid hydrogen carriers; and third, surface storage systems, which take up hydrogen by adsorption, i.e. attachment to the surface.

Hydride storage systems

In metal hydride storage systems the hydrogen forms interstitial compounds with metals. Here molecular hydrogen is first adsorbed on the metal surface and then incorporated in elemental form (H) into the metallic lattice with heat output and released again with heat input. Metal hydrides are based on elemental metals such as palladium, magnesium and lanthanum, intermetallic compounds, light metals such as aluminium, or certain alloys. Palladium, for example, can absorb a hydrogen gas volume up to 900 times its own volume.

Liquid organic hydrogen carriers

Liquid organic hydrogen carriers represent another option for binding hydrogen chemically. They are chemical compounds with high hydrogen absorption capacities. They currently include, in particular, the carbazole derivative N-ethylcarbazole, but also toluene

Surface storage systems (sorbents)

Finally, hydrogen can be stored as a sorbate by attachment (adsorption) on materials with high specific surface areas. Such sorption materials include, among others, microporous organometallic framework compounds (metal-organic frameworks (MOFs)), microporous crystalline aluminosilicates (zeolites) or microscopically small carbon nanotubes. Adsorption materials in powder form can achieve high volumetric storage densities.

Underground Storage

When it comes to the industrial storage of hydrogen, salt caverns, exhausted oil and gas fields or aquifers can be used as underground stores. Although being more expensive, cavern storage facilities are most suitable for hydrogen storage. Underground stores have been used for many years for natural gas and crude oil/oil products, which are stored in bulk to balance seasonal supply/demand fluctuations or for crisis preparedness.

To date, operational experience of hydrogen storage caverns exists only on a in a few locations in the USA and Europe. In particular, the underground natural gas stores in Europe and North America could potentially be used as large reservoirs for hydrogen generated from surplus renewable energies. However, only a relatively small proportion of these are storage caverns; the most prominent and common form of underground storage consists of depleted gas reservoirs. In addition, the natural gas stores are unevenly distributed at a regional level.

Gas Grid

Another possibility for storing surplus renewable energy in the form of hydrogen is to feed it into the public natural gas network (Hydrogen Enriched Natural Gas or HENG).

Until well into the 20th century, hydrogen-rich town gas or coke-oven gas with a hydrogen content above 50 vol% was distributed to households in Germany, the USA and England, for example, via gas pipelines – although not over long distances, for which as yet no experience is available.

Infrastructure elements that were installed at the time, such as pipelines, gas installations, seals, gas appliances etc., were designed for the hydrogen-rich gas and were later modified with the switch to natural gas. Many countries have looked at adding hydrogen into the existing natural gas networks. For the USA, it would be possible to introduce amounts from 5 vol% to 15 vol% hydrogen without substantial negative impact on end users or the pipeline infrastructure. At the same time, the larger additions of hydrogen would in some cases require expensive conversions of appliances. In Germany this limit has been set somewhat lower, at up to 10 vol%. In principle, gas at concentrations of up to 10 vol% hydrogen can be transported in the existing natural gas network without the risk of damage to gas installations, distribution infrastructure, etc. However, a number of components have been listed that are still considered to be critical and to be generally unsuitable for operation with these hydrogen concentrations. For CNG vehicles, the currently authorized limit value for the proportion of hydrogen used is only 2 vol%, depending on the materials built in (UNECE 2013).

It can be assumed that many of the gas transport networks, distribution lines and storage facilities that were operated in the past are still in use today. In Leeds (UK), for instance, the possibility has been explored of converting the existing natural gas network in the region (used primarily for municipal heating supply) entirely to hydrogen. Given their length, the large gas networks in many industrial countries could store considerable amounts of hydrogen.

Fuel cell :

A fuel cell is an electrochemical cell that converts the chemical energy of a fuel (often hydrogen) and an oxidizing agent (often oxygen) into electricity through a pair of redox reactions. Fuel cells are different from most batteries in requiring a continuous source of fuel and oxygen (usually from air) to sustain the chemical reaction, whereas in a battery the chemical energy usually comes from metals and their ions or oxides that are commonly already present in the battery, except in flow batteries. Fuel cells can produce electricity continuously for as long as fuel and oxygen are supplied.

There are many types of fuel cells, but they all consist of an anode, a cathode, and an electrolyte that allows ions, often positively charged hydrogen ions (protons), to move between the two sides of the fuel cell. At the anode a catalyst causes the fuel to undergo oxidation reactions that generate ions (often positively charged hydrogen ions) and electrons. The ions move from the anode to the cathode through the electrolyte. At the same time, electrons flow from the anode to the cathode through an external circuit, producing direct current electricity. At the cathode, another catalyst causes ions, electrons, and oxygen to react, forming water and possibly other products. Fuel cells are classified by the type of electrolyte they use and by the difference in startup time ranging from 1 second for proton exchange membrane fuel cells (PEM fuel cells, or PEMFC) to 10 minutes for solid oxide fuel cells (SOFC). A related technology is flow batteries, in which the fuel can be regenerated by recharging. 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. In addition to 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%; however, if waste heat is captured in a cogeneration scheme, efficiencies of up to 85% can be obtained.

Types of fuel cells

Fuel cells come in many varieties; however, they all work in the same general manner. They are made up of three adjacent segments: the anode, the electrolyte, and the cathode. Two chemical reactions occur at the interfaces of the three different segments. The net result of the two reactions is that fuel is consumed, water or carbon dioxide is created, and an electric current is created, which can be used to power electrical devices, normally referred to as the load.

At the anode a catalyst oxidizes the fuel, usually hydrogen, turning the fuel into a positively charged ion and a negatively charged electron. The electrolyte is a substance specifically designed so ions can pass through it, but the electrons cannot. The freed electrons travel through a wire creating the electric current. The ions travel through the electrolyte to the cathode. Once reaching the cathode, the ions are reunited with the electrons and the two react with a third chemical, usually oxygen, to create water or carbon dioxide.

Design features in a fuel cell include:

- The electrolyte substance, which usually defines the type of fuel cell, and can be made from a number of substances like potassium hydroxide, salt carbonates, and phosphoric acid.
- The fuel that is used. The most common fuel is hydrogen.
- The anode catalyst, usually fine platinum powder, breaks down the fuel into electrons and ions.
- The cathode catalyst, often nickel, converts ions into waste chemicals, with water being the most common type of waste.
- Gas diffusion layers that are designed to resist oxidization.

A typical fuel cell produces a voltage from 0.6–0.7 V at full rated load. Voltage decreases as current increases, due to several factors:

- Activation loss
- Ohmic loss (voltage drop due to resistance of the cell components and interconnections)
- Mass transport loss (depletion of reactants at catalyst sites under high loads, causing rapid loss of voltage).

To deliver the desired amount of energy, the fuel cells can be combined in series to yield higher voltage, and in parallel to allow a higher current to be supplied. Such a design is called a fuel cell stack. The cell surface area can also be increased, to allow higher current from each cell.

Proton-exchange membrane fuel cells (PEMFCs)

In the archetypical hydrogen–oxide proton-exchange membrane fuel cell design, a proton-conducting polymer membrane (typically nafion) contains the electrolyte solution that separates the anode and cathode sides. This was called a solid polymer electrolyte fuel cell (SPEFC) in the early 1970s, before the proton exchange mechanism was well understood.

On the anode side, hydrogen diffuses to the anode catalyst where it later dissociates into protons and electrons. These protons often react with oxidants causing them to become what are commonly referred to as multi-facilitated proton membranes. The protons are conducted through the membrane to the cathode, but the electrons are forced to travel in an external circuit (supplying power) because the membrane is electrically insulating. On the cathode catalyst, oxygen molecules react with the electrons (which have traveled through the external circuit) and protons to form water.

In addition to this pure hydrogen type, there are hydrocarbon fuels for fuel cells, including diesel, methanol (see: direct-methanol fuel cells and indirect methanol fuel cells) and chemical hydrides. The waste products with these types of fuel are carbon dioxide and water. When hydrogen is used, the CO2 is released when methane from natural gas is combined with steam, in a process called steam methane reforming, to produce the hydrogen. This can take place in a different location to the fuel cell, potentially allowing the hydrogen fuel cell to be used indoors—for example, in fork lifts.

The different components of a PEMFC are

1. bipolar plates,
2. electrodes,
3. catalyst,
4. membrane, and
5. the necessary hardware such as current collectors and gaskets.

The materials used for different parts of the fuel cells differ by type. The bipolar plates may be made of different types of materials, such as, metal, coated metal, graphite, flexible graphite, C–C composite, carbon–polymer composites etc. The membrane electrode assembly (MEA) is referred as the heart of the PEMFC and is usually made of a proton exchange membrane sandwiched between two catalyst-coated carbon papers. Platinum and/or similar type of noble metals are usually used as the catalyst for PEMFC. The electrolyte could be a polymer membrane.

Proton-exchange membrane fuel cell design issues

- Cost

  In 2013, the Department of Energy estimated that 80-kW automotive fuel cell system costs of US$67 per kilowatt could be achieved, assuming volume production of 100,000 automotive units per year and US$55 per kilowatt could be achieved, assuming volume production of 500,000 units per year. Many companies are working on techniques to reduce cost in a variety of ways including reducing the amount of platinum needed in each individual cell. Ballard Power Systems has experimented with a catalyst enhanced with carbon silk, which allows a 30% reduction (1.0–0.7 mg/cm^2) in platinum usage without reduction in performance. Monash University, Melbourne uses PEDOT as a cathode. A 2011-published study documented the first metal-free electrocatalyst using relatively inexpensive doped carbon nanotubes, which are less than 1% the cost of platinum and are of equal or superior performance. A recently published article demonstrated how the environmental burdens change when using carbon nanotubes as carbon substrate for platinum.

  - Water and air management (in PEMFCs)

  In this type of fuel cell, the membrane must be hydrated, requiring water to be evaporated at precisely the same rate that it is produced. If water is evaporated too quickly, the membrane dries, resistance across it increases, and eventually it will crack, creating a gas "short circuit" where hydrogen and oxygen combine directly, generating heat that will damage the fuel cell. If the water is evaporated too slowly, the electrodes will flood, preventing the reactants from reaching the catalyst and stopping the reaction. Methods to manage water in cells are being developed like electroosmotic pumps focusing on flow control. Just as in a combustion engine, a steady ratio between the reactant and oxygen is necessary to keep the fuel cell operating efficiently.

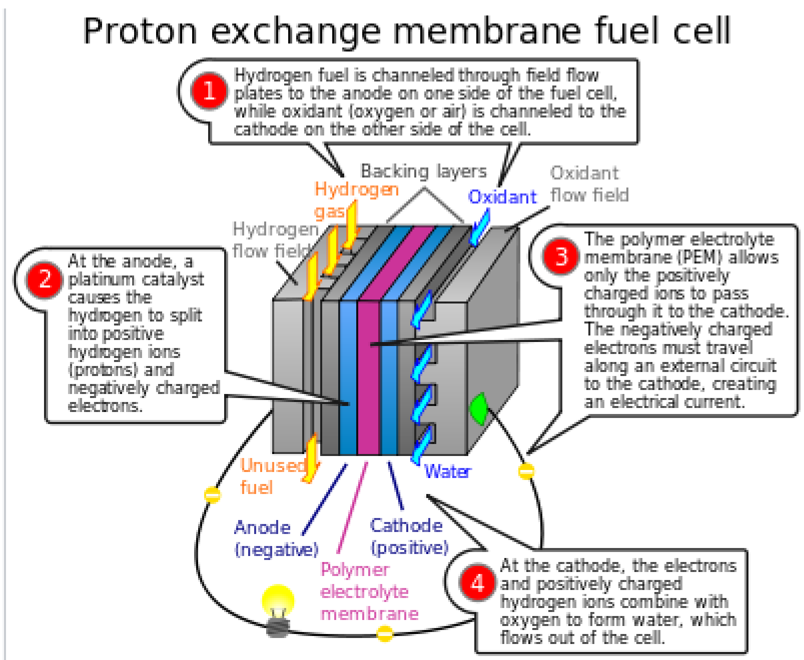
    - Temperature management

The same temperature must be maintained throughout the cell in order to prevent destruction of the cell through thermal loading. This is particularly challenging as the 2H2 + O2 → 2H2O reaction is highly exothermic, so a large quantity of heat is generated within the fuel cell.

- Durability, service life, and special requirements for some type of cells

Stationary fuel cell applications typically require more than 40,000 hours of reliable operation at a temperature of −35 °C to 40 °C (−31 °F to 104 °F), while automotive fuel cells require a 5,000-hour lifespan (the equivalent of 240,000 km (150,000 mi)) under extreme temperatures. Current service life is 2,500 hours (about 75,000 miles). Automotive engines must also be able to start reliably at −30 °C (−22 °F) and have a high power-to-volume ratio (typically 2.5 kW/L).

- Limited carbon monoxide tolerance of some (non-PEDOT) cathodes



Phosphoric acid fuel cell (PAFC)

Phosphoric acid fuel cells (PAFC) were first designed and introduced in 1961 by G. V. Elmore and H. A. Tanner. In these cells phosphoric acid is used as a non-conductive electrolyte to pass positive hydrogen ions from the anode to the cathode. These cells commonly work in temperatures of 150 to 200 degrees Celsius. This high temperature will cause heat and energy loss if the heat is not removed and used properly. This heat can be used to produce steam for air conditioning systems or any other thermal energy consuming system. Using this heat in cogeneration can enhance the efficiency of phosphoric acid fuel cells from 40–50% to about 80%.Phosphoric acid, the electrolyte used in PAFCs, is a non-conductive liquid acid which forces electrons to travel from anode to cathode through an external electrical circuit. Since the hydrogen ion production rate on the anode is small, platinum is used as catalyst to increase this ionization rate. A key disadvantage of these cells is the use of an acidic electrolyte. This increases the corrosion or oxidation of components exposed to phosphoric acid.

Solid acid fuel cell (SAFC)

Solid acid fuel cells (SAFCs) are characterized by the use of a solid acid material as the electrolyte. At low temperatures, solid acids have an ordered molecular structure like most salts. At warmer temperatures (between 140–150 °C for $CsHSO_4$), some solid acids undergo a phase transition to become highly disordered "superprotonic" structures, which increases conductivity by several orders of magnitude. The first proof-of-concept SAFCs were developed in 2000 using cesium hydrogen sulfate ($CsHSO_4$). Current SAFC systems use cesium dihydrogen phosphate (CsH_2PO_4) and have demonstrated lifetimes in the thousands of hours.

Alkaline fuel cell (AFC)

The alkaline fuel cell or hydrogen-oxygen fuel cell was designed and first demonstrated publicly by Francis Thomas Bacon in 1959. It was used as a primary source of electrical energy in the Apollo space program. The cell consists of two porous carbon electrodes impregnated with a suitable catalyst such as Pt, Ag, CoO, etc. The space between the two electrodes is filled with a concentrated solution of KOH or NaOH which serves as an electrolyte. H_2 gas and O_2 gas are bubbled into the electrolyte through the porous carbon electrodes. Thus the overall reaction involves the combination of hydrogen gas and oxygen gas to form water. The cell runs continuously until the reactant's supply is exhausted. This type of cell operates efficiently in the temperature range 343–413 K and provides a potential of about 0.9 V. AAEMFC is a type of AFC which employs a solid polymer electrolyte instead of aqueous potassium hydroxide (KOH) and it is superior to aqueous AFC.

High-temperature fuel cells:

Solid oxide fuel cell

Solid oxide fuel cells (SOFCs) use a solid material, most commonly a ceramic material called yttria-stabilized zirconia (YSZ), as the electrolyte. Because SOFCs are made entirely of solid materials, they are not limited to the flat plane configuration of other types of fuel cells and are often designed as rolled tubes. They require high operating temperatures (800–1000 °C) and can be run on a variety of fuels including natural gas.

SOFCs are unique since in those, negatively charged oxygen ions travel from the cathode (positive side of the fuel cell) to the anode (negative side of the fuel cell) instead of positively charged hydrogen ions travelling from the anode to the cathode, as is the case in all other types of fuel cells. Oxygen gas is fed through the cathode, where it absorbs electrons to create oxygen ions. The oxygen ions then travel through the electrolyte to react with hydrogen gas at the anode. The reaction at the anode produces electricity and water as by-products. Carbon dioxide may also be a by-product depending on the fuel, but the carbon emissions from an SOFC system are less than those from a fossil fuel combustion plant. The chemical reactions for the SOFC system can be expressed as follows:

Anode reaction: $2H_2 + 2O^{2-} \rightarrow 2H_2O + 4e^-$

Cathode reaction: $O_2 + 4e^- \rightarrow 2O^{2-}$

Overall cell reaction: $2H_2 + O_2 \rightarrow 2H_2O$

SOFC systems can run on fuels other than pure hydrogen gas. However, since hydrogen is necessary for the reactions listed above, the fuel selected must contain hydrogen atoms. For the fuel cell to operate, the fuel must be converted into pure hydrogen gas.

SOFCs are capable of internally reforming light hydrocarbons such as methane (natural gas), propane and butane. These fuel cells are at an early stage of development.

Challenges exist in SOFC systems due to their high operating temperatures. One such challenge is the potential for carbon dust to build up on the anode, which slows down the internal reforming process. Research to address this "carbon coking" issue at the University of Pennsylvania has shown that the use of copper-based cermet (heat-resistant materials made of ceramic and metal) can reduce coking and the loss of performance. Another disadvantage of SOFC systems is slow start-up time, making SOFCs less useful for mobile applications. Despite these disadvantages, a high operating temperature provides an advantage by removing the need for a precious metal catalyst like platinum, thereby reducing cost. Additionally, waste heat from SOFC systems may be captured and reused, increasing the theoretical overall efficiency to as high as 80–85%.

The high operating temperature is largely due to the physical properties of the YSZ electrolyte. As temperature decreases, so does the ionic conductivity of YSZ. Therefore, to obtain optimum performance of the fuel cell, a high operating temperature is required. According to their website, Ceres Power, a UK SOFC fuel cell manufacturer, has developed a method of reducing the operating temperature of their SOFC system to 500–600 degrees Celsius. They replaced the commonly used YSZ electrolyte with a CGO (cerium gadolinium oxide) electrolyte. The lower operating temperature allows them to use stainless steel instead of ceramic as the cell substrate, which reduces cost and start-up time of the system.

Molten-carbonate fuel cell (MCFC)

Molten carbonate fuel cells (MCFCs) require a high operating temperature, 650 °C (1,200 °F), similar to SOFCs. MCFCs use lithium potassium carbonate salt as an electrolyte, and this salt liquefies at high temperatures, allowing for the movement of charge within the cell – in this case, negative carbonate ions.

Like SOFCs, MCFCs are capable of converting fossil fuel to a hydrogen-rich gas in the anode, eliminating the need to produce hydrogen externally. The reforming process creates CO
2 emissions. MCFC-compatible fuels include natural gas, biogas and gas produced from coal. The hydrogen in the gas reacts with carbonate ions from the electrolyte to produce water, carbon dioxide, electrons and small amounts of other chemicals. The electrons travel through an external circuit creating electricity and return to the cathode. There, oxygen from the air and carbon dioxide recycled from the anode react with the electrons to form carbonate ions that replenish the electrolyte, completing the circuit. The chemical reactions for an MCFC system can be expressed as follows:

Anode reaction: $CO_3^{2-} + H_2 \rightarrow H_2O + CO_2 + 2e^-$

Cathode reaction: $CO_2 + ½O_2 + 2e^- \rightarrow CO_3^{2-}$

Overall cell reaction: $H_2 + ½O_2 \rightarrow H_2O$

As with SOFCs, MCFC disadvantages include slow start-up times because of their high operating temperature. This makes MCFC systems not suitable for mobile applications, and this technology will most likely be used for stationary fuel cell purposes. The main challenge of MCFC technology is the cells' short life span. The high-temperature and carbonate electrolyte lead to corrosion of the anode and cathode. These factors accelerate the degradation of MCFC components, decreasing the durability and cell life. Researchers are addressing this problem by exploring corrosion-resistant materials for components as well as fuel cell designs that may increase cell life without decreasing performance.

MCFCs hold several advantages over other fuel cell technologies, including their resistance to impurities. They are not prone to "carbon coking", which refers to carbon build-up on the anode that results in reduced performance by slowing down the internal fuel reforming process. Therefore, carbon-rich fuels like gases made from coal are compatible with the system. The United States Department of Energy claims that coal, itself, might even be a fuel option in the future, assuming the system can be made resistant to impurities such as sulfur and particulates that result from converting coal into hydrogen. MCFCs also have relatively high efficiencies. They can reach a fuel-to-electricity efficiency of 50%, considerably higher than the 37–42% efficiency of a phosphoric acid fuel cell plant. Efficiencies can be as high as 65% when the fuel cell is paired with a turbine, and 85% if heat is captured and used in a combined heat and power (CHP) system.

FuelCell Energy, a Connecticut-based fuel cell manufacturer, develops and sells MCFC fuel cells. The company says that their MCFC products range from 300 kW to 2.8 MW systems that achieve 47% electrical efficiency and can utilize CHP technology to obtain higher overall efficiencies. One product, the DFC-ERG, is combined with a gas turbine and, according to the company, it achieves an electrical efficiency of 65%.

Electric storage fuel cell

The electric storage fuel cell is a conventional battery chargeable by electric power input, using the conventional electro-chemical effect. However, the battery further includes hydrogen (and oxygen) inputs for alternatively charging the battery chemically.

Applications

- Power

Stationary fuel cells are used for commercial, industrial and residential primary and backup power generation. Fuel cells are very useful as power sources in remote locations, such as spacecraft, remote weather stations, large parks, communications centers, rural locations including research stations, and in certain military applications. A fuel cell system running on hydrogen can be compact and lightweight, and have no major moving parts. Because fuel cells have no moving parts and do not involve combustion, in ideal conditions they can achieve up to 99.9999% reliability. This equates to less than one minute of downtime in a six-year period.

Since fuel cell electrolyzer systems do not store fuel in themselves, but rather rely on external storage units, they can be successfully applied in large-scale energy storage, rural areas being one example. There are many different types of stationary fuel cells so efficiencies vary, but most are between 40% and 60% energy efficient. However, when the fuel cell's waste heat is used to heat a building in a cogeneration system this efficiency can increase to 85%.This is significantly more efficient than traditional coal power plants, which are only about one third energy efficient. Assuming production at scale, fuel cells could save 20–40% on energy costs when used in cogeneration systems. Fuel cells are also much cleaner than traditional power generation; a fuel cell power plant using natural gas as a hydrogen source would create less than one ounce of pollution (other than CO 2) for every 1,000 kW·h produced, compared to 25 pounds of pollutants generated by conventional combustion systems. Fuel Cells also produce 97% less nitrogen oxide emissions than conventional coal-fired power plants.

One such pilot program is operating on Stuart Island in Washington State. There the Stuart Island Energy Initiative has built a complete, closed-loop system: Solar panels power an electrolyzer, which makes hydrogen. The hydrogen is stored in a 500-U.S.-gallon (1,900 L) tank at 200 pounds per square inch (1,400 kPa), and runs a ReliOn fuel cell to provide full electric back-up to the off-the-grid residence. Another closed system loop was unveiled in late 2011 in Hempstead, NY.

Fuel cells can be used with low-quality gas from landfills or waste-water treatment plants to generate power and lower methane emissions. A 2.8 MW fuel cell plant in California is said to be the largest of the type.

- Cogeneration

Combined heat and power (CHP) fuel cell systems, including micro combined heat and power (MicroCHP) systems are used to generate both electricity and heat for homes (see home fuel cell), office building and factories. The system generates constant electric power (selling excess power back to the grid when it is not consumed), and at the same time produces hot air and water from the waste heat. As the result CHP systems have the potential to save primary energy as they can make use of waste heat which is generally rejected by thermal energy conversion systems.A typical capacity range of home fuel cell is 1–3 kWel, 4–8 kWth. CHP systems linked to absorption chillers use their waste heat for refrigeration.

The waste heat from fuel cells can be diverted during the summer directly into the ground providing further cooling while the waste heat during winter can be pumped directly into the building. The University of Minnesota owns the patent rights to this type of system.

Co-generation systems can reach 85% efficiency (40–60% electric and the remainder as thermal).[5] Phosphoric-acid fuel cells (PAFC) comprise the largest segment of existing CHP products worldwide and can provide combined efficiencies close to 90%. Molten carbonate (MCFC) and solid-oxide fuel cells (SOFC) are also used for combined heat and power generation and have electrical energy efficiencies around 60%. Disadvantages of co-generation systems include slow ramping up and down rates, high cost and short lifetime. Also their need to have a hot water storage tank to smooth out the thermal heat production was a serious disadvantage in the domestic market place where space in domestic properties is at a great premium.

Delta-ee consultants stated in 2013 that with 64% of global sales the fuel cell micro-combined heat and power passed the conventional systems in sales in 2012.[73] The Japanese ENE FARM project will pass 100,000 FC mCHP systems in 2014, 34.213 PEMFC and 2.224 SOFC were installed in the period 2012–2014, 30,000 units on LNG and 6,000 on LPG.

- Fuel cell electric vehicles (FCEVs)

Automobiles

Buses

Forklifts

Motorcycles and bicycles

Boats

Submarines

- Portable power systems

Portable fuel cell systems are generally classified as weighing under 10 kg and providing power of less than 5 kW.[155] The potential market size for smaller fuel cells is quite large with an up to 40% per annum potential growth rate and a market size of around $10 billion, leading a great deal of research to be devoted to the development of portable power cells.[156] Within this market two groups have been identified. The first is the microfuel cell market, in the 1-50 W range for power smaller electronic devices. The second is the 1-5 kW range of generators for larger scale power generation.

0ther applications

- Providing power for base stations or cell sites
- Distributed generation
- Emergency power systems are a type of fuel cell system, which may include lighting, generators and other apparatus, to provide backup resources in a crisis or when regular systems fail. They find uses in a wide variety of settings from residential homes to hospitals, scientific laboratories, data centers,
- Telecommunication equipment and modern naval ships.
- An uninterrupted power supply (UPS) provides emergency power and, depending on the topology, provide line regulation as well to connected equipment by supplying power from a separate source when utility power is not available. Unlike a standby generator, it can provide instant protection from a momentary power interruption.
- Base load power plants
- Solar Hydrogen Fuel Cell Water Heating
- Hybrid vehicles, pairing the fuel cell with either an ICE or a battery.
- Notebook computers for applications where AC charging may not be readily available.
- Portable charging docks for small electronics (e.g. a belt clip that charges a cell phone or PDA).
- Smartphones, laptops and tablets.
- Small heating appliances
- Food preservation, achieved by exhausting the oxygen and automatically maintaining oxygen exhaustion in a shipping container, containing, for example, fresh fish.
- Breathalyzers, where the amount of voltage generated by a fuel cell is used to determine the concentration of fuel (alcohol) in the sample.
- Carbon monoxide detector, electrochemical sensor.

Energy storge system:

Types of Energy Storage

Storage options include batteries, thermal, or mechanical systems. All of these technologies can be paired with software that controls the charge and discharge of energy.

There are many types of energy storage; this list serves as an informational resource for anyone interested in getting to know some of the most common technologies available. You can learn more about these and other energy storage technologies in the U.S. Department of Energy's Energy Storage Handbook .

Batteries

There are various forms of batteries, including: lithium-ion, flow, lead acid, sodium, and others designed to meet specific power and duration requirements.

Initially used for consumer products, lithium-ion batteries now have a range of applications including smaller residential systems and larger systems that can store multiple megawatt hours (MWh) and can support the entire electric grid. These systems typically house a large number of batteries together on a rack, combined with monitoring and management units. These systems have a small footprint for the amount of energy they store. For example, a system the size of a small refrigerator could power an average home for several days. A utility-scale system of 100 MWh could fit on less than 0.5 acres.

Lithium-ion batteries have received a lot of press for their rapidly declining costs, due to the growing popularity of electric vehicles.

A different type of battery is a flow battery in which energy is stored and provided by two chemicals that are dissolved in liquids and stored in tanks. These are well suited for longer duration storage.

Thermal

Thermal systems use heating and cooling methods to store and release energy. For example, molten salt stores solar-generated heat for use when there is no sunlight. Ice storage in buildings reduces the need to run compressors while still providing air conditioning over a period of several hours. Other systems use chilled water and dispatchable hot water heaters. In all cases, excess energy charges the storage system (heat the molten salts, freeze the water, etc.) and is later released as needed.

Mechanical Systems

Flywheels

Flywheels store energy in a rapidly spinning mechanical rotor and are capable of absorbing and releasing high power for typically 15 minutes or less, although longer duration systems are being developed. These systems can balance fluctuations in electricity supply and demand where they respond to a control signal adjusted every few seconds. They also recapture braking energy from electric trains in some installations or provide short-term power until backup generation comes online during a grid outage, such as in a critical manufacturing process where product would be lost by a momentary electric interruption.

Pumped Hydro Power

Pumped hydroelectric facilities are the most common form of energy storage on the grid and account for over 95% of the storage in use today. During off-peak hours, turbines pump water to an elevated reservoir using excess electricity. When electricity demand is high, the reservoir opens to allow the retained water to flow through turbines and produce electricity. Siting these systems can be difficult because of the terrain needed (an upper and lower pool of water) and large footprint.

Emerging Technologies

Compressed air, superconducting magnets, underground pumped storage, and hydrogen storage are all forms of emerging energy storage that are in different stages of development. Like NYSERDA, many storage vendors are technology agnostic—they can use their software to dispatch different storage technologies and will procure the storage technology from a manufacturing partner that best suits the requirements of the site.

Hybrid renewable energy 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.

The potential benefits of hybrid systems could include:

- Optimise performance of overall scheme as compared with individual technologies
- Minimise mismatch between energy generation and usage
- Reduce overall demand or wastage
- Reduce carbon emissions
- Optimise cost of the installation

Hybrid energy systems include 2 major parts:

◊ Electricity generation
◊ Heat generation

We will assess the feasibility of hybrid energy systems according to the following priorities:

- The building should be 'low carbon'
- Physical integration of the technologies within the building must be possible
- If possible, the system cost should be viable

♦ Electricity Generation

In electricity generation we will assess what contribution individual technologies can provide (wind, PV and CHP) and how a hybrid combination could improve the scheme. Electricity storage on site is not considered since we have assumed grid connection in the scope of the project.

The inter-connection of different sources using inverters and other devices is well established and therefore will not be addressed.

♦ Heat Generation

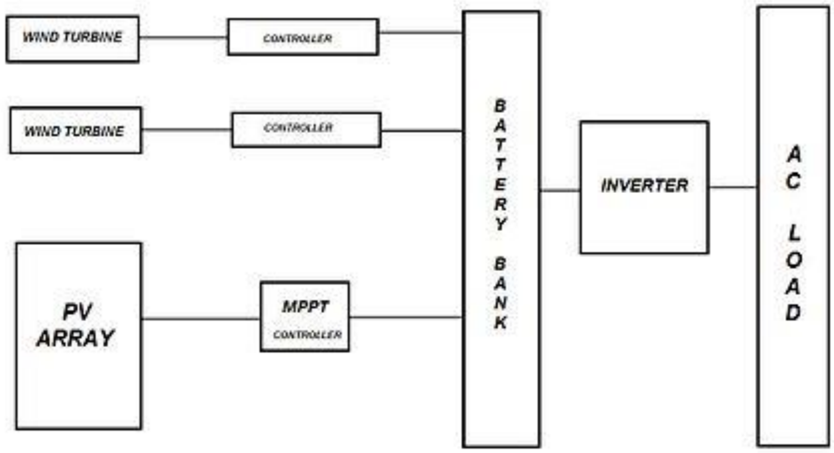
Heat generating options are assessed according to the demand in the various case-studies.
The inter-connection between different sources of heat will be analysed, more particularly the problem to combine various inputs and outputs of heat which have different temperatures.

The hybrid systems should also include heat storage options (short term and long term). The potential benefits are to manage the surplus energy generated but also to deal with the different output temperature of various heat systems.

Furthermore, heat recovery systems are also applied since air to air heat exchangers are devices designed to recover heat from exhaust to inlet ducts in order to preheat or pre cool fresh air introduced to a building. Natural ventilation options are also considered within the hybrid system, in order to reduce accordingly either the heating or the cooling loads.

.

Photovoltaic and wind



Another example of a hybrid energy system is a photovoltaic array coupled with a wind turbine. This would create more output from the wind turbine during the winter, whereas during the summer, the solar panels would produce their peak output. Hybrid energy systems often yield greater economic and environmental returns than wind, solar, geothermal or trigeneration stand-alone systems by themselves.

Biomass-wind-fuel cell

For example, consider a load of 100% power supply and there is no renewable system to fulfill this need, so two or more renewable energy system can be combined. For example, 60% from a biomass system, 20% from wind system and the remainder from fuel cells. Thus combining all these renewable energy systems may provide 100% of the power and energy requirements for the load, such as a home or business.

Completely Renewable Idea

Completely Renewable Hybrid Power Plant (solar, wind, biomass, hydrogen) A hybrid power plant consisting of these four renewable energy sources can be made into operation by proper utilization of these resources in a completely controlled manner. Hybrid Energy Europe-USA. Caffese in Europe introduce hybridizing HVDC transmission with Marine hydro pumped Energy Storage via elpipes. The project of Caffese is 3 marine big lakes producing 1800 GW and transmission with elpipes. A part 1200 GW produce water fuels-wind fuels-solar fuels 210 billion liter year. (IEEE Power and Engineering Society-General Meeting Feb.9.2011,Arpa-E,Doe USA,MSE Italy, European Commission-Energy-Caffese plan and Consortium 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.