Introduction To Renewable Energy

Environmental consequences of fossil fuel use-

3 Impacts of Fossil Fuel Use on the Environment

According to the United States Environmental Protection Agency (EPA), the burning of fossil fuels causes community health risks, pollution, and global warming. The environmental impacts of fossil fuels include:

Air pollution: The burning of fossil fuels, particularly coal, can release harmful chemicals like sulfur dioxide and carbon monoxide into the air. The health effects of air pollution include severe asthma, which has been observed in regions downwind of coal power plants.

Water pollution: The sulfur dioxide released from untreated coal smoke can mix with other elements and produce acid rain, and oil spills poison marine ecosystems. While water pollution is not unique to fossil fuels (even so-called clean energy sources like nuclear can pollute water), unregulated fuel spillage pollutes water and endangers plants, animals, and human health.

Global warming: Methane and carbon dioxide emissions stemming from electricity plants, gasoline-burning vehicles, cement manufacturing, and other industrial processes trap heat in Earth's atmosphere, leading to a surge in global temperatures in recent decades.

Importance of renewable sources of energy-

Renewable energy is important because of the benefits it provides.

The key benefits are:

Environmental Benefits

Renewable energy technologies are clean sources of energy that have a much lower environmental impact than conventional energy technologies.

Energy for our children's children's children

Renewable energy will not run out. Ever. Other sources of energy are finite and will some day be depleted.

Jobs and the Economy

Most renewable energy investments are 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 United States, frequently in the same state, and often in the same town. This means your energy dollars stay home to create jobs and fuel local economies, rather than going overseas.Meanwhile, renewable energy technologies developed and built in the United States are being sold overseas, providing a boost to the U.S. trade deficit.

Energy Security

After the oil supply disruptions of the early 1970s, our nation has increased its dependence on foreign oil supplies instead of decreasing it. This increased dependence impacts more than just our national energy policy.

Sustainable design and development-

The main goals of sustainable design were to reduce depletion of critical resources such as energy, water, and raw materials; prevent environmental degradation caused by facilities and infrastructure throughout their life cycle; and create built environments that are safe, productive and effective utility of the water.

Types of RE sources-

The most popular renewable energy sources currently are:

Solar energy

Wind energy

Hydro energy

Tidal energy

Geothermal energy

Biomass energy

1) 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.

2) Wind energy

Wind is a plentiful source of clean energy. Wind farms are an increasingly familiar sight in the UK 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.

3) Hydro energy

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.

4) Tidal energy

This is another form of hydro energy that uses twice-daily tidal currents to drive turbine generators. Although tidal flow unlike some other hydro energy sources isn't constant, it is highly predictable and can therefore compensate for the periods when the tide current is low.

5) Geothermal energy

By harnessing the natural heat below the earth's surface, geothermal energy can be used to heat homes directly or to generate electricity. Although it harnesses a power directly below our feet, geothermal energy is of negligible importance in the UK compared to countries such as Iceland, where geothermal heat is much more freely available.

6) Biomass Energy

This is the conversion of solid fuel made from plant materials into electricity. Although fundamentally, biomass involves burning organic materials to produce electricity, and nowadays this is a much cleaner, more energy-efficient process. By converting agricultural, industrial and domestic waste into solid, liquid and gas fuel, biomass generates power at a much lower economic and environmental cost.

Limitations of renewable energy resources

- The Electricity Generation Capacity is Still Not Large Enough. ...
- Renewable Energy Can be Unreliable. ...
- Low-efficiency Levels. ...
- Requires a Huge Upfront Capital Outlay. ...
- Takes a Lot of Space to Install. ...
- Expensive Storage Costs. ...
- Not Always a Commercially-viable Option. ...
- It Still Generates Pollution.

Present india and international energy scenario of conventional and RE sources

Majority of the power generation in India is carried out by conventional energy sources, coal and fossil fuels being the primary ones, which contribute heavily to greenhouse gas emission and global warming. The Indian power sector is witnessing a revolution as excitement grips the nation about harnessing electricity from various renewable energy sources. Electricity generation from renewable sources is increasingly recognized to play an important role for the achievement of a variety of primary and secondary energy policy goals, such as improved diversity and security of energy supply, reduction of local pollutant and global greenhouse gas emissions, regional and rural development, and exploitation of opportunities for fostering social cohesion, value addition and employment generation at the local and regional level. This focuses the solution of the energy crisis on judicious utilization of abundant the renewable energy resources, such as biomass, solar, wind, geothermal and ocean tidal energy. This paper reviews the renewable energy scenario of India as well as extrapolates the future developments keeping in view the consumption, production and supply of power.

Fossil Fuel

Fossil Fuel is an umbrella term used to refer to hydrocarbons like petroleum, coal, natural gas, tar sands which are found on the earth's surface. The fuels were formed from the fossilized remains of plants and animals that died millions of years ago. The remains were then pushed deeper and deeper into the earth's crust where they were subjected to intense heat and pressure. Additionally, these fuels are also termed as a non-renewable source of energy as they are finite. The effect of fossil fuels has been explained below.

Types of Fossil Fuels

The three conventional fuels and their environmental impacts have been explained below.

- **Natural Gas**

It is a gaseous form of hydrocarbon which is non-toxic, odourless, and colourless. It has methane as its major component. They are generally found near other fossil fuel reserves like coal and petroleum. However, in certain cases, gas reservoirs also exist without any oil. This is known as dry gas.

Natural Gas in its purest form cannot be used. Instead, it is processed into much cleaner fuel for mass consumption. During processing, many other gases are also extracted as by-products. This includes nitrogen, propane, ethane, carbon dioxide, which can be utilized for other purposes.

Among all the other fossil fuels, natural gas is the cleanest. Compared to coal, it releases around half of the carbon dioxide and only one-tenth of air pollutants when it is used for electricity generation. Consequently, the effect of fossil fuels like natural gas on the environment is also less.

- **Petroleum**

Petroleum or crude oil is another fossil fuel that is found buried deep beneath the earth's surface. The word Petroleum was derived from the two Latin words 'Petra' which means rock and 'oleum' meaning oil. Much of the Petroleum found in the world today formed during the Mesozoic period when plankton, algae, and other living organisms got buried deep under the seafloor.

This fuel whose main components are carbon and hydrogen holds significant influence as a world energy source. Petroleum is used to manufacture several essential objects that we require on a day to day basis. Accordingly, the effect of fossil fuel like petroleum on the environment is also the highest.

This includes products like gasoline, plastics, paints, detergents, dyes, pesticides, rubber, and the likes. Indeed due to its high demand in almost every country of the world, it is sometimes termed as liquid gold. Some of the major Petroleum producing countries include the USA, Saudi Arabia, and Russia, which constitute around 40% of the world's petroleum supply.

- **Coal**

This fossil fuel was formed from the remains of plants and vegetation in swamp areas and peat bogs that got buried deep under the earth's crust due to tectonic plate movement and other natural processes. Due to extreme heat and pressure, during the burial process, the remains of vegetation were first converted to peat and then finally into coal.

This process of conversion of vegetable matter to peat to anthracite is known as coalification. It is a crucial process in the sense that many of the physical and chemical properties of coal are determined during this process which is known as the 'rank' of coal. Based on this rank, coal can be subdivided into several types – Anthracite, Bituminous, Subbituminous, and Lignite.

Effect of Fossil Fuels on the Environment

Conventional sources of energy fossil fuels are one of the world's biggest sources of energy. It is used to generate electricity, heat homes, run vehicles, power industries, as well as manufacture many essential products.

As such, our life as we know it is heavily dependent on these fuels – Petroleum, coal, natural gas.

However, like everything, it comes at a price. The harmful effects of fuels have had a significant impact on our environment in several ways.

- **Harmful Effects of Fossil Fuels on the Ecosystem**

First and foremost drilling in sea beds and coal mining significantly impacts the natural ecosystem of a particular place. For instance, when new coal mines are found, forests, grasslands, and even villages are cleared in most cases to build roads for smooth transportation of coals. This disturbs the everyday lifestyle of not only human beings living in that area but also of animals and birds residing in that particular area.

- **Effect of Fossil Fuel on Human Health**

Digging for natural gas and oil around human habitat may have a severe health impact on nearby communities. For instance, due to some unforeseen damage, the air or drinking water may get contaminated, resulting in fatalities or disabilities.

- **Environmental Impact of Fossil Fuels**

The use of the latest technology to derive Petroleum from the sea bed reduces groundwater level and results in land degradation. Burning fossil fuels affects the air too by creating pollution.

- **The Harmful Effect of Burning Fuel**

Lastly, fossil fuels when burned emit harmful carbon and other poisonous gases that trap heat, thereby accelerating global warming and other climate changes. The oceans which absorb most human-made carbon have become more acidic compared to at the start of the industrial revolution.

Lastly, it is essential to remember that these fossil fuels are a non-renewable source of energy. This means they are not abundant in nature. If we use them without paying any heed to sustainable consumption, then they will get exhausted quickly, and there will not be fuel left for future generations.

So besides responsible usage, it is now high time that we look for other renewable sources of energy to meet our needs and to avoid the toxic effect of fossil fuels.

The Effects of Burning Fossil Fuel:

Burning fossil fuel can affect the environment, air quality, climatic conditions, and human health. Every recent study by the scientist states that the burning of the fossil fuels such as coal, oil, gas for energy is the main contributor to the rapidly rising level of carbon dioxide that is driving the climate change. As the burning of fossil fuel increases, the climatic condition will change and increase the temperature. Fossil fuel extraction, processing, and burning can have negative health effects on the communities.

1. Global Warming Pollution

Fossil fuel and global warming are closely associated with each other. The presence of high levels of carbon dioxide in the atmosphere results in an increase in the amount of heat and temperature on the surface of the Earth. This is because carbon dioxide traps heat obtained from sunlight and it does not dissipate out of the atmosphere, this process known as the greenhouse effect. Since fossil fuels are hydrocarbons (made from hydrogen and carbon), burning fossil fuels releases an enormous amount of carbon dioxide into the air. When there's a major rise in the percentage of carbon dioxide in the air, the amount of heat captured by the carbon dioxide gas also increases. This, in turn, results in an overall rise in the surface temperature of the earth, that is additionally referred to as global warming.

2. Higher Rise in the Sea Level

The rise in the sea level can adversely affect the climate of the earth. We will witness a drastic change in the weather conditions in various parts of the world. The glaciers of the Earth will melt at a much faster rate. As a result of this, the areas which are located near the water bodies like, the coastal regions and the banks of the river are likely to get submerged under water.

Lots of islands, deltas, thickly inhabited cities will get enclosed by water. Droughts and floods can occur more frequently in several inland areas that have extreme weather. The cities that are situated near the sea would also suffer the consequences.

3.Other Forms of Air Pollution

We also cause air pollution indirectly, like when we buy goods and services that make use of energy in their manufacture and delivery. Most of this air pollution we tend to cause results from the burning of fossil fuels, such as coal, oil, natural gas, and gasoline to produce electricity and power for our vehicles. Fossil fuels emit more than simply carbon dioxide when burned. Due to the burning of Fossil fuels, many harmful pollutants are formed such as Nitrogen Oxides (NOx), Carbon Monoxide (CO), Volatile Organic Compounds (VOCs), Particulate Matter, Lead, Mercury and Sulfur dioxide (SO_2). Coal-fired power plants singlehandedly generate 42 percent of dangerous mercury emissions and the vast majority of the particulate matter in our air. In the meantime, fossil fuel powered trucks, cars, and boats are the main suppliers of toxic carbon monoxide gas and nitrogen oxide, which produces smog (and metabolism illnesses) on hot days. Fuels such as coal, petroleum release unburnt particles in the environment. The particles result in air pollution and cause respiratory diseases such as respiratory illness, lung damage, ozone (smog) effect, reduces the ability of blood to bring oxygen to the blood cells and tissues, liver and kidney etc.

1. Toxic Gases Causing Acid Rain

The burning of fossil fuel gives out harmful compounds like sulfur dioxide and nitrogen oxides. These substances will rise terribly high into the atmosphere, wherever they combine and react with water, oxygen, and other chemicals to form a lot of acidic pollutants, called air pollution. Sulfur dioxide and nitrogen oxides dissolve very easily with water and are carried very far by the wind. As a result, both the compounds can travel long distances where they become part of the rain, sleet, snow, and fog that we experience on certain days.

Human activities are the main reason for acid rain. Over the past few decades, we humans have released so many different chemicals into the air that they have changed the mix of gases in the atmosphere. Huge Power plants release the majority of sulfur dioxide and much of the nitrogen oxides when they burn fossil fuels, such as coal, to produce electricity. In addition to this, the gases from cars, trucks, and buses release nitrogen oxides and sulfur dioxide into the air. These pollutants cause acid rain by the wind.

2. Oil Spills

Crude oil or petroleum is often transported from one place to another by tankers and ships. Any leakage in these tankers causes oil spills. This issue can lead to water pollution and poses a problem for marine lives. Thus, we can see that the issue of fossil fuels, global warming, and climate change are all interwoven with each other. We all have to play a vital role in controlling their harmful effects. If we take some small measures from our side, then we can save our mother earth from any major disaster. We should reduce energy consumption in our homes when not in use and use our vehicles only for travelling short distances. We also have to stop cutting trees and plant more saplings regularly. This is because plants use up the carbon dioxide from the atmosphere and thus check its level from rising and protects the environment. Our activities have put the earth at risk, and it's now our responsibility to reverse the trend.

3. Ocean Acidification

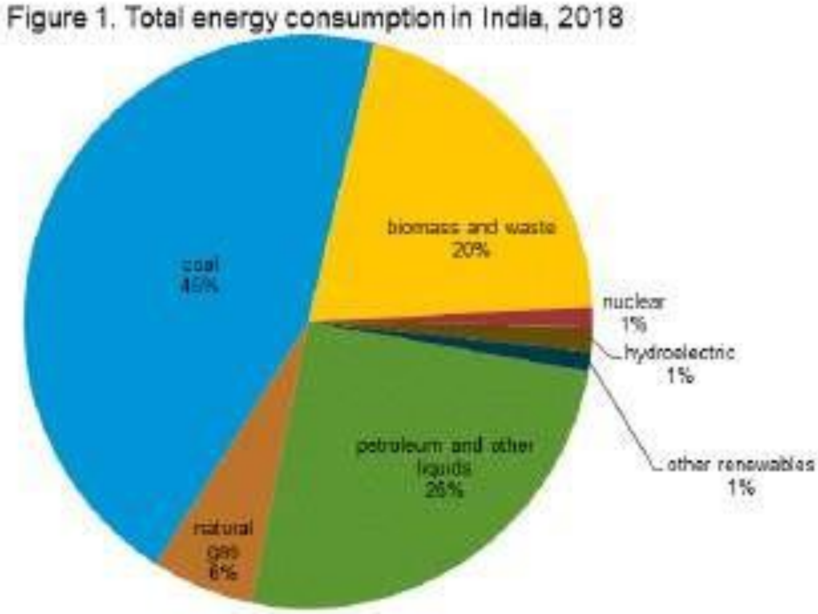
When we burn crude oil, coal, and gas, we change the ocean's basic chemistry, making it more acidic. Our seas absorb as much as a quarter of all carbon emitted. Since the start of the Industrial Revolution and our fossil fuel burning ways, the ocean has become 30 percent more acidic. As the acidity in our waters increases, the amount of calcium carbonate which is a substance used by oysters, lobsters, and countless other marine organisms to form shells will go down. The growth rate of the species when reduced weakens the shells and imperils entire food chains.

When we start analyzing the effects caused by burning fossil fuels, we can conclude that all the problems are interlinked. We have to reduce the burning of fuels and save our environment.

INDIAN ENERGY SCINARIO

- India was the third-largest energy consumer in the world after China and the United States in 2018, according to the BP Statistical Review of 2019, and its need for energy supply continues to climb as a result of the country's dynamic economic growth, population growth, and modernization over the past several years. In 2019, the economy struggled with a financial and lending crisis, consumption and investment declines, and regulatory issues &The outbreak of the coronavirus (COVID-19) in India that began at the start of 2020 and the country's ensuing national lockdown from late March through mid-May to stop the spread of the virus has adversely impacted industrial and economic activity, labor mobility, and energy use within India and is likely to push GDP growth much lower in 2020, according to several experts.
- Indian government continues to face several challenges to meet the country's growing energy demand, including securing affordable energy supplies and attracting investment for upstream projects and transmission infrastructure. The government has made considerable headway with energy reforms since the BJP was first elected in 2014, and it pledges to continue focusing on greater energy security, infrastructure development, and market liberalization.
- Primary energy consumption in India has nearly tripled between 1990 and 2018, reaching an estimated 916 million tons of oil equivalent.Coal continued to supply most (45%) of India's total energy consumption in 2018, followed by petroleum and other liquids (26%), and traditional biomass and waste (20%). Other renewable fuel sources make up a small portion of primary energy consumption, although the capacity potential is significant for several of these resources, such as solar, wind, and hydroelectricity.
- The country has moved away from traditional biomass and waste over the past several years as the availability of electricity connections spread for the residential and commercial sectors. Although natural gas accounts for 6% of the country's energy consumption, India plans to boost the natural gas market share to 15% by 2030 as part of the country's plan to reduce air pollution and use cleaner-burning fuels.7 (Figure 1)

Figure 1. Total energy consumption in India, 2018



Source: International Energy Agency, World Energy Outlook 2019

Petroleum and other liquids

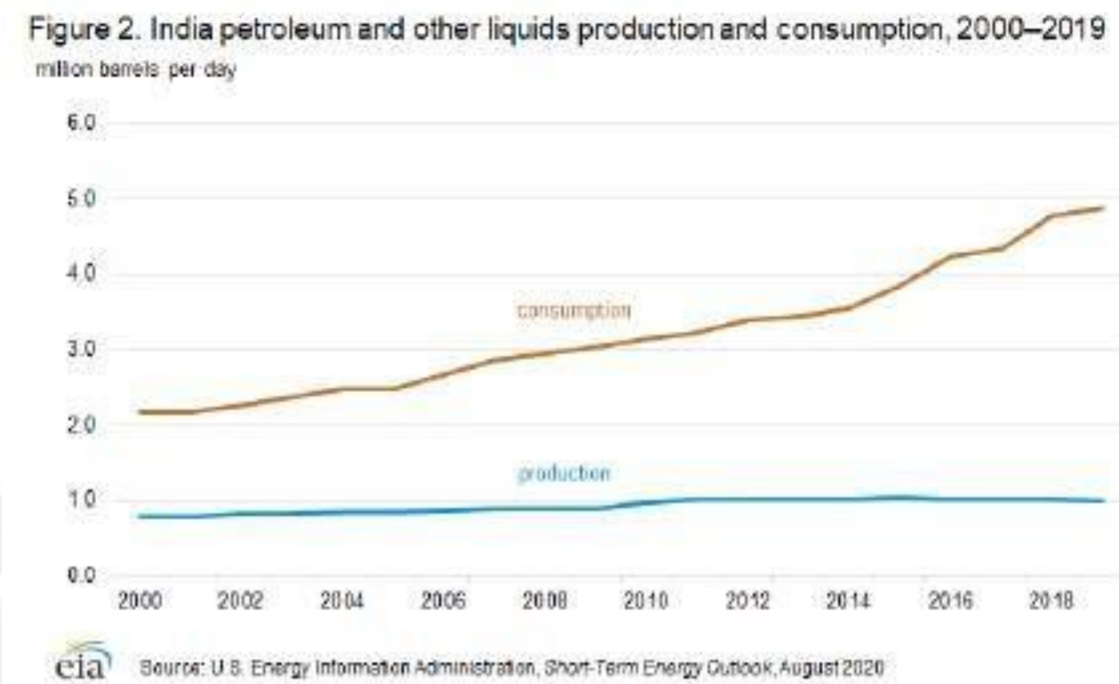
Exploration and production

- India's total petroleum and other liquids production has hovered at about 1 million b/d since 2010, although EIA expects production to fall in 2020 (Figure 2). About two-thirds of India's total liquids production is from crude oil and condensate, which has gradually declined over the past few years and fell 40,000 barrels per day (b/d) to 667,000 b/d in 2019.
- The nationwide lockdown in response to the COVID-19 pandemic in India in the second quarter of 2020 has caused labor and equipment shortages for some oil fields and demand destruction, forcing some immediate curtailment of production.
- Almost half of India's crude oil production is from offshore fields, although this share has dropped in the past several years as production from the large, aging Mumbai High field has declined. The only sizeable project expected to come online in the next few years is Oil and Natural Gas Corporation's 78,000 b/d KG-D5 deepwater oil and natural gas development starting in 2021.8 This project could offset some of the declines in mature fields.
- India has struggled to offset production declines of its mature fields because of insufficient investment and technical issues. Domestic crude oil production from many of India's mature fields and from technically-challenging deepwater developments is cost-prohibitive at low oil prices. India's government is trying to attract more investment and reduce India's oil import dependency by improving the contract terms for private and foreign companies and prompting the national oil companies to invest more in upstream development.
- In early 2019, India further allowed marketing and pricing freedom for all new oil and natural gas fields. In addition, India pledged to invest $58 billion in oil and natural gas upstream development by 2023. However, this announcement came just before the oil price crash in early 2020, which could alter investment decisions.

Consumption

- India was the third-largest consumer of crude oil and petroleum products after the United States and China in 2019. The gap between India's oil demand and supply is widening. Demand for crude oil in 2019 reached 4.9 million b/d, compared to less than 1 million b/d of total domestic liquids production (Figure 2). The economic slowdown and heavy monsoon season eased the pace of India's oil demand growth, which grew 2% in 2019 compared to the 2018 level.
- As of August 2020, EIA expects the ongoing COVID-19 pandemic to drastically lower India's growth in petroleum products—primarily jet fuel, gasoline, and diesel—with the most acute demand destruction occurring during the second quarter of 2020.
- India's refiners began curtailing oil product output in March 2020. Once the country's economy recovers from the pandemic, India's transportation and industrial sectors is likely to expand under economic development; a rising population; and government policy initiatives that increase highway and airport infrastructure, promote Indian manufacturing, and increase liquefied petroleum gas (LPG) use in the residential sector.
- Diesel remains the most-consumed oil product in India, accounting for 39% of petroleum product consumption in 2019, and is used primarily for commercial transportation and, to a lesser degree, in the industrial and agricultural sectors.13 Gasoline consumption, which accounts for 14% of India's total oil consumption and has increased at an accelerated rate over the past few years, has been replacing diesel in the swiftly-growing passenger vehicle sector since 2014.
- India has supported LPG consumption through targeted subsidies for the lowest income population since 2016, which is likely to sustain LPG growth through 2020. However, LPG

households reached nearly 97% at the beginning of 2020 compared to 56% in 2016. LPG consumption growth may slow once all households have LPG access.15



Refining

- As of 2019, India had 5.0 million b/d of nameplate refining capacity, making it the second-largest refiner in Asia after China (Table 1). The two largest refineries by crude oil capacity, located in the Jamnagar complex in Gujarat, are world-class export facilities and are owned by Reliance Industries. The Jamnagar refineries account for 27% of India's current capacity. Several refiners have incrementally increased the crude oil processing capacity through small expansions at existing facilities. However, bringing on new facilities has been slow over the past few years, and no new projects are slated to come online until the mid-2020s.17
- India's state refiners are upgrading their facilities to comply with a new government requirement to produce oil products with the equivalent of Euro VI emission standards by April 2020.18

Natural gas

Exploration and production

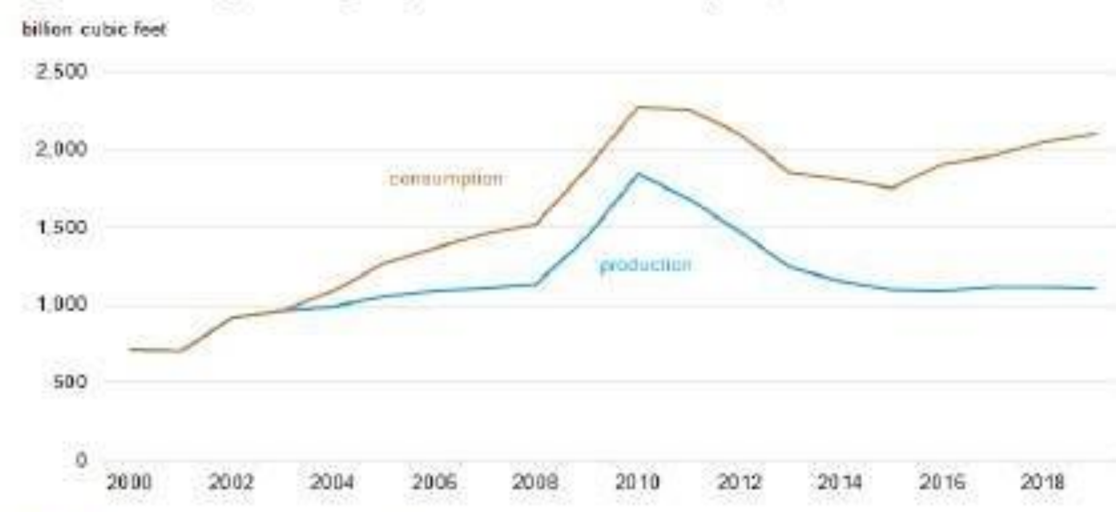
- After sharply declining from peak production in 2010, India's dry natural gas production remained flat at about 1.1 trillion cubic feet (Tcf) between 2015 and 201923 (Figure 4). Production in the first few months of 2020 fell substantially from the year before because of the COVID-19 pandemic and the national lockdown on domestic natural gas demand. Producers have shut in some natural gas as the market has retracted.As a result of the government's major upstream policy change implemented in 2016, companies have invested in more exploration and production for technically challenging natural gas fields (mainly unconventional and deepwater basins).
- These policy changes gave companies more pricing freedom by allowing them to market natural gas at higher prices to all sectors. Companies can also explore and produce unconventional natural gas from existing production contracts at conventional natural gas fields and can bid on all hydrocarbon blocks of interest without waiting for an official government bidding round. These regulatory reforms have attracted some private investment in small marginal, deepwater, and coalbed methane

- The government also plans to provide India's major state-owned companies with financial incentives to produce more natural gas from more technically challenging fields. As a result, India intends to double the current production by 2022.25
- Notable projects expected to come online in 2020 are Reliance Industries' R-Cluster in the KG-D6 block and state-run ONGC's KG-DWN-98/2 oil and natural gas deepwater project in the KG-D5 block. Both fields are located in the Krishna Godavari Basin, offshore from India's east coast. The first set of fields from the KG-DWN-98/2 project, which began producing natural gas in March 2020, will reach a peak of 190 billion cubic feet (Bcf) per year and have a 15-year lifespan.26 Reliance Industries' R-Cluster has a production capacity of 160 Bcf per year and a 13-year lifespan, and it is slated to come online by late 2020.2

Consumption

- Falling domestic natural gas production and insufficient import capacity constrained natural gas demand in India for several years. In 2015, imports began rising, and the country's natural gas demand rose to 2.1 Tcf in 201928 (Figure 4). Most of the natural gas demand in 2018 came from the power sector (22%), the fertilizer industry (28%), the residential and commercial sectors (17%), and other industrial uses (33%), according to India's official statistics
- India's government supports extension of the natural gas pipeline network and further developing the domestic fertilizer industry, which could bolster more natural gas use. However, renewable energy and coal are formidable competitors to natural gas in the power sector. EIA expects the effects of the COVID-19 pandemic to slow India's natural gas demand growth, especially in the industrial sector in the first part of 2020.

Figure 4. India dry natural gas production and consumption, 2000–2019



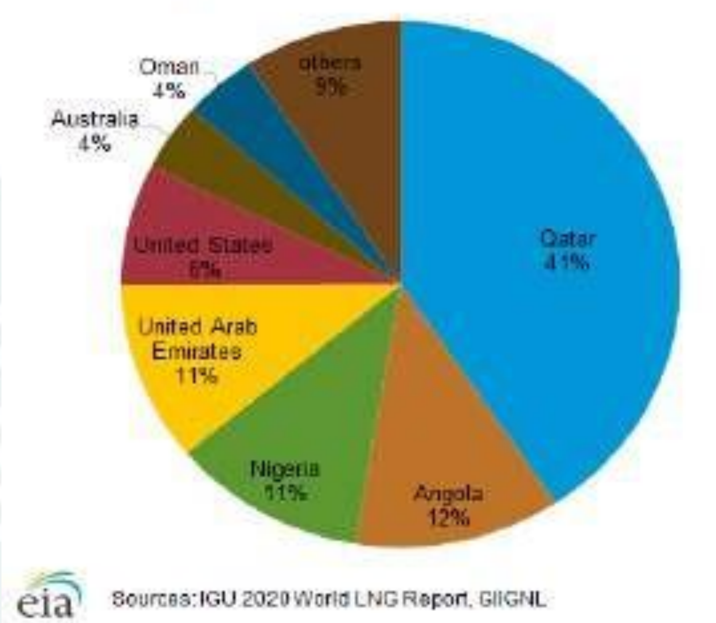
Source: U.S. Energy Information Administration
Note: 2019 data are preliminary estimates

Liquefied natural gas and trade

- In 2019, India was the world's fourth-largest LNG importer, importing about 1.2 Tcf (7%) of global trade. During the past two years, India has imported 25% more LNG. Qatar was the primary source of India's LNG imports with a 41% share, down from 83% in 2014. India has diversified its LNG sources over the past few years and increased its supplies from several African producers, Australia, Oman, and the United States31 (Figure 5).
- Because India's natural gas demand has outstripped its production for several years, the country is expected to increasingly rely on LNG imports and build on its natural gas import infrastructure. In mid-2020, India's total regasification capacity stood at 1.9 Tcf, of which 0.6 Tcf was added since the beginning of 2019. Another 1.0 Tcf is under construction at new terminals and expected to come

- As a result of the national lockdown from the COVID-19 pandemic in 2020, India has deferred some LNG cargoes because natural gas demand has contracted since February. The pandemic will likely slow India's LNG growth in 2020.

Figure 5. India LNG imports by source, 2019



Coal

Consumption

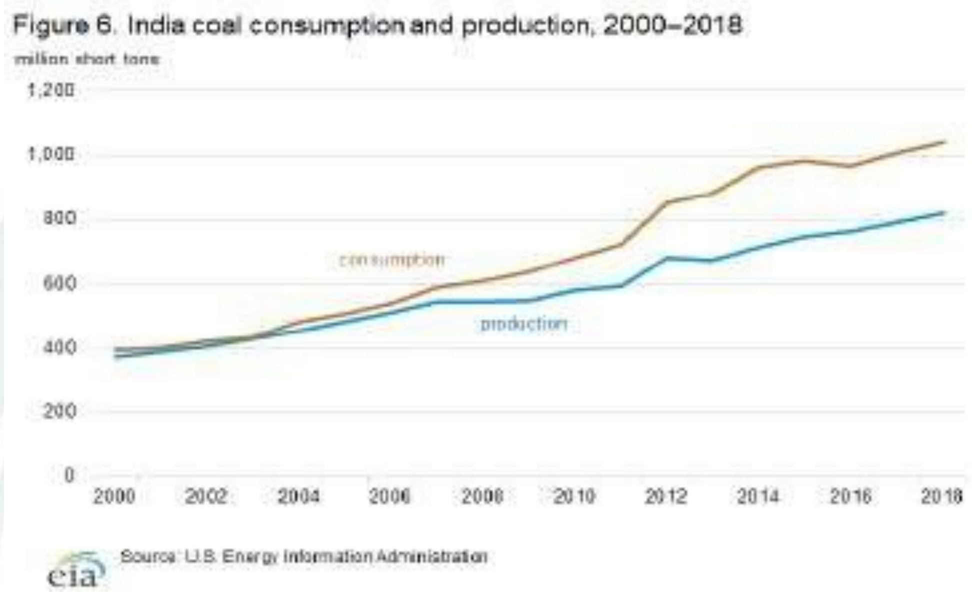
- In 2018, India's coal consumption increased to an estimated 1,037 million short tons, up 3% from 201739 (Figure 6). India's coal consumption, the second-largest in the world behind China, is driven by the power sector, which makes up about two-thirds of consumption, iron and steel industries, and cement production. Greater connection to the electricity grid for the rural population, industrial growth, and the government's massive infrastructure program have contributed to higher coal growth in the past two years in 2017 and 2018.40 India's coal consumption growth slowed in 2019 as a result of slower growth in electricity demand, more fuel substitution from renewable sources, and economic easing.41 Coal-fired power plants are facing competition from growing renewable-based sources, which could ease the growth of coal use in the power sector in the next several years.
- India's coal demand in 2020 is likely to be determined by the magnitude of the COVID-19 pandemic in India and its impact on the electricity and industrial demand growth. The national lockdown in the first half of 2020 has significantly decreased electricity production and halted many construction projects that rely on coal as a fuel.42

Exploration and production

- India ranks as the second-largest coal producer in the world on a volumetric basis. India's coal production increased to 817 million short tons in 2018, up 3% from 2017, mainly reflecting higher investments by the large state-owned coal companies and improved mining efficiency and production43 (Figure 6). Preliminary estimates indicate that coal production by the main producers declined in 2019 because of significant mine flooding from a heavy monsoon season and a series of labor strikes.
- India continues to experience supply shortages and systemic problems with its mining industry. Many coal deposits are located in areas that have environmental challenges or involve potential dislocation of people. Regulatory hurdles continue to impose delays in obtaining environmental and

heavily on rail (about 50% of coal production) to transport coal to demand centers. Insufficient rail capacity and a monopoly on transportation costs could slow India's coal production.

- In efforts to bolster investment in India's coal development and allow the country to rely less on imports, the government passed policies in 2018 and 2019 to promote competition in the sector and break the market control primarily held by Coal India Limited. The policies allow local and foreign private companies to produce and sell coal at market prices. The government intends to invite the first bids for foreign firms in 2020.



Trade

- Because coal output cannot keep pace with demand, particularly from the power sector, India has met more of its coal needs with imports than domestic production. In 2019, India purchased 275 million short tons of coal from overseas, making it the second-largest coal importer after China. Coal imports grew by 10% from 2018 levels and have been increasing since 2016.
- Indonesia was the largest source of coal imports to India in 2019, accounting for 49% of total coal imports. Other major sources are Australia (20%) and South Africa (16%). India has increased imports from the United States and Mozambique in recent years, although these sources still make up small shares of the overall import portfolio.47 India imports thermal (steam) coal used in power plants mainly from Indonesia and South Africa and coking coal for steel production from Australia48 (Figure 7).
- Although India's government encourages electric power producers to purchase domestic coal over imports during the COVID-19 pandemic and lockdown, logistical and transportation issues will likely not halt all coal imports in 2020. India plans to significantly reduce imports by 2024 and become more self-sufficient in coal

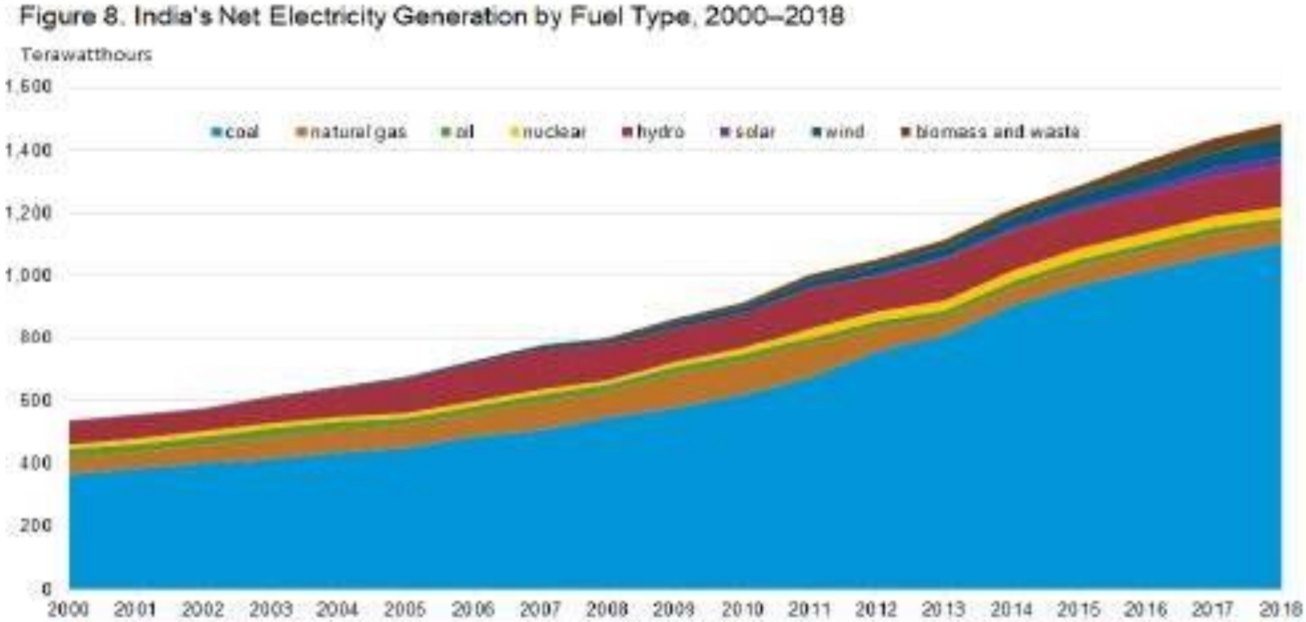
Electricity

- Because of insufficient fuel supply for power generation and transmission capacity, India suffers from electricity shortages, leading to rolling blackouts.. However, India has made strides over the past few years to increase capacity, introduce more renewable energy generation, improve market efficiencies, and enhance electricity access and reliability.
- Although electrification rates in India vary by source, based on definitional differences of electricity access, the International Energy Agency estimates that 5% of the population lacked basic access to electricity in 2018. By mid-2018, India's government announced that it had connected 100% of Indian villages to the electric grid. As of early-2019, real-time tracking data from India's government reported virtually 100% of rural households in India had electricity.

Generation

- India produced about 1,487 terawatthours (TWh) of net electricity in 2018, up more than 3% from 2017 (Figure 8). The economic and industrial slowdown over the past few years caused a deceleration in India's power generation since 2018.52 In 2019, EIA estimates that power generation growth has slowed considerably as a result of economic slowdown.53 Further erosion of electricity demand growth is set to occur in 2020 as a result of the effects of the COVID-19 pandemic and the associated national lockdown on India's economy and industrial output.
- Coal, which accounted for 74% of India's electric generation in 2018, is the cheapest and most abundant power source for the country. Renewable energy made up the second-largest portion (18%) of power generation and is the fastest-growing power source. Solar energy has increased by an average of 50% each year since 2013. Natural gas, oil, and nuclear power together make up less than 10% of India's power supply.
- Although coal accounts for the majority of India's electricity fuel supply, India experiences fuel shortages with coal and natural gas. Utilization rates in India's coal-fired power plants have fallen steadily since 2007 (from a peak of about 79%) to 56% in 2019.56 Many natural gas-fired power plants remain suspended from operation as a result of domestic natural gas production that fell sharply after 2010 and insufficient infrastructure. Renewable energy production has increased significantly and is taking some market share from fossil fuel-fired power.

Figure 8. India's Net Electricity Generation by Fuel Type, 2000–2018

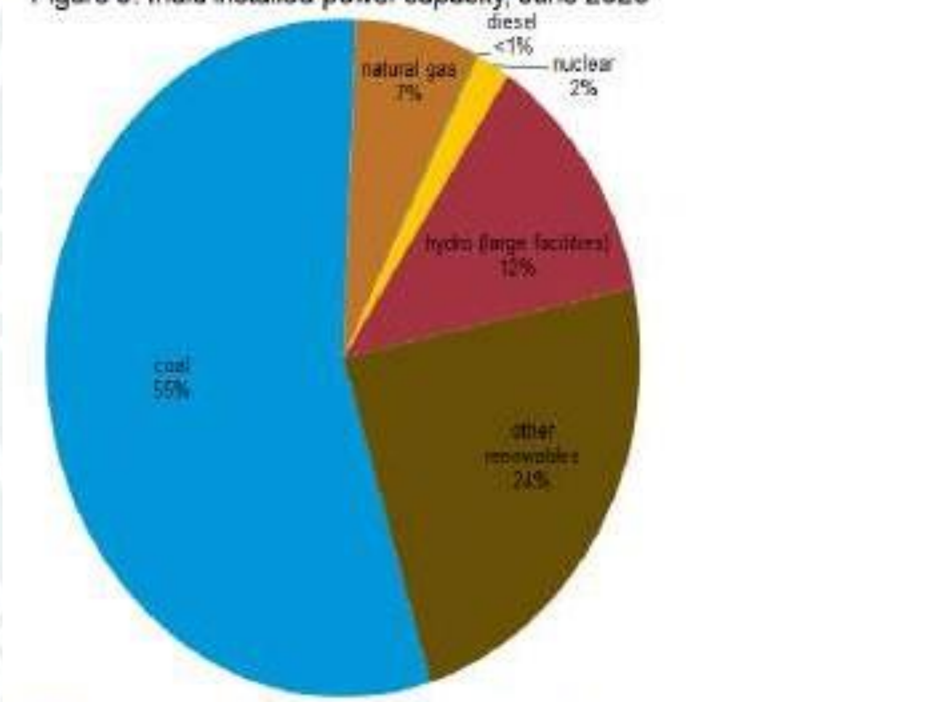


Sources: U.S. Energy Information Administration and International Energy Agency, World Energy Statistics database

Capacity

- India had more than 370 gigawatts (GW) of utility-based installed electricity generating capacity connected to the national network by June 2020, according to India's Central Electricity Authority (CEA).57 Coal contributed to most of the capacity (55%). Renewable energy made up a sizeable share of India's electricity capacity (12% for large hydropower projects and almost 24% for other renewables) and grew in share size over the past several years. Natural gas (7%), diesel fuel (less than 1%), and nuclear power (2%) accounted for much smaller shares (Figure 9). Generation capacity from smaller captive power plants, or those that serve specific industries for in-house consumption and are not connected to the grid, was about 55 GW in 2018..
- As part of India's goal to reduce emissions and address acute problems of air pollution, particularly in urban areas, and mitigate the use of coal-fired power, the government set a target for renewables other than large hydroelectric plants to increase to 175 GW of capacity by 2022 from about 87 GW in early 2020. Solar and wind power are intended to meet most of this growth.
- India has seven nuclear power plants with a net generation capacity of 6.3 GW, representing about 2% of total utility-based generation capacity. As of August 2020, seven reactors with a combined net installed capacity of 4.8 GW are under construction and several others are in the planning stages

Figure 9. India installed power capacity, June 2020



Source: U.S. Energy Information Administration, India's Central Electricity Authority
Note: Includes utility-based power facilities, not captive power plants. Small hydro facilities included in other renewables category

CHAPTER-2

SOLAR ENERGY

The sun is the source of the vast majority of the energy we use on earth. Most of the energy we use has undergone various transformations before it is finally utilized, but it is also possible to tap this source of solar energy as it arrives on the earth's surface.
Solar energy is quite simply the energy produced directly by the sun and collected elsewhere, normally the Earth. The sun creates its energy through a thermonuclear process that converts about 650,000,0001 tons of hydrogen to helium every second. The process creates heat and electromagnetic radiation.

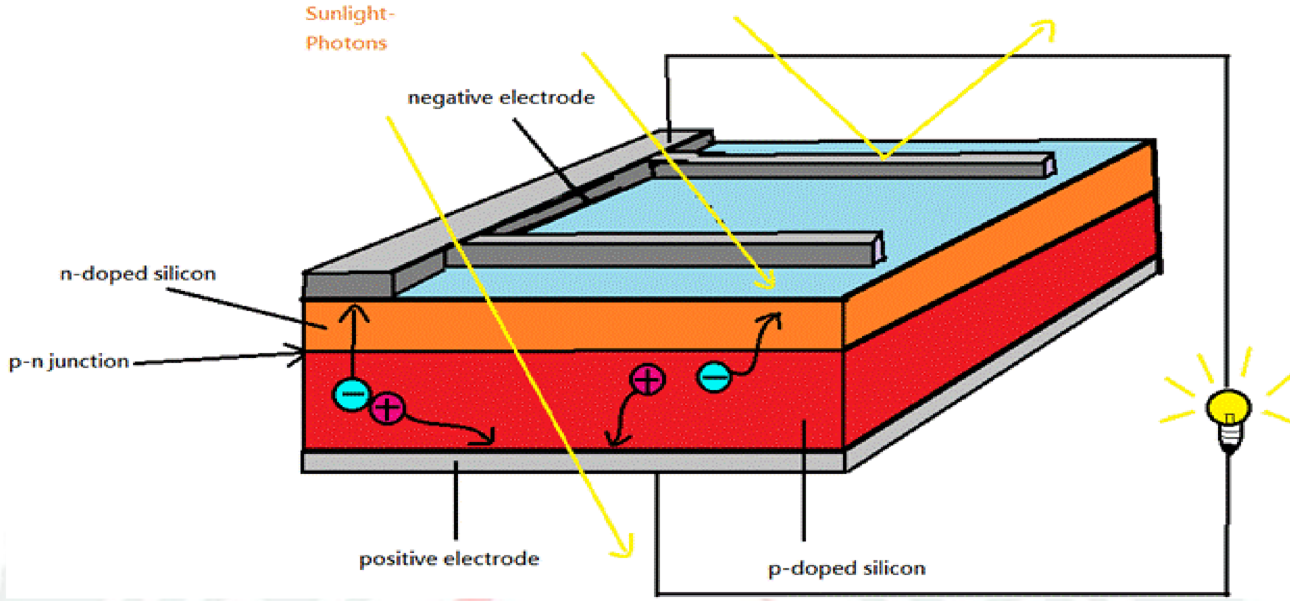
What is a Solar Cell?

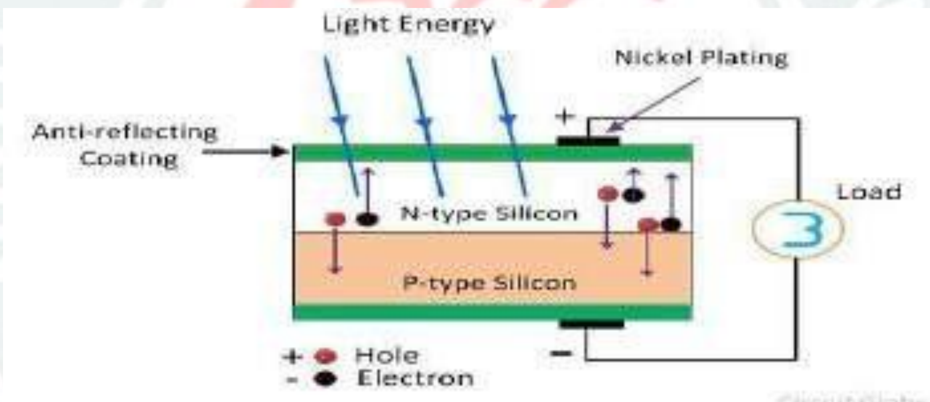
A **solar cell** (also known as a photovoltaic cell or PV cell) is defined as an electrical device that converts light energy into electrical energy through the photovoltaic effect. A solar cell is basically a p-n junction diode. Solar cells are a form of photoelectric cell, defined as a device whose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

Individual solar cells can be combined to form modules commonly known as solar panels. The common single junction silicon solar cell can produce a maximum open-circuit voltage of approximately 0.5 to 0.6 volts. By itself this isn't much – but remember these solar cells are tiny. When combined into a large solar panel, considerable amounts of renewable energy can be generated. The electrons of the semiconductor material are joined together by the covalent bond. The electromagnetic radiations are made of small energy particles called photons. When the photons are incident on the semiconductor material, then the electrons become energised and starts emitting.**The energises electron is known as the Photoelectrons. And the phenomenon of emission of electrons is known as the photoelectric effect**

Construction of Solar Cell

A solar cell is basically a junction diode, although its construction it is little bit different from conventional p-n junction diodes. A very thin layer of p-type semiconductor is grown on a relatively thicker n-type semiconductor. We then apply a few finer electrodes on the top of the p-type semiconductor layer.
These electrodes do not obstruct light to reach the thin p-type layer. Just below the p-type layer there is a p-n junction. We also provide a current collecting electrode at the bottom of the n-type layer. We encapsulate the entire assembly by thin glass to protect the **solar cell** from any mechanical shock.





Working Principle of Solar Cell

When light reaches the p-n junction, the light photons can easily enter in the junction, through very thin p-type layer. The light energy, in the form of photons, supplies sufficient energy to the junction to create a number of electron-hole pairs. The incident light breaks the thermal equilibrium condition of the junction. The free electrons in the depletion region can quickly come to the n-type side of the junction
Similarly, the holes in the depletion can quickly come to the p-type side of the junction. Once, the newly created free electrons come to the n-type side, cannot further cross the junction because of barrier potential of the junction.

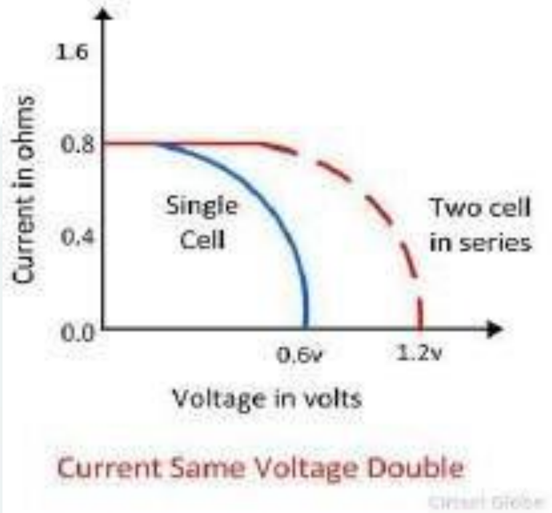
Similarly, the newly created holes once come to the p-type side cannot further cross the junction became of same barrier potential of the junction. As the concentration of electrons becomes higher in one side, i.e. n-type side of the junction and concentration of holes becomes more in another side, i.e. the p-type side of the junction, the p-n junction will behave like a small battery cell. A voltage is set up which is known as photo voltage. If we connect a small load across the junction, there will be a tiny current flowing through it.

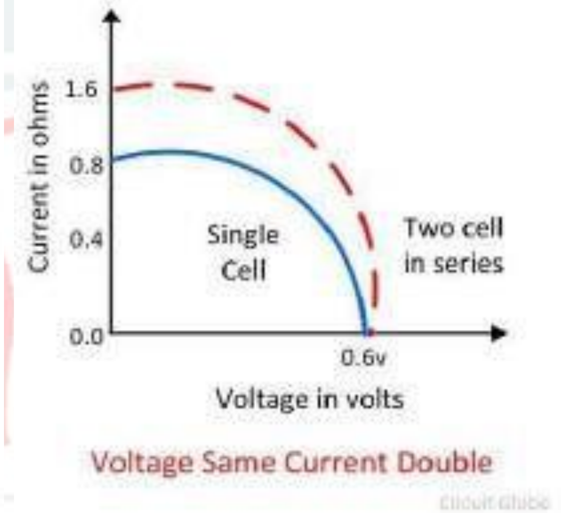
Series Combination of PV Cells

If more than two cells are connected in series with each other, then the output current of the cell remains same, and their input voltage becomes doubles. The graph below shows the output characteristic of the PV cells when connected in series.

Parallel Combination of PV cells

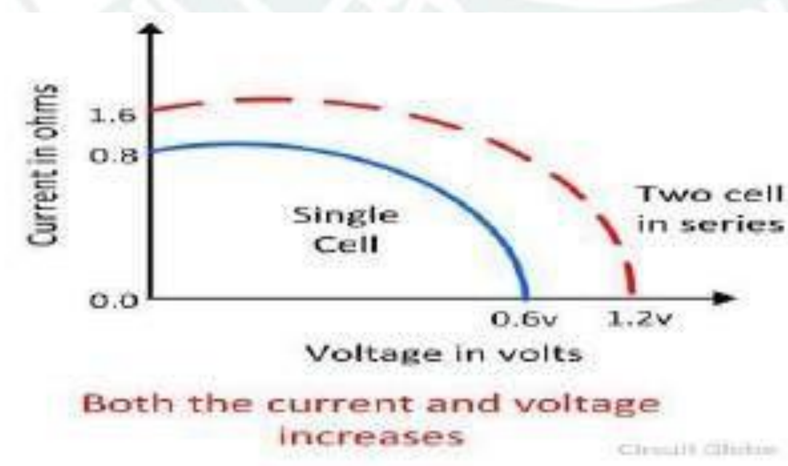
In the parallel combination of the cells, the voltage remains same, and the magnitude of current becomes double. The characteristic curve of the parallel combination of cells is represented below.



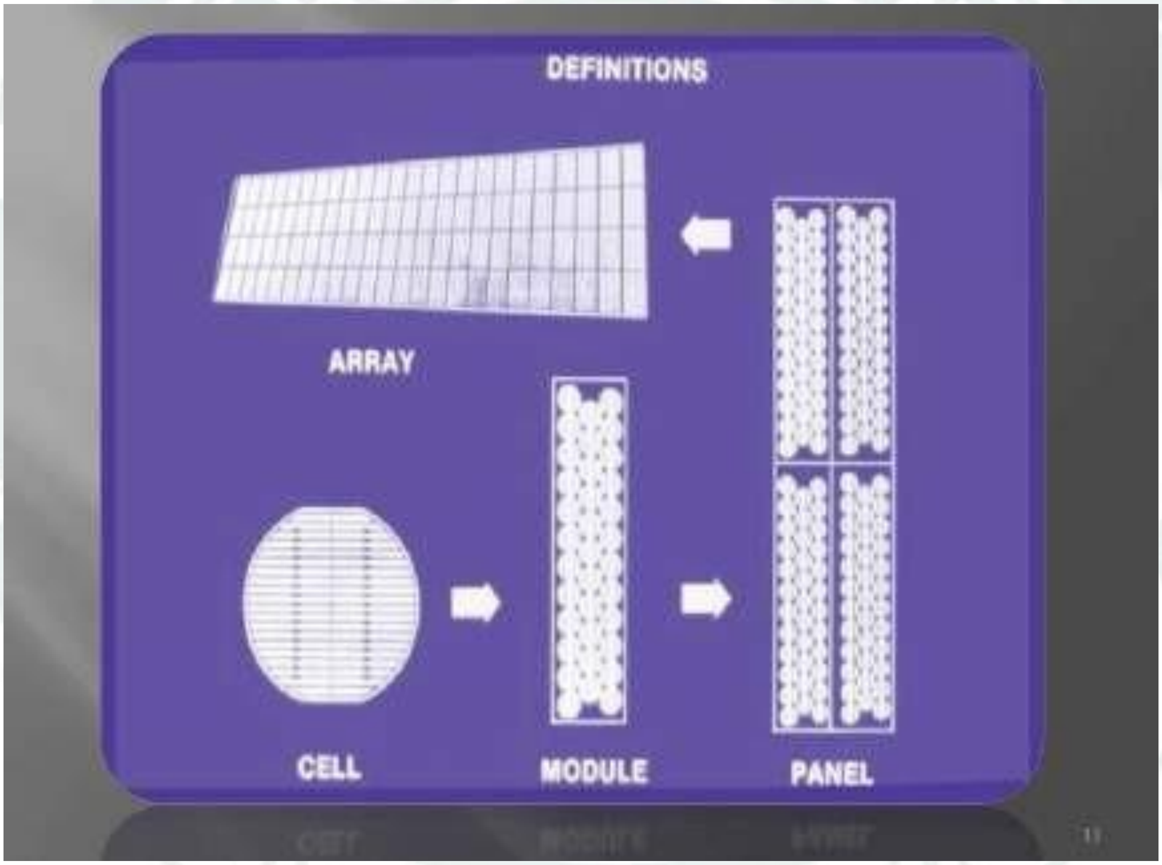


<u>Series-Parallel Combination of PV cells</u>

In the series-parallel combination of cells the magnitude of both the voltage and current increases. Thereby, the solar panels are made by using the series-parallel combination of the cells.



- **SOLAR CELL**:- It is basically a bulk silicon cell where the bulk material is the p-type silicon. A thin layer of n- type silicon is formed at the top surface. There is anti-reflective coating, textured rear surface.
- **SOLAR PV MODULE**:-It is the basic building block of a PV system. It is the interconnection of a number of cells and all these cells should have the same characteristics. Partial shadowing may damage the module.
- **SOLAR PV PANEL**:-Several solar modules are connected in series/parallel to increase the voltage/current ratings. Solar panel is a group of several modules connected in series parallel combination in a frame that can be mounted on a structure. The combination of such panels are called as an **SOLAR ARRAY**.



Solar cell

The basic cell structure of a typical *n*-on-*p*, bulk silicon cell is shown in Fig. 6.16. The bulk material is *p*-type silicon with a thickness of 100 to 350 microns, depending on the technology used. A thin layer of *n*-type silicon is formed at the top surface by diffusing an impurity from the Vth group (phosphorus being the most common) to get a *pn* junction. The top active surface of the *n* layer has an ohmic contact with metallic grid structure to collect the current produced by impinging photons. The metallic grid covers minimum possible top surface area (less than 10% of the total area) to leave enough uncovered surface area for incoming photons. Similarly, the bottom inactive surface has an ohmic metallic contact over the entire area. These two metallic contacts on p and n layers respectively form the positive and negative terminals of the solar cell. In addition to basic elements, several enhancement features are also included in the construction. For example, providing antireflective coating, textured finish of the top surface and reflective, textured rear surface, to capture maximum photons and direct them toward the junction.

6.4.2 Solar PV Module

A bare single cell cannot be used for outdoor energy generation by itself. It is because (i) the output of a single cell is very small, and (ii) it requires protection (capsulation) against dust, moisture, mechanical shocks and outdoor harsh conditions. Workable voltage and reasonable power is obtained by interconnecting an appropriate number of cells. The unit is fixed on a durable back cover of several square feet, with a transparent cover on the top and hermetically sealed to make it suitable for outdoor applications. This assembly is known as solar module—a basic building block of a PV system. The most common commercial modules have a series connection of 32 or 36 silicon cells to make it capable of charging a 12-V storage battery. However, larger and smaller capacity modules are also available in the international market.

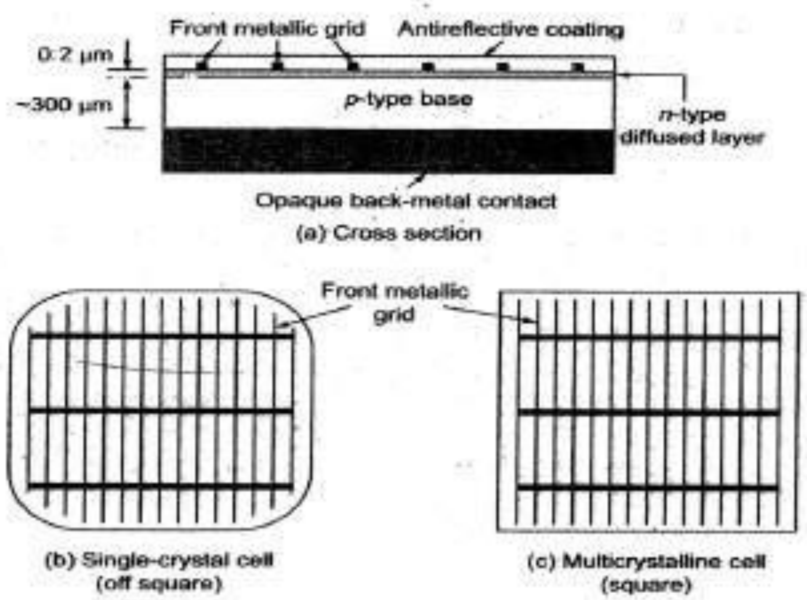


Fig. 6.16 *Construction of bulk silicon cell*

6.4.3 Solar PV Panel

Several solar modules are connected in series/parallel to increase the voltage/current ratings. When modules are connected in series, it is desirable to have each module's maximum power production occur at the same current. When modules are connected in parallel, it is desirable to have each module's maximum power production occur at the same voltage. Thus while interconnecting the modules, the installer should have this information available for each module. Solar panel is a group of several modules connected in a series–parallel combination in a frame that can be mounted on a structure. Fig. 6.20 shows the construction of module and panel.

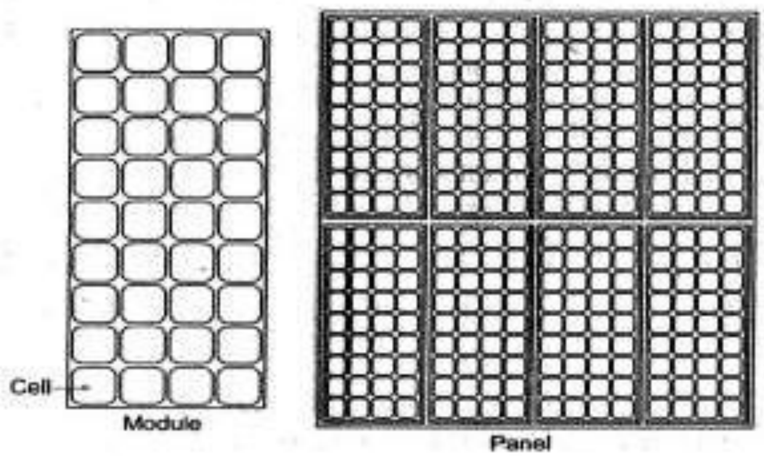


Fig. 6.20 *Cell, module and panel*

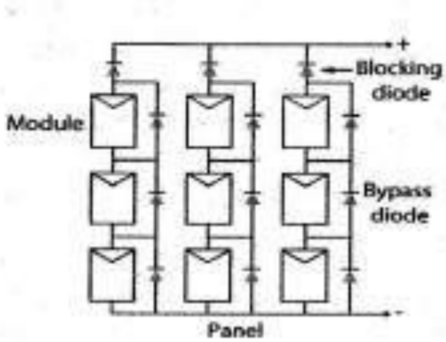


Fig. 6.21 *A typical panet series-parallel connection of modules*

Figure 6.21 shows a series–parallel connection of modules in a panel. In a parallel connection, blocking diodes are connected in series with each series string of modules, so that if any string should fail, the power output of the remaining series strings will not be absorbed by the failed string. Also, bypass diodes are installed across each module, so that if one module should fail, the output of the remaining modules in a string will bypass the failed module. Some modern PV modules come with such internally embedded bypass diodes.

6.4.4 Solar PV Array

In general, a large number of interconnected solar panels, known as solar PV array, are installed in an array field. These panels may be installed as stationary or with sun tracking mechanism. It is important to ensure that an installed panel does not cast its shadow on the surface of its neighbouring panels during a whole year. The layout and mechanical design of the array such as tilt angle of panels, height of panels, clearance among the panels, etc., are carried out taking into consideration the local climatic conditions, ease of maintenance, etc.

6.6 MAXIMUM POWER POINT TRACKER (MPPT)

When a solar PV system is deployed for practical applications, the I–V characteristic keeps on changing with insolation and temperature. In order to receive maximum power, the load must adjust itself accordingly to track the maximum power point. The I–V characteristics of PV system along with some common loads are shown in Fig. 6.23. An ideal load is one that tracks the maximum power point.

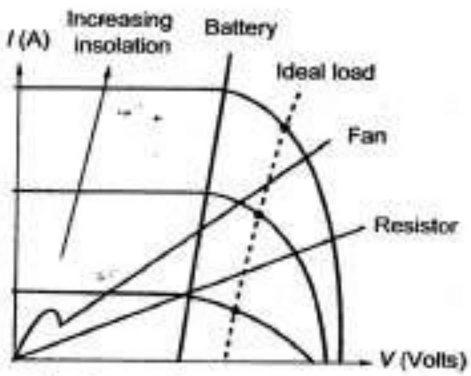


Fig. 6.23 *Characteristic fo PV and some loads*

If the operating point departs significantly from the maximum power point, it may be desirable to interpose an electronic maximum power point tracker (MPPT) between PV system and load. Generally, MPPT is an adaptation of dc–dc switching voltage regulator. Coupling to the load for maximum power transfer may require either providing a higher voltage at a lower current or lower voltage for higher current. A buck-boost scheme is commonly used with voltage and current sensors tied into a feedback loop using a controller to vary the switching times. Basic elements of a buck-boost converter that may be used in an MPPT are shown in Fig. 6.24. The output voltage of the buck-boost converter is given by

$$V_{out} = \frac{D}{1 - D} V_{in} \tag{6.13}$$

where D is the duty cycle of the MOSFET, expressed as fraction ($0 < D < 1$). Details of operation and design of the converter may be found in any standard book of power electronics.

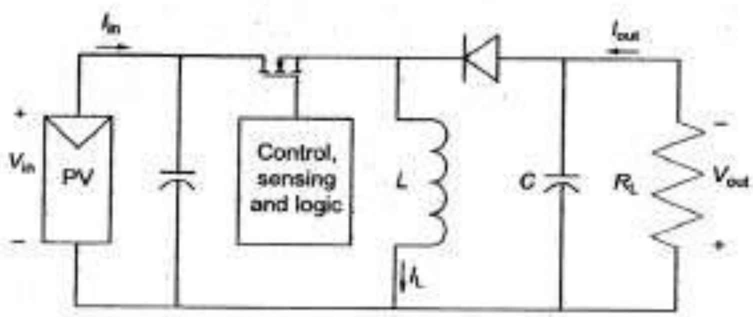


Fig. 6.24 *Maximum point tracker using buck-boost converter*

Solar PV systems are broadly classified as follows:

(i) Central Power Station System Central PV power stations are conceptually similar to any other conventional central power station. They feed power to grid. These are being proposed in few MW range to meet daytime peak loads only. Central PV power stations of up to 6 MW_p (peak MW) capacities have already been experimented within USA and Europe. While the concept has been demonstrated through such experimental plants, the capital costs are currently somewhat high for their commercial exploitation.

(ii) Distributed System Distributed form of energy use is unique and much more successful with solar and most other renewable energy sources. These systems can be further divided into three groups:

(a) Stand-alone System It is located at the load centre and dedicated to meet all the electrical loads of a village/community or a specific set of loads. Energy storage is generally essential. It is most relevant and successful in remote and rural areas having no access to grid supply. Indicative capacity of such a system is 10 W_p–100 kW_p.

(b) Grid-interactive System This system is connected to the utility grid with two-way metering system. It may be a small rooftop system owned and operated by the house owner or a relatively bigger system meant for the whole village or a community. It meets daytime requirements of the house owner without any battery backup and surplus power is fed to the grid. During peak hours and during nights, the energy shortage may be met from grid.

(c) Small System for Consumer Applications These systems are meant for low energy consumer devices requiring power in the range of microwatts to 10 W_p and mostly designed for indoor applications, e.g., calculators, watches, electronic games, etc.

6.8.2 Stand–Alone Solar PV System

The main components of a general stand-alone solar PV system are shown in Fig. 6.26. The MPPT senses the voltage and current outputs of the array and adjusts the operating point to extract maximum power under the given climatic conditions. The output of the array after converting to ac is fed to loads. The array output in excess of load requirement is used to charge the battery. If excess power is still available after fully charging the battery, it may be shunted to dump heaters. When the sun is not available, the battery supplies the load through an inverter. The battery discharge diode D_B prevents the battery from being overcharged after the charger is opened. The array diode D_A is to isolate the array from the battery to prevent battery discharge through array during nights. A mode controller is a central controller for the entire system. It collects the system signals and keeps track of charge/discharge state of the battery, matches the generated power and load and commands the charger and dump heater on-off operation.

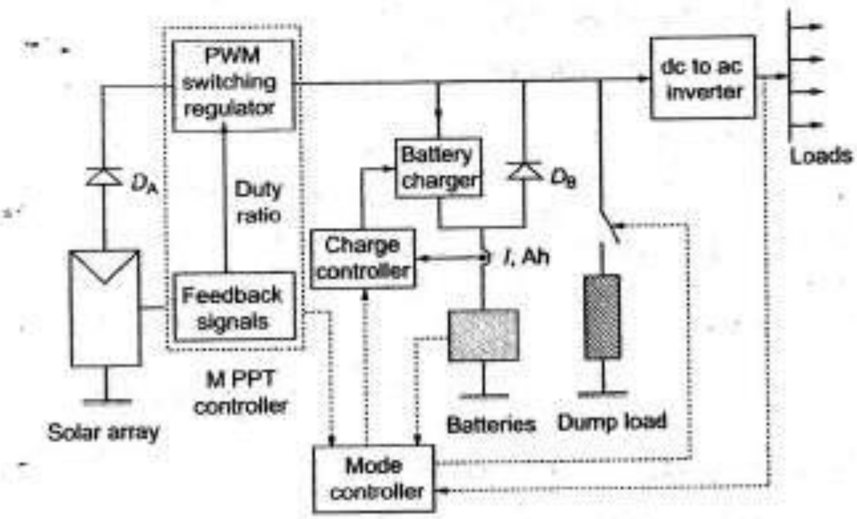


Fig. 6.26 *A general stand-alone solar PV system*

6.8.3 Grid-Interactive Solar PV System

In a grid-interactive system, all excess power is fed to a grid and dump heaters are not required. Also, during absence or inadequate sunshine, supply of power is maintained from the grid, and thus battery is eliminated. The mechanism for synchronized operation is incorporated. The dc power is first converted to ac by inverter, harmonics are filtered and then only the filtered power is fed into the grid after adjusting the voltage level. Recently, PV modules are being made with inverters as an integral component in the junction box of the module, what is known as *ac-PV modules*. It provides utility grade 60 Hz power directly from the module junction box. This greatly simplifies the design of a PV system. The schematic diagram of a general grid-interactive solar PV system is given in Fig. 6.27.

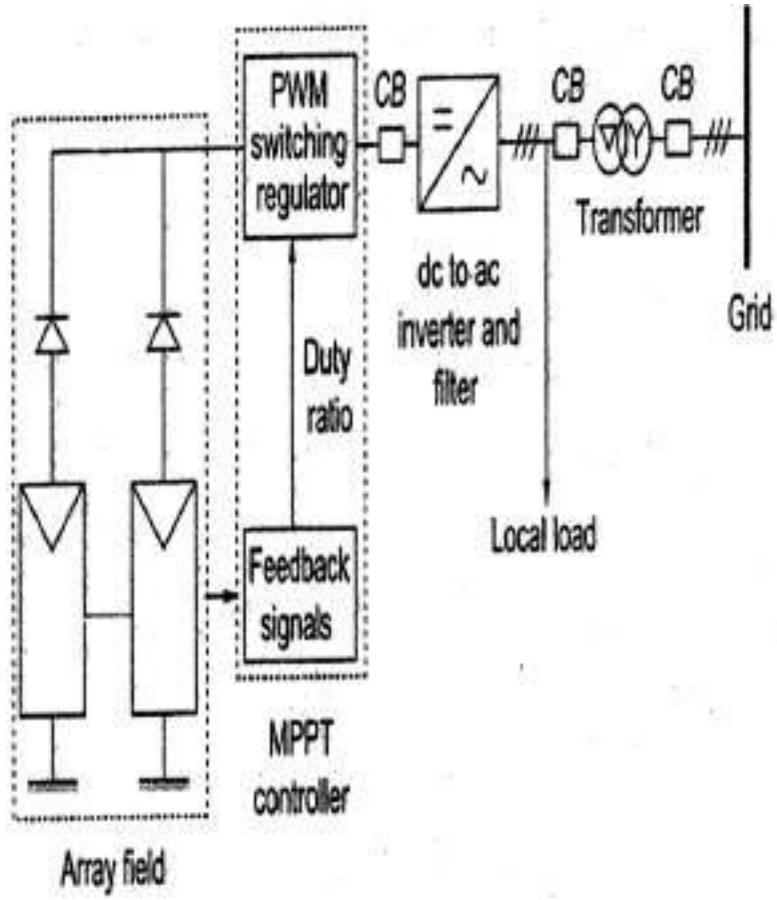


Fig. 6.27 A general grid-interactive solar PV system

6.8.4 Hybrid Solar PV System

Sometimes, it is not economical or practical to provide all energy from a PV system. In such cases, it may be more economical to provide some of the system energy needs by other means, such as diesel/gasoline generators or any other non-conventional source like wind or fuel cells. Such a system is called a *hybrid system*. The best cost-effectiveness is generally obtained when none of the PV-generated energy is wasted.

Solar collector

A **solar collector** is a device that collects and/or concentrates solar radiation from the Sun. These devices are primarily used for active solar heating and allow for the heating of water for personal use.[2] These collectors are generally mounted on the roof and must be very sturdy as they are exposed to a variety of different weather conditions.[2]

The use of these solar collectors provides an alternative for traditional domestic water heating using a water heater, potentially reducing energy costs over time. As well as in domestic settings, a large number of these collectors can be combined in an array and used to generate electricity in solar thermal power plants.

5.1.1 Classification

The overall view of classification of solar collectors into categories and subcategories is shown in Fig. 5.1. The classification is based on the way they collect solar radiation. The non-concentrating type absorbs the radiation as it is received on the surface of the collector while the concentrating type first increases the concentration of radiation per unit area before absorbing it. Further, based on the techniques employed for concentration of radiation, the concentrating type is further subdivided into focus and non-focus types. The focus type is further divided into line or point focus depending on the focusing method.

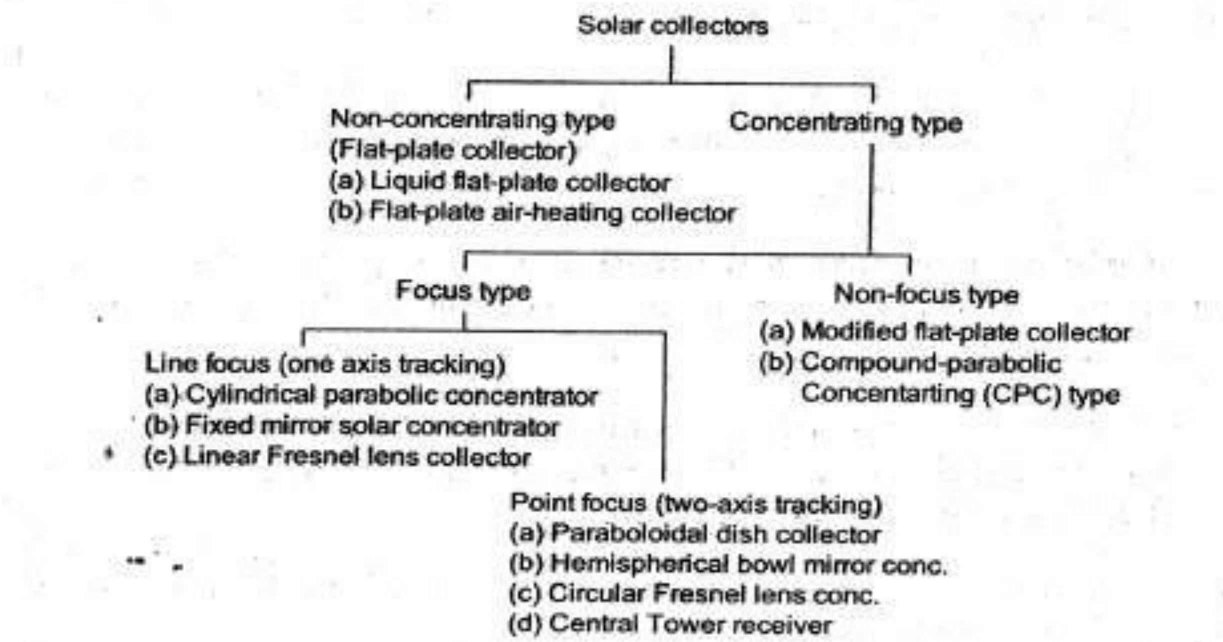


Fig. 5.1 *Types of solar collectors*

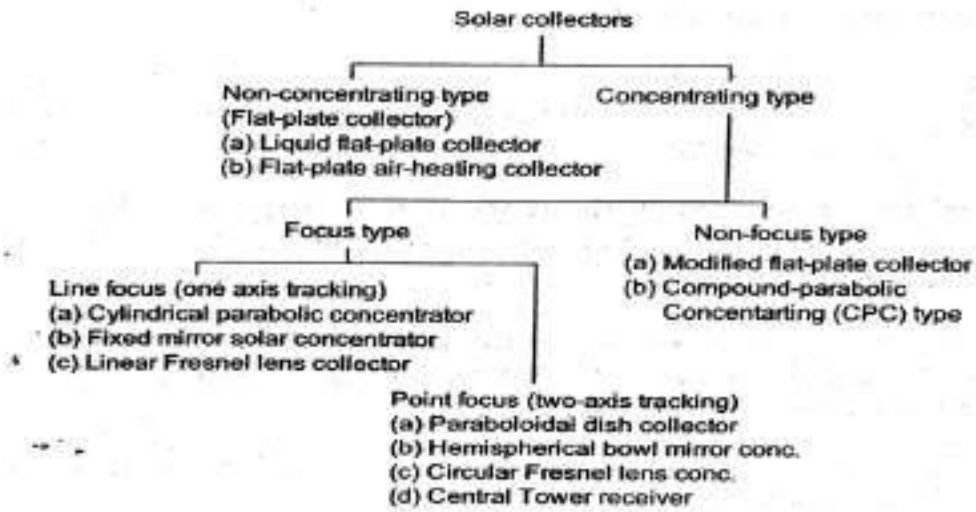


Fig. 5.1 *Types of solar collectors*

5.1.2 Comparison of Concentrating and Non-concentrating Types (Flat-plate Type) of Solar Collectors

In concentrating-type solar collectors, solar radiation is converged from a large area into a smaller area using optical means. Beam radiation, which has a unique direction and travels in a straight line, can be converged by reflection or refraction techniques. Diffused radiation however, has no unique direction and so does not obey optical principles. Therefore, the diffused component cannot be concentrated. Thus, concentrating-type solar collectors mainly make use of the beam radiation component (plus very little diffuse-component coming directly over the absorber), while non-concentrating (flat plate) collectors absorb both beam as well as diffused radiation, a distinct advantage of a flat-plate collector.

A flat-plate collector is simple in construction and does not require sun tracking. Therefore, it can be properly secured on a rigid platform, and thus becomes mechanically stronger than those requiring flexibility for tracking purpose. As the collector is installed outdoors and exposed to atmospheric disturbances (rain, storm, etc.), the flat-plate type is more likely to withstand harsh outdoor conditions. Also, because of its simple stationary design, a flat-plate collector requires little maintenance.

The principal disadvantage of a flat-plate collector is that because of the absence of optical concentration, the area from which heat is lost is large. Also, due to the same reason high temperatures cannot be attained.

The main advantage of concentrating-type collectors is that high temperatures can be attained due to concentration of radiation. This also yields high-temperature thermal energy.

FLAT PLATE COLLECTORS

The flat plate collectors forms the heat of any solar energy collection system designed for operation in the low temperature range, from ambient to 60 or the medium temperature, form ambient to 100. A well engineered flat plate collector is delivers heat at a relatively low cost for a long duration. The flat plat collectors is basically a heat exchanger which transfer the radiant energy of the incident sunlight to the sensible heat of a working fluid-liquid or air. The term 'flat plate' is slightly misleading in the sense that the surface may not be truly flat-it may be combination of flat, grooved or of other shapes as the absorbing surface, with some kind of heat removal device like tubes or channels. Flat plate collectors is used to convert at much solar radiation as possible into heat at the highest attainable temperature with the lowest possible investment in material and labour.

Flat plate collector have the following advantage over other types of solar energy collectors:

(i) Absorb direct, diffuse and reflected components o solar radiation,

(ii) Are fixed in tilt and orientation and thus, there is no needed of tracking the Sun,

(iii) Are easy to make and are low in cost,

(iv) Have comparatively low maintenance cost and Long lie, and

(v) Operate at comparatively high efficiency.

Principle of Flat Plate Collector

The principal behind a flat collector is simple. If a metal sheet is exposed to solar radiation, the temperature will rise until the rate at which energy is received is equal to the rate at which heat is lost from the plate; this temperature is termed as the 'equilibrium' temperature. If the back of the plate is protected by a heat insulting material, and the exposed surface of the plate is painted black and is coved by one or two glass sheets, then the equilibrium temperature will be much higher than that for the simple exposed sheet. This plate may be covered into a heat collector by adding a water circulating system, either by making it hollow or by soldering metal pipes to the surface, and transferring the heated liquid to a tank for storage. For heat with withdrawal from the system the equilibrium temperature must decrease, since no useful heat can be extracted at he maximum equilibrium temperature at which the collection efficiency is zero. The other extreme condition is when the flow of liquid is so flat that the temperature rise is very small; in such a case although the losses are small and the efficiency of the heat collection approaches 100 percent, yet no useful heat can be extracted. The optimum is approximately midway between the equilibrium temperature, whereby an output of hot liquid at a useful temperature is obtained.

5.1.3 Performance Indices

The important performance indices of a solar collector are (i) collector efficiency, (ii) concentration ratio, and (iii) temperature range. The performance of a solar collector is evaluated on the basis of these features.

Collector efficiency is defined as the ratio of the energy actually absorbed and transferred to the heat-transport fluid by the collector (useful energy) to the energy incident on the collector.

Concentration ratio (CR) is defined as the ratio of the area of aperture of the system to the area of the receiver. The aperture of the system is the projected area of the collector facing (normal) the beam.

Temperature range is the range of temperature to which the heat-transport fluid is heated up by the collector.

In flat-plate collectors, no optical system is utilized to concentrate the solar radiation and hence the concentration ratio is only 1. The temperature range is less than 100°C. Line focus collectors have CR up to 100 and a temperature range of the order of 150°C to 300°C. A concentration ratio of the order of thousands and temperature range of 500°C to 1000°C can be obtained by using point-focus collectors.

5.1.4 Liquid Flat-plate Collector

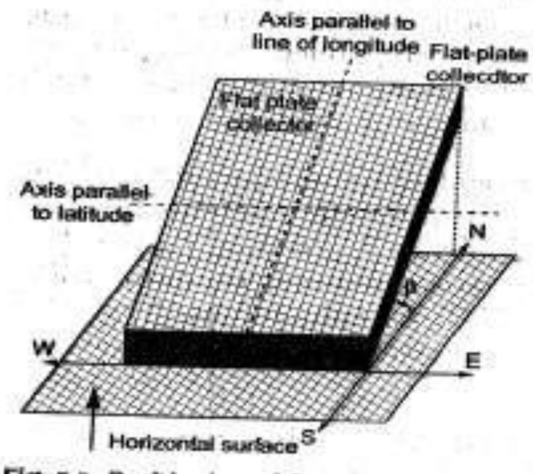


Fig. 5.2 *Positioning of flat-plate collector*

A flat-plate collector is placed at a location in a position such that its length aligns with the line of longitude and is suitably tilted towards south to have maximum collection. The positioning of the collector is shown in Fig. 5.2. The constructional details of a simple flat-plate collector are shown in Fig. 5.3. The basic elements in a majority of these collectors are:

(i) transparent cover (one or two sheets) of glass or plastic
(ii) blackened absorber plate usually of copper, aluminium or steel
(iii) tubes, channels or passages in thermal contact with the absorber plate—in some designs, the tubes form an integral part of absorber plate
(iv) weather tight, insulated container to enclose the above components

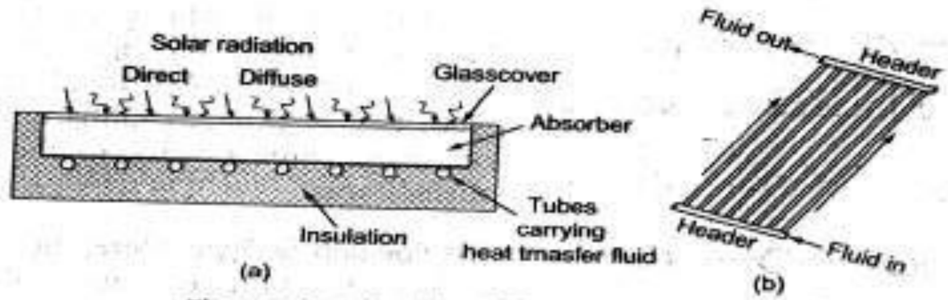


Fig. 5.3 *Construction of flat-plate collector*

A liquid, most commonly water, is used as the heat-transport medium from the collector to the next stage of the system. However, sometimes a mixture of water and ethylene glycol (antifreeze mixture) is also used if the ambient temperatures are likely to drop below 0°C during nights. As solar radiation strikes on a specially treated metallic absorber plate, it is absorbed and raises the plates temperature. The absorber plate is usually made from a metal sheet ranging in thickness from 0.2 to 1 mm. The heat is transferred to the heat-transfer liquid circulating in the tube (or channels), beneath the absorber plate and in intimate contact with it. The metallic tubes range in diameter from 1 to 1.5 cm. These are soldered, brazed, welded or pressure bonded to the absorber plate with a pitch ranging from 5 to 12 cm. In some designs, the tubes are bonded to the top or are in line and integral to the absorber plate. Some of these arrangements are shown in Fig. 5.4. Header pipes, which are of slightly larger diameter of typically 2 to 2.5 cm, lead the water in and out of the collector and distribute to tubes. The metal that is most commonly used, both for the absorber plate, the tubes and the header pipes, is copper, but other metals and plastics have also been tried. In the bottom and along the side walls, thermal insulation provided by a 2.5 to 8-cm thick layer of glass wool prevents heat loss from the rear surface and sides of the collector. The glass cover permits the entry of solar radiation as it is transparent for incoming short wavelengths but is largely opaque to the longer infrared radiation reflected from the absorber. As a result, the heat remains trapped in the airspace between the absorber plate and glass cover in a manner similar to a green house. The glass cover also prevents heat loss due to convection by keeping the air stagnant. The glass cover may reflect some 15% of incoming solar radiation, which can be reduced by applying anti-reflective coating on the outer surface of the glass. The usual practice is to have one or two covers with spacing ranging from 1.5 to 3 cm. Plain or toughened glass of 4 to 5-mm thickness is the most favoured material. Transparent plastics may also be used in place of glass but they often offer inferior performance as compared to glass. Most plastics are not as opaque to infrared radiation as glass. Also, their transparency for incoming solar radiation decreases with aging. The life of a plastic material is short when exposed to sunrays as it breaks down and cracks develop over a span of time.

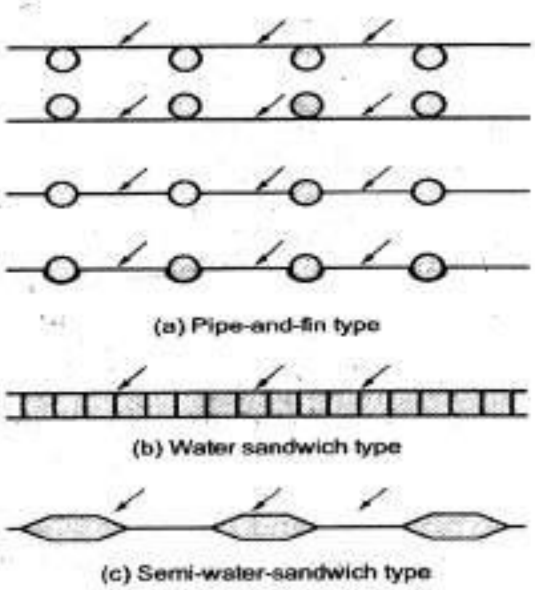


Fig. 5.4 *Cross-sections through collector plates*

A variety of absorber-plate designs have been developed as shown in Fig. 5.4. These absorber plates can be broadly divided into three basic types depending on the extent of wetted area relative to the absorbing surface area.

(i) Pipe-and-fin Type Here, the liquid flows only in the pipe and hence they have a comparatively low wetted area and liquid capacity.

(ii) Rectangular or Cylindrical Full-sandwich Type In this, both the wetted area and water capacity are high.

(iii) Roll-bond or Semi-sandwich Type It is an intermediate between the above two types.

The best choice depends on the particular application. For low-temperature requirements, such as warming of a swimming pool, the plastic, full water-sandwich plate may be the most appropriate. For domestic and industrial applications, high temperatures are required and hence the pipe-and-fin-type plate may be more suitable.

5.1.5 Liquid Flat-plate Collector Efficiency

The instantaneous collection efficiency of a flat-plate solar collector is defined as follows:

$$\eta_i = \frac{\text{useful heat gain}}{\text{solar radiation incident on the collector}} = \frac{q_u}{A_p I_T} \quad (5.1)$$

where q_u = useful heat gain (i.e., rate of heat transfer to the working fluid)

A_P = area of absorbing plate

I_T = instantaneous radiation energy incident on the collector face (kW/ m²)

The above expression is also valid for calculating the hourly collecting efficiency. In that case, q_u will be taken as useful heat gain in one hour and I_T as the energy incident on the collector face in one hour (kJ/m²-h).

An energy balance on the absorber plate yields the following equation:

$$q_u = A_p S - q_L \quad (5.2)$$

Each of these loss components may also be expressed in terms of individual loss coefficients, that is, top loss coefficient, bottom loss coefficient and side loss coefficient respectively, defined by the following equations.

$$q_t = U_t A_p (T_{pm} - T_a) \quad (5.7)$$

$$q_b = U_b A_p (T_{pm} - T_a) \quad (5.8)$$

$$q_s = U_s A_p (T_{pm} - T_a) \quad (5.9)$$

It is to be noted here that in the above three equations, the coefficients are defined on the basis of common area A_p and also the common temperature difference. This simplifies the analysis and gives a simple additive equation for overall loss component of the collector. Thus:

$$U_L = U_t + U_b + U_s \quad (5.10)$$

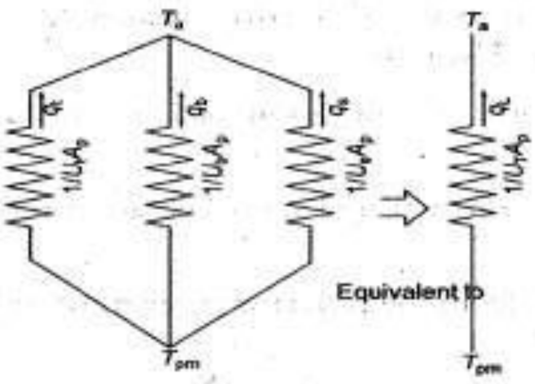


Fig. 5.5 *Thermal resistance network showing collector losses*

These losses can also be depicted in terms of thermal resistances as shown in Fig. 5.5. The typical value of the overall loss coefficient is in the range of 2 to 10 kW/m²-K.

Equation (5.2) can now be written as

$$q_u = A_p S - U_L A_p (T_{pm} - T_a) \quad (5.11)$$

A modified equation in which the plate temperature T_{pm} is replaced by the local fluid temperature T_f (temperature of fluid flowing in the tubes) can also be obtained as follows:

$$q_u = F' [A_p S - U_L A_p (T_f - T_a)] \quad (5.12)$$

where F' is known as the *collector efficiency factor* and defined as the ratio of the actual useful heat collection rate to the useful heat-collection rate which would occur if the collector–absorber plate were at the temperature T_f. Its value ranges from 0.90 to 0.95.

The heat loss from the collector can thus be calculated if either the average plate temperature or local fluid temperature is known. However, these temperatures are generally not known. By considering the heat-removal process due to fluid flow, a modified expression can be obtained in terms of the inlet fluid temperature, T_{fi}. This is usually a known quantity and hence the expression is more convenient to use. Thus:

$$q_u = F_R A_p [S - U_L (T_{fi} - T_a)] \quad (5.13)$$

$$\text{where } F_R = \frac{\dot{m} C_p}{U_L A_p}\left[1 - \exp\left(-\frac{F' U_L A_p}{\dot{m} C_p}\right)\right] \quad (5.14)$$

The term F_R is called the collector heat-removal factor. It represents the ratio of the actual useful heat-collection rate to the useful heat-collection rate which would occur if the collector absorber plate were at the temperature T_{fi} everywhere. The terms $\dot{m}$, and C_p have their usual meanings. Its value ranges from 0 to 1. Equation 5.14 is often referred as the Hottel–Whillier–Bliss equation.

Using the procedure described above, the efficiency of a flat-plate collector may be calculated. For a properly designed flat-plate collector, an instantaneous efficiency of the order of 50–60% may be achieved.

Effect of Various Parameters on Performance

(i) Selective Surface Absorber plate surfaces which exhibit characteristics of a high value of absorptivity for incoming solar radiation and low value of emissivity for outgoing re-radiation are called selective surfaces. Such surfaces are desirable because they maximize the net energy collection. Some examples of selective surface layers are copper oxide, nickel black and black chrome.

(ii) Number of Covers With increase in the number of covers, the values of both $(\tau\alpha)_b$ and $(\tau\alpha)_d$ decrease and thus the flux absorbed by the absorber plate decreases. The value of heat loss from the absorber plate also decreases. However, the amount of decrease is not the same in both cases. Maximum efficiency is obtained with one or two covers.

(iii) Spacing Heat loss also varies with spacing between two covers and that between the absorber plate and first cover. The spacing at which minimum loss occurs varies with temperature and also with tilt. Since collectors are designed to operate at different locations with varying tilts and under varying service conditions, an optimum value of spacing is difficult to specify. Spacing in the range from 4 to 8 cm is normally suggested.

(iv) Collector Tilt Flat-plate collectors are normally used in a fixed position and do not track the sun. Therefore, the tilt angle at which they are fixed is very important. Optimum tilt depends on the nature of the application. The usual practice is to recommend a value of $(\phi + 10°)$ or $(\phi + 15°)$ for winter applications (e.g. water heating, space heating, etc.) and $(\phi - 10°)$ or $(\phi - 15°)$ for summer applications (e.g., absorption refrigeration plant etc.).

(vi) Dust on the Top of the Cover When a collector is deployed in a practical system, dust gets accumulated over it, reducing the transmitted flux through the

cover. This requires continuous cleaning of the cover, which is not possible in a practical situation. Cleaning is generally done once in a few days. For this reason, it is recommended that the incident flux be multiplied by a correction factor which accounts for the reduction in intensity because of accumulation of dust. In general, a correction factor from 0.92 to 0.99 seems to be indicated.

5.1.6 Flat-Plate Air-Heating Collector (Solar Air Heater, Solar Air Collector)

A solar air-heating collector is similar to a liquid flat-plate collector with a change in the configuration of the absorber and tube (riser), as shown in Fig. 5.6. The value of the heat-transfer coefficient between the absorber plate and the air is low. For this reason, the surfaces are sometimes roughened or longitudinal fins are provided in the air-flow passage. Corrugated, V-shaped, matrix, etc., are some of the other variations of shapes of the absorber plate. The principal applications of these collectors are drying for agricultural and industrial purposes, and space heating.

It has the following advantages over a liquid flat-plate collector:

- It is compact, simple in construction and requires little maintenance.
- The need to transfer thermal energy from the working fluid to another fluid is eliminated as air is used directly as the 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.

The major disadvantages of air collectors are the following:

- A 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 the absorber plate and air is poor.
- There is less storage of thermal energy due to low heat capacity.

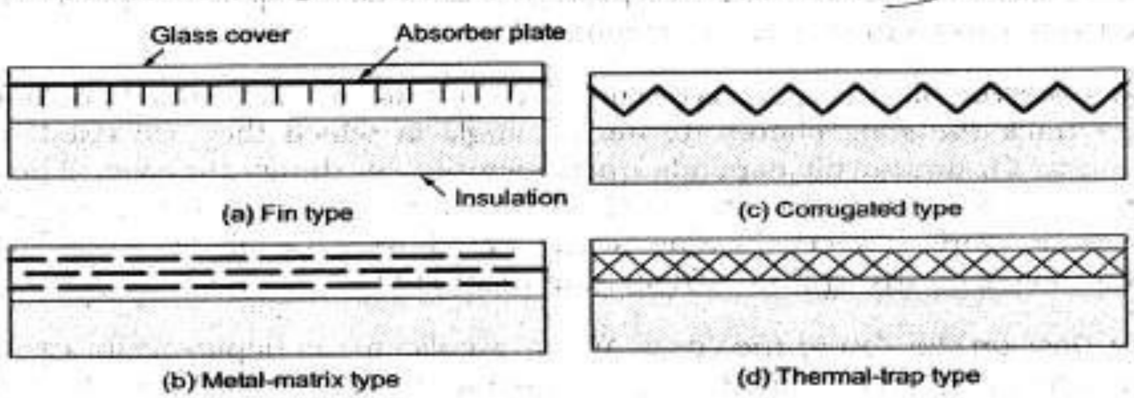


Fig. 5.6 *Various types of flat-plate air heating collector*

5.1.9 Compound Parabolic Concentrator (CPC)

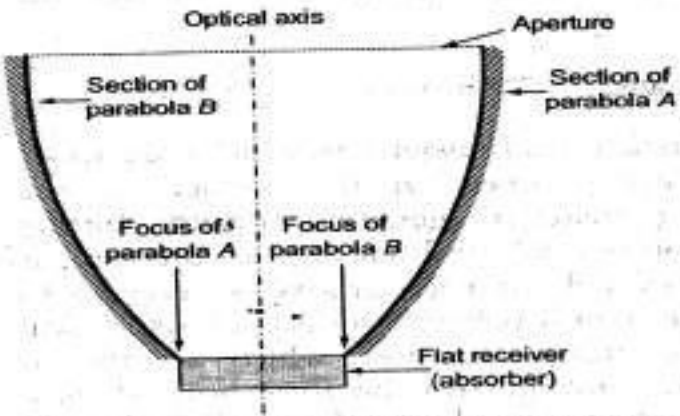


Fig. 5.10 *Compound parabolic concentrator*

A compound parabolic concentrator (shown in Fig. 5.10) consists of two parabolic mirror segments, attached to a flat receiver. The segments are oriented such that the focus of one is located at the bottom end point of the other in contact with the receiver. It has a large acceptance angle and needs to be adjusted intermittently. Rays in the central region of the aperture reach the absorber directly whereas those near the edges undergo one or more reflections before reaching the absorber. The concentration ratio achieved from this collector is in the range of 3–7.

5.1.10 Cylindrical Parabolic Concentrator

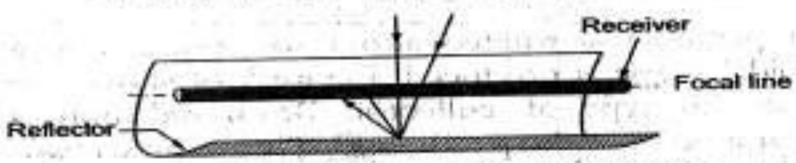


Fig. 5.11 *Cylindrical parabolic concentrator*

It consists of a cylindrical parabolic trough reflector and a metal tube receiver at its focal line as shown in Fig. 5.11. The receiver tube is blackened at the outside surface to increase absorption. It is rotated about one axis to track the sun. The heat-transfer fluid flows through the receiver tube, carrying the thermal energy to the next stage of the system. This type of collector may be oriented in any one of the three directions: east–west, north–south or polar. The polar configuration intercepts more solar radiation per unit area as compared to other modes and thus gives the best performance. The concentration ratio in the range of 5–30 may be achieved from these collectors.

5.1.11 Fixed-mirror Solar Concentrator

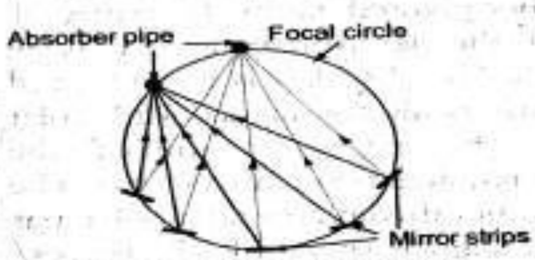


Fig. 5.12 *Fixed mirrors solar concentrator*

Due to practical difficulty in manufacturing a large mirror in a single piece in a cylindrical parabolic shape, long narrow mirror strips are used in this concentrator. The concentrator consists of fixed mirror strips arranged on a circular reference cylinder with a tracking receiver tube as shown in Fig. 5.12. The receiver tube is made to rotate about the centre of curvature of the reflector module to track the sun. The image width at the absorber is ideally the same as the projected width of a mirror element; the concentration ratio is approximately the same as the number of mirror strips.

5.1.12 Linear Fresnel Lens Collector

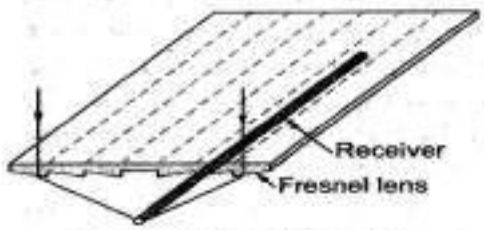


Fig. 5.13 *Linear Fresnel lens collector*

In this collector, a Fresnel lens, which consists of fine, linear grooves on the surface of the refracting material (generally optical quality plastic) on one side and flat on the other side, is used. The angle of each groove is designed to make the optical behavior similar to a spherical lens. The beam radiation, which is incident normally, converges on the focal line, where a receiver tube is provided to absorb the radiation. A concentration ratio of 10 to 30 may be realized which yields temperatures between 150 to 300°C. The construction of this type of collector is shown in Fig. 5.13.

5.1.13 Paraboloidal Dish Collector (Scheffler Solar Concentrator)

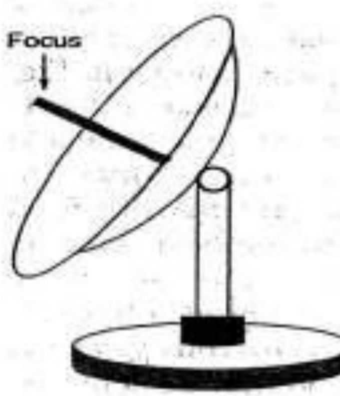


Fig. 5.14 *Paraboloidal dish collector (Scheffler solar concentrator)*

When a parabola is rotated about its optical axis, a paraboloidal shape is produced. Figure 5.14 shows the details of this type of collector. Beam radiation is focused at a point in the paraboloid. This requires two-axis tracking. It can have a concentration ratio ranging from 10 to few thousands and can yield a temperature up to 3000°C. Paraboloidal dish collectors of 6–7m in diameter are commercially manufactured.

5.1.14 Hemispherical Bowl Mirror Concentrator

It consists of a hemispherical fixed mirror, a tracking absorber and a supporting structure as shown in Fig. 5.15. All rays entering the hemisphere after reflection cross the paraxial line at some point between the focus and the mirror surface. Therefore, a linear absorber pivoted about the centre of curvature of the hemisphere intercepts all reflected rays. The absorber is to be moved so that its axis is always aligned with solar rays passing through the centre of the sphere. This requires two-axis tracking. The absorber is either driven around a polar axis at a constant angular speed of 15 degrees/

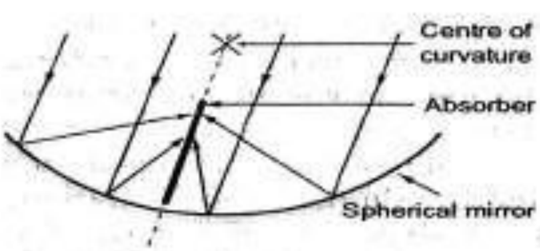


Fig. 5.15 *Hemispherical mirror concentrator*

hour or adjusted periodically during the day. This type of concentrator gives lesser concentration, owing to spherical aberration, than that obtained in paraboloidal concentrator.

5.1.15 Circular Fresnel Lens Concentrator

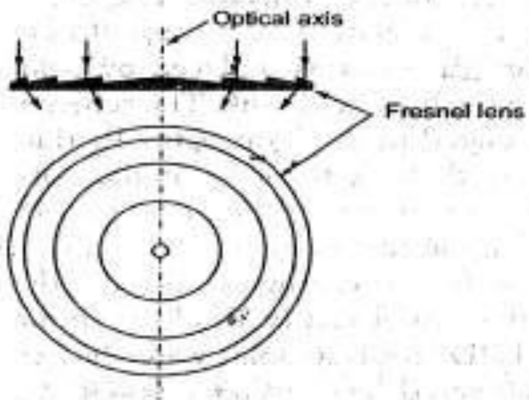


Fig. 5.16 *Circular Fresnel lens*

These lenses are generally used where high flux is desired, such as with silicon solar cells or with gallium arsenide solar cells as receiver. Figure 5.16 shows the construction of a circular Fresnel lens. It is divided into a number of thin circular zones. The tilt of each zone is so adjusted that optically, the lens approximates a thin spherical lens. The concentration ratio may be as high as 2000, but is less than that obtained from a parboloidal reflector. In solar-cell applications, tracking is required to keep the small solar image centered on the receiver.

5.1.16 Central Tower Receiver

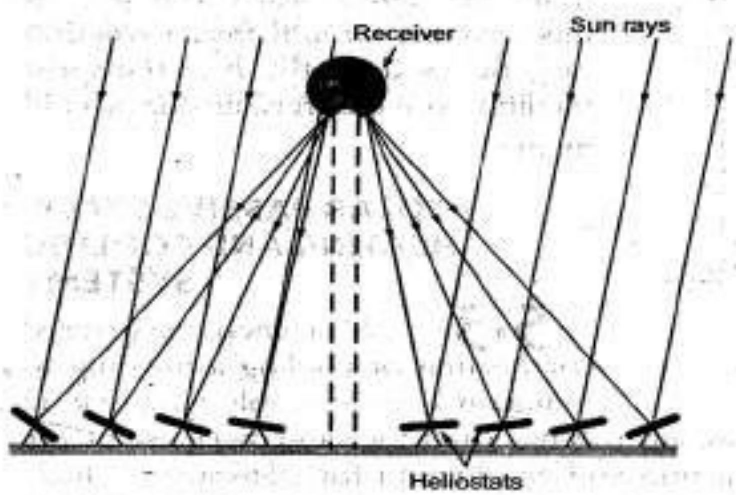


Fig. 5.17 *Central tower receiver*

In a central tower receiver collector, the receiver is located at the top of a tower. Beam radiation is reflected on it from a large number of independently controlled, almost flat mirrors, known as *heliostats*, spread over a large area on the ground, surrounding the tower. Thousands of such heliostats track the sun to direct the beam radiation on the receiver from all sides. The heliostats together act like a dilute paraboloid of very big size. Concentration ratio of as high a value as 3000 can be obtained. The absorbed energy can be extracted from the receiver and delivered at a temperature and pressure suitable for driving turbines for power generation. The schematic view of a central tower receiver is shown in Fig. 5.17.

Radiation:

Normally ,we can say that radiation is something that is being oozes out in form of wave . The process in which energy i.e., electromagnetic energy is emitted in the form of particles is said to be as radiation..

Solar Radiation:

The word "Solar Radiation" is the electromagnetic radiation which is emitted by the sun. Solar Radiation drives the physical and biological cycles in reaching the earth.

In other words, we can say solar radiation is the electromagnetic energy emitted from the sun. One of the main cause of climate change is due to solar radiation.

NOTE-(Solar radiations while passing through the earth's atmosphere are subjected to the mechanism of atmospheric absorption and scattering. A fraction of the radiation reaching the earth's surface is reflected back into the atmosphere and is subjected to these atmospheric phenomenon again, the remainder is absorbed by the earth's surface. Absorption occurs due to the presence of water vapour and ozone in the atmosphere and other particulate matter. The sattered radiation redistributed in all directions, some going back into space and some reaching the earth surface.)

Extraterrestrial Radiation:

The solar radiation which are incident outside the atmosphere is called extra Terrestrial solar radiation. The extra Terrestrial solar radiation different because the the Earth rotates around the sun in elliptical orbits and hence it is sometimes nearest to the sun while on the other time it is at a distant place to the sun

The extraterrestrial radiation is the radiation which is incident outside the earth's surface. The extraterrestrial radiation is 1367 watts/m^2.

Due to the change in distance between earth and sun, there is a seasonal variation in the extraterrestrial rate.

Terrestrial Solar Radiation:

Depending upon the nature of the surface, the radiation will be absorbed, reflected or transmitted through the object. This take place when solar radiation strikes any object. Solar radiation is the term which is used to describe visible and nearly visible radiation which is emitted by the sun. Terrestrial radiation is the term which is used to describe the infrared radiation radiated by the atmosphere.

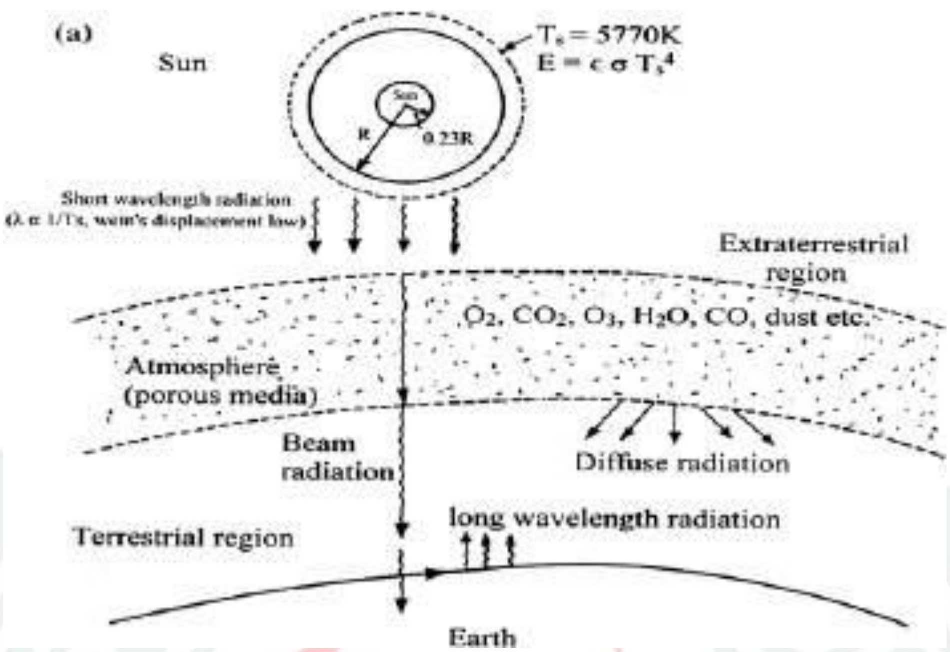
It is the electromagnetic radiation which originates from earth and its atmosphere.

Terrestrial Radiation is a longer wavelength which is totally infrared.

When the terrestrial solar radiation reaches the earth's surface,it is broken into two components i.e.,diffuse radiation and beam radiation.

Beam Radiation is the solar radiation which moves through the atmosphere in a straight line without being scattered, reflected or absorbed by particles in the air.

Diffuse Radiation is the solar radiation which is being scattered, reflected or absorbed by the particles while passing through the atmosphere but ultimately reaches the earth's surface.



Solar constant

Considering the Sun's temperature of 5760K, the total power emitted by thye Sun is about 3.8×10^{30} W (or) $6.25 \times 10^{11} W/m^2$. Because of large distance between the Sun and the earth, the amount of solar radiation that reaches just outside the earths atmosphere is quite low. And also orientation of the earth's around the Sun is such that the Sun-earth distances varzies only by 1.7 percent and since the solar radiation outside the earth's atmosphere is nearly of fixed intensities, the radiant energy flux received per second by a surface of unit area held normal to the direction of sun's rays at the mean earth-Sun distance, outside the atmosphere, is practically constant throughout the year. This is termed as the Solar Constant I_{sc} and its value is now adopted to be 1367 W/m^2. It is measured at the surface perpendicular to the sunrays at the average sun-earth distance on the top of the atmosphere. Due to the variation in the Sun-earth distance over the years the actual radiation reaching the earth's atmosphere varies through out the year. Variation in the solar radiation is also caused by the difference in the emission intensity from the sun itself. The extra-teriestrial solar radiation increase to about 1367 W/m^2. The solar constant used for calculation is only the average values of extra-terrestrial solar radiation over a year. However, this extraterrestrial radiation suffers variation due to the fact that the earth revolves around the Sun not in a circular orbit but follows an elliptic path, with Sun at one of the foci. The indensity of extraterrestrial radiation I_{ext} measured on a plane normal to the radiation on the n^{th} day of the year is given in terms of solar constant (I_{sc}) as follows,

$$I_{ext} = I_{sc}\left[1 + 0.033\cos\left(\frac{360n}{365}\right)\right]$$

The variation of extraterrestrial radiation with n^{th} day of the year is shown in ig.4.5.
Since, the cosine function varies from +1 to -1, the extraterrestrial radiation flux varies by +-3.3

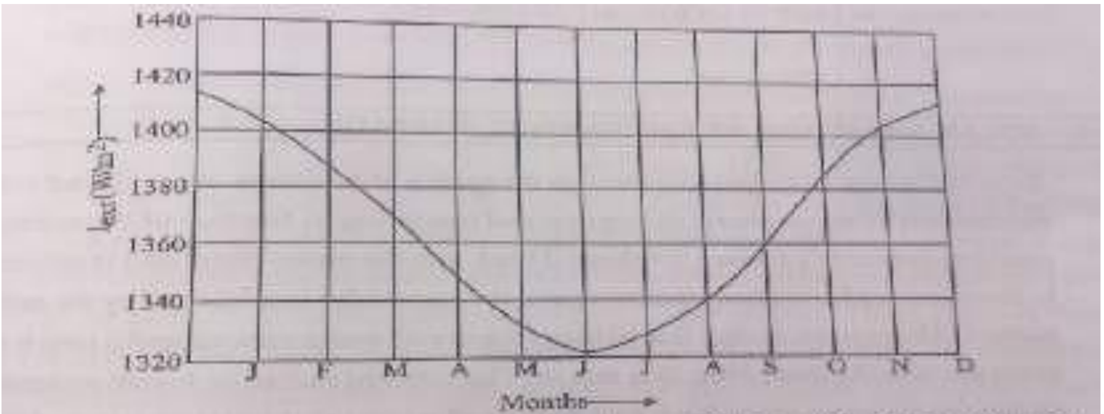


Fig. 4.5 Variation of extraterrestrial solar radiation with time of the year

Solar radiaion geometry

In order to find the beam energy falling on a surface having any orientation, it is necessary to convert the value of the beam flux coming from the direction of the sun to an equivalent value corresponding to the normal direction to the surface.

If ‘θ’ is the angle between an incident beam of flux ‘I_{bn}’ and the normal to a plane surface, then the equivalent flux falling normal to the surface is given by $I_{bn}\text{Cos}\Theta$. The angle ‘Θ’ can be related by a general equation to ‘ϕ’ latitude , ‘β’ the slope ‘γ’ the surface azimuth angle, ‘δ’ the declination and ‘ω’ the hour angle.

The Latitude ‘ϕ’ of a location is the angle made by the radial line joining the location to the centre of the earth with the projection of the line on the equatorial plane. It varies from –90^o to $+90^o$. By convention, the latitude is measured as positive for the northern hemisphere.

The slope ‘β’ is the angle made by the plane surface with the horizontal. It varies from 0 to 180^o.

The surface Azimuth Angle ‘γ’ is the angle made in the horizontal plane between the horizontal line due south and the projection of the normal to the surface on the horizontal plane. It varies from -180^o to $+ 180^o$.

We adopt the convention that the angle is positive, if the normal is East of South and Negative if West of South.

The Declination ‘δ’ is the angle made by the line joining the centres of the Sun and the Earth with the projection of this line on the equatorial plane.

$$\delta \text{ (in degrees)} = 23.45 \sin\left[\frac{360}{365}(284+n)\right] \quad \text{... (4.9)}$$

Where, *n* is the day of the year(or Day Number).

The hour angle ‘ω’ is an angular measure of time. It varies from -90^o to $+90^o$.

It is the angle through which the earth must be rotated to bring the meridian of plane directly under the sun. In order words, it is the angular displacement of sun east and west of the local meridian, due to the rotation of the earth on its axis 15^o per hour. The hour angle is zero at solar noon, negative in the morning and positive in the afternoon(Table 4.2) for northern hemisphere and vice-versa for southern hemisphere. Expression for hour angle by ω= (ST-12) 15°.

Table 4.2 The value of hour angle (ω) with time of the day (For Northern Hemisphere)

Time of the day (Hours)	6	7	8	9	10	11	12	13	14	15	16	17	18
Hour angle ω in deg	−90	−75	−60	−45	−30	−15	0	+15	+30	+45	+60	+75	+90

✓ It can be shown that

$$\cos\theta = \sin\phi\,(\sin\delta\cos\beta + \cos\delta\cos\gamma\cos\omega\sin\beta) + \cos\phi\,(\cos\delta\cos\omega\cos\beta - \sin\delta\cos\gamma\sin\beta) + \cos\delta\sin\omega\sin\beta\sin\gamma \quad \ldots (4.10)$$

✓ Some special cases of Equ.(4.10) are follows

(i) For Vertical surface $\beta = 90^0$.

$$\therefore \cos\theta = \sin\phi\cos\delta\cos\omega\cos\gamma - \cos\phi\sin\delta\cos\gamma + \cos\delta\sin\gamma\sin\omega \quad \ldots (4.11)$$

(ii) For Horizontal surface $\beta = 0^0$ [Sun's Altitude Angle (α)].

$$\sin\alpha = \cos\theta_z = \sin\phi\sin\delta + \cos\phi\cos\delta\cos\omega \quad \ldots (4.12)$$

✓ The angle 'θ' in this case is the zenith angle θ_z. It is also called as the solar altitude.

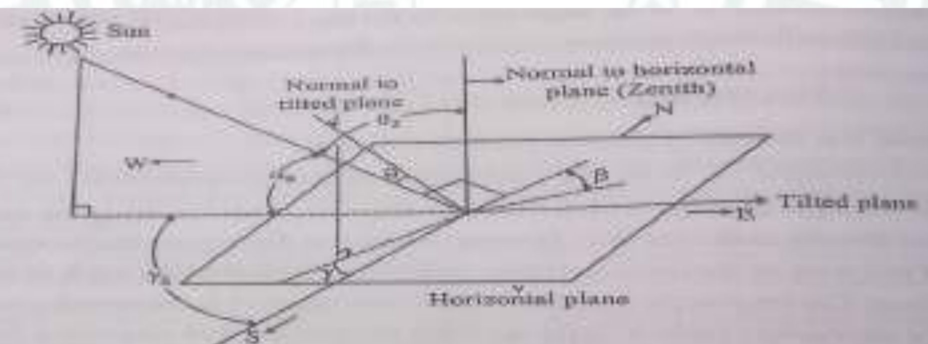


Fig. 4.11 Diagram illustrating the angle of incidance 'θ', the zenith angle 'θ_z', the solar altitude angle 'α_a', the slope 'β', the surface azimuth angle 'γ' and the solar azimuth angle 'γ_s'.

✓ The solar azimuth angle γ_s is the angle made is the horizontal plane between the horizontal line due south and the projection of the line of sight of the Sun on the horizontal plane.

$$\cos\gamma_s = (\cos\theta_z\sin\phi - \sin\delta)/\sin\theta_z\cos\phi \quad \ldots (4.17)$$

Sun Surface angles:-

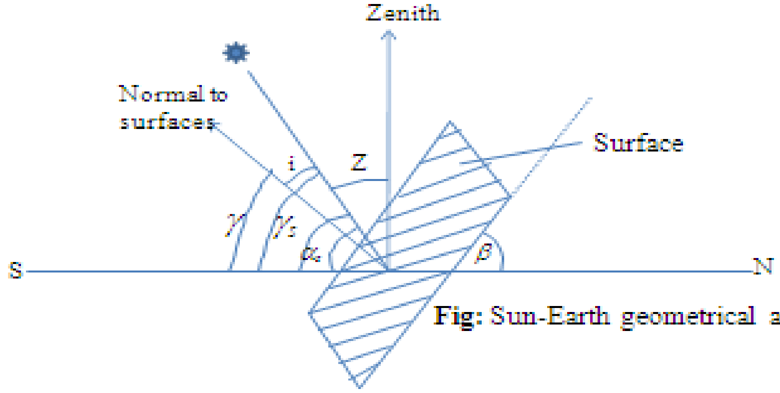


Fig: Sun-Earth geometrical angles

β = Inclination angle of a surface to the horizontal
i = angle of incidence.
α_s = solar altitude angle: East of south negative and west of south positive.
γ_s = solar azimuth angle: East of south negative and west of south positive.
Z = zenith angle.
γ = surface azimuth.

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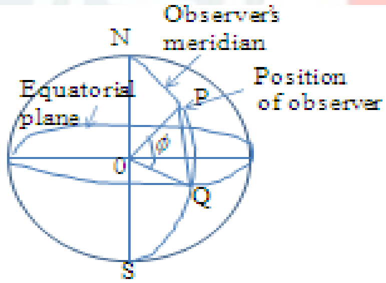
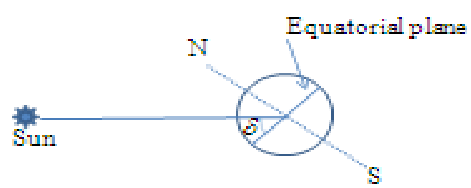


(a) Latitude



(b) Declination angle, δ

(a) Latitude angle (ϕ):-

The latitude of a location on the earth's surface is the angle made by a radial line joining the given location to the centre of the earth with its projection on the equator plane. It is positive for northern hemisphere and negative for southern hemisphere.

(b) Declination(δ):-

It is defined as the angular displacement of the sun from the plane of the earth's equator. It is positive when measured above the equatorial plane or in the northern hemisphere. The declination , δ can be approximately determined from the equation

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$$\delta = 23.45 \times \sin\left[\frac{360}{365}(284 + n)\right] \text{degrees}\ldots\ldots\ldots\ldots(5)$$

where 'n' is the day of the year counted from first January.

© Hour angle (ω):-

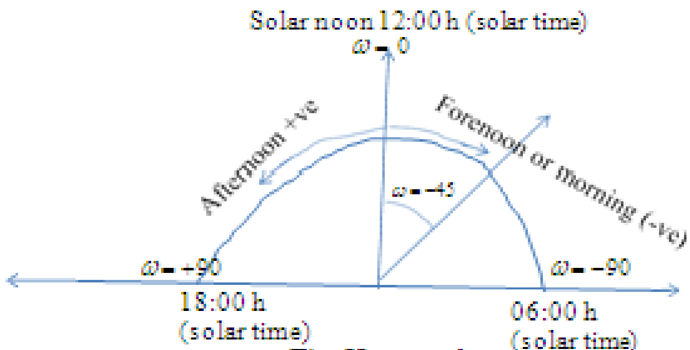

Fig: Hour angle

The hour angle at any moment is the angle through which the earth must turn to bring the meridian of the observer directly in line with the sun's rays. In other words, at any moment, it is the angular displacement of the sun towards east or west of local meridian (due to rotation of earth on its axis).

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(f) Solar azimuth angle (γ_s):-

It is the angle on a horizontal plane, between the line due south and the projection of sun's ray on the horizontal plane. It is taken as positive when measured from south towards west.

(g) Slope (tilt angle), (β):-

It is the angle between the inclined plane surface, between (collector), under consideration and the horizontal. It is taken to be positive for the surface sloping towards west.

(h) Surface Azimuth angle (γ) :-

It is the angle in the horizontal plane, between the line due south and the horizontal projection of the normal to the inclined plane surface (collector). It is taken as positive when measured from south towards west.

(i) Angle of incidence (θ_i):- It is the angle between the sun's ray incident on the plane surface (collector) and normal to that surface.

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Application of solar energy

SOLAR POND

A **solar pond** is a solar energy collector, generally fairly large in size, that looks like a pond. This type of solar energy collector uses a large, salty lake as a kind of a flat plate collector that absorbs and stores energy from the Sun in the warm, lower layers of the pond. These ponds can be natural or man-made, but generally speaking the solar ponds that are in operation today are artificial.

How they Work

The key characteristic of solar ponds that allow them to function effectively as a solar energy collector is a salt-concentration gradient of the water. This gradient results in water that is heavily salinated collecting at the bottom of the pond, with concentration decreasing towards the surface resulting in cool, fresh water on top of the pond. This collection of salty water at the bottom of the lake is known as the "storage zone", while the freshwater top layer is known as the "surface zone". The overall pond is several meters deep, with the "storage zone" being one or two meters thick.[2]

These ponds *must* be clear for them to operate properly, as sunlight cannot penetrate to the bottom of the pond if the water is murky. When sunlight is incident on these ponds, most of the incoming sunlight reaches the bottom and thus the "storage zone" heats up. However, this newly heated water cannot rise and thus heat loss upwards is prevented. The salty water cannot rise because it is heavier than the fresh water that is on top of the pond, and thus the upper layer prevents convection currents from forming. Because of this, the top layer of the pond acts as a type of insulating blanket, and the main heat loss process from the storage zone is stopped. Without a loss of heat, the bottom of the pond is warmed to extremely high temperatures - it can reach about 90°C.[1] If the pond is being used to generate electricity this temperature is high enough to initiate and run an organic Rankine cycle engine.[1]

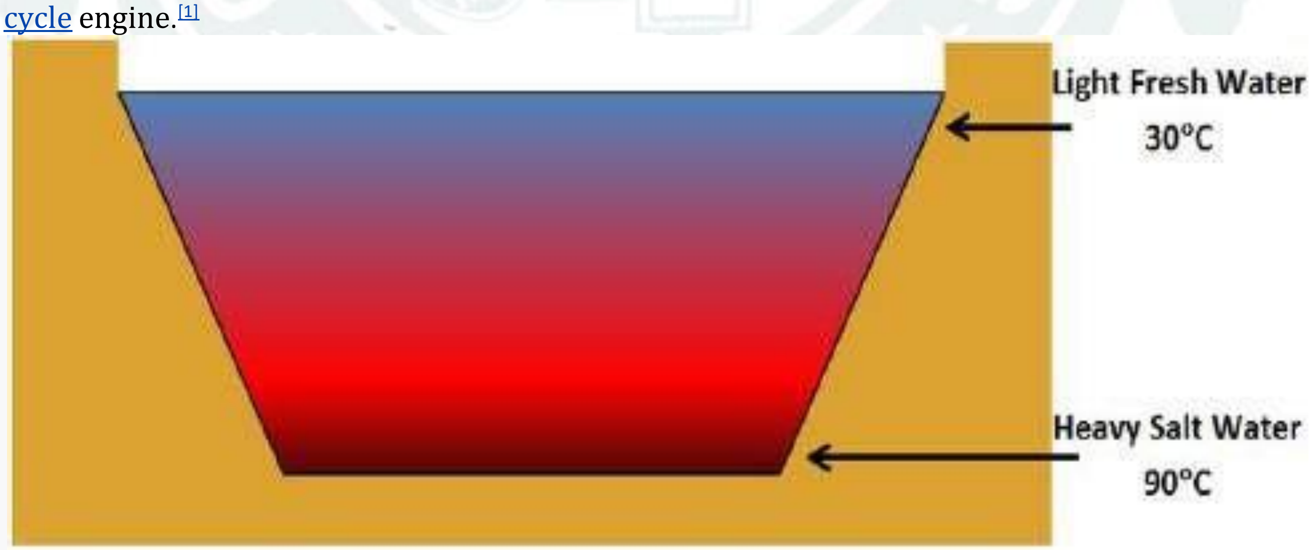


Figure 1. Diagram of a solar pond showing the temperature and saline gradient.[3]

It is vital that the salt concentrations and cool temperature of the top layer are maintained in order for these ponds to work. The surface zone is mixed and kept cool by winds and heat loss by evaporation. This top zone must also be flushed continuously with fresh water to ensure that there is no accumulation of salt in the top layer, since the salt from the bottom layer diffuses through the saline gradient over time.[2] Additionally, a solid salt or brine mixture must be added to the pond frequently to make up for any upwards salt loses.

Applications of solar pond

The heat from solar ponds can be used in a variety of different ways. First, since the heat storing abilities of solar ponds are so great they are ideal for use in heating and cooling buildings as they can maintain a fairly stable temperature.[4] These ponds can also be used to generate electricity either by driving a thermo-electric device or some organic Rankine engine cycle - simply a turbine powered by evaporating a fluid (in this case a fluid with a lower boiling point). Finally, solar ponds can be used for desalination purposes as the low cost of this thermal energy can be used to remove the salt from water for drinking or irrigation purposes.[4]

Benefits and Drawbacks

One benefit of using these ponds is that they have an extremely large thermal mass. Since these ponds can store heat energy very well, they can generate electricity during the day when the Sun is shining as well as at night.[2]

Despite being a source of energy, there are numerous thermodynamic limitations as a result of the relatively low temperatures achieved in these ponds. Because of this, the solar-to-electricity conversion is fairly inefficient - generally less than 2%.[1] As well, large amounts of fresh water are necessary to maintain the right salt concentrations all through the pond. This is an issue in places where fresh water is hard to come by, especially in desert environments. These ponds also do not work well at high latitudes as the collection surface is horizontal and cannot be tilted to collect more sunlight.

SOLAR WATER PUMPING

Solar water Pumping System is an important and popular application of Solar Photovoltaic Modules. This Solar Pump controller can be used on any AC 3 phase pumps, whether Mono-block or Submersible as per given rating. The Solar Inverter cum Pump Controller is housed in powder coated, rugged MS enclosure. It is designed with MPPT technology to maximize water delivery at various solar energy levels. The pump controller can take solar power input and give three phase ac output to the ac pump such that when full solar power is available the

motor will run at full rated speed and when it is cloudy or in the morning/evening (i.e. when solar power is limited) it will run at lower speed proportional to the availability of solar energy. The pump controller has the optional function to automatically shift the input power from Solar to Grid if the solar power is not sufficient to drive the pump. The system is best suitable for water pumps which are designed to lift water for Irrigation, Horticulture, Farming, Gardening, Drinking and various domestic uses. These systems are best alternatives for areas where there is no electricity or have scarcity of other power sources like hydrocarbons based fueling system. SPV modules used in SOLAR WATER PUMPING SYSTEM are specifically designed considering operation under Indian weather conditions. This System can withstand extreme weather conditions from Hot, Humid,

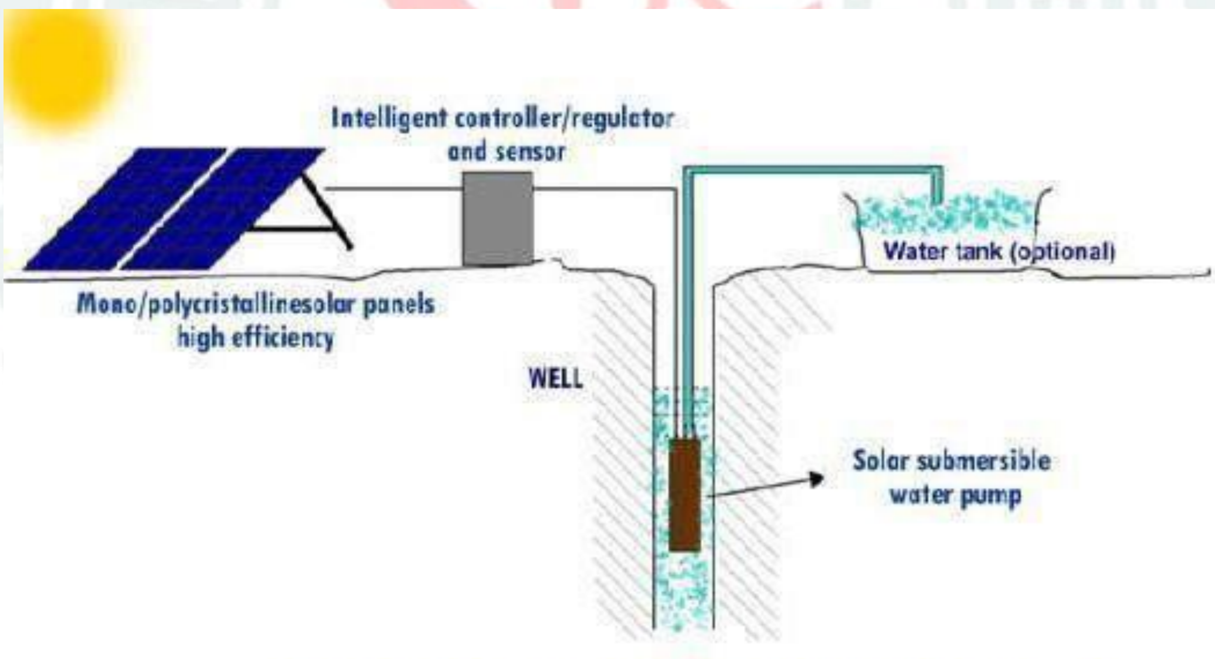
Solar water pumping system component

• **SOLAR PV Array:**
It consists of an array of solar panels connected in series and parallel combination to achieve the desired voltage and current necessary to drive the AC pump. The power rating of solar array is to be decided as per the power requirement of the existing pump set.

• **Solar Inverter cum Pump Controller:**
A high frequency transformer less inverter system, output Three Phase 415V AC and V/F control to manage starting condition of pump eliminates the requirement of large Battery Banks. The equipment is DSP based and operated with software for digital control of inverter parameters, fault finding diagnostic and digital IO signaling.

• **MPPT Charge Controller (Inbuilt with Solar Inverter Unit) :**
With this function (Maximum Power Point Tracking), it regulates the output frequency according to irradiation in real time to achieve the maximum power. Adopting the proposed dynamic VI maximum power point tracking (MPPT) control method, fast response and stable operation can be achieved. (much better than conventional charging method, which may lead to the problems including poor tracking performance, unstable or even cause water hammer damaging when the irradiation on the array changes rapidly).

• **Mounting Structure:**
MS Galvanized mounting structure (Fixed Type) will ensure the long life and hassle free operation of entire system. (Manual tracking option is also available).



BASIC SOLAR PUMPING SYSTEM DIAGRAM

• High efficiency (96%-99%), better quality low cost compact design for better reliability.
• Very low harmonic current
• Dual mode unit for operating pump either on solar power or on grid power (Optional).
• Inverse exponential speed variation during lack of solar radiation
• Modular design hence can be integrated with existing system.
• Pumps operate automatically depending on rise and fall of sun.
• Solar water pumps are used for irrigation of crops, water livestock and provide portable drinking water.
• Solar water pump uses peak solar array output which frequently coincides with high water demand during long, dry summer days.
• In the event of cloudy weather solar water pump systems often use storage tanks to store excess water.
• Solar water pumps do not require fuel or constant maintenance.
• Solar water pumps can also be designed for portability to be moved based on water demand or change of season requires.
• Their operating cost is less compared to diesel pumps.
• Recent fuel price increases and generally intensive maintenance schedules however can make diesel pumps expensive.

SOLAR COOKER

We normally use a stove or an oven for cooking vegetables, meat and rice. Using a solar cooker, we cook the same things, but by using sunlight instead of gas or electricity. In the article, let us discuss the working and construction of a solar cooker. A **solar cooker** is a device which uses the energy of direct sunlight to heat, cook or pasteurize drink and other food materials

Using Light to Cook

Sunlight isn't hot in and of itself. It is radiation generated by fluctuating electric and magnetic fields. The sunlight to heat conversion occurs when the photons of light waves interact with molecules of the substance. The electromagnetic radiation emitted by the Sun possesses energy in them. When they strike, the energy causes the molecules of the matter to vibrate. The molecules get excited and jump to higher levels. This activity generates heat.

Working Principle

Concentrating Sunlight:

A mirror surface with high specular reflection is used to concentrate and channelise light from the sun into a small cooking space. The sunlight can be concentrated by several orders of magnitude, producing magnitudes high enough to melt salt and metal. For household solar cooking applications, such high temperatures are not required. Solar cookers available in the market are designed to achieve temperatures of 65^0C to 400^0C.

Converting Light Energy to Heat Energy:

The concentrated sunlight is focused onto a receiver such as a cooking pan. The interaction between the light energy and the receiver material helps to converts light into heat by a process called conduction. The conversion is maximised by making use of materials that conduct and retain heat. Pots and pans used in solar cookers should be matte black in colour to maximise the absorption.

Trapping Heat Energy:

The occurrence of convection is reduced by isolating the air inside the cooker from the air outside. Using a glass lid on the pot enhances light absorption from the top of the pan and decreases the convection energy loss along with improving heat holding capacity of the cooker. The glazing taps the incoming sunlight but is opaque to escaping infrared thermal rays.

CLASSIFICATION

1. Direct Type : Use some solar energy concentrator to focus sunlight onto an area. Eg: Parabolic solar cooker

2. Indirect Type: A box covered with transparent material like glass. Employs greenhouse effect for cooking Eg: Solar box cooker

3. Advanced Type: The cookers use either a flat piece or focusing collector, which collect the solar heat and transfer this to the cooking vessel. Eg: Thermal storage solar cooker

• Box Cooker

• Panel Cooker

• Parabolic Cooker

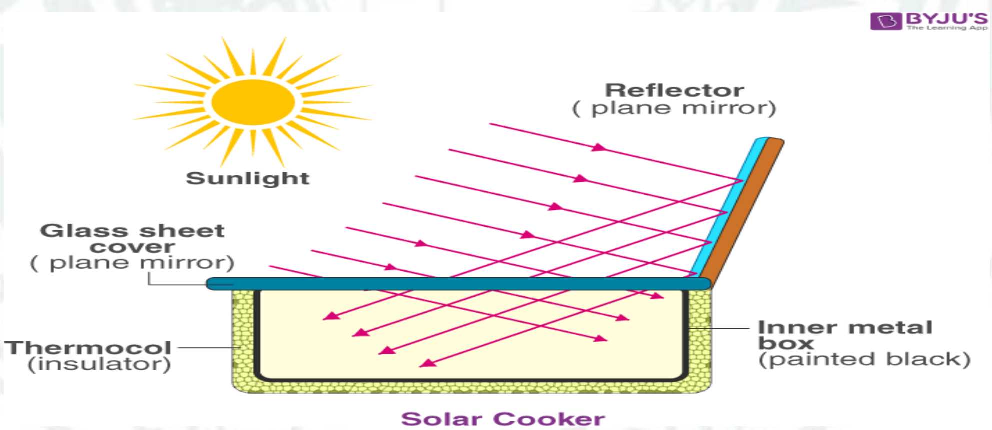
Box-Type Solar Cooker

The most commonly used form of solar cooker is the box-type solar cooker. In this section, we will be discussing the construction and working principle of a box-type solar cooker.

A box-type solar cooker consists of the following components:

- **Black Box –** The box is an insulated metal or wooden box which is painted black from the inside to absorb more heat.
- **Glass Cover –** A cover made two sheets of toughened glass held together in an aluminium frame is used as a cove for box B.
- **Plane Mirror reflector –** The plane mirror reflector is fixed to the box B with the help of hinges. The mirror reflector can be positioned at any desired angle to the box. The mirror is positioned so as to allow the reflected sunlight to fall on the glass cover of the box.
- **Cooking Containers –** A set of aluminium containers blackened from the outside are kept in box B.

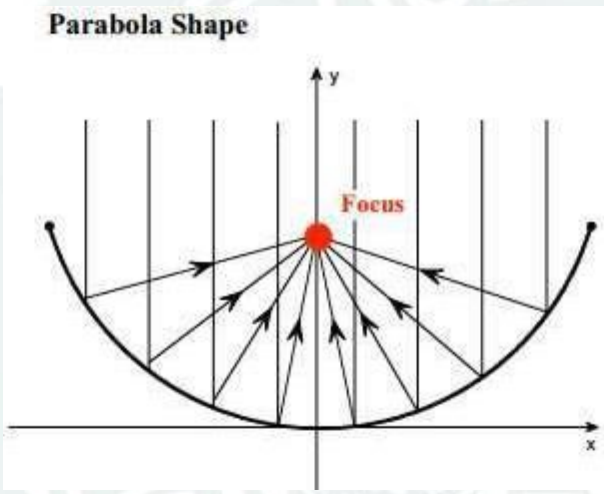
The solar cooker placed in sunlight and a plane mirror reflector is adjusted in a way such that the strong beam of sunlight enters the box through the glass sheet. The blackened metal surfaces in the wooden box absorb infra-red radiations from the beam of sunlight and heat produced raises the temperature of a blackened metal surface to about 100°C.

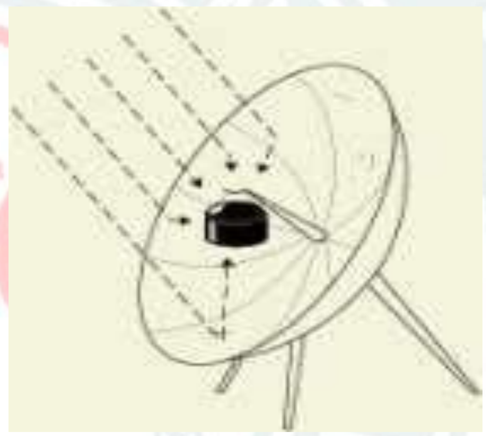


Parabolic Cooker

Parabolic solar cookers concentrate sunlight to a single point. When this point is focused on the bottom of a pot, it can heat the pot quickly to very high temperatures which can often be comparable with the temperatures achieved in gas and charcoal grills. These types of solar cookers are widely used in several regions of the world, most notably in China and India where hundreds of thousands of families currently use parabolic solar cookers for preparing food and

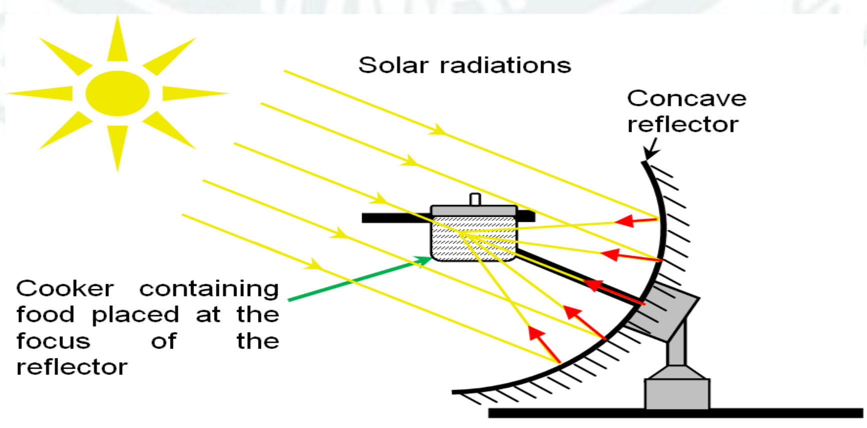
- It Focus a lot of sun energy onto a very small space, using parabolic shapes .
- It Works on the principle that when a 3D parabola is aimed at sun , the rays are reflected on to the focus.
- It Cooks nearly as fast as a conventional oven
- It Costly and complicated to make and use –have to turn frequently to follow the sun Consists of a large parabolic reflector and cooking pot holder.
- When the reflector surface is aimed at the sun , the rays falling on the parabolic surface converges to the focus of the parabola.
- The cooking pot is placed at the focus of the reflector.
- The pot surfaces are blacked to improve the absorption.





Spherical Reflector Type Solar Cooker

A spherical reflector type solar cooker consists of a large spherical (concave) reflector which reflects the sun's energy to a single focus point due to which a high temperature is produced in the focus area. Since, a spherical reflector type solar cooker reflects and concentrates the heat energy of sunlight into a small area; it is referred as solar concentrator. As much higher temperature is produced in spherical reflector type solar cooker as compared to box type solar cooker, so they are used to cook those food materials which require strong heating.



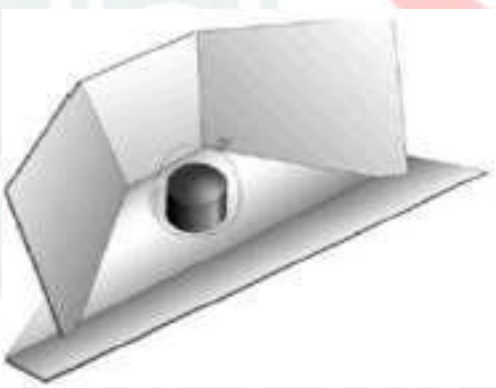
Spherical reflector type solar cooker

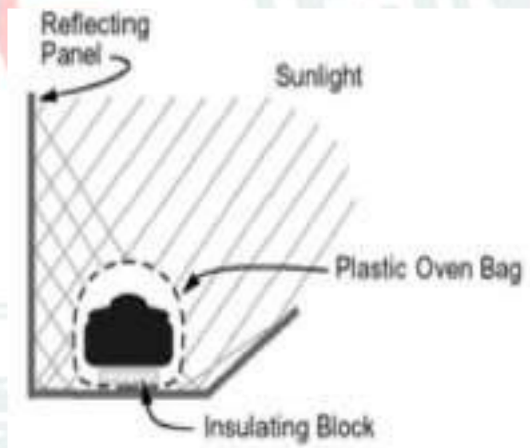
To cook food by this cooker the position of spherical reflector is adjusted in such a manner that it receives maximum sun rays. When sun rays fall on spherical reflector, they get reflected and concentrated at the focus point and produce very high temperature. Now, the cooking utensil containing raw food is placed at the focus of the cooker with the help of a stand. The temperature produced in solar concentrator is usually in the range of 180^0C to 200^0C depending on its size and the quality of reflecting surface

Panel Cooker

In this type of cooker Cooking pot is enclosed by a panel of reflectors..unlight is reflected off of multiple panels onto a pot under a glass lid or in a bag .It Can be built quickly and at low cost. Many different varieties are available.

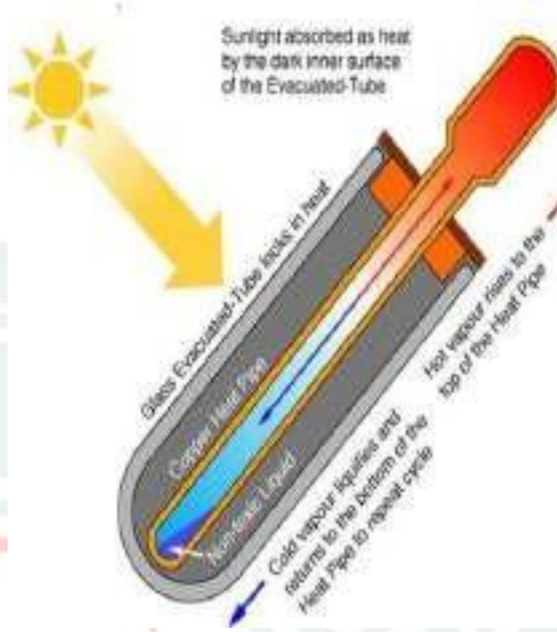
WORKING -It incorporates elements of both parabolic andmbox solar cookers.The reflective panel directs sunlight onto a dark colored pot. The pot is enclosed in an insulating shell such as high temperature cooking bag or an inverted bowl.Can attain temperatures in the range of 95 – 125 oC.





VACCUM OR EVACUATED TUBE SOLAR COOKER

The design is a simple flat plate collector housed in an evacuated glass tube.The tubes are made from a type of glass called Borosilicate, which is resistant to thermal shock. Borosilicate glass has the characteristic of being very strong and also has excellent light transparency.



It consists of two concentric glass tubes with vacuum in between. The outer tube is transparent while the inner is coated with Aluminium nitride for better absorption. The evacuated glass tube tube receives the solar rays that pass through and is absorbed by the inner lining. The combination of the highly efficient absorber coating and the vacuum insulation means that the coating can be well over 200o C. Due to the presence of vacuum , the heat losses will be negligible.A reflector is provided for concentrating sunlight onto the tubes.A tray is provided inside the glass tube for cooking purposes.

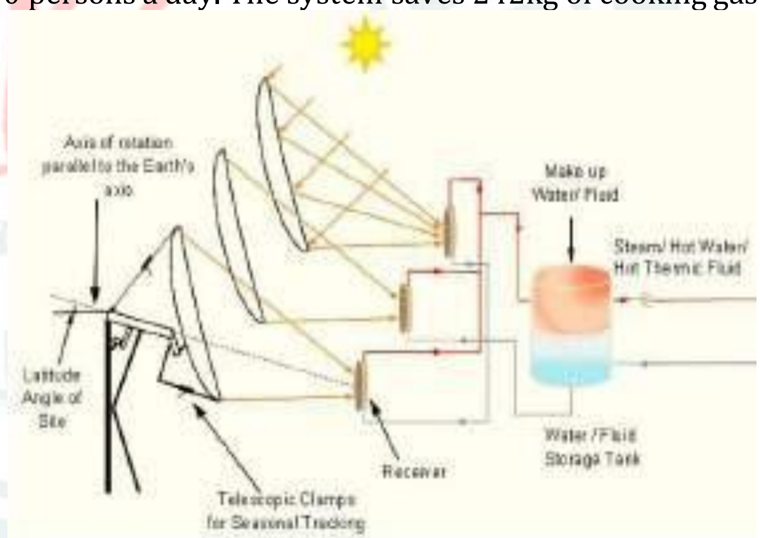
COMMUNITY SOLAR COOKER

Cook using solar energy within the kitchen itself. Due to high temperature and power at focal point, the cooking rate is significantly higher. Cooking for about 40 to 50 persons is possible with 7 sq. m,. size dish cooker. The most popular version is the scheffler community kitchen

HELIOSTAT

A device that reflects sunlight in a fixed direction as the sun moves is known as a Heliostat. The heliostats are mirrors with solar tracking on two axes and capable of concentrating the reflected solar radiation on a focal point. Heliostats are generally made from iron glass. Scheffler heliostats are used for community solar cookers. A Scheffler reflector is a small lateral section of a paraboloid which concentrates sun's radiation over a fixed focus. The collector of Scheffler Dish is an assembly of flat shaped solar grade glass mirrors or Aluminium mirror reflectors arranged on a structural steel framework. The receiver of scheffler dish is placed at the focus of the dish to capture the incident solar radiation and transfer it to the thermal medium. Tracking system enables the dish to be focused towards the sun to capture maximum possible direct radiation during the day. It Consists of heliostat and secondary reflector. Heliostat concentrates the beam on to the secondary reflector which focuses it on to the bottom of pot. When not cooking the

energy can be used for heating water or can be stored. The Sai Baba temple complex at Shirdi, Maharashtra's Ahmednagar district, has installed one of the world's largest solar cooking system based on schfeller dishes.The solar rays are used to heat up water to generate steam which is directed through pipes in to steam cookers to cook food .The steam cooked food along with food cooked with LPG is enough to feed 50,000 persons a day. The system saves 242kg of cooking gas



Advantages

- High-performance parabolic solar cookers and vacuum tube cookers can attain temperatures above 290 °C (550 °F). They can be used to grill meats, stir-fry vegetables, make soup, bake bread, and boil water in minutes. Vacuum tube type cookers can heat up even in the clouds and freezing cold.
- Conventional solar box cookers attain temperatures up to 165 °C (325 °F). They can sterilize water or prepare most foods that can be made in a conventional oven or stove, including bread, vegetables and meat over a period of hours.

- Solar cookers use no fuel. This saves cost as well as reducing environmental damage caused by fuel use. Since 2.5 billion people cook on open fires using biomass fuels, solar cookers could have large economic and environmental benefits by reducing deforestation.
- When solar cookers are used outside, they do not contribute inside heat, potentially saving fuel costs for cooling as well. Any type of cooking may evaporate grease, oil, and other material into the air, hence there may be less cleanup.
- Reduces your carbon footprint by cooking without the use of carbon based fuels or grid electricity from traditional sources.

Disadvantages

- Solar cookers are less useful at night, in cloudy weather and near the poles, where the sun is low in the sky, so an alternative cooking source is still required in these conditions. Solar cooking advocates suggest three devices for an integrated cooking solution: a) a solar cooker; b) a fuel-efficient cookstove; c) an insulated storage container such as a basket filled with straw to store heated food. Very hot food may continue to cook for hours in a well-insulated container. With this three-part solution, fuel use is minimized while still providing hot meals at any hour, reliably.
- Some solar cookers, especially solar ovens, take longer to cook food than a conventional stove or oven. Using solar cookers may require food preparation start hours before the meal. However, it requires less hands-on time during the cooking, so this is often considered a reasonable trade-off.
- Cooks may need to learn special cooking techniques to fry common foods, such as fried eggs or flatbreads like chapatis and tortillas. It may not be possible to safely or completely cook some thick foods, such as large roasts, loaves of bread, or pots of soup, particularly in small panel cookers; the cook may need to divide these into smaller portions before cooking.
- Some solar cooker designs are affected by strong winds, which can slow the cooking process, cool the food due to convective losses, and disturb the reflector. It may be necessary to anchor the reflector, such as with ring and weighted objects like bricks.

Solar home lighting system

Home lighting System is powered by solar energy using solar cells that convert solar energy (sunlight) directly to electricity. The electricity is stored in batteries and used for the purpose of lighting whenever required.
Places where it can be used

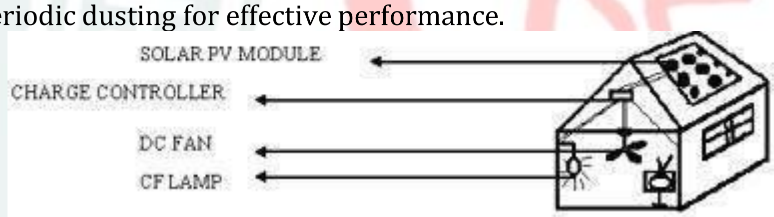
- Non-electrified rural areas
- As an emergency lighting system in houses and commercial establishments

Parts and operation of a solar Home Lighting system

The Solar Home Lighting system is a fixed installation designed for domestic application.
The system comprises of

- Solar PV Module (Solar Cells)
- charge controller
- battery and
- lighting system (lamps & fans).

The solar module is installed in the open on roof/terrace - exposed to sunlight and the charge controller and battery are kept inside a protected place in the house. The solar module requires periodic dusting for effective performance.

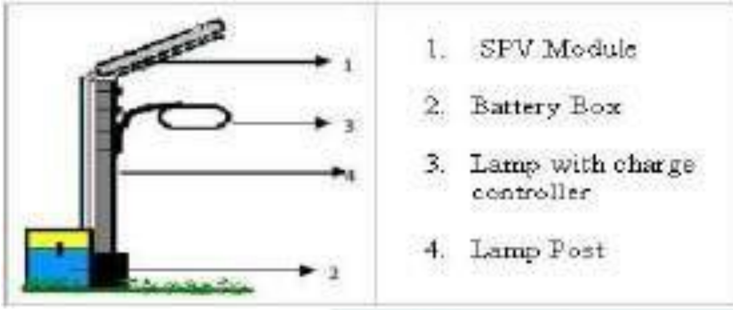


Operation Time--- It depends on the capacity of the system. However, most systems are designed to give a daily working time of 3-4 hours with a fully charged battery. The system provides for buffer storage for 1-2 non-sunny /cloudy days.

Solar street lighting system

1. Parts of a solar street lighting system
2. Approximate cost
3. Advantages

Solar street lighting system uses the photovoltaic technology to convert the sunlight into DC electricity through solar cells. The generated electricity can either be used directly during the day or may be stored in the batteries for use during night hours.



Parts of a solar street lighting system

The solar street lighting system comprises of

- Solar photovoltaic module
- Battery box
- Lamp with charge controller
- Lamp post

In general, the specifications of the parts are

- 74 Watt Solar PV Module
- 12 V, 75 Ah Tubular battery with battery box
- Charge Controller cum inverter (20-35 kHz)
- 11 Watt CFL Lamp with fixtures4 metre mild steel lamp post above ground level with weather proof paint and mounting hardware.
- Solar street lighting system is ideal for street lighting in remote villages. The system is provided with battery storage backup sufficient to operate the light for 10-11 hours daily. The system is provided with automatic ON/OFF time switch for dusk to dawn operation and overcharge / deep discharge prevention cut-off with LED indicators.

The SPV modules are reported to have a service life of 15-20 years. Tubular Batteries provided with the solar street lighting system require lower maintenance; have longer life and give better performance.

Approximate cost-The approximate cost for the most common specification is around Rs 24,000. It varies based on models.

Advantages

- No requirement of electricity
- Easy to install
- Simple to operate and low maintenance cost
- Eco friendly

SOLAR BATTERY CHARGER

A **solar charger** is a charger that employs solar energy to supply electricity to devices or batteries. They are generally portable.

Solar chargers can charge lead acid or Ni-Cd battery banks up to 48 V and hundreds of ampere hours (up to 4000 Ah) capacity. Such type of solar charger setups generally use an intelligent charge controller. A series of solar cells are installed in a stationary location (ie: rooftops of homes, base-station locations on the ground etc.) and can be connected to a battery bank to store energy for off-peak usage. They can also be used in addition to mains-supply chargers for energy saving during the daytime.

Most portable chargers can obtain energy from the sun only. Examples of solar chargers in popular use include:

- Small portable models designed to charge a range of different mobile phones, cell phones, iPods or other portable audio equipment.
- Fold out models designed to sit on the dashboard of an automobile and plug into the cigar/12v lighter socket to keep the battery topped up while the vehicle is not in use.
- Flashlights/torches, often combined with a secondary means of charging, such as a kinetic (hand crank generator) charging system.
- Public solar chargers permanently installed in public places, such as parks, squares and streets, which anyone can use for free.

What Is A Solar Battery Charger?

A solar charger is a device that uses sunlight to generate electricity.

This electricity is then used to charge electrical devices which can include but are not limited to: cell phones, laptops, car batteries, reading lights and personal fans. Because these chargers do not have the ability to directly expel electricity into the devices, an extended-life battery pack is included within the device. This way, the electricity that the solar cells generate are stored in the battery and available to discharge through the use of a charging supercapacitor at a later time. This charging supercapacitor is the key to being able to charge devices on demand even if the charger is not in direct sunlight at the time of use. These solar chargers can range in size from fitting into the palm of your hand all the way up to the size of a picnic table to be used for charging larger things such as an RV battery.

How Does A Solar Charger Work?

A battery charger bank works very similar to both a solar photovoltaic system and a more traditional battery storage system. First, sunlight strikes the surface of the device. This sunlight is then absorbed by the individual solar cells which make up the entirety of the solar device.

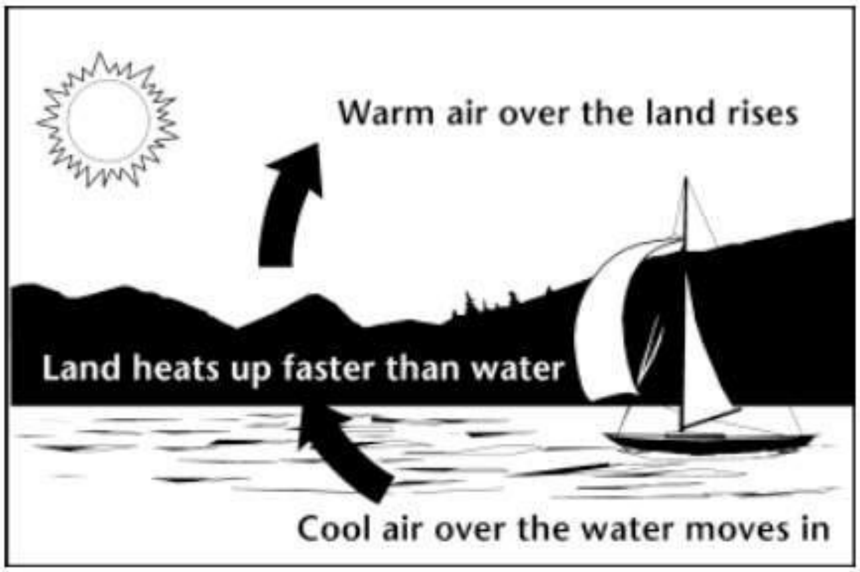
Next, photons from the sunlight excite the electrons within the material, usually silicon, to create an electric field. This electric field is the force by which electrons travel to a solar battery charger kit. This battery then stores the electricity until you are ready to charge any device that is compatible. Next, a charge inverter, which is in charge of switching electricity from direct current (DC) to alternating current (AC), turns the electricity back into a more usable form. It is important to note that certain devices use DC electricity to charge their batteries while other devices primarily use AC electricity and thus some devices do not require the use of charge inverter. Finally, the electricity is expelled out of the extended-life battery and poured into the desired electrical device. Although this process appears to be rather complicated, consumers need nothing more than clear sunlight and a few seconds to begin to see the benefits of these devices.

CHAPTER-3

ENERGY FROM WIND

Wind generation

Wind is simple air in motion. It is caused by the uneven heating of the earth's surface by the sun. Since the earth's surface is made of very different types of land and water, it absorbs the sun's heat at different rates.



During the day, the air above the land heats up more quickly than the air over water. The warm air over the land expands and rises, and the heavier, cooler air rushes in to take its place, creating winds. At night, the winds are reversed because the air cools more rapidly over land than over water. In the same way, the large atmospheric winds that circle the earth are created because the land near the earth's equator is heated more by the sun than the land near the North and South Poles. Today, wind energy is mainly used to generate electricity. Wind is called a renewable energy source because the wind will blow as long as the sun shines.

Or we can say Wind results from the movement of air due to atmospheric pressure gradients. Wind fl ows from regions of higher pressure to regions of lower pressure. The larger the atmospheric pressure gradient, the higher the wind speed and thus, the greater the wind power that can be captured from the wind by means of wind energy-converting machinery. The generation and movement of wind are complicated due to a number of factors. Among them, the most important factors are uneven solar heating, the Coriolis effect due to the earth's self-rotation, and local geographical conditions.

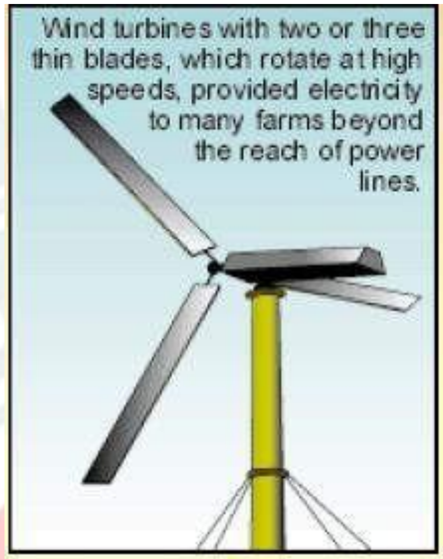
The History of Wind

Since ancient times, people have harnessed the winds energy. Over 5,000 years ago, the ancient Egyptians used wind to sail ships on the Nile River. Later, people built windmills to grind wheat and other grains. The earliest known windmills were in Persia (Iran). These early windmills looked like large paddle wheels. Centuries later, the people of Holland improved the basic design of the windmill. They gave it propeller-type blades, still made with sails. Holland is famous for its windmills. American colonists used windmills to grind wheat and corn, to pump water, and to cut wood at sawmills. As late as the 1920s, Americans used small windmills to generate

History of Wind-Mills:

- The wind is a by-product of solar energy. Approximately 2% of the sun's energy reaching the earth is converted into wind energy. The surface of the earth heats and cools unevenly, creating atmospheric pressure zones that make air flow from high- to low-pressure areas.
- The wind has played an important role in the history of human civilization . The first known use of wind dates back 5,000 years toEgypt, where boats used sails to travel from shore to shore.
- The first true windmill, a machine with vanes attached to an axis to produce circular motion, may have been built as early as 2000 B.C. In ancient Babylon. By the 10th century A.D., windmills with wind-catching surfaces having 16 feet length and 30 feet height were grinding grain in the areas in eastern Iran and Afghanistan.
- The earliest written references to working wind machines in western world date from the 12th century.These too were used for milling grain. It was not until a few hundred years later that windmills were modified to pump water and reclaim much of Holland from the sea.The multi-vane "farm windmill" of the American Midwest and West was invented in the United States during the latter half of the l9th century.
- In 1889 there were 77 windmill factories in the United States, and by the turn of the century, windmills had become a major American export.
- Until the diesel engine came along, many transcontinental rail routes in the U.S. depended on large multi-vane windmills to pump water for steam locomotives.
- Farm windmills are still being produced and used, though in reduced numbers. They are best suited for pumping ground water in small quantities to livestock water tanks.
- In the 1930s and 1940s, hundreds of thousands of electricity producing wind turbines were built in the U.S. They had two or three thin blades which rotated at high speeds to drive electrical generators. These wind turbines provided electricity to farms beyond the reach of power lines and were typically used to charge storage batteries, operate radio receivers and power a light bulb.
- By the early 1950s, however, the extension of the central power grid to nearly every American household, via the Rural Electrification Administration, eliminated the market for these machines. Wind turbine development lay nearly dormant for the next 20 years

A typical modern windmill looks as shown in the following figure.The wind-mill contains three blades about a horizontal axis installed on a tower.A turbine connected to a generator is fixed about the horizontal axis



Like the weather in general, the wind can be unpredictable. It varies from place to place, and from moment to moment. Because it is invisible, it is not easily measured without special instruments. Wind velocity is affected by the trees, buildings, hills and valleys around us.Wind is a diffuse energy source that cannot be contained or stored for use elsewhere or at another time. Like old fashioned windmills, today's wind machines use blades to collect the wind's kinetic energy. Windmills work because they slow down the speed of the wind. The wind flows over the airfoil shaped blades causing lift, like the effect on airplane wings, causing them to turn. The blades are connected to a drive shaft that turns an electric generator to produce electricity.

wind energy conversion system

A wind energy conversion system is an apparatus for converting the kinetic energy available in the wind to mechanical energy that can be used to power machinery.The most modern generations of windmills are more properly called wind turbines, or wind generators, and are primarily used to generate electricity and electrical energy. Modern windmills are designed to convert the energy of the wind into electricityLike old fashioned windmills, today's wind machines use blades to collect the wind's kinetic energy. Windmills work because they slow down the speed of the wind. The wind flows over the airfoil shaped blades causing lift, like the effect on airplane wings, causing them to turn. The blades are connected to a drive shaft that turns an electric generator to produce electricity. The major components of a typical wind energy conversion system include a wind turbine, a **generator**, interconnection apparatus, and control systems. At the present time and for the near future, generators for wind turbines will be synchronous generators, permanent magnet synchronous generators, and **induction generators**, including the squirrel-cage type and wound rotor type. For small to medium power wind turbines, permanent magnet generators and squirrel-cage induction generators are often used because of their reliability and cost advantages. Induction generators, permanent magnet synchronous generators, and wound field synchronous generators are currently used in various high p

Interconnection apparatuses are devices to achieve power control, soft start, and interconnection functions. Very often, power electronic converters are used as such devices. Most modern turbine inverters are forced commutated PWM inverters to provide a fixed voltage and fixed frequency output with a high power quality. Both voltage source voltage controlled inverters and voltage source current controlled inverters have been applied in wind turbines. For certain high power wind turbines, effective power control can be achieved with double PWM (pulse-width modulation) converters which provide a bidirectional power flow between the turbine generator and the utility grid.ower wind turbines.

Wind turbines

A wind turbine is a machine which utilizes the kinetic energy of wind to produce rotational mechanical energy in its shaft. The rotational motion of the shaft turns an electrical generator to generate electricity. There are mainly two types of wind turbine available one is the horizontal axis type another is vertical axis type.

Types of wind turbine

There are two types of wind machines (turbines) used today based on the direction of the rotating shaft (axis): horizontal–axis wind machines and vertical-axis wind machines. The size of wind machines varies widely. Small turbines used to power a single home or business may have a capacity of less than 100 kilowatts. Some large commercial sized turbines may have a capacity of 5 million watts, or 5 megawatts. Larger turbines are often grouped together into wind farms that provide power to the electrical grid.

1. Horizontal-axis wind turbine
   We call the wind turbines that have horizontal shaft as horizontal axis wind turbines. This is a horizontal axis: a propeller-style design with blades that rotate around a horizontal axis. Horizontal axis turbines are either upwind (the wind hits the blades before the tower) or downwind (the wind hits the tower before the blades). Most wind machines being used today are the horizontal-axis type. Horizontal-axis wind machines have blades like airplane propellers. A typical horizontal wind machine stands as tall as a 20-story building and has three blades that span 200 feet across. The largest wind machines in the world have blades longer than a football field! Wind machines stand tall and wide to capture more wind.

***Horizontal axis wind turbine** can be further divided into three types*:

- Dutch type grain grinding wind mills
- Multi blade water pumping windmills
- High speed propeller type windmills

Dutch Windmill:

Man has used Dutch windmills for a long time. In fact the grain grinding windmills that were widely used in Europe since the middle ages were Dutch. These windmills were operated on the thrust exerted by the wind. The blades, generally four, were inclined at an angle to the plane of rotation. The wind being deflected by the blades exerted a force in the direction of rotation. The blades were made of sails or wooden slats.

Multiblade Water Pumping Windmill:

Modern water pumping windmills have a large number of blades- generally wooden or metallic- driving a reciprocating pumps. As the mill has to be placed directly over the well, the criterion for site selection concerns about water availability & not windiness. Therefore the mill must be able to operate at slow winds. The large number of blades gives a high torque, required for driving a centrifugal pump, even at low wind speeds. Hence sometimes these are called as fan mills. As these windmills are supposed to be installed at remote places, mostly as single units, reliability, sturdiness, and low cost are the prime criteria and not efficiency. The blades are made of flat steel plates, working on the thrust of wind. These are hinged to a metal ring to ensure structural strength, and the low speed of rotation adds to the reliability. The orientation is generally achieved by tail vane.

High speed propeller type wind machines:

The horizontal axis wind turbines that are used today for electricity generation do not operate on thrust force. They depend mainly on the aerodynamic forces that develop when wind flows around a blade of aerofoil design. Windmills working on thrust force are inherently less efficient. So all the modern wind turbine blades are designed based on aerofoil section.

Vertical axis wind turbines:

There is another type of wind turbine which uses vertically aligned rotating shaft. We call this turbine Vertical Axis Wind Turbines or VAWTs. As it has the vertical axis, it does not have to align itself with the wind and hence using these turbines are more suitable where the direction of wind significantly varies. We can install this turbine even on the rooftop since the height of this turbine is much lesser than that of HAWT. Another significant advantage is that as the shaft is vertical, we can extend it to the bottom level where we can couple a generator with the vertical shaft with the help of ground-based gearbox which facilitates easier maintenance.

***Vertical axis wind turbine** It comes in two different designs*

- The savonius rotor
- The darrieus rotor

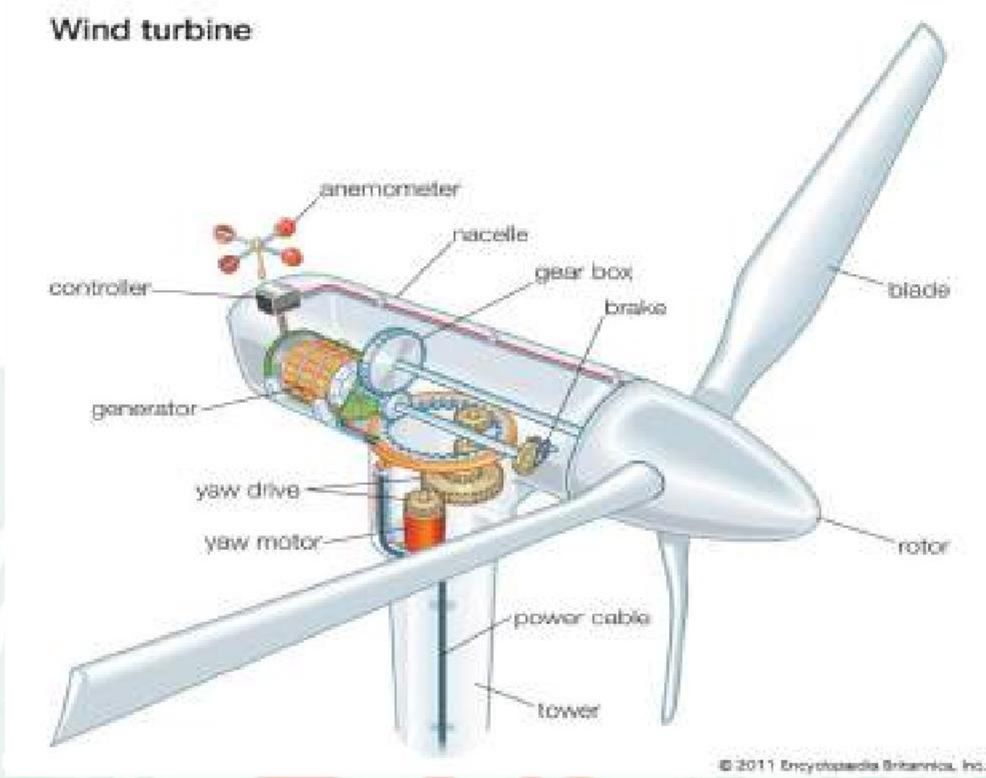
The savonius rotor:

The savonius rotor is extremely simple vertical axis device that works entirely because of the thrust force of wind. The basic equipment is a drum cut in two halves vertically. The two parts are attached to the two opposite sides of a vertical shaft. As the wind blowing into the structure meets with two dissimilar surfaces – one convex and the other concave – the forces exerted on the two surfaces are different, which gives the rotor a torque. By providing a certain amount of overlap between the two drums, the torque can be increased. This is because the wind blowing into the concave surface turn around and give a push to the inner surface of the other drum, partly cancelling the wind thrust on the convex side. It has been found that an overlap of about one third the drum diameter gives optimum result.

The darrieus wind turbine:

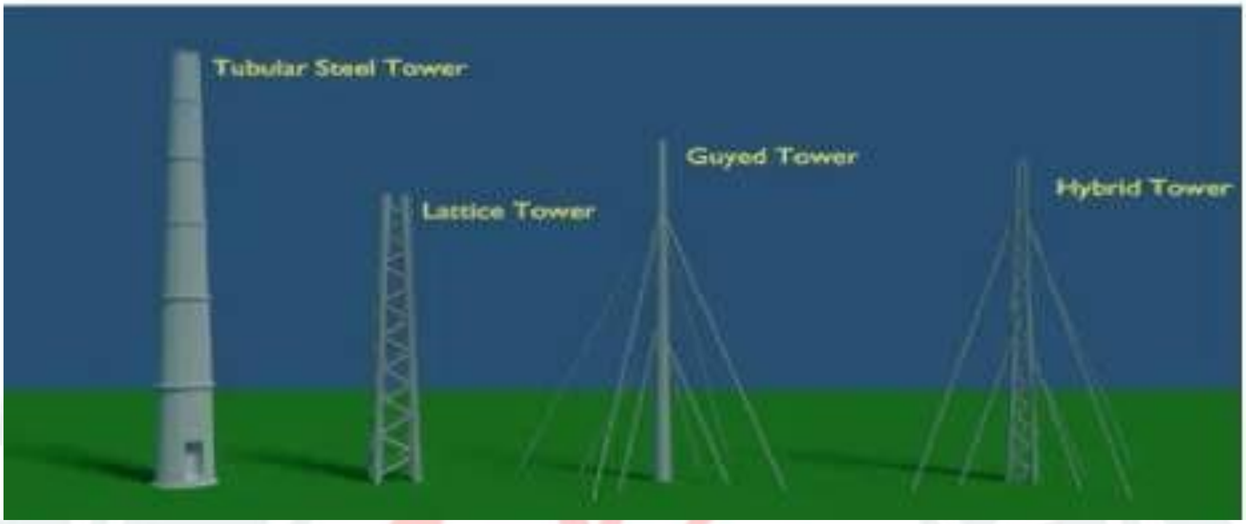
The particularity of Darrieus rotor is that its working is not at all evident from its appearance. Two or more flexible blades are attached to a vertical shaft. The blades bow outwards, taking approximately the shape of a parabola and are of symmetrical airfoil section. Here the torque is zero when the rotor is stationary. It develops a positive torque only when it is already rotating. This means that such a rotor has mo starting torque and has to be start using some external means.

Major Parts of Wind Turbine



Tower of Wind Turbine

Tower is very crucial part of wind turbine that supports all the other parts. It not only supports the turbine but raises the turbine to sufficient height so that its blades tips would be at safe height during rotation. Not only that, we have to maintain the height of the tower, so that it can get sufficiently strong wind. The height of tower ultimately depends on the power capacity of wind turbines. The tower of the turbines in commercial wind power plants usually ranges from 40 meters to 100 meters. These towers may be either tubular steel towers, lattice towers, or concrete towers. We use a tubular steel tower for a large wind turbine. These are normally manufactured in a section of 30 to 40 meters in length. Each section has flanges with holes. Such sections are fitted together by nut bolts at the site to form a complete tower. The complete tower is slight conical shape to provide better mechanical stability. We assemble a lattice tower by different members of steel or GI angles or tubes. All members are bolted or welded together to form a complete tower of desired height. The cost of these towers are much less than that of steel tubular tower, but it aesthetically looks not as good as steel tubular tower. Although, transportation, assembling, and maintenance are quite easy but still use of lattice tower is avoided in modern wind turbine plant due to its aesthetic look. There is another type of tower used for small wind turbines, and this is guyed pole tower. Guyed pole tower is a single vertical pole supported by guy wired from different sides. Because of numbers of guy wires, it is difficult to access the footing area of the tower. Because of that, we avoid this type of tower in the agricultural field. There is another type of wind turbine tower used for small plant, and this is a hybrid type tower. Hybrid type tower is also a guyed type tower, but the only difference is that instead of using a single pole in the middle it uses a thin and tall lattice type tower. Hybrid type tower is hybrid of both lattice type and guyed type tower.



Nacelle of Wind Turbine

The nacelle is a big box or kiosk that sits on the tower and houses all the **components of a wind turbine**. It houses an electrical generator, power converter, gearbox, turbine controller, cables, a yaw drive**.**

Rotor Blades of Wind Turbine

Blades are the main mechanical parts of a wind turbine. The blades convert wind energy into usable mechanical energy. When the wind strikes on the blades, the blades rotate. This rotation transfers its mechanical energy to the shaft. We design the blades like airplane wings. The wind turbine blades can be 40 meters to 90 meters long. The blades should be mechanically strong enough to withstand strong wind even during the storm. At the same time, the wind turbine blades should be made as light as possible to facilitate smooth rotation of the blades. For that, we make the blades with fiberglass and carbon fiber layers on synthetic reinforce.In a modern turbine, normally three identical blades are fitted to a central hub using nut bolts. Each identical blades are aligned at 120^o to each other. The process makes a better distribution of mass and gives the system more smooth rotation.

Shaft of Wind Turbine

The shaft directly connected to the hub is a low-speed shaft. When the blades rotate, this shaft spins with the same rpm as the rotating hub. We couple this shaft directly to the electrical generator in case of a low-speed generator. But in most cases, the low-speed main shaft is geared with a high-speed shaft through a gearbox. In this way, the rotor blades transfer its mechanical energy to the shaft which ultimately enters into an electrical generator**.**

Gearbox

The wind turbine does not rotate at high speed rather it rotates gently at low speed. But most of the electrical generators require high-speed rotation, to generate electricity at a desired voltage level. So there must be some speed multiplication arrangement to achieve the high speed of the generator shaft. The gearbox of the wind turbine does this. Gearbox increases the speed to much higher value. For example, if the gearbox ratio is 1:80 and if the rpm of a low-speed main shaft is 15, the gearbox will increase the speed of generator shaft to 15 × 80 = 1200 rpm

Generator

The generator is an electrical device that converts mechanical energy received from the shaft into electrical energy. Normally, we use induction generators in modern wind turbines. Previously, synchronous generators were popular for this purpose. Permanent Magnet DC generator also used in some wind turbines. The speed of the shaft can be made high by using gearbox assembly, but we can not make the shaft speed constant. There may be a fluctuation in shaft speed since it depends on wind speed. So, the speed of the rotor also varies. This variation affects the frequency, voltage of the generated electric power. To, overcome these issues, we normally use an induction generator for the purpose.

Because the induction generator always produces electric power synchronized to the connected grid irrespective of the speed of the rotor. If we use the three-phase synchronous generator, then we first rectify the output power to DC and then convert it to AC of desired voltage and frequency using inverter circuit. Because the alternating power generated by the synchronous generator is not constant in voltage and frequency, rather it varies with speed of the rotor. Because, for the same reason, in some cases, we use a DC generator for the purpose. In these cases, the output DC power from generator inverted to AC of desired voltage and frequency, before feeding it to the grid

Power Converter Because wind is not always constant, so electrical potential generated from a generator is not constant, but we need a very stable voltage to feed the grid. A power converter is an electrical device that stabilizes the alternating output voltage transferred to the grid.

Turbine Controller Turbine controller is a computer (PLC) that controls the entire turbine. It starts and stops the turbine and runs self diagnostic in case of any error in the turbine.

Anemometer It measures the wind speed and passes the speed information to PLC to control the turbine power.

Wind Vane It senses the direction of the wind and passes the direction to PLC then PLC faces the blades in such a way that it cuts the maximum wind.

Pitch drive Pitch drive motors control the angle of blades whenever the wind changes it rotates the angle of blades to cut the maximum wind, which is called pitching of blades.

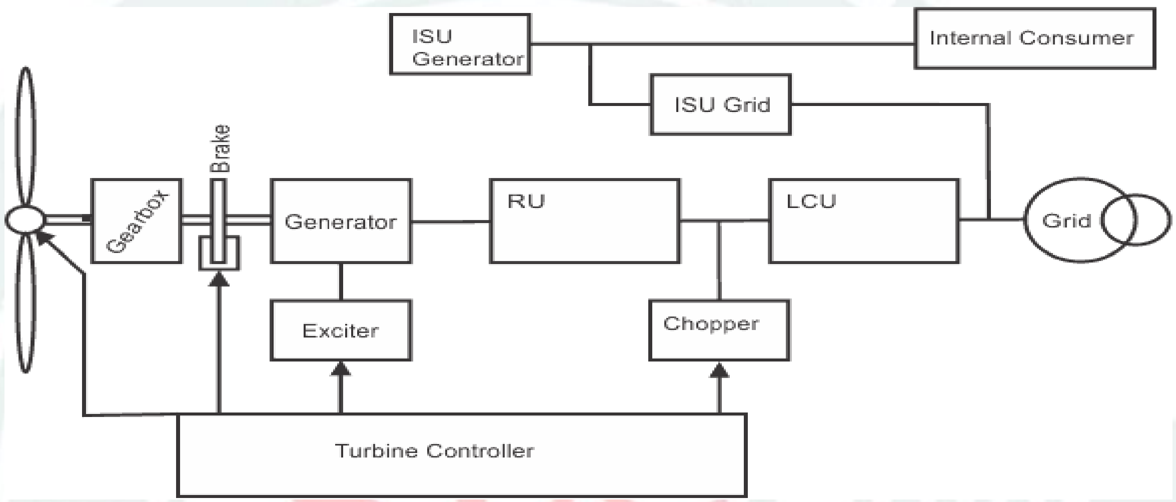
Yaw Drive Blades and other components in wind turbine are housed in a nacelle, whenever any change in wind direction is there, the nacelle has to face in the direction of the wind to extract the maximum energy from wind. For this purpose yaw drive, a motor is used to rotate the nacelle. It is controlled by PLC that uses the wind vane information to sense the wind direction**.**

Working of Wind Turbine

- When the wind strikes the rotor blades, blades start rotating. The turbine rotor is connected to a high-speed gearbox. Gearbox transforms the rotor rotation from low speed to high speed. The high-speed shaft from the gearbox is coupled with the rotor of the generator and hence the electrical generator runs at a higher speed.
- An exciter is needed to give the required excitation to the magnetic coil of the generator field system so that it can generate the required electricity.
- The generated voltage at output terminals of the alternator is proportional to both the speed and field flux of the alternator.
- The speed is governed by wind power which is out of control. Hence to maintain uniformity of the output power from the alternator, excitation must be controlled according to the availability of natural wind power. The exciter current is controlled by a turbine controller which senses the wind speed.
- Then output voltage of electrical generator(alternator) is given to a rectifier where the alternator output gets rectified to DC. Then this rectified DC output is given to line converter unit to convert it into stabilized AC output which is ultimately fed to either electrical transmission network or transmission grid with the help of step up transformer.
- An extra units is used to give the power to internal auxiliaries of **wind turbine** (like motor, battery etc.), this is called Internal Supply Unit.
  There are other two control mechanisms attached to a modern big wind turbine.
  - Controlling the orientation of the turbine blade.
  - Controlling the orientation of the turbine face.
- The orientation of turbine blades is governed from the base hub of the blades. The blades are attached to the central hub with the help of a rotating arrangement through gears and small electric motor or hydraulic rotary system. The system can be electrically or mechanically controlled depending on its design. The blades are swiveled depending upon the speed of the wind. The technique is called pitch control. It provides the best possible orientation of the turbine blades along the direction of the wind to obtain optimized wind power.

- The orientation of the nacelle or the entire body of the turbine can follow the direction of changing wind direction to maximize mechanical energy harvesting from the wind. The direction of the wind along with its speed is sensed by an anemometer (automatic speed measuring devices) with wind vanes attached to the back top of the nacelle. The signal is fed back to an electronic microprocessor-based controlling system which governs the yaw motor which rotates the entire nacelle with gearing arrangement to face the air turbine along the direction of the wind.

  An internal Block diagram of a wind turbine



AERODYNAMICS OF WIND TURBINES

What is aerodynamics?

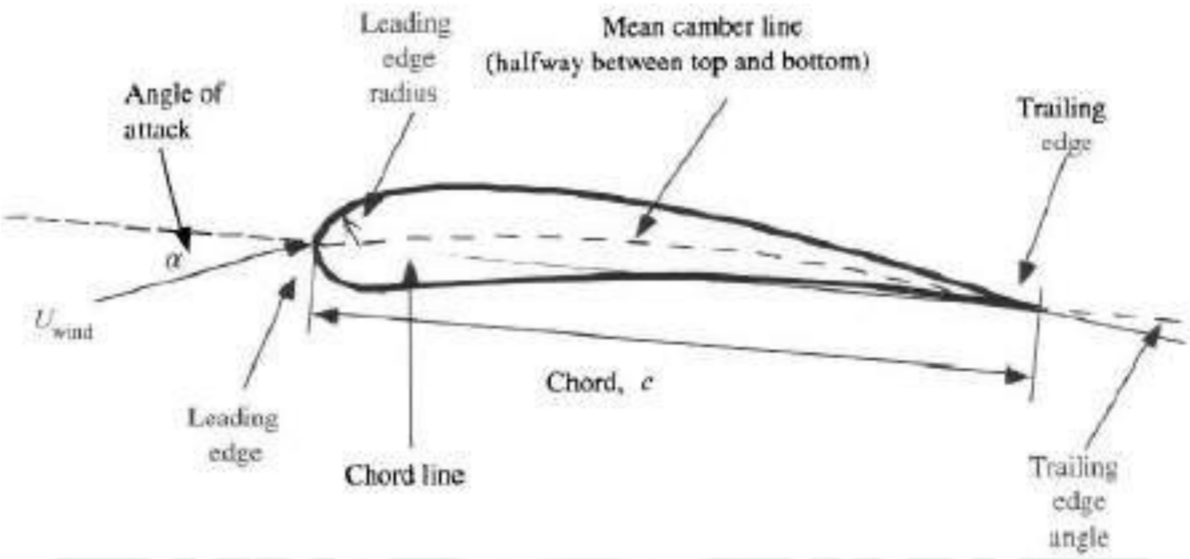
- A branch of dynamics- how things move under the action of forces.
- Aerodynamics is the study of motion of air and how it interacts with a moving or stationary object.
- Aerodynamics is a necessary tool for modeling the loads and power output of a wind turbine. A wind turbine turns wind energy into electricity using the aerodynamic force from the rotor blades, which work like an airplane wing or helicopter rotor blade.
- When wind flows across the blade, the air pressure on one side of the blade decreases. The difference in air pressure across the two sides of the blade creates both lift and drag. The force of the lift is stronger than the drag and this causes the rotor to spin. The rotor connects to the generator, either directly (if it's a direct drive turbine) or through a shaft and a series of gears (a gearbox) that speed up the rotation and allow for a physically smaller generator. This translation of aerodynamic force to rotation of a generator creates electricity.

Airfoils and general aerodynamic concepts

- Wind turbine blades use airfoil sections to develop mechanical power.
- The width and length of the blades are a function of the desired aerodynamic performance and the maximum desired rotor power (as well as strength considerations).
- Before examining the details of wind turbine power production, some airfoil aerodynamic principles are reviewed here.

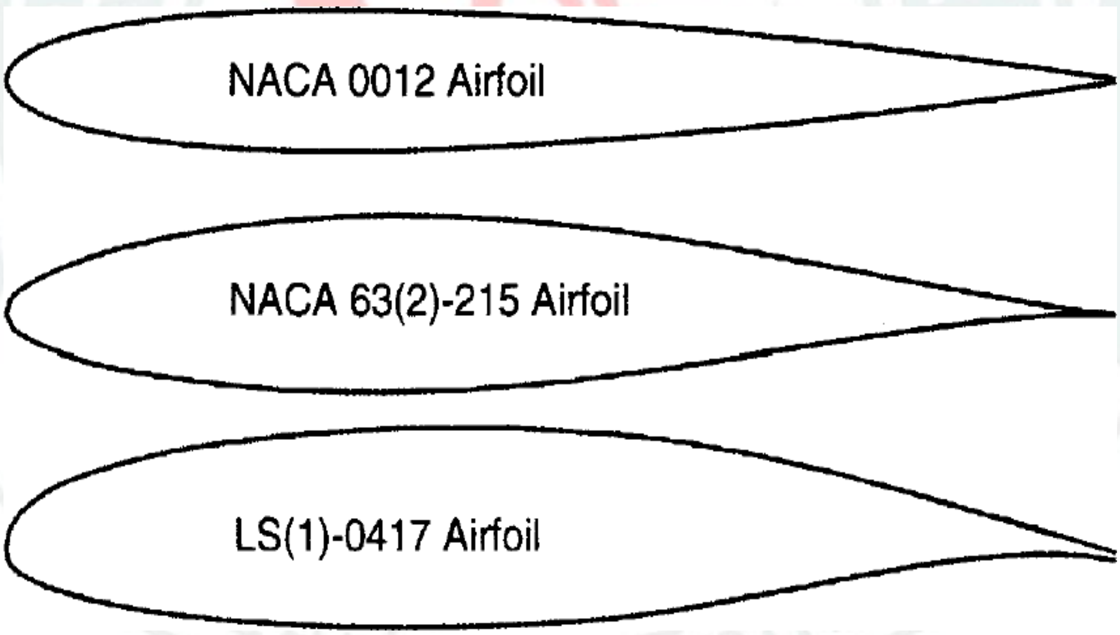
Basic airfoil terminology

- **Camber** = distance between mean camber line (mid-point of airfoil) and the chord line (straight line from leading edge to trailing edge)
- **Thickness** = distance between upper and lower surfaces (measured perpendicular to chord line)
- **Span** = length of airfoil normal to the cross-section



Examples of standard airfoil shapes

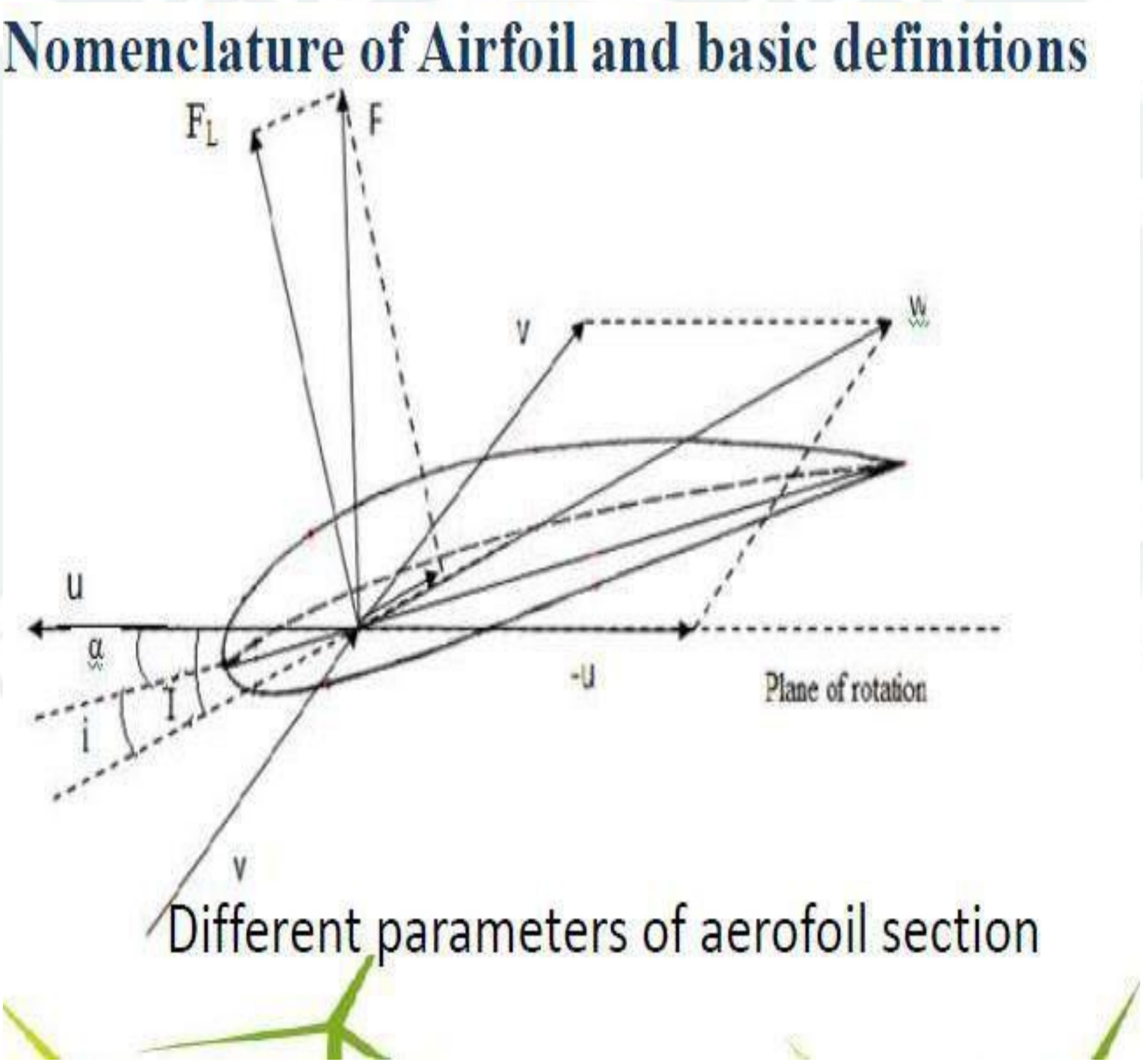
National Advisory Committee for Aeronautics



NACA 0012 = 12% thick symmetric airfoil
NACA 63(2)-215 = 15% thick airfoil with slight camber
LS(1)-0417 = 17% thick airfoil with larger camber

Lift, drag and non-dimensional parameters

- Airflow over an airfoil produces a distribution of forces over the airfoil surface.
- The flow velocity over airfoils increases over the convex surface resulting in lower average pressure on the 'suction' side of the airfoil compared with the concave or 'pressure' side of the airfoil.
- Meanwhile, viscous friction between the air and the airfoil surface slows the airflow to some extent next to the surface.

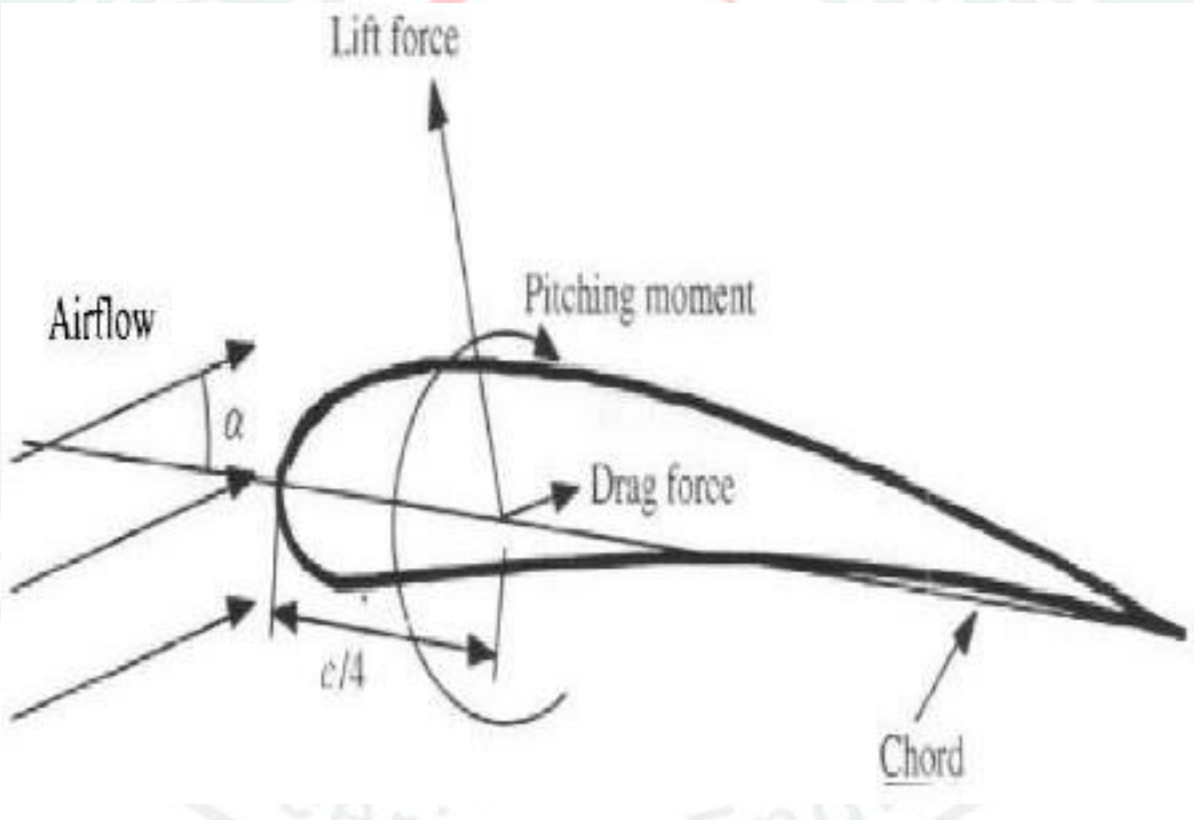


Different parameters of aerofoil section

Lift force - defined to be perpendicular to direction of the oncoming airflow. The lift force is a consequence of the unequal pressure on the upper and lower airfoil surfaces.

Drag force - defined to be parallel to the direction of oncoming airflow. The drag force is due both to viscous friction forces at the surface of the airfoil and to unequal pressure on the airfoil surfaces facing toward and away from the oncoming flow

Pitching moment - defined to be about an axis perpendicular to the airfoil cross-section



- The resultant of all of these pressure and friction forces is usually resolved into two forces and a moment that act along the chord at *c* / 4 from the leading edge (at the 'quarter chord').
- These forces are a function of Reynolds number ***Re = U L /*** ν (*L* is a characteristic length, e.g. *c*)

The 2-D airfoil section lift, drag and pitching moment coefficients are normally defined as:

$$c_l = \frac{L/l}{\frac{1}{2}\rho U^2 C} = \frac{\text{Lift force/unit length}}{\text{Dynamic force/Unit length}}$$

$$c_d = \frac{D/l}{\frac{1}{2}\rho U^2 C} = \frac{\text{Drag force/Unit length}}{\text{Dynamic force/Unit length}}$$

$$C_m = \frac{M}{\frac{1}{2}\rho U^2 AC} = \frac{\text{Pitching moment}}{\text{Dynamic moment}}$$

A = projected airfoil area = chord x span = *c l*

Other dimensionless parameters that are important for analysis and design of wind turbines include the power and thrust coefficients and tip speed ratio, mentioned earlier and also the pressure coefficient:

$$C_p = \frac{P - P_\infty}{\frac{1}{2}\rho U^2} = \frac{\text{Static pressure}}{\text{Dynamic pressure}}$$

And blade surface roughness ratio:

$$\frac{\varepsilon}{L} = \frac{\text{Surface roughness height}}{\text{Body length}}$$

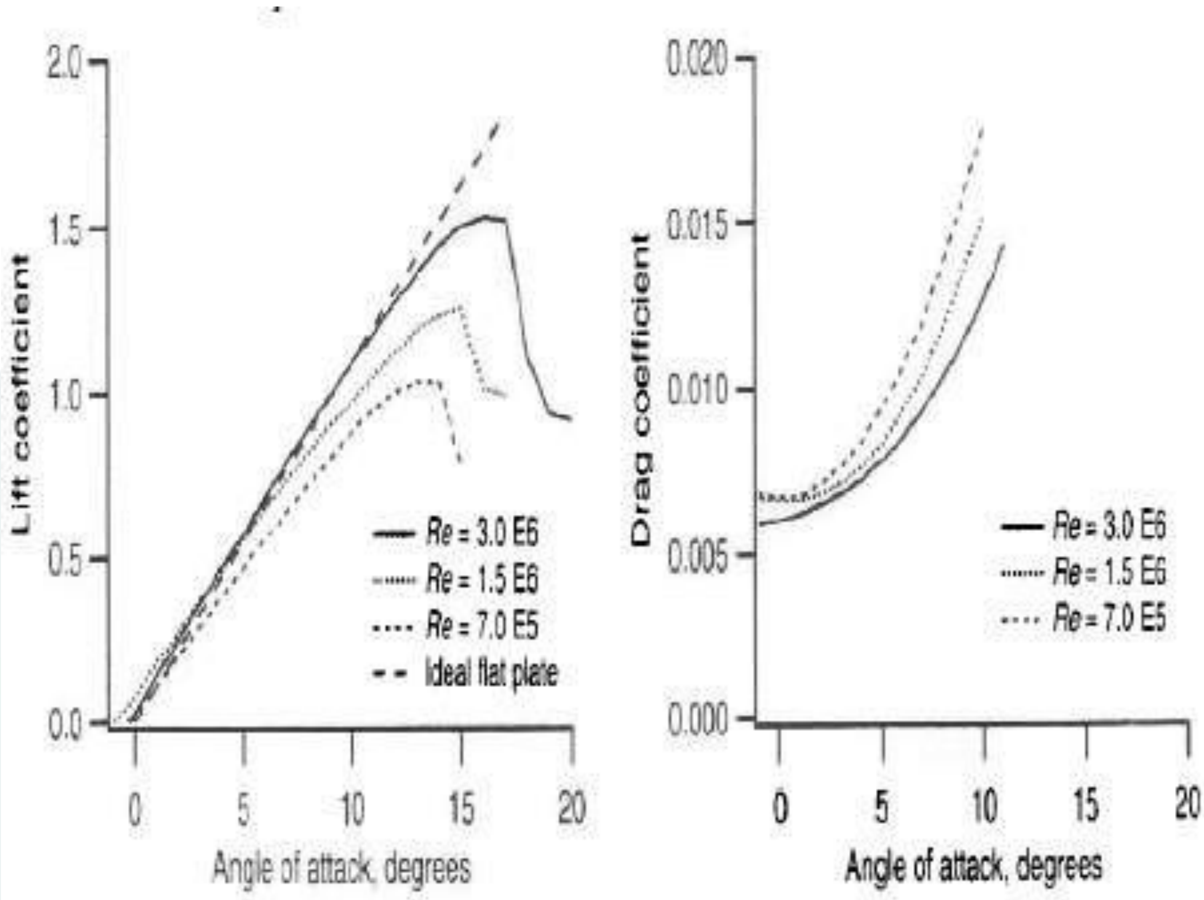
Airfoil aerodynamic behaviour

The theoretical lift coefficient for a flat plate is:

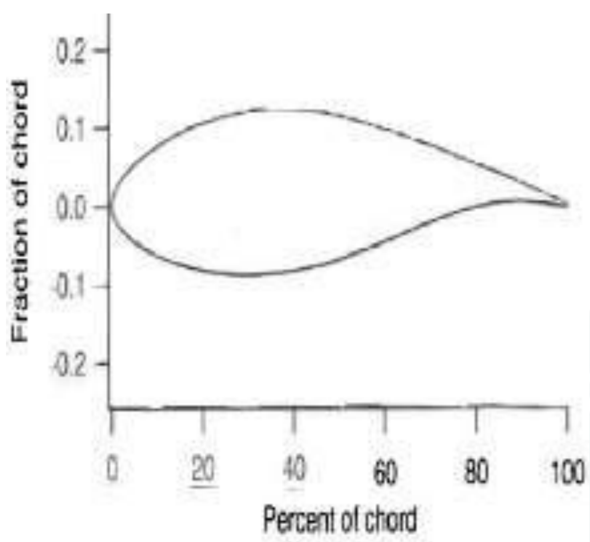
$$C_l = \mathbf{2\pi \, sin}(a)$$

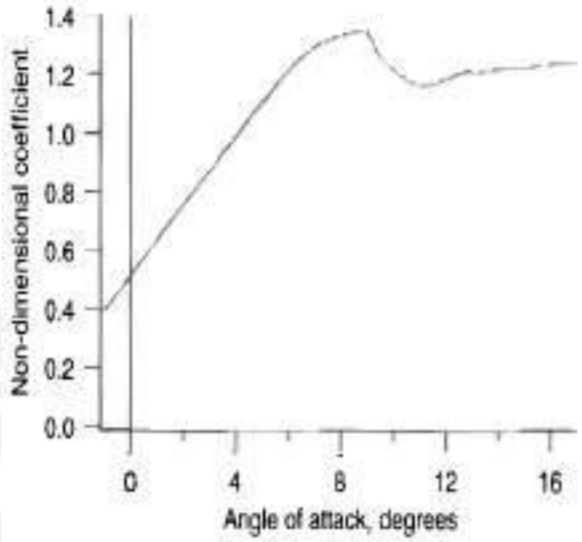
Which is also a good approximation for real, thin airfoils, but only for small α **.**

Lift and drag coefficients for a NACA 0012 airfoil as a function of α and *Re*:-



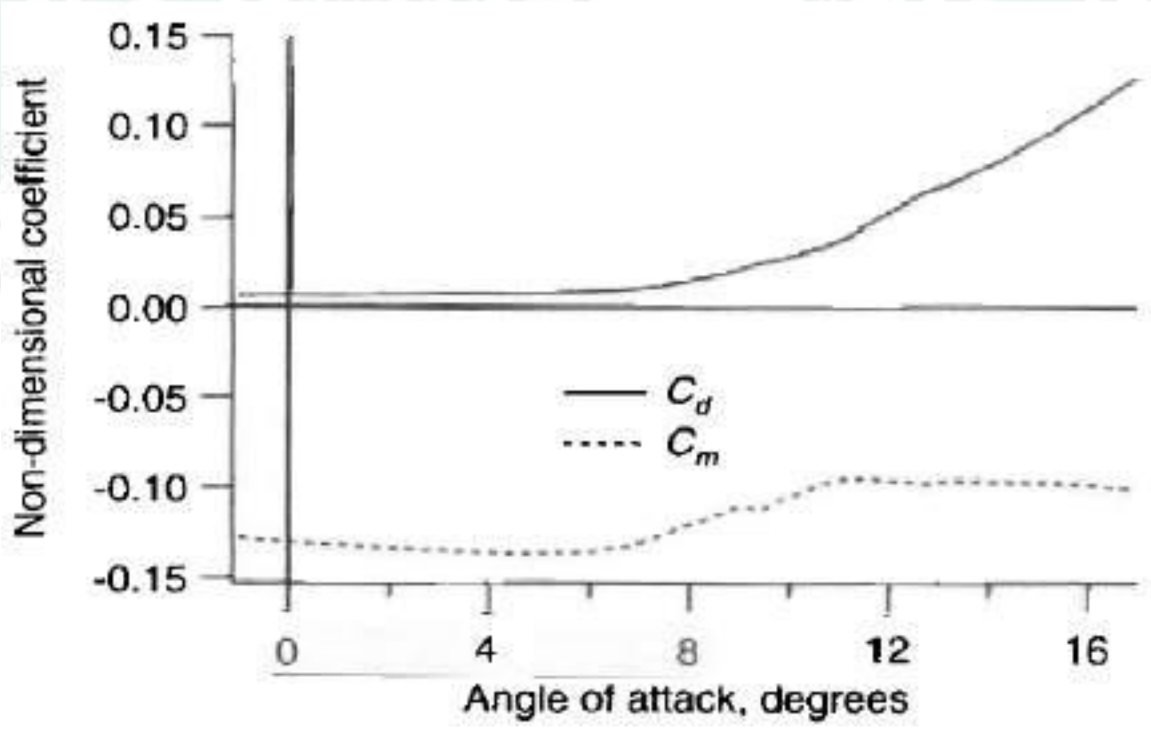
- Airfoils for HAWT are often designed to be used at low angles of attack, where lift coefficients are fairly high and drag coefficients are fairly low.
- The lift coefficient of this symmetric airfoil is about zero at an angle of attack of zero and increases to over 1.0 before decreasing at higher angles of attack.
- The drag coefficient is usually much lower than the lift coefficient at low angles of attack. It increases at higher angles of attack.
- Note the significant differences in airfoil behaviour at different *Re*. Rotor designers must make sure that appropriate *Re* data are available for analysis.





Lift at low α can be increased and drag reduced by using a cambered airfoil such as this DU-93-W-210 airfoil used in some European wind turbines:

Note non-zero lift coefficient at zero incidence.
Data shown: Re = 3 x10^{6}



Attached flow regime

At low α (up to about 7^o for DU-93-W-210), flow is attached to upper surface of the airfoil. In this regime, lift increases with α and drag is relatively low.

High lift/stall development regime

Here (from about 7-11^o for DU-93-W-210), lift coefficient peaks as airfoil becomes increasingly stalled. Stall occurs when α exceeds a critical value (10-16^o, depending on *Re*) and separation of the boundary layer on the upper surface occurs. This causes a wake above the airfoil, reducing lift and increasing drag. This can occur at certain blade locations or conditions of wind turbine operation. It is sometimes used to limit wind turbine power in high winds. For example, many designs using fixed pitch blades rely on power regulation control via aerodynamic stall of the blades. That is, as wind speed increases, stall progresses outboard along the span of the blade (toward the tip) causing decreased lift and increased drag. In a well designed, stall regulated machine, this results in nearly constant power output as wind speeds increase.

Flat plate/fully stalled regime

In the flat plate/fully stalled regime, at larger α up to 90^o, the airfoil acts increasingly like a simple flat plate with approximately equal lift and drag coefficients at α of 45^o and zero lift at 90^o.

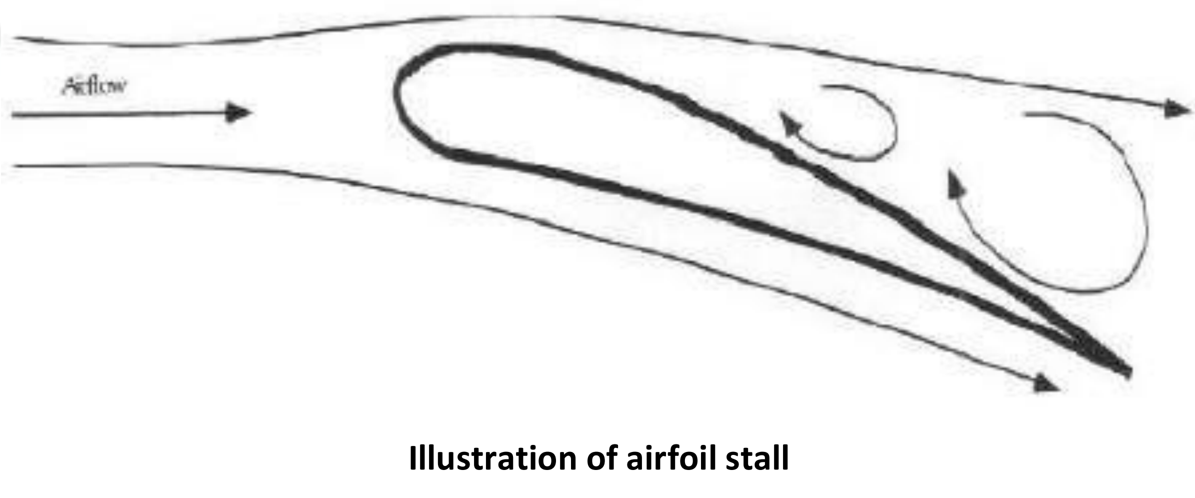


Illustration of airfoil stall

Airfoils for wind turbines

- Typical blade chord *Re* range is $5 \times 10^5 - 1 \times 10^7$
- 1970s and 1980s – designers thought airfoil performance was less important than optimizing blade twist and taper.
- Hence, helicopter blade sections, such as NACA 44xx and NACA 230xx, were popular as it was viewed as a similar application (high max. lift, low pitching moment, and low min. drag).

But the following shortcomings have led to more attention on improved airfoil design:

- Operational experience showed shortcomings (e.g. stall controlled HAWT produced too much power in high winds, causing generator damage).
- Turbines were operating with some part of the blade in deep stall for more than 50% of the lifetime of the machine.
- Peak power and peak blade loads were occurring while turbine was operating with most of the blade stalled and predicted loads were 50 – 70% of the measured loads!
- Leading edge roughness affected rotor performance. Insects and dirt → output dropped by up to 40% of clean value!

Momentum theory and Blade Element theory

- The actuator disk approach yields the pressure change across the disk that is, in practice, produced by blades.
- This, and the axial and angular induction factors that are a function of rotor power extraction and thrust, will now be used to define the flow at the airfoils.
- The rotor geometry and its associated lift and drag characteristics can then be used to determine
  - Rotor shape if some performance parameters are known, or
  - Rotor performance if the blade shape has been defined.

Analysis uses

Momentum theory - CV analysis of the forces at the blade based on the conservation of linear and angular momentum.

Blade element theory – analysis of forces at a section of the blade, as a function of blade geometry.

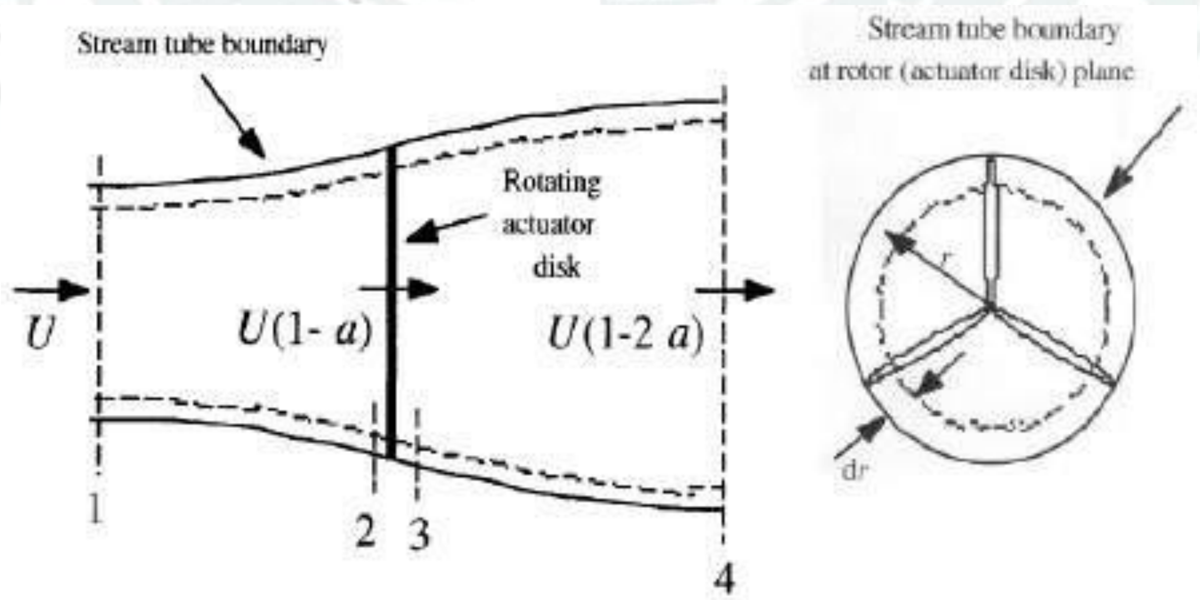
Results combined into "strip theory" or blade element momentum (BEM) theory.
This relates blade shape to the rotor's ability to extract power from the wind.

Analysis encompasses

- Momentum and blade element theory.
- The simplest 'optimum' blade design with an infinite number of blades and no wake rotation.
- Performance characteristics (forces, rotor airflow characteristics, power coefficient) for a general blade design of known chord and twist distribution, including wake rotation, drag, and losses due to a finite number of blades.
- A simple 'optimum' blade design including wake rotation and an infinite number of blades. This blade design can be used as the start for a general blade design analysis.

Momentum theory

We use the annular control volume, as before, with induction factors (*a*, *a'*) being a function of radius *r*.



Applying linear momentum conservation to the CV of radius *r* and thickness *dr* gives the thrust contribution as:

$$dT = \rho U^2 4(1-a)\pi r dr$$

Similarly, from conservation of angular momentum, the differential torque, *Q*, imparted to the blades (and equally, but oppositely, to the air) is:

$$dQ = 4a'(1-a)\rho U \pi r^3 \Omega \, dr$$

Together, these define thrust and torque on an annular section of the rotor as functions of axial and angular induction factors that represent the flow conditions.

Rotor Design
(Blade element theory)

The forces on the blades of a wind turbine can also be expressed as a function of C_l, C_d and α.
For this analysis, the blade is assumed to be divided into *N* sections (or elements).

Assumptions

- There is no aerodynamic interaction between elements.
- The forces on the blades are determined solely by the lift and drag characteristics of the airfoil shape of the blades.

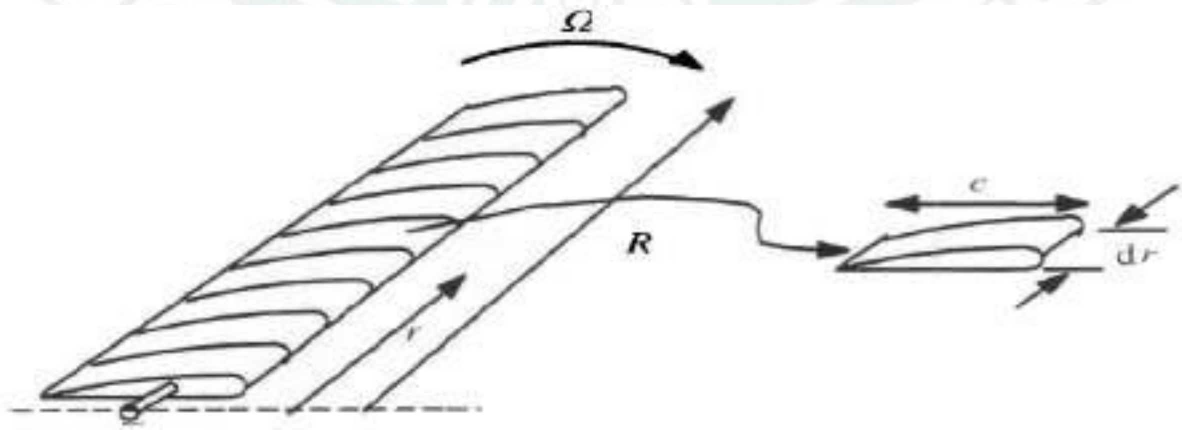
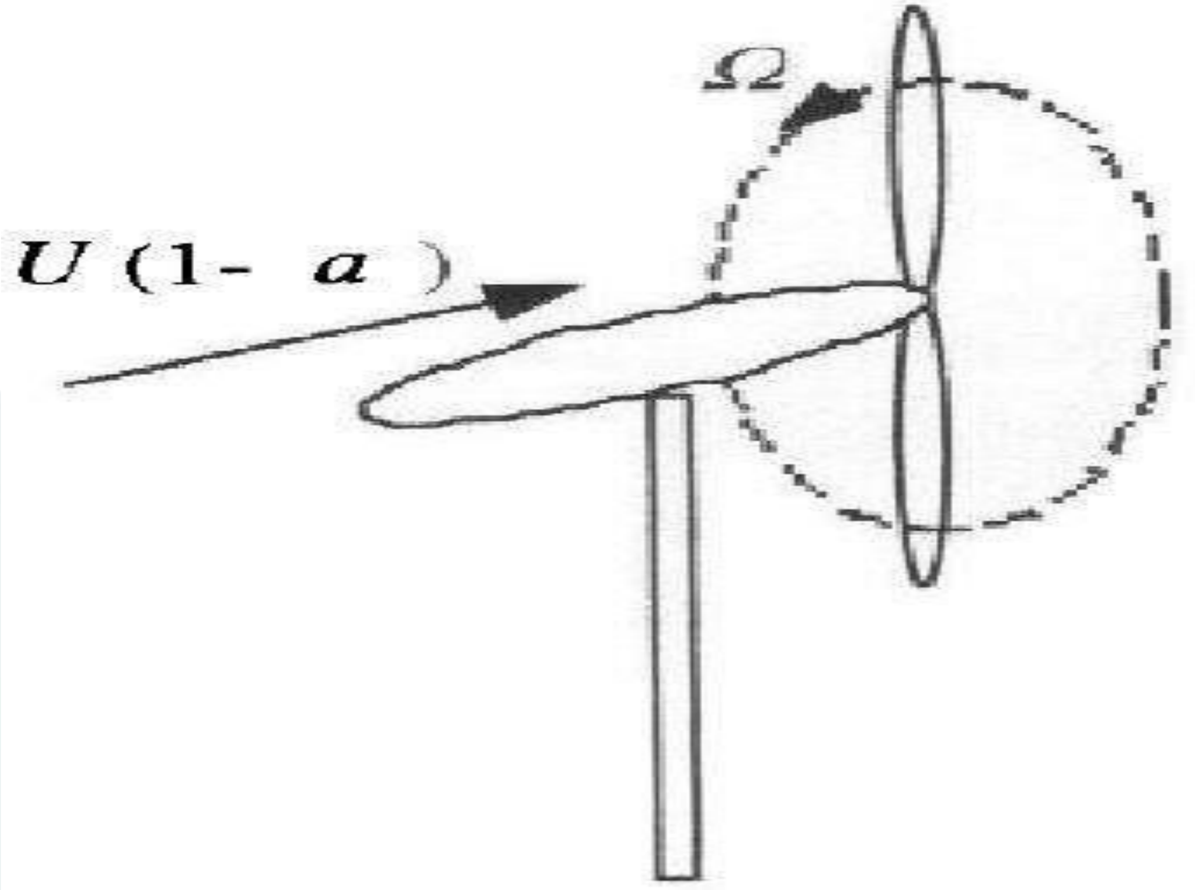


Diagram of blade elements

c = airfoil chord length; d*r* = radial length of element
r = radius; *R* = rotor radius; Ω = rotor angular velocity



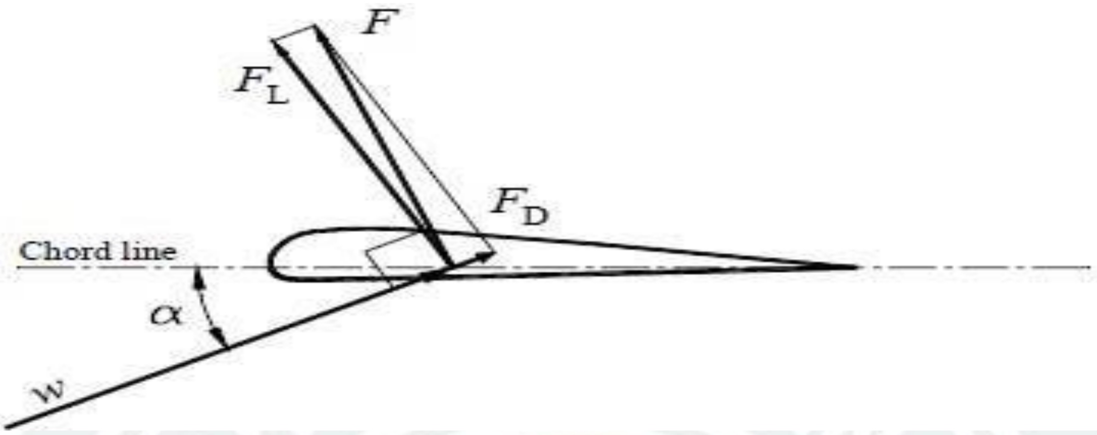
Overall geometry for a downwind HAWT analysis;
U = velocity of undisturbed flow;
Ω = angular velocity of rotor;
a = axial induction factor

Note:

- Lift and drag forces are perpendicular and parallel, respectively, to an effective, or relative, wind.
- The relative wind is the vector sum of the wind velocity at the rotor, *U (1 - a)*, and the wind velocity due to rotation of the blade.
- This rotational component is the vector sum of the blade section velocity, Ω *r*, and the induced angular velocity at the blades from conservation of angular momentum, ω *r* / 2, or:

$$\Omega \mathbf{r} + (\omega/\mathbf{2})\mathbf{r} = \Omega \mathbf{r} + \Omega \mathbf{a}'\mathbf{r} = \Omega \mathbf{r}(\mathbf{1} + \mathbf{a}')$$

Rotor Design
(Blade element theory)



- The air hits the blade in an angle α which is called the "angle of attack". The reference line" for the angle on the blade is most often "the chord line" .
- The force on the blade *F can be divided into two components – the lift force F $_L$ and the drag force F $_D$ and the* lift force is – per definition – perpendicular to the wind direction.

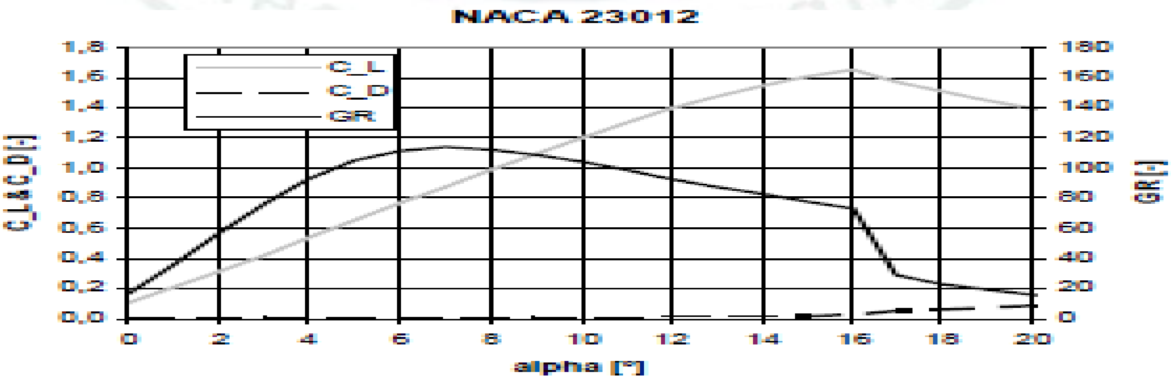
The lift force is given as

$$\mathbf{F_L = C_L \frac{1}{2} \rho W^2 (bc)}$$

And the drag force

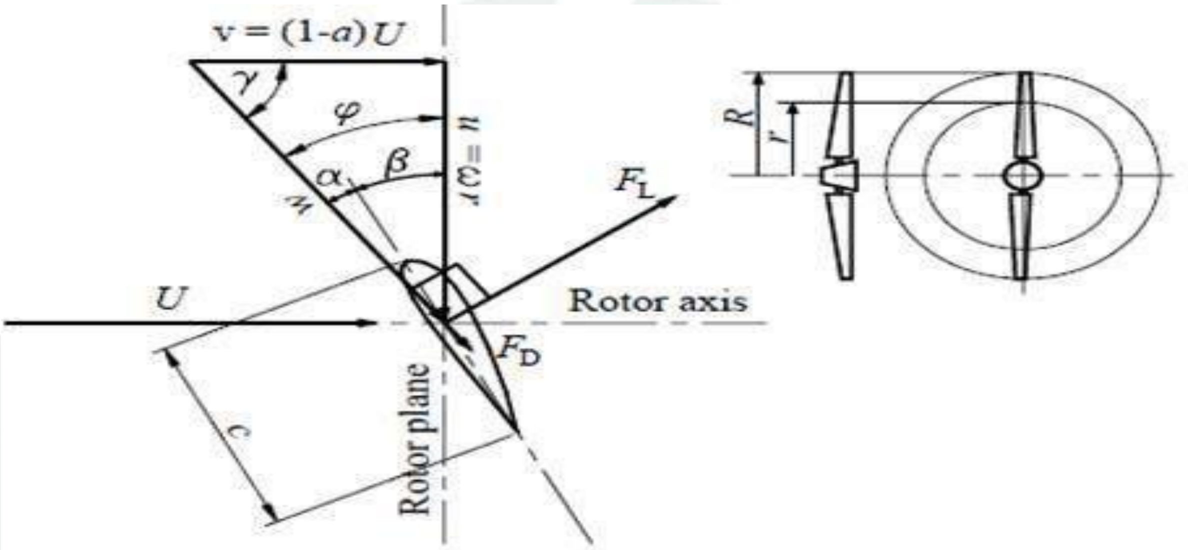
$$\mathbf{F_D = C_D \frac{1}{2} \rho W^2 (bc)}$$

- The ratio *GR=C_L / C_D is called the "glide ratio",*
- *Normally we are interested in at high* glide ratio for wind turbines as well as for air planes.



Pitch angle, β, and chord length, c, after Betz

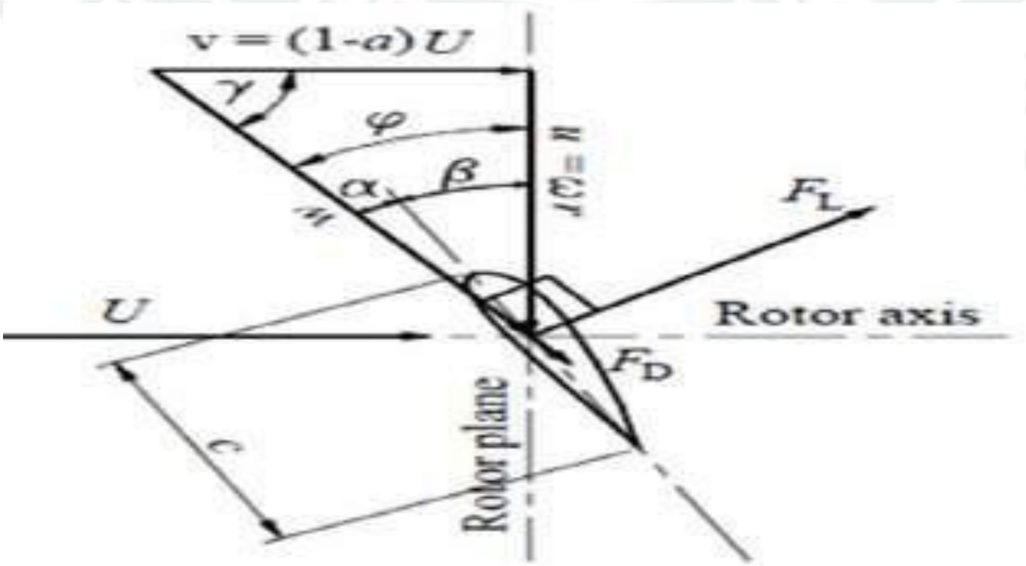
To design the rotor we have to define the pitch angle β and the chord length c. Both of them depend on the given radius, that we are looking at therefore we sometimes write β(r) and c(r).



Angles, that all depends on the given radius
- γ(r) = angle of relative wind to rotor axis
- ϕ(r) = angle of relative wind to rotor plane
- β(r) = pitch angle of the blade

The blade is moving up wards, thus the wind speed, seen from the blade, is moving down wards with a speed of *u.*

$$\mathbf{W^2 = V^2 + U^2}$$



Betz does not include rotation of the wind (No Wakes). Therefore

$$\mathbf{U} = \Omega\mathbf{r}$$

Here ω is the angular speed of the rotor

$$\lambda = \frac{\Omega R}{U}$$

$$\emptyset(\boldsymbol{r}) = a + Q$$

$$(\boldsymbol{r}) = \tan^{-1} \frac{\Omega \boldsymbol{R}}{(1-\boldsymbol{a})\boldsymbol{u}}$$

For *a=1/3*

$$(\boldsymbol{r}) = \tan^{-1} \frac{3\lambda r}{2\boldsymbol{R}}$$

And

$$\emptyset(\boldsymbol{r}) = \tan^{-1} \frac{2\boldsymbol{R}}{3\lambda r}$$

The pitch angle

$$Q(\boldsymbol{r}) = \tan^{-1} \frac{2\boldsymbol{R}}{3\lambda r} - a$$

Most often the angle is chosen to be close to the angle, that gives maximum glide ration that means in the range from 5 to 10° but near the tip of the blade the angle is sometimes reduced.

Chord length, c(r):

For one blade element in the distance r from the rotor axis with the thickness *dr* the lift force is

$$dF_L = \frac{1}{2}\rho W^2 c dr C_L$$

And the drag force

$$dF_D = \frac{1}{2}\rho W^2 c\,dr\,C_D$$

For the rotor plane (torque) we have

$$dQ = \left(dF_L \sin\emptyset - dF_D \cos\emptyset\right) r = \frac{\rho}{2}\Omega^2 c(r)\,d(C_L \sin\emptyset - C_D \cos\emptyset)r$$
$$= \frac{\rho}{2}\Omega^2(r)r\,dr\,C_X$$

The thrust

$$dT = \frac{1}{2}\rho W^2 c\,dr\,C_Y$$

AND

$$C_\gamma = C_L \cos\emptyset + C_D \sin\emptyset$$

Now, in the design situation, we have $C_L >> C_D$

$$dQ = \frac{\rho}{2}\Omega^2 C(r)\,dr\,C_L r \sin\emptyset$$

For *N blades*

$$dP = N\frac{\rho}{2}\Omega^2 c(r)\,dr\,C_L r\Omega \sin\emptyset$$

According to Betz, the blade element would also give

$$dP = 2\rho(1-a)^2 U^3 A = \frac{16}{27}N\frac{\rho U^3}{2}(2\pi r dr)$$

Using

$$U = \frac{3}{2}W\cos\gamma \quad , \qquad u = \Omega r \sin\gamma$$

$$(r) = \frac{16}{9N}\frac{\pi R}{C_L D}\frac{1}{\sqrt{\lambda^2 \left(\frac{r}{R}\right)^2 + \frac{4}{9}}}$$

Note:

- Effect of drag is to decrease torque and, hence, power, but to increase the thrust loading.
- Thus, blade element theory gives 2 equations: normal force (thrust) and tangential force (torque), on the annular rotor section as a function of the flow angles at the blades and airfoil characteristics.
- These equations will be used to get blade shapes for optimum performance and to find rotor performance for an arbitrary shape.
- These equations may be used to find the chord and twist distribution of the Betz optimum blade.

Example: Given λ = 7, R = 5m, C_L= 1, C_D / C_L is minimum at α = 7, and there are 3 blades (N = 3) we can use:

$$\emptyset(r) = \tan^{-1}\frac{2R}{3\lambda r}$$

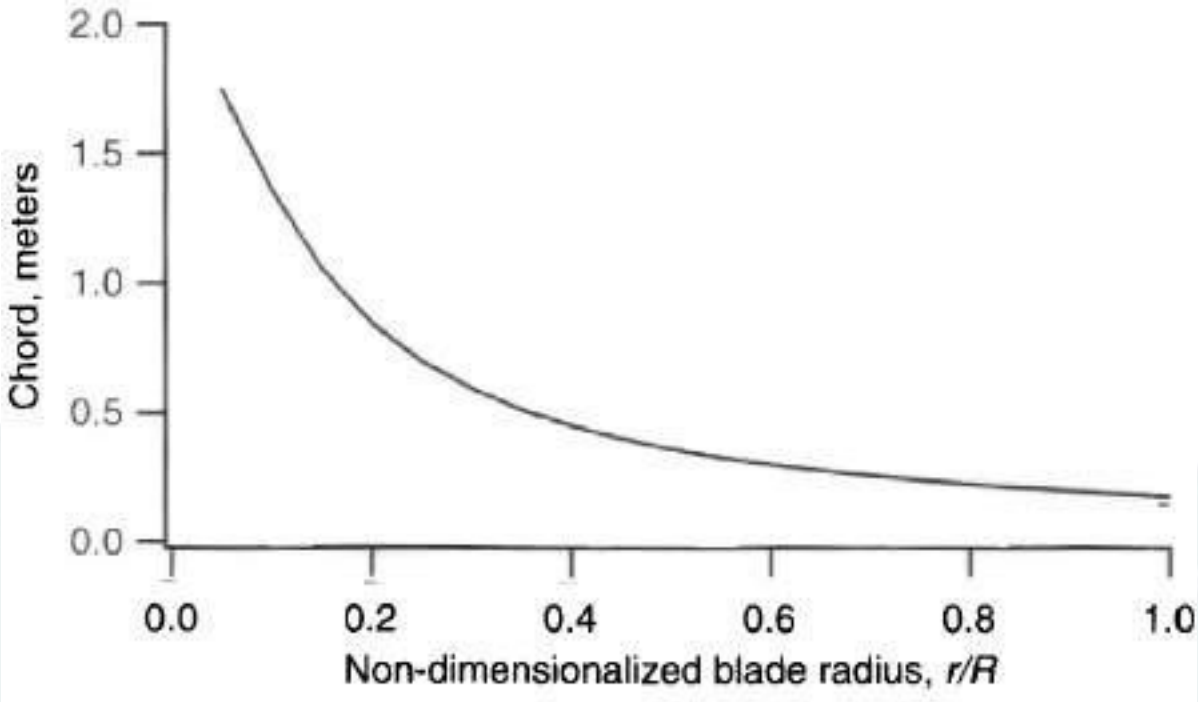
$$(r) = \frac{16}{9N}\frac{\pi R}{C_L D}\frac{1}{\sqrt{\lambda^2 \left(\frac{r}{R}\right)^2 + \frac{4}{9}}}$$

Together with $\emptyset(r) = \alpha + \beta$ to obtain the changes in chord, twist angle (= 0 at tip), angle of relative wind, and section pitch, with radial distance, *r*/*R*, along the blade:

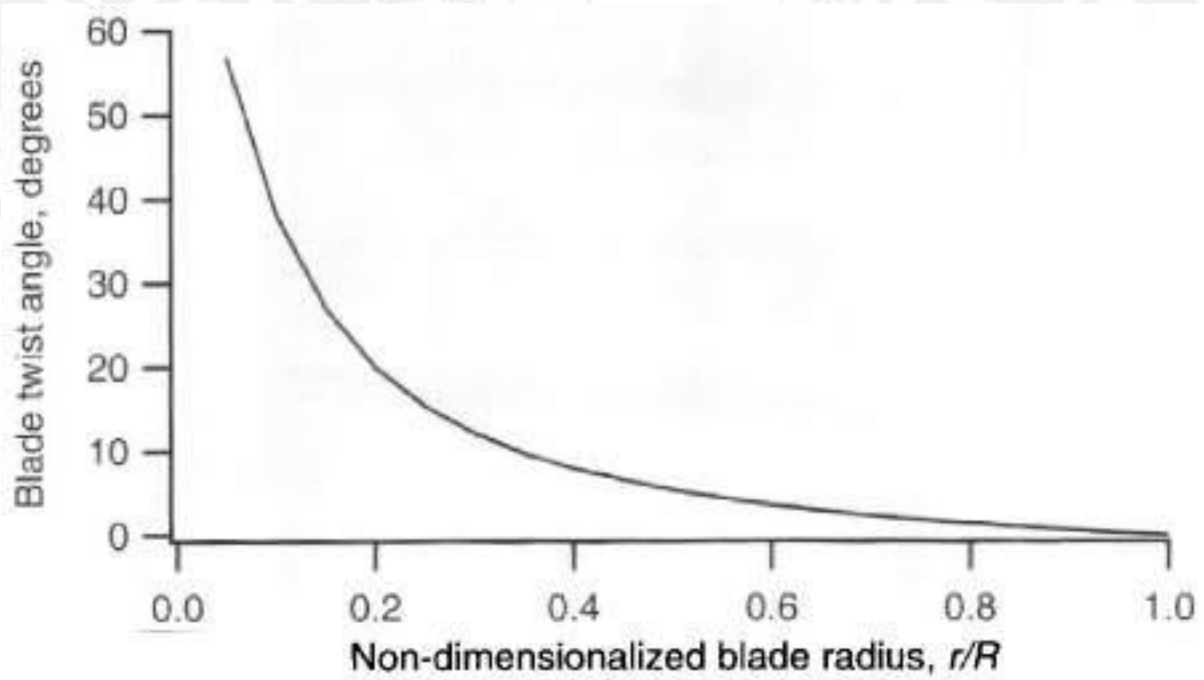
r/R	Chord, m	Twist Angle (deg)	Angle of Rel. Wind (deg)	Section Pitch (deg)
0.1	1.375	38.2	43.6	36.6
0.2	0.858	20.0	25.5	18.5
0.3	0.604	12.2	17.6	10.6
0.4	0.462	8.0	13.4	6.4
0.5	0.373	5.3	10.8	3.8
0.6	0.313	3.6	9.0	2.0
0.7	0.269	2.3	7.7	0.7
0.8	0.236	1.3	6.8	-0.2
0.9	0.210	0.6	6.0	-1.0
1	0.189	0	5.4	-1.6

Twist and chord distribution for a Betz optimum blade
(r/ R = fraction of rotor radius)

- Hence, blades with optimized power production have increasingly larger chord and twist angle on approaching the blade root ($r \rightarrow 0$). Actual shape depends on difficulty/cost of manufacturing it.



Blade chord for example Betz optimum blade



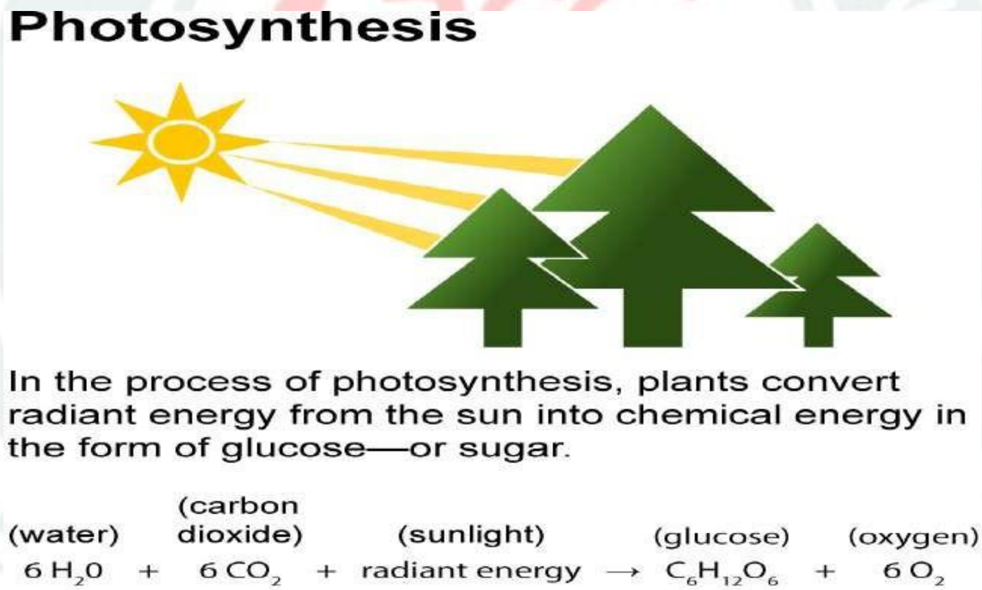
Blade twist angle for example Betz optimum blade

CHAPTER -4

BIOMASS POWER

Introduction

Biomass is a term for all organic material that stems from plants (including algae, trees and crops). Biomass is produced by green plants converting sunlight into plant material through photosynthesis and includes all land and water-based vegetation, as well as all organic wastes. Biomass is the plant material derived from the reaction between CO2 in the air, water and sunlight by photosynthesis, to produce carbohydrates that form the building blocks of biomass. The biomass resource can be considered as organic matter, in which the energy of sunlight is stored in chemical bonds. When the bonds between adjacent carbon, hydrogen and oxygen molecules are broken by digestion, combustion, or decomposition, these substances release their stored, chemical energy. The value of a particular type of biomass depends on the chemical and physical properties of the large molecules from which it is made. Burning new biomass contributes no new carbon dioxide to the atmosphere, because replanting harvested biomass ensures that CO2 is absorbed and returned for a cycle of new growth. Biomass can be converted three main types of products: electrical/heat energy, transport fuel and chemical feedstock.



It is a renewable energy source because we canalways grow more trees and crops, and waste will always exist. The biomass is fast renewable forms of energy and available freely as waste anddiscarded matters

Categories of biomass

1. Woody biomass

Forest industry provides woody biomass material as by-products such as logging residues and as main-products which is cut directly from trees and forests. The planted forests are usually thinned biomass energy materials, because they have no commercial values and leave in a stand after thinning operation Wood fuel accounts for about 53 percent of total round wood produced in the world. These residues are utilized for modern and traditional biomass energy source in many countries. However wood fuel accounts for only several percent in industry countries at present, tough industry countries used to depend on wood fuel until 1960s. The use of woody biomass energy has grown in importance as part of the efforts to reduce dependence on non-renewable energy sources such as fossil fuels.

2. Herbaceous Biomass

Herbaceous biomass includes energy crops and grasses on grasslands. An energy crop is a plant grown as a low-cost and low-maintenance harvest used to make biofuels , such as bioethanol, or combusted for its energy content to generate electricity or heat. . Commercial energy crops are typically densely planted, high-yielding crop species where the energy crops will be burnt to generate power. Most common energy crops are switch grass, straw, miscanthus, agave, barley, canola, corn, sugar cane, sun flowers, wheat, coconuts, oil palm, pine and poplar. Grasses such as switch grass Food crops, such as rice, wheat, maize, and sugarcane represent sources of herbaceous biomass. By-products or residues, such as rice straw, are also considered herbaceous biomass.

3. Aquatic Plant (Algae) Biomass

Aquatic plant biomass is produced in freshwater and marine environments and has some potential human uses. Most current aquatic plant biomasses include seed plants, seaweeds and micro-algae, which are mostly produced naturally as well as some with man-made culture production. Algae include multi-cellular macro-algae (seaweeds) and unicellular micro-algae.

4. Agricultural residue

Agricultural residue refers to residue produced in fields or farm during harvesting and other activities. As energy resources, available agricultural residue includes those from cereals, crops, and sugarcane. Like residue from cotton ginning, olive pits, fruit pits, wheat straw, walnut shells, corncobs, corn Stover, sugarcane bagasse, rice hulls and peach pits.

5. Animal waste

There are a wide range of animal wastes that can be used as sources of biomass energy. The most common sources are animal and poultry manures. In the past this waste was recovered and sold as a fertilizer or simply spread onto agricultural land, but the introduction of tighter environmental controls on odour and water pollution means that some form of waste management is now required, which provides further incentives for waste-to-energy conversion. The most attractive method of converting these waste materials to useful form is anaerobic digestion which gives biogas that can be used as a fuel for internal combustion engines, to generate electricity from small gas turbines, burnt directly for cooking, or for space and water heating.

6. Sewage sludge

Sewage sludge is defined in this text as the solid matters discharged from an activated sludge wastewater treatment facility as the result of aerobic wastewater treatment. The sewage sludge, which is usually a mixture of settle able matters in sewage and reproduced microorganisms, is high in organic contents that are possibly considered as reusable biomass.

7. Municipal solid waste

Millions of tons of household waste are collected each year with the vast majority disposed of in open fields. The biomass resource in MSW comprises the putrescibles, paper and plastic and averages 80% of the total MSW collected. Municipal solid waste can be converted into energy by direct combustion, or by natural anaerobic digestion in the engineered landfill. At the landfill sites the gas produced by the natural decomposition of MSW (approximately 50% methane and 50% carbon dioxide) is collected from the stored material and scrubbed and cleaned before feeding into internal combustion engines or gas turbines to generate heat and power. The organic fraction of MSW can be an aerobically stabilized in a high-rate digester to obtain biogas for electricity or steam generation

8. Industrial waste

The food industry produces a large number of residues and by-products that can be used as biomass energy sources. These waste materials are generated from all sectors of the food industry with everything from meat production to confectionery producing waste that can be utilized as an energy source. Solid wastes include peelings and scraps from fruit and vegetables, food that does not meet quality control standards, pulp and fiber from sugar and starch extraction, filter sludge and coffee grounds. These wastes are usually disposed of in landfill dumps Liquid wastes are generated by washing meat, fruit and vegetables, blanching fruit and vegetables, pre-cooking meats, poultry and fish, cleaning and processing operations as well as wine making. These waste waters contain sugars, starches and other dissolved and solid organic matter. The potential exists for these industrial wastes to be an-aerobically digested to produce biogas, or fermented to produce ethanol, and several commercial examples of waste-to energy conversion already exist.

9. Food waste

Food waste is an untapped energy source which mostly ends up rotting in landfills thereby releasing greenhouse gases into the atmosphere. Food waste is difficult to treat or recycle since it contains high levels of sodium salt and moisture, and is mixed with other waste during collection. Major generators of food wastes include hotels, restaurants, supermarkets, residential blocks, cafeterias, airline caterers, food processing industries etc.

What is biomass power?

Biomass power is carbon neutral electricity generated from renewable organic waste that would otherwise be dumped in landfills, openly burned, or left as fodder for forest fires.

When burned, the energy in biomass is released as heat. If you have a fireplace, you already are participating in the use of biomass as the wood you burn in it is a biomass fuel.

In biomass power plants, wood waste or other waste is burned to produce steam that runs a turbine to make electricity, or that provides heat to industries and homes. Fortunately, new technologies — including pollution controls and combustion engineering — have advanced to the point that any emissions from burning biomass in industrial facilities are generally less than emissions produced when using fossil fuels (coal, natural gas, oil). ReEnergy has included these technologies in our facilities.

Converting biomass to energy

Biomass is converted to energy through various processes, including:

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

`Biomass conversion technologies

Biomass can be converted into different forms of energy by using various processes. Many factors affect the choice of the process like quantity of biomass feedstock, desired energy form, environmental standards, economic conditions, and project specific factors. Biomass can be converted into three main products: power or heat generation, transportation fuels and chemical feedstock.

Biomass conversion technologies are shown in tree following chart.

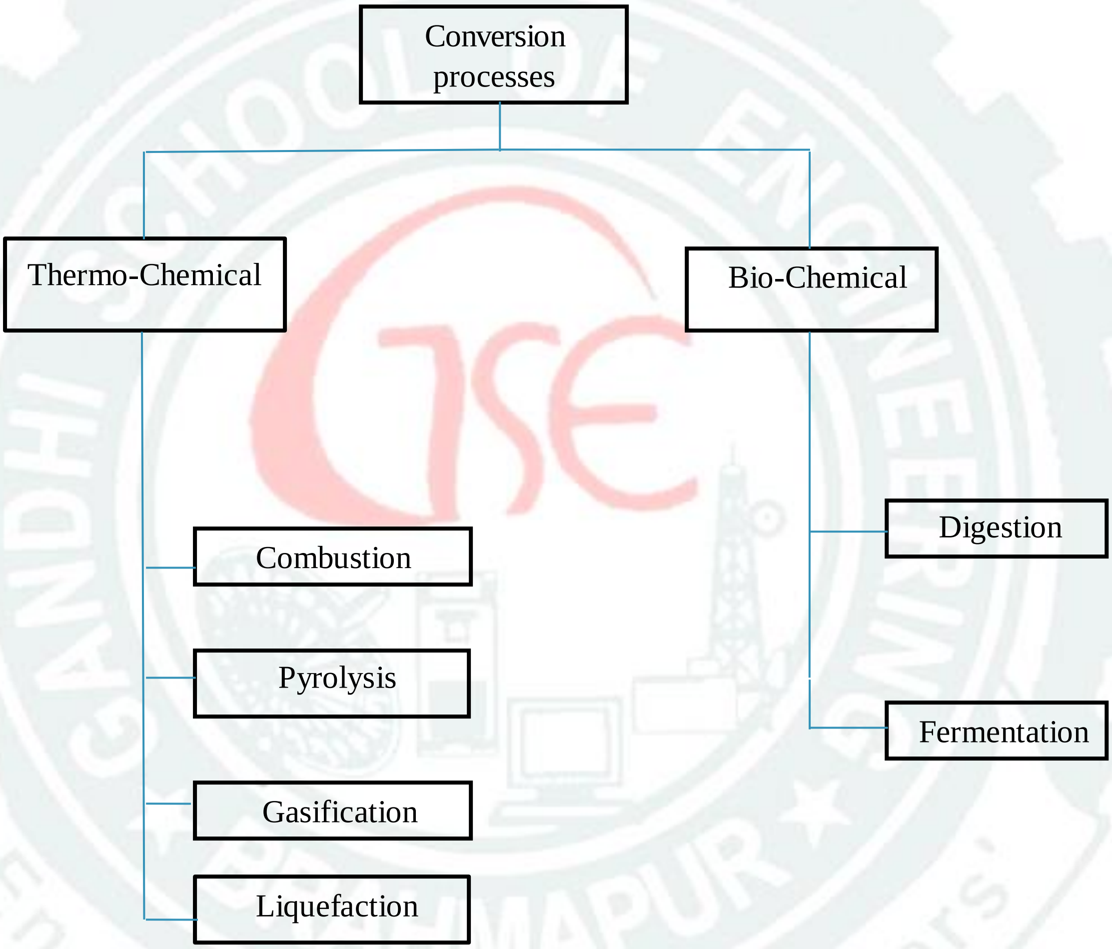


Diagram. 1. Biomass conversion processes.

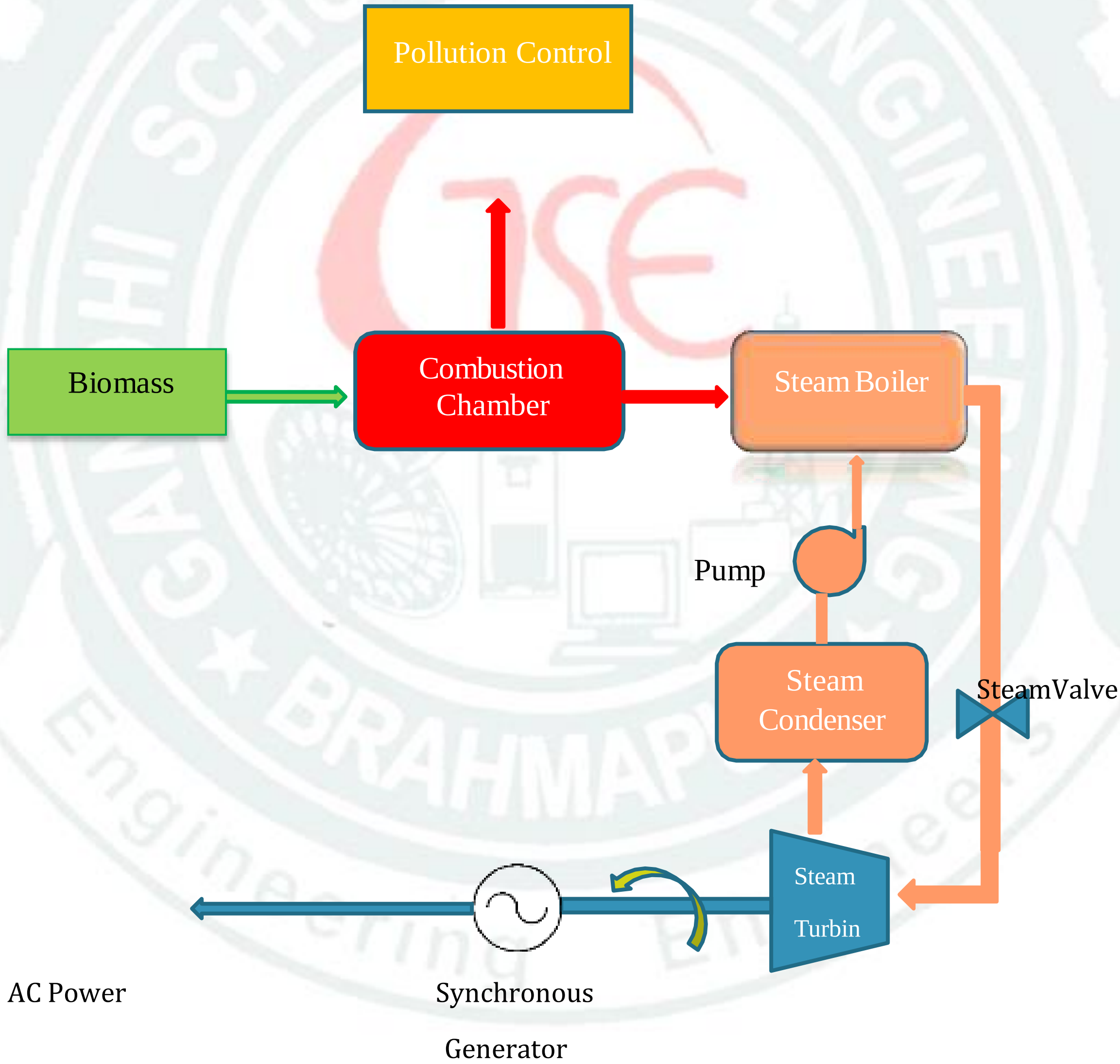
1. Thermo-chemical conversion

In thermo-chemical conversion, energy is produces by applying heat and chemical processes. There are four thermo-chemical conversion processes, which are given below.

Combustion process

Combustion is an exothermic chemical reaction, in which biomass is burned in the presence of air. In this process chemical energy which is stored in the biomass is converted in the mechanical and electrical energies. This process is suitable for dry biomass containing moisture less than 50%. Biomass is burned at the temperature of 800-1000 °C. This process is used for domestic applications as well as commercially in biomass power plants in order to produce electricity.

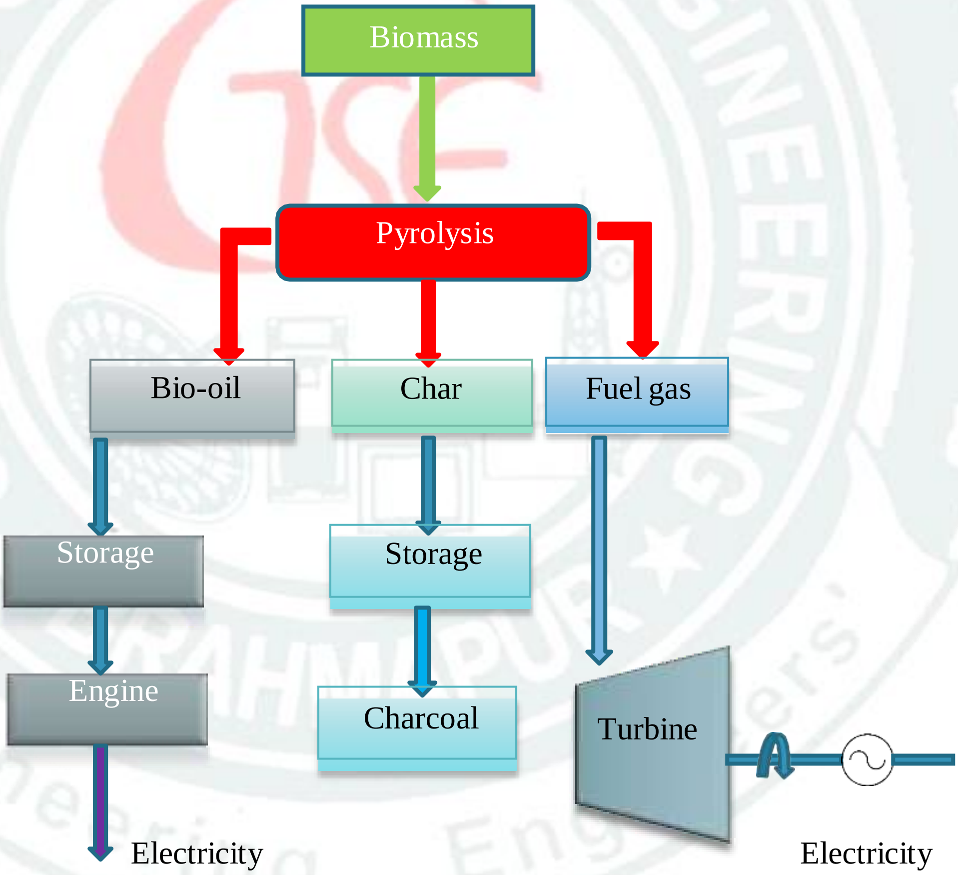
The typical efficiencies for stand-alone biomass combustion power plants (using wood and forest residue as a fuel) range between 20-50 MWe, with related the electrical efficiencies in the 25-30%. These power plants are suitable where fuels are available at low costs. In recent years advanced combustion technology is being used. The application of fluid bed system and advanced gas cleaning allows for production of electricity from biomass, on scale of 50-80 MWe, with 30-40% electrical efficiencies .



Flow chart.2. Production of electricity by combustion of Biomass

Pyrolysis Process

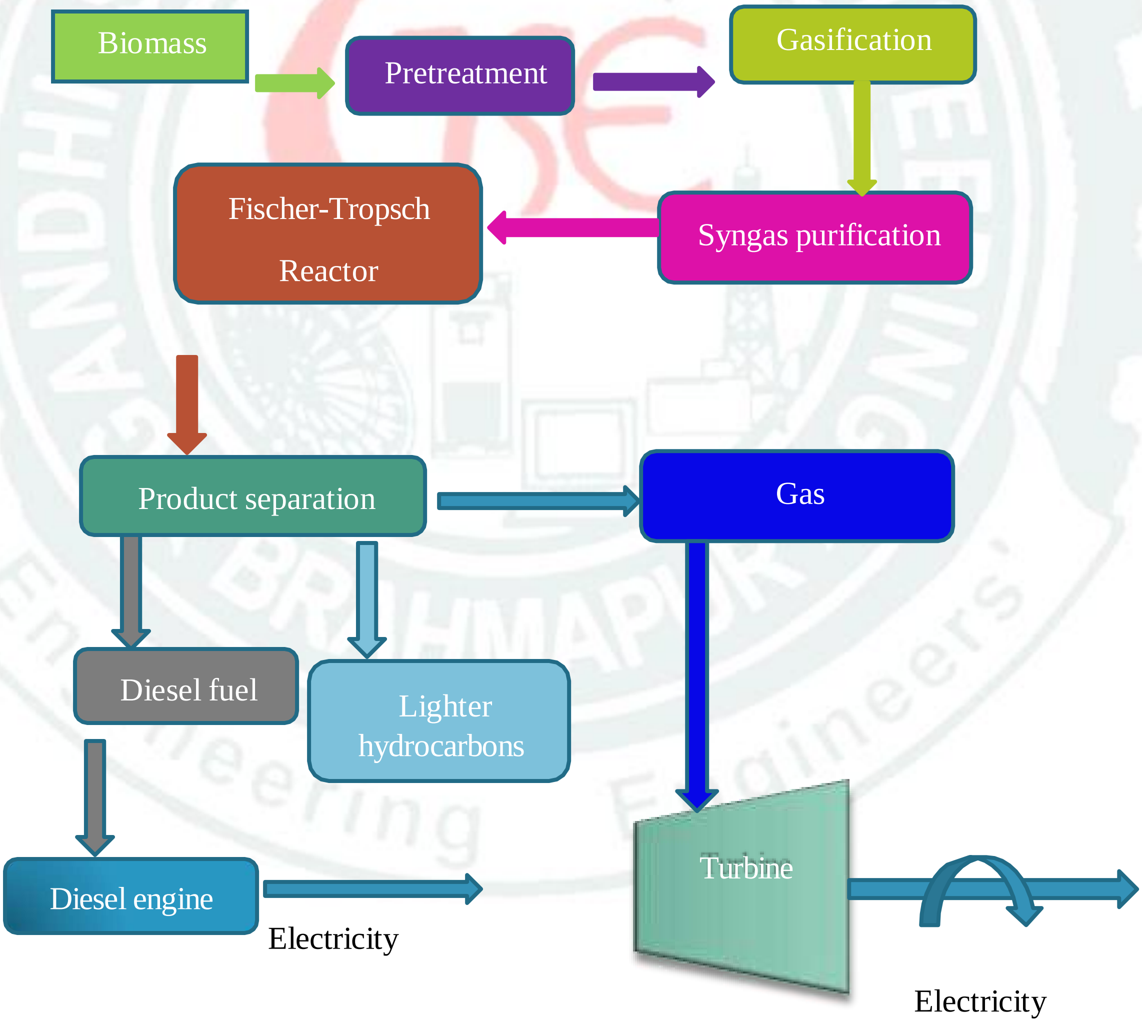
It is the process of conversion of biomass to liquid (bio-oil), solid (charcoal) and gaseous (fuel gases) products by heating in the absence of air at 500 °C. There are two types of pyrolysis : Fast pyrolysis, conventional (Carbonization) pyrolysis and slow pyrolysis. Fast pyrolysis process has high heating value and heat transfer rate and completes within seconds. Fast pyrolysis yields 60% bio-oil, 20% bio-char and 20% biogas. Conventional pyrolysis process is the process in which mostly carbon (35%) is leaved as residue. Slow pyrolysis takes more time than fast pyrolysis, it also has low temperature and heating values. Flash pyrolysis is the type of fast pyrolysis, in which 80% bio-oil is obtained at keeping temperature low. If flash pyrolysis is used for converting biomass to bio-crude, it has up to 80% efficiency .



Flow chart. 3. Production of electricity by pyrolysis of Biomass

Gasification process

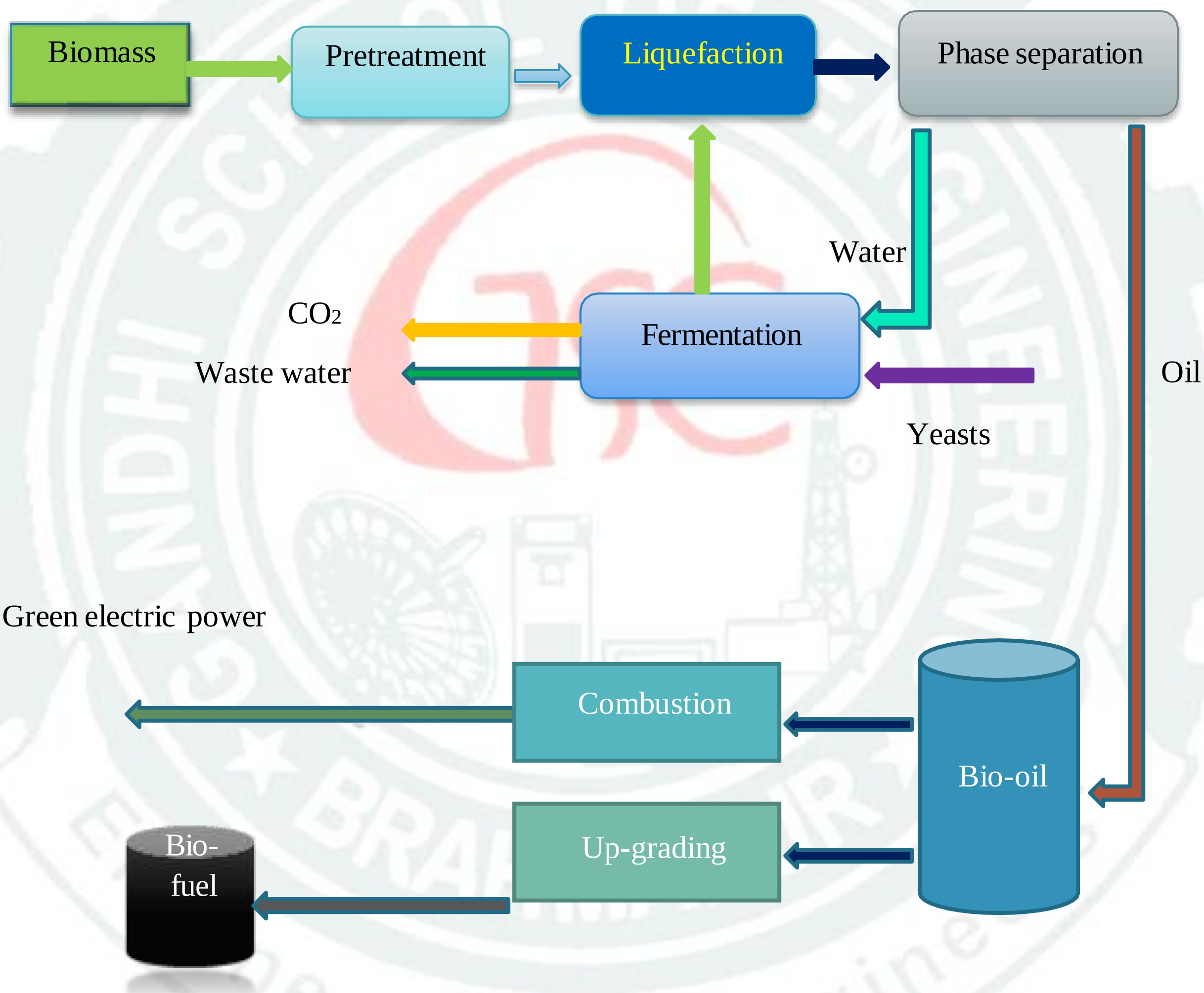
In biomass gasification, charcoal, wood chips, energy crops, forestry residues, agricult ural waste and other wastes are transformed into flammable gases at high temperature (800-1000°C. In this process fuel (biomass) reacts with a gasifying medium such as oxygen enriched air, pure oxygen, steam or a combination of both. The product gas composition and energy content depends upon the gasifying media's nature and amount of it. Low calorific Value (CV) gas obtained by gasification about 4-6 MJ/N m^3. The product gas can be used as a feedstock (syngas) in the production of chemicals like methanol. One promising concept is the biomass integrated gasification/ combined cycle (BIG/CC), in which gas turbines convert the gaseous fuel to electricity with a high overall conversion efficiency. The integration of gasification and combustion/ heat recovery ensures 40-50% conversion efficiency for a 30-60 MW. The syngas can be converted into hydrogen gas, and it may have a future as fuel for transportation



Flow chart. 4. Production of electricity by Gasification of Biomass

Liquefaction process

It is the process in which biomass is converted into liquid phase at low temperatures (250-350 °C) and high pressures (100-200 bar), usually with a high hydrogen partial pressure and catalysts to increase the rate of reaction. This process is used to get maximum liquid yields with higher quality than from the pyrolysis process. The product have higher heating value and lower oxygen content which makes the fuel chemically stable. The main purpose of the liquefaction is to obtain high H/C ratio of the product oil .



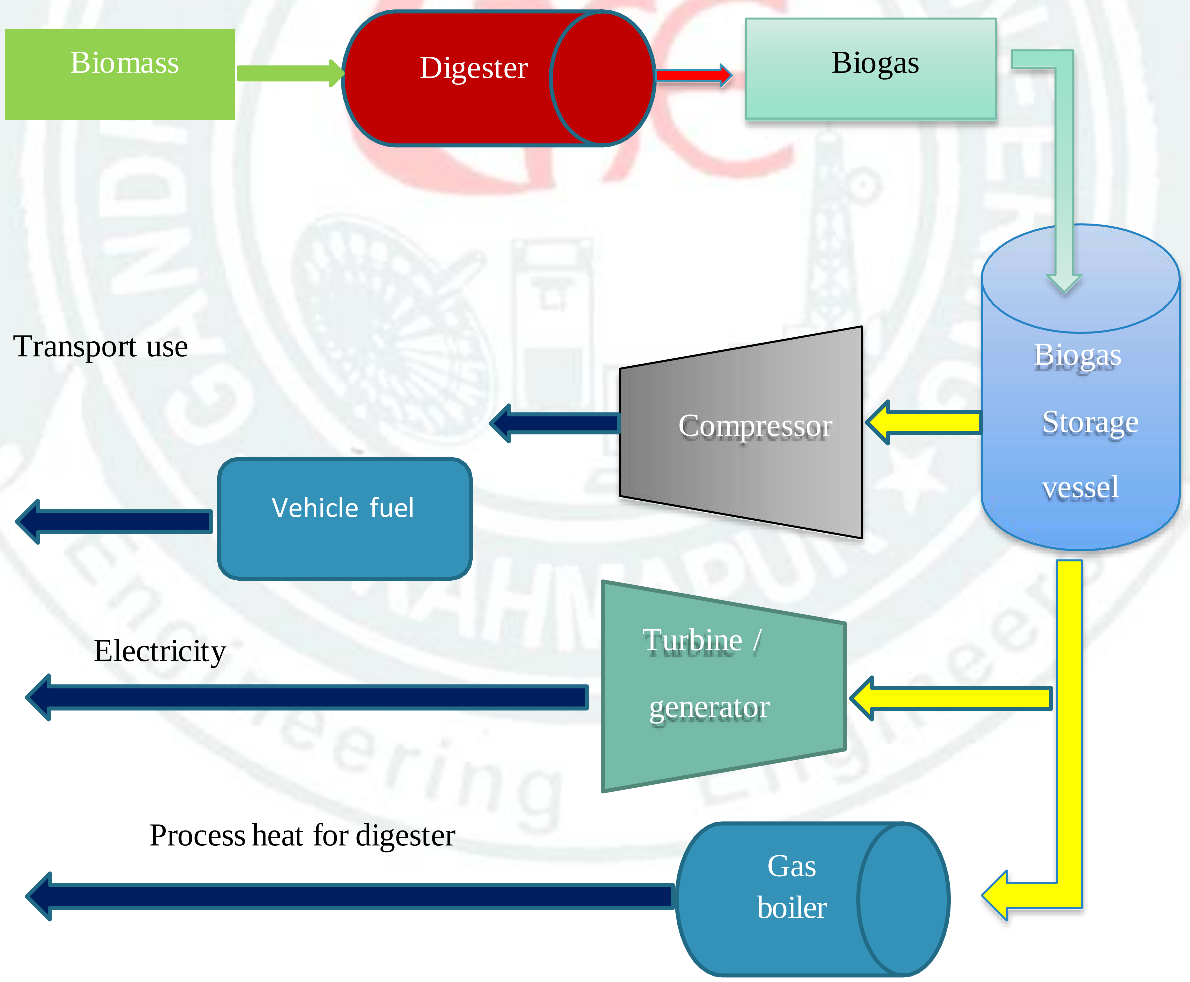
Flow chart. 5. Liquefaction process of Biomass

2. Bio-Chemical conversion

Biochemical conversion makes use of the enzymes of bacteria and other living organisms to break down biomass and convert it into fuels. This conversion process includes anaerobic digestion and fermentation.

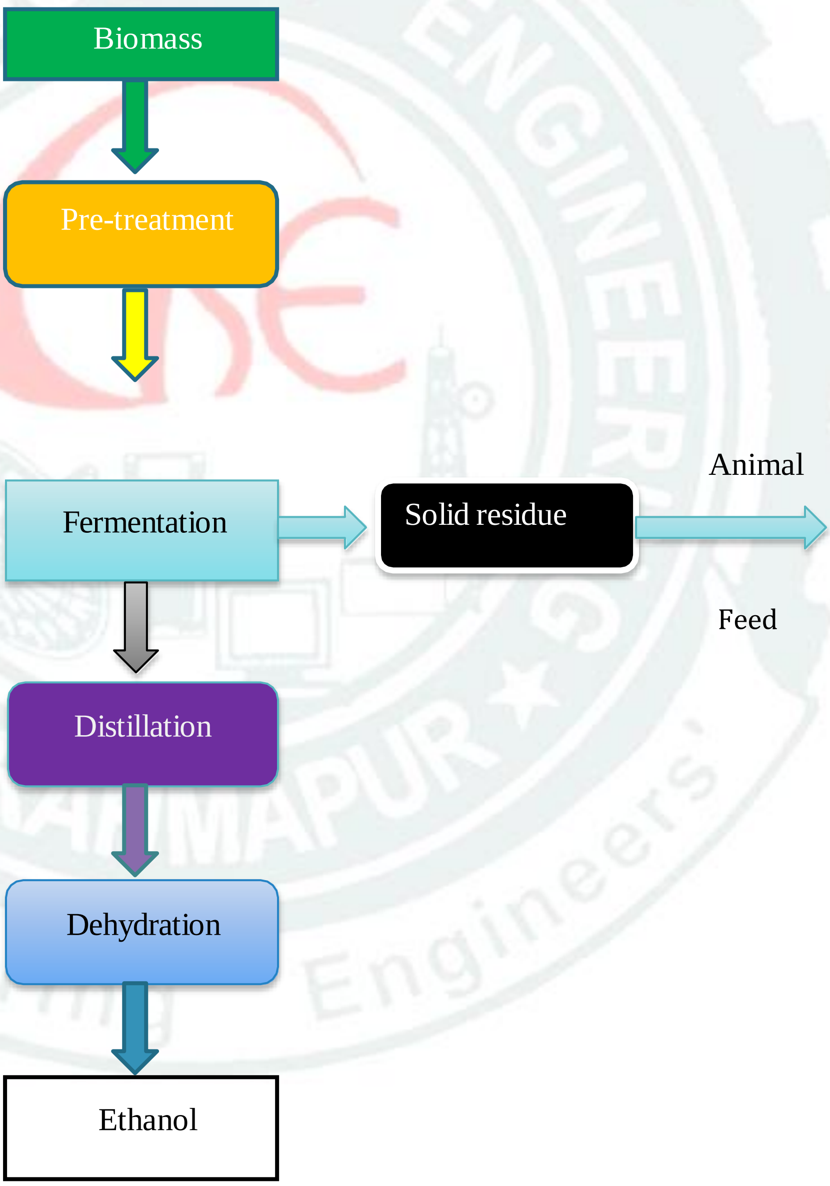
Anaerobic digestion process

This is a process in which organic material directly converted to a gas which is termed as biogas. It is mixture of methane, carbon dioxide and other gases like hydrogen sulphide in small quantities. Biomass is converted in anaerobic environment by bacteria, which produces a gas having an energy of 20-40% of lower heating value of the feedstock. This process is suitable for organic wastes having high moisture about 80-90%. This biogas can be directly used in spark ignition gas engines and gas turbines and can be upgraded to higher quality natural gas by removing carbon dioxide. The overall conversion efficiency of this process is 21%. Waste heat from engines and turbines can be recovered by using combined heat and power system .



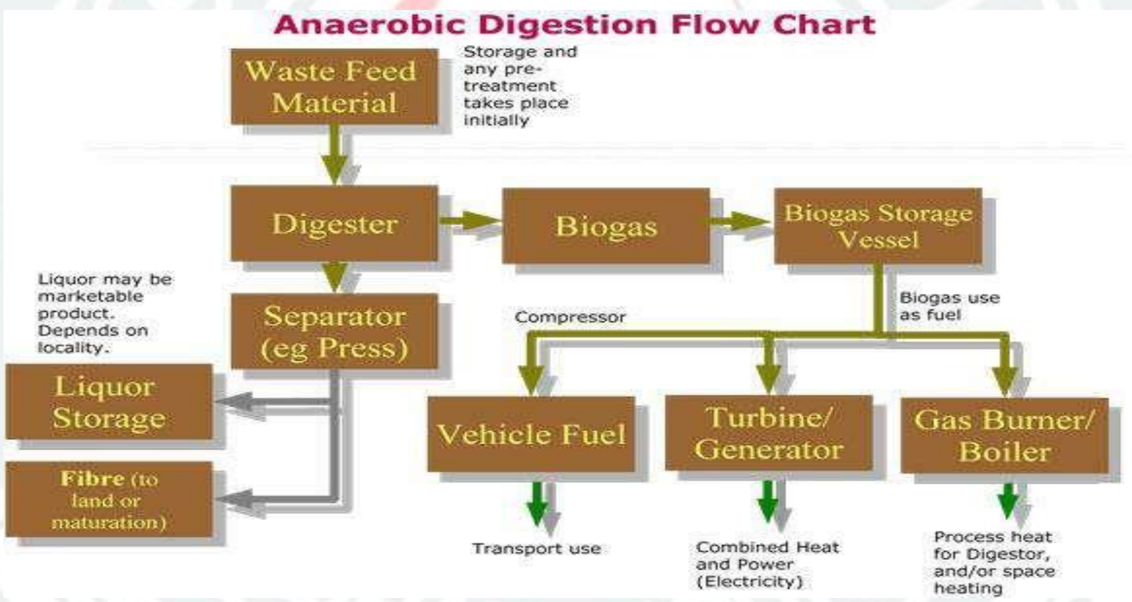
Fermentation process

Fermentation is an anaerobic process that breaks down the glucose within organic materials. It is a series of chemical reactions that convert sugars to ethanol. The basic fermentation process involves the conversion of a plant's glucose (or carbohydrate) into an alcohol or acid. Yeast or bacteria are added to the biomass material, which feed on the sugars to produce ethanol and carbon dioxide. The ethanol is distilled and dehydrated to obtain a higher concentration of alcohol to achieve the required purity for the use as automotive fuel. The solid residue from the fermentation process can be used as cattle-feed and in the case of sugar cane; the bagasse can be used as a fuel for boilers or for subsequent gasification .

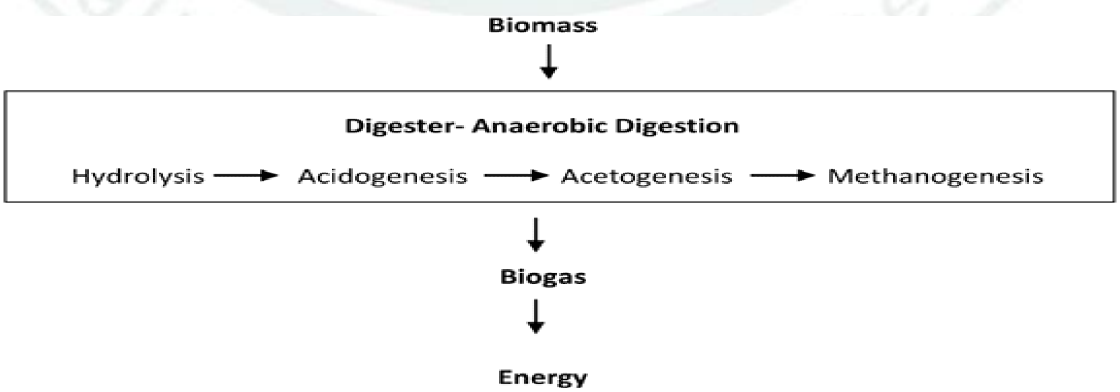


Anaerobic Digestion.

Anaerobic digestion is a natural biological process of converting biomass into energy. Anaerobic digestion (AD) is a natural process and is the microbiological conversion of organic matter to methane in the absence of oxygen. The decomposition is caused by natural bacterial action in various stages. It takes place in a variety of natural anaerobic environments, including water sediment, water-logged soils, natural hot springs, ocean thermal vents and the stomach of various animals (e.g. cows). The digested organic matter resulting from the anaerobic digestion process is usually called digestate. Anaerobic digestion is a multistep biological and chemical process that is beneficial in not only waste management but also energy creation. There are four fundamental steps of anaerobic digestion that include hydrolysis, acidogenesis, acetogenesis, and methanogenesis. Throughout this entire process, large organic polymers that make up Biomass are broken down into smaller molecules by chemicals and microorganisms. Upon completion of the anaerobic digestion process, the Biomass is converted into Biogas, namely carbon dioxide and methane, as well as digestate and wastewater.



Anaerobic Digester—Fundamental Steps



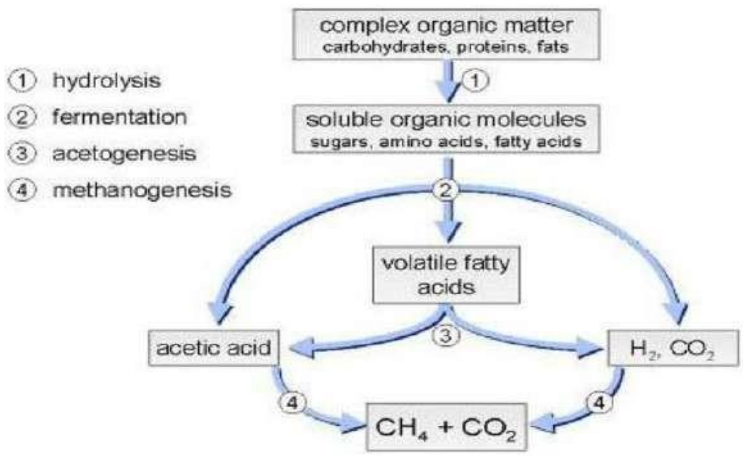


Figure 2. The chemical reactions that occur during anaerobic digestion

Hydrolysis

In general, hydrolysis is a chemical reaction in which the breakdown of water occurs to form H+ cations and OH- anions. Hydrolysis is often used to break down larger polymers, often in the presence of an acidic catalyst. In anaerobic digestion, hydrolysis is the essential first step, as Biomass is normally comprised of very large organic polymers, which are otherwise unusable. Through hydrolysis, these large polymers, namely proteins, fats and carbohydrates, are broken down into smaller molecules such as amino acids, fatty acids, and simple sugars. While some of the products of hydrolysis, including hydrogen and acetate, may be used by methanogens later in the anaerobic digestion process, the majority of the molecules, which are still relatively large, must be further broken down in the process of acidogenesis so that they may be used to create methane.

Acidogenesis

Acidogenesis is the next step of anaerobic digestion in which acidogenic microorganisms further break down the Biomass products after hydrolysis. These fermentative bacteria produce an acidic environment in the digestive tank while creating ammonia, H_2, CO_2, H_2S, shorter volatile fatty acids, carbonic acids, alcohols, as well as trace amounts of other byproducts. While acidogenic bacteria further breaks down the organic matter, it is still too large and unusable for the ultimate goal of methane production, so the biomass must next undergo the process of acetogenesis.

Acetogenesis

In general, acetogenesis is the creation of acetate, a derivative of acetic acid, from carbon and energy sources by acetogens. These microorganisms catabolize many of the products created in acidogenesis into acetic acid, CO_2 and H_2. Acetogens break down the Biomass to a point to which Methanogens can utilize much of the remaining material to create Methane as a Biofuel.

Methanogenesis

Methanogenesis constitutes the final stage of anaerobic digestion in which methanogens create methane from the final products of acetogenesis as well as from some of the involving the use of acetic acid and carbon dioxide, the two main products of the first three steps of anaerobic digestion, to create methane in methanogenesis:

$CO_2 + 4\ H_2 \rightarrow CH_4 + 2H_2O$

$CH_3COOH \rightarrow CH_4 + CO_2$

While CO_2 can be converted into methane and water through the reaction, the main mechanism to create methane in methanogenesis is the path involving acetic acid. This path creates methane and CO_2, the two main products of anaerobic digestion.

Advantages of biomass energy and anaerobic digestion

- You can use waste by-products to generate energy and reduce your waste disposal costs.
- It can be used in combination with a combined heat and power plant to generate both electricity and heat.
- Burning biomass fuels releases lower net carbon dioxide emissions than burning coal and gas.

Disadvantages of biomass energy and anaerobic digestion

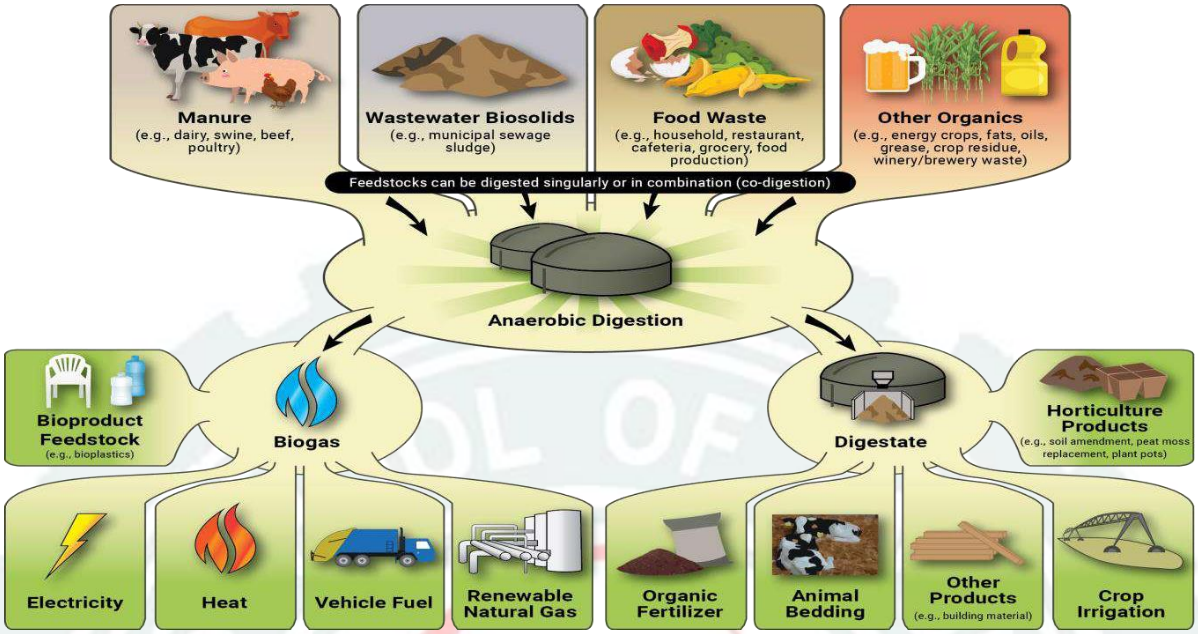
- You need to control emissions from burning biomass materials to prevent local air pollution. Any system you install must comply with legislation such as the Clean Air (Northern Ireland) Order.
- Storing biomass fuels can require a large amount of space.
- It can be difficult to find a secure supply of fuel. If you intend to use by-products from your business you must ensure that suitable quantities will be available.
- If you're having fuel delivered, you'll need to consider the environmental impact of fuel transportation.

Biogas digester:

Anaerobic digestion for biogas production takes place in a sealed vessel called a reactor, which is designed and constructed in various shapes and sizes specific to the site and feedstock conditions. These reactors contain complex microbial communities that break down (or digest) the waste and produce resultant biogas and digestate (the solid and liquid material end-products of the AD process) which is discharged from the digester.

Multiple organic materials can be combined in one digester, a practice called co-digestion. Co-digested materials include manure; food waste (i.e., processing, distribution and consumer generated materials); energy crops; crop residues; and fats, oils, and greases (FOG) from restaurant grease traps, and many other sources. Co-digestion can increase biogas production from low-yielding or difficult-to-digest organic waste.

The following figure illustrates the flow of feedstocks through the AD system to produce biogas and digestate.



Anaerobic Digester Outputs

Anaerobic digestion produces two valuable outputs: biogas and digestate.

Biogas

Biogas is composed of methane (CH_4), which is the primary component of natural gas, at a relatively high percentage (50 to 75 percent), carbon dioxide (CO_2), hydrogen sulfide (H_2S), water vapor, and trace amounts of other gases. The energy in biogas can be used like natural gas to provide heat, generate electricity, and power cooling systems, among other uses. Biogas can also be purified by removing the inert or low-value constituents (CO_2, water, H_2S, etc.) to generate renewable natural gas (RNG). This can be sold and injected into the natural gas distribution system, compressed and used as vehicle fuel, or processed further to generate alternative transportation fuel, energy products, or other advanced biochemicals and bioproducts.

Digestate

Digestate is the residual material left after the digestion process. It is composed of liquid and solid portions. These are often separated and handled independently, as each have value that can be realized with varying degrees of post processing. With appropriate treatment, both the solid and liquid portions of digestate can be used in many beneficial applications, such as animal bedding (solids), nutrient-rich fertilizer (liquids and solids), a foundation material for bio-based products (e.g., bioplastics), organic-rich compost (solids), and/or simply as soil amendment (solids), the latter of which may include the farm spreading the digestate on the field as fertilizer. Digestate products can be a source of

Types of bio gas digester

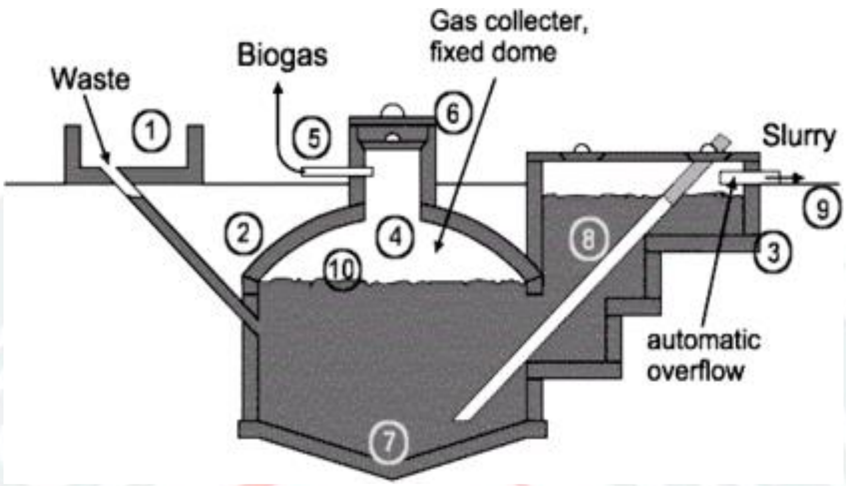
Choosing a right biogas digester is a very important while constructing a biogas plant. From the standpoint of fluid dynamics and structural strength, an egg-shaped vessel is about the best possible solution. This type of construction, however, is comparatively expensive, therefore, its use is usually restricted to large-scale sewage treatment plants.

1. Types of Small-Scale Digesters
   - Fixed Dome Biogas Plants
   - Floating Drum Plants
   - Low-Cost Polyethylene Tube Digester
   - Balloon Plants
   - Horizontal Plants
   - Earth-pit Plants
   - Ferro-cement Plants
2. Industrial Digester Types (Batch plants)
   - Continuous plants
   - Semi-batch basis
3. Dry Fermentation Plants

Fixed dome biogas 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. The costs of a fixed-dome biogas plant are relatively low. It is simple as no moving parts exist. There are also no rusting steel parts and hence a long life of the plant (20 years or more) can be expected. The plant is constructed underground, protecting it from physical damage and saving space. While the underground digester is protected from low temperatures at night and during cold seasons, sunshine and warm seasons take longer to heat up the digester. No day/night fluctuations of temperature in the digester positively influence the bacteriological processes. The construction of fixed dome plants is labor-intensive, thus creating local employment. Fixed-dome plants are not easy to build. They should only be built where construction can be supervised by experienced biogas technicians. Otherwise plants may not be gas-tight (porosity and cracks).

The basic elements of a fixed dome plant are shown in the figure below.



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 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.

Digester

Fixed-dome plant in Tunesia. The final layers of the masonry structure are being fixed.

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

- availability in the region and transport costs;
- 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.

A fixed-dome gas-holder can be either the upper part of a hemispherical digester (CAMARTEC design) or a conical top of a cylindrical digester (e.g. Chinese fixed-dome plant). In a fixed-dome plant the gas collecting in the upper part of the dome displaces a corresponding volume of digested slurry.

<u>The following aspects must be considered with regard to design and operation:</u>

- An overflow into and out of the compensation tank must be provided to avoid over-filling of the plant.
- The gas outlet must be located about 10 cm higher than the overflow level to avoid plugging up of the gas pipe.
- A gas pressure of 1 m WC or more can develop inside the gas space. Consequently, the plant must be covered sufficiently with soil to provide an adequate counter-pressure.
- Special care must be taken to properly close the man hole, which may require to weigh down the lid with 100 kg or more. The safest method is to secure the lid with clamps. Fixed-dome plants must be covered with earth up to the top of the gas-filled space to counteract the internal pressure (up to 0,15 bar). The earth cover insulation and the option for internal heating makes them suitable for colder climates. Due to economic parameters, the recommended minimum size of a fixed-dome plant is 5 m^3. Digester volumes up to 200 m^3 are known and possible.

Types of Fixed-dome Plants

- **Chinese fixed-dome plant** is the archetype of all fixed dome plants. Several million have been constructed in China. The digester consists of a cylinder with round bottom and top.
- **Janata model** was the first fixed-dome design in India, as a response to the Chinese fixed dome plant. It is not constructed anymore. The mode of construction lead to cracks in the gasholder - very few of these plant had been gas-tight.
- **Deenbandhu,** the successor of the Janata plant in India, with improved design, was

- **CAMARTEC model** has a simplified structure of a hemispherical dome shell based on a rigid foundation ring only and a calculated joint of fraction, the so-called weak / strong ring. It was developed in the late 80s in Tanzania.
- **AKUT fixed dome plant** is an improvement of the above mentioned Nicaragua design. Digester volumes ranges from 8 to 124 m^3 with gas storages from 2 to 19,4 m^3; the gas production can reach 60 m^3/d. The units from 32 m^3 onwards are often used for small scale productive use including electricity generation. It has a cylindrical base with a spheric top. The expansion chamber acts as overpressure outlet.
- **AKUT Maendaleo** (kisuaheli "progress") adds a gas storage ballon to collect access gas from the digestion chamber. This can be used for converted Diesel generators.

Advantages:

Low initial costs and long useful life-span; no moving or rusting parts involved; basic design is compact, saves space and is well insulated; construction creates local employment. Advantages are the relatively low construction costs, the absence of moving parts and rusting steel parts. If well constructed, fixed dome plants have a long life span. The underground construction saves space and protects the digester from temperature changes. The construction provides opportunities for skilled local employment.

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. Disadvantages are mainly the frequent problems with the gas-tightness of the brickwork gas holder (a small crack in the upper brickwork can cause heavy losses of biogas). Fixed-dome plants are, therefore, recommended only where construction can be supervised by experienced biogas technicians. The gas pressure fluctuates substantially depending on the volume of the stored g*as. Even though the underground construction buffers temperature extremes, digester temperatures are generally low. Fixed dome plants can be recommended only where construction can be supervised by experienced biogas technicians.*

- *A specific environmental disadvantage is methane emission from the expansion chamber.*

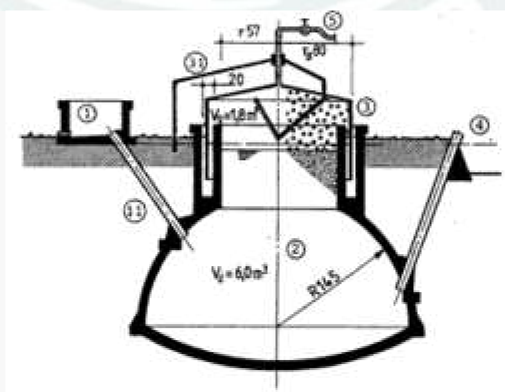
Floating Drum Biogas Plants

Floating drum plant in Mauretania

Om 1956, Jashu Bhai J Patel from India designed the first floating drum biogas plant, popularly called Gobar gas plant. Floating-drum plants consist of an underground digester (cylindrical or dome-shaped) and a moving gas-holder. The gas-holder 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. When biogas is produced, the drum moves up adn when it is consumed, the drum goes down.

If the drum floats in a water jacket, it cannot get stuck, even in substrate with high solid content. After the introduction of cheap Fixed-dome Chinese model, the floating drum plants became obsolete as they have high investment and maintenance cost along with other design weakness

Size



Water-jacket plant with external guide frame: 1 Mixing pit, 11 Fill pipe, 2 Digester, 3 Gasholder, 31 Guide frame, 4 Slurry store, 5 Gas pipe input. They are used most frequently by small to middle-sized farms (digester size: 5-15m^3) or in institutions and larger agro-industrial estates (digester size: 20-100m^3).

Disadvantages: The steel drum is relatively expensive and maintenance-intensive. Removing rust and painting has to be carried out regularly. The life-time of the drum is short (up to 15 years; in tropical coastal regions about five years). If fibrous substrates are used, the gas-holder shows a tendency to get "stuck" in the resultant floating scum.

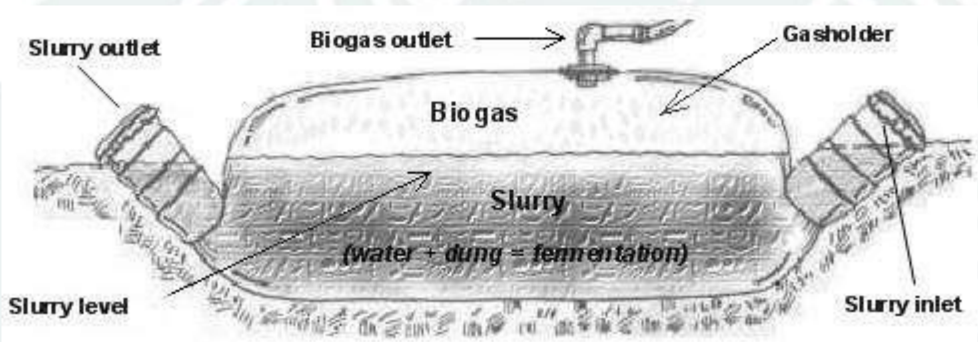
Water-jacket Floating-drum Plants

Water-jacket plants are universally applicable and easy to maintain. The drum cannot get stuck in a scum layer, even if the substrate has a high solids content. Water-jacket plants are characterized by a long useful life and a more aesthetic appearance (no dirty gas-holder). Due to their superior sealing of the substrate (hygiene!), they are recommended for use in the fermentation of night soil. The extra cost of the masonry water jacket is relatively modest.

The digester is usually made of brick, concrete or quarry-stone masonry with plaster. The gas drum normally consists of 2.5 mm steel sheets for the sides and 2 mm sheets for the top. It has welded-in braces which break up surface scum when the drum rotates. The drum must be protected against corrosion. Suitable coating products are oil paints, synthetic paints and bitumen paints. Correct priming is important. There must be at least two preliminary coats and one topcoat. Coatings of used oil are cheap. They must be renewed monthly. Plastic sheeting stuck to bitumen sealant has not given good results. In coastal regions, repainting is necessary at least once a year, and in dry uplands at least every other year. Gas production will be higher if the drum is painted black or red rather than blue or white, because the digester temperature is increased by solar radiation. Gas drums made of 2 cm wire-mesh-reinforced concrete or fiber-cement must receive a gas-tight internal coating. The gas drum should have a slightly sloping roof, otherwise rainwater will be trapped on it, leading to rust damage. An excessively steep-pitched roof is unnecessarily expensive and the gas in the tip cannot be used because when the drum is resting on the bottom, the gas is no longer under pressure. Floating-drums made of glass-fiber reinforced plastic and high-density polyethylene have been used successfully, but the construction costs are higher compared to using steel. Floating-drums made of wire-mesh-reinforced concrete are liable to hairline cracking and are intrinsically porous. They require a gas-tight, elastic internal coating. PVC drums are unsuitable because they are not resistant to UV.

Low-Cost Polyethylene Tube Digester

In the case of the Low-Cost Polyethylene Tube Digester model which is applied in Bolivia (Peru, Ecuador, Colombia, Centro America and Mexico), the tubular polyethylene film (two coats of 300 microns) is bended at each end around a 6 inch PVC drainpipe and is wound with rubber strap of recycled tire-tubes. With this system a hermetic isolated tank is obtained. One of the 6" PVC drainpipes serves as inlet and the other one as the outlet of the slurry. In the tube digester finally, a hydraulic level is set up by itself, so that as much quantity of added prime matter (the mix of dung and water) as quantity of fertilizer leave by the outlet.



Balloon Plants

A balloon plant consists of a heat-sealed plastic or rubber bag (balloon), combining digester and gas-holder. The gas is stored in the upper part of the balloon. The inlet and outlet are attached directly to the skin of the balloon. Gas pressure can be increased by placing weights on the balloon. If the gas pressure exceeds a limit that the balloon can withstand, it may damage the skin. Therefore, safety valves are required. If higher gas pressures are needed, a gas pump is required. Since the material has to be weather- and UV resistant, specially stabilized, reinforced plastic or synthetic caoutchouc is given preference. Other materials which have been used successfully include RMP (red mud plastic), Trevira and butyl. The useful life-span does usually not exceed 2-5 years.

Advantages:

- Standardized prefabrication at low cost,
- low construction sophistication,

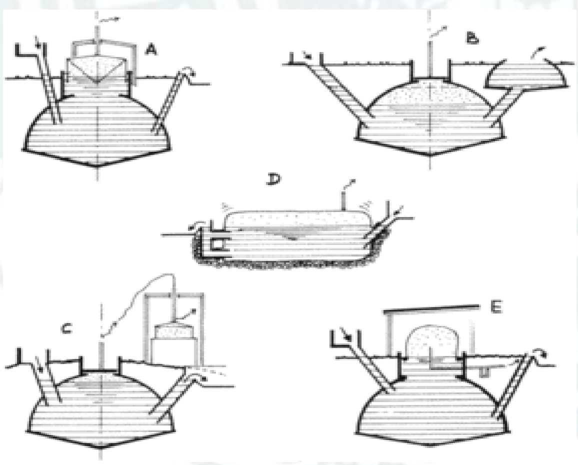
- high temperature digesters in warm climates;
- uncomplicated cleaning,
- emptying and maintenance;
- difficult substrates like water hyacinths can be used

Balloon biogas plants are recommended, if local repair is or can be made possible and the cost advantage is substantial.

Disadvantages:

- Low gas pressure may require gas pumps;
- scum cannot be removed during operation;
- the plastic balloon has a relatively short useful life-span and is susceptible to mechanical damage and usually not available locally. In addition, local craftsmen are rarely in a position to repair a damaged balloon. There is only little scope for the creation of local employment and, therefore, limited self-help potential.

A variation of the balloon plant is the channel-type digester, which is usually covered with plastic sheeting and a sunshade (fig.1-E). Balloon plants can be recommended wherever the balloon skin is not likely to be damaged and where the temperature is even and high.



Earth-pit Plants

Masonry digesters are not necessary in stable soil (e.g. laterite). It is sufficient to line the pit with a thin layer of cement (wire-mesh fixed to the pit wall and plastered) in order to plastic sheeting is used, it must be attached to a quadratic wooden frame that extends down into the slurry and is anchored in place to counter its buoyancy. The requisite gas pressure is achieved by placing weights on the gas-holder. An overflow point in the peripheral wall serves as the slurry outlet.

Advantages

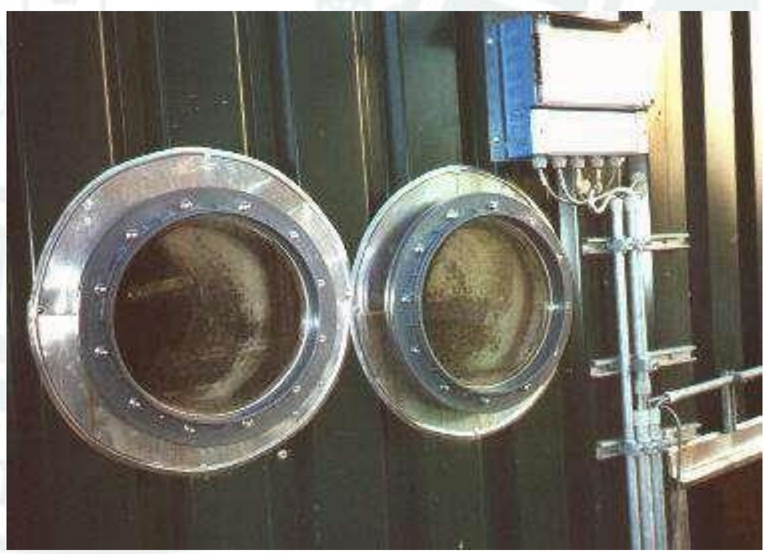
- Low cost of installation (as little as 20% of a floating-drum plant);
- high potential for self help approaches.

Disadvantages

- Short useful life; serviceable only in suitable, impermeable types of soil.
- Earth-pit plants can only be recommended for installation in impermeable soil located above the groundwater table. Their construction is particularly inexpensive in connection with plastic sheet gas-holders.

Industrial Digester Types

To give an overview, some fictitious designs have been chosen as they could be found in, for example, Europe. The designs are selected in a way that all the typical elements of modern biogas technology appear at least once. All designs are above-ground, which is common in Europe. Underground structures, however, do exist.



Control glasses for an industrial digester for solid organic waste, Germany[2]

Mixing pit varies in size and

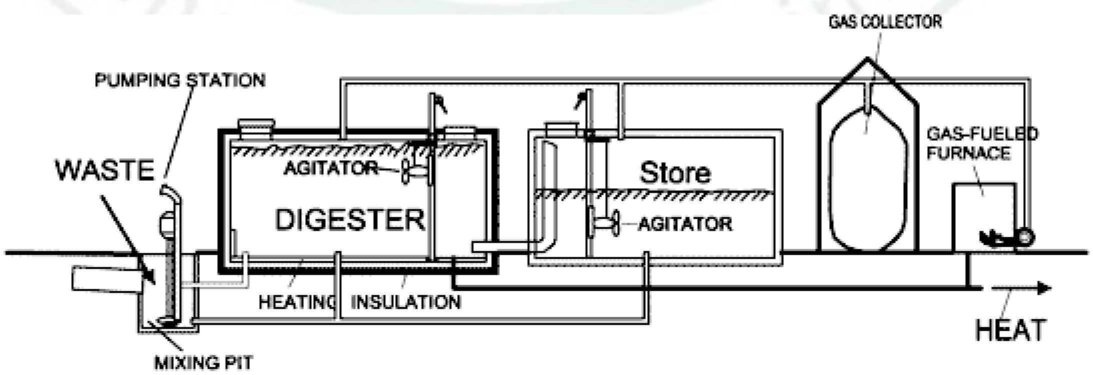
At times, the substrate is also pre-heated in the mixing pit in order to avoid a temperature shock inside the digester.

Fermenter or digester is insulated and made of concrete or steel. To optimize the flow of substrate, large digesters have a longish channel form. Large digesters are almost always agitated by slow rotating paddles or rotors or by injected biogas. Co-fermenters have two or more separated fermenters. The gas can be collected inside the digester, then usually with a flexible cover. The digester can also be filled completely and the gas stored in a separate gas-holder.

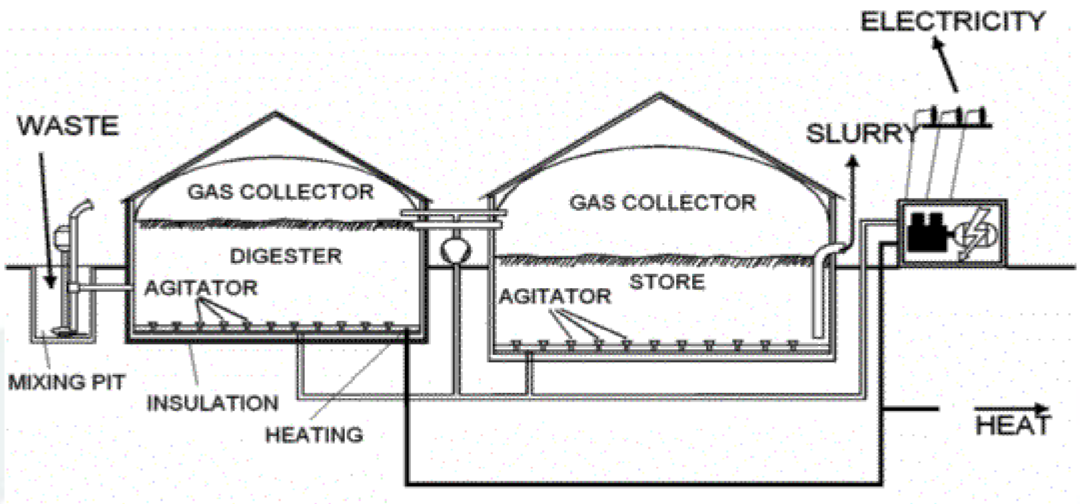
Gas-holder is usually of flexible material, therefore to be protected against weather. It can be placed either directly above the substrate, then it acts like a balloon plant, or in a separate 'gas-bag'.

Slurry store for storage of slurry during winter. The store can be open (like conventional open liquid manure storage) or closed and connected to the gas-holder to capture remaining gas production. Normally, the store is not heated and only agitated before the slurry is spread on the field.

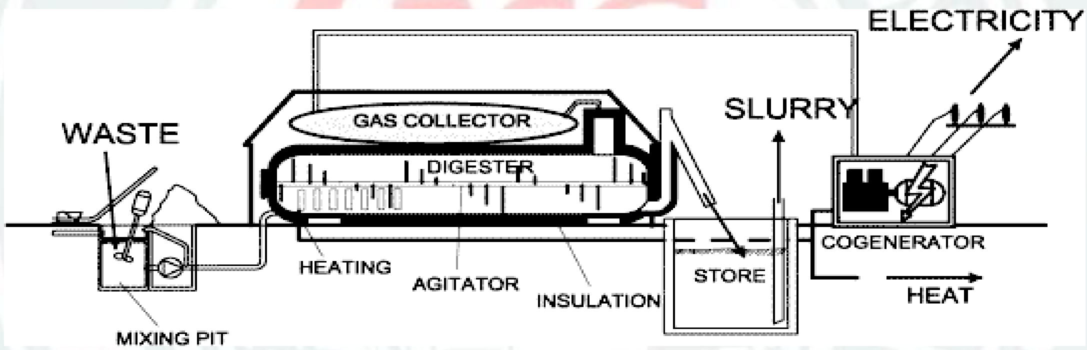
Gas use element is in Europe in 95% of the cases a thermo-power unit which produces electricity for the farm, the grid and heat for the house, greenhouses and other uses. The thermo-power unit has the advantage, that the required energy can be produced in any mixture of gas and fossil energy. It can, therefore, react to periods of low gas production and high energy requirements or vice versa.



storage)[2]



Concrete digester with integrated plastic gas-holder[2]



Steelvessel fermenter with seperate ballon gas-holder[2]

Batch plants

Batch plants are filled and then emptied completely after a fixed retention time. Each design and each fermentation material is suitable for batch filling, but batch plants require high labor input. As a major disadvantage, their gas-output is not steady.

Continuous plants

Continuous plants are fed and emptied continuously. They empty automatically through the overflow whenever new material is filled in. Therefore, the substrate must be fluid and homogeneous. Continuous plants are suitable for rural households as the necessary work fits well into the daily routine. Gas production is constant, and higher than in batch plants.

Semi-batch basis

If straw and dung are to be digested together, a biogas plant can be operated on a semi-batch basis. The slowly digested straw-type material is fed in about twice a year as a batch load. The dung is added and removed regularly.

Dry Fermentation Plants

Dry fermentation is an anaerobic process in which micro-organism break down biodegradable material. Renewable organic feedstocks are used as a the source of energy for the process. The nutrient-rich solids resulting from the digestion can be used as a fertiliser subsequently.

Almost any organic material can be processed with dry fermentation. This includes biodegradable waste materials such as waste paper, grass clippings, leftover food, sewage and animal waste.

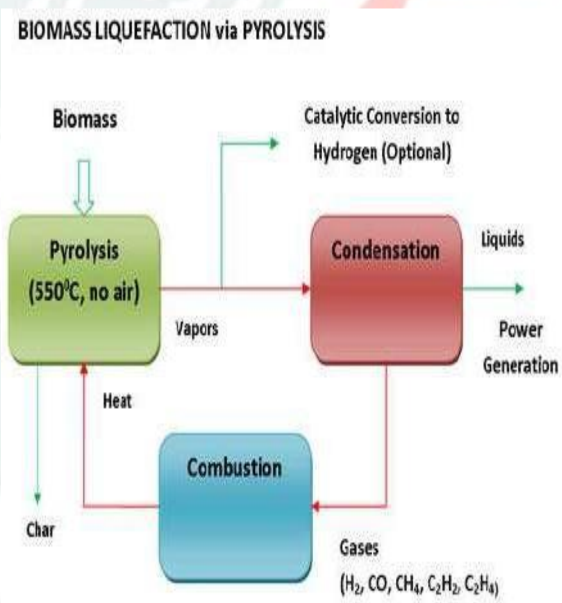
Biomass refers to organic materials, such as wood, straw and energy crops, which can be used to generate electricity, heat and motive power. The energy is released by burning and fermentation. **Anaerobic digestion** is another method of converting biomass into energy. In this process, organic material is broken down by bacteria, in the absence of oxygen, to create methane-rich biogas. This can then be burned to generate heat and electricity. The solid waste from the process is called digestate and can be used in a similar way to compost.

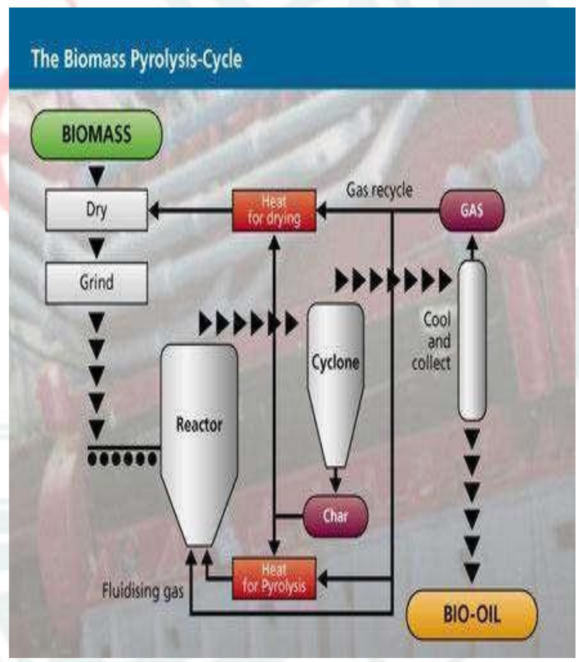
The payback periods for anaerobic digestion plants vary widely, but could be between five and ten years.

Pyrolysis

Pyrolysis is the thermal decomposition of biomass occurring in the absence of oxygen. It is the fundamental chemical reaction that is the precursor of both the combustion and gasification processes and occurs naturally in the first two seconds. The products of biomass pyrolysis include biochar, bio-oil and gases including methane, hydrogen, carbon monoxide, and carbon dioxide. Depending on the thermal environment and the final temperature, pyrolysis will yield mainly biochar at low temperatures, less than 450 0C, when the heating rate is quite slow, and mainly gases at high temperatures, greater than 800 0C, with rapid heating rates. At an intermediate temperature and under relatively high heating rates, the main product is bio-oil.

Pyrolysis can be performed at relatively small scale and at remote locations which enhance energy density of the biomass resource and reduce transport and handling costs. Heat transfer is a critical area in pyrolysis as the pyrolysis process is endothermic and sufficient heat transfer surface has to be provided to meet process heat needs. Pyrolysis offers a flexible and attractive way of converting solid biomass into an easily stored and transported liquid, which can be successfully used for the production of heat, power and chemicals.





Feedstock for Pyrolysis

A wide range of biomass feedstocks can be used in pyrolysis processes. The pyrolysis process is very dependent on the moisture content of the feedstock, which should be around 10%. At higher moisture contents, high levels of water are produced and at lower levels there is a risk that the process only produces dust instead of oil. High-moisture waste streams, such as sludge and meat processing wastes, require drying before subjecting to pyrolysis.

The efficiency and nature of the pyrolysis process is dependent on the particle size of feedstocks. Most of the pyrolysis technologies can only process small particles to a maximum of 2 mm keeping in view the need for rapid heat transfer through the particle. The demand for small particle size means that the feedstock has to be size-reduced before being used for pyrolysis.

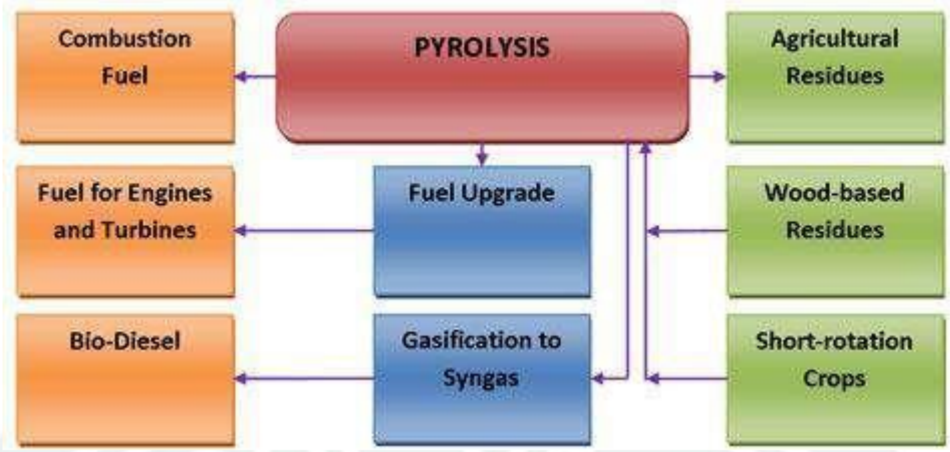


Figure 2 A glance at feedstock availability and energy products from biomass pyrolysis

Types of Pyrolysis

Pyrolysis processes can be categorized as slow pyrolysis or fast pyrolysis. Fast pyrolysis is currently the most widely used pyrolysis system. Slow pyrolysis takes several hours to complete and results in biochar as the main product. On the other hand, fast pyrolysis yields 60% bio-oil and takes seconds for complete pyrolysis. In addition, it gives 20% biochar and 20% syngas. Fast pyrolysis processes include open-core fixed bed pyrolysis, ablative fast pyrolysis, cyclonic fast pyrolysis, and rotating core fast pyrolysis systems. The essential features of a fast pyrolysis process are:

- Very high heating and heat transfer rates, which require a finely ground feed.
- Carefully controlled reaction temperature of around 500oC in the vapour phase
- Residence time of pyrolysis vapours in the reactor less than 1 sec
- Quenching (rapid cooling) of the pyrolysis vapours to give the bio-oil product.

Uses of Bio-Oil
Bio-oil is a dark brown liquid and has a similar composition to biomass. It has a much higher density than woody materials which reduces storage and transport costs. Bio-oil is not suitable for direct use in standard internal combustion engines. Alternatively, the oil can be upgraded to either a special engine fuel or through gasification processes to a syngas and then bio-diesel. Bio-oil is particularly attractive for co-firing because it can be more readily handled and burned than solid fuel and is cheaper to transport and store. Co-firing of bio-oil has been demonstrated in 350 MW gas fired power station in Holland, when 1% of the boiler output was successfully replaced. It is in such applications that bio-oil can offer major advantages over solid biomass and gasification due to the ease of handling, storage and combustion in an existing power station when special start-up procedures are not necessary. In addition, bio-oil is also a vital source for a wide range of organic compounds and speciality chemicals.

Importance of Biochar
The growing concerns about climate change have brought biochar into limelight. Combustion and decomposition of woody biomass and agricultural residues results in the emission of a large amount of carbon dioxide. Biochar can store this CO_2 in the soil leading to reduction in GHGs emission and enhancement of soil fertility. In addition to its potential for carbon sequestration,

- Biochar can increase the available nutrients for plant growth, water retention and reduce the amount of fertilizer by preventing the leaching of nutrients out of the soil.
- Biochar reduces methane and nitrous oxide emissions from soil, thus further reducing GHGs emissions.
- Biochar can be utilized in many applications as a replacement for other biomass energy systems.
- Biochar can be used as a soil amendment to increase plant growth yield.

Conclusions
Biomass pyrolysis has been attracting much attention due to its high efficiency and good environmental performance characteristics. It also provides an opportunity for the processing of agricultural residues, wood wastes and municipal solid waste into clean energy. In addition, biochar sequestration could make a big difference in the fossil fuel emissions worldwide and act as a major player in the global carbon market with its robust, clean and simple production technology.

Gasification

- Gasification is a physicochemical process in which chemical transformations occur along with the conversion of energy.
- Gasification is a process that converts organic or fossil based carbonaceous materials into carbon monoxide, hydrogen and carbon dioxide. This is achieved by reacting the material at high temperatures (>700 °C), without combustion, with a controlled amount of oxygen and/or steam. The resulting gas mixture is called syngas which is itself a fuel. The power derived from gasification and combustion of the resultant gas is considered to be a source of renewable energy if the gasified compounds were obtained from biomass.
- Gasification is one form of combustion, i.e. incomplete or choked combustion. The process takes place in the reactor called gasifier at high temperatures in presence or absence of oxygen. Later, the unburnt gases are moved out to burn elsewhere.

Wood gas generator/Wood gasssifier

- It is a gasification unit which converts timber or charcoal into wood gas, a syngas consisting of atmospheric nitrogen, carbon monoxide, hydrogen, traces of methane, and other gases, which – after cooling and filtering – can then be used to power an internal combustion engine or for other purposes.
- Historically wood gas generators were often mounted on vehicles, but present studies and developments concentrate mostly on stationary plants. The purpose of a Gasifier, then, is to transform solid fuels into gaseous ones and to keep the gas free of harmful constituents.
- A gas generator unit is simultaneously an energy converter and a filter. In these twin tasks lie its advantages and its difficulties.
- In a sense, gasification is a form of incomplete combustion-heat from the burning solid fuel creates gases which are unable to burn completely because of the insufficient amounts of oxygen from the available supply of air. There are many solid biomass fuels suitable for gasification - from wood and paper to peat, lignite, and coal, including coke derived from coal. All of these solid fuels are composed primarily of carbon with varying amounts of hydrogen, oxygen, and impurities, such as sulfur, ash, and moisture. Thus, the aim of gasification is the almost complete transformation of these constituents into gaseous form so that only the ashes and inert materials remain.
- In a gasifier, the carbonaceous material undergoes several different processes: The dehydration or drying process occurs at around 100°C. The pyrolysis (or de-volatilization) process occurs at around 200-300°C. Volatiles are released and char is produced, resulting in up to 70% weight loss for coal. The combustion occurs as the volatile

reactions. The gasification process occurs as the char reacts with carbon and steam to produce carbon monoxide and hydrogen. In addition, the reversible gas phase water gas shift reaction reaches equilibrium very fast at the temperatures in a gasifier. This balances the concentrations of carbon monoxide, steam, carbon dioxide and hydrogen.

- In essence, a limited amount of oxygen or air is introduced into the reactor to allow some of the organic material to be "burned" to produce carbon monoxide and energy, which drives a second reaction that converts further organic material to hydrogen and additional carbon dioxide. Further reactions occur when the formed carbon monoxide and residual water from the organic material react to form methane and excess carbon dioxide. This third reaction occurs more abundantly in reactors that increase the residence time of the reactive gases and organic materials, as well as heat and pressure. Catalysts are used in more sophisticated reactors to improve reaction rates, thus moving the system closer to the reaction equilibrium for a fixed residence time.
- The choice of feedstock determines the gasifier design. Three designs are common in wood gasification: updraft, downdraft and crossdraft. In an updraft gasifier, wood enters the gasification chamber from above, falls onto a grate and forms a fuel pile. Air enters from below the grate and flows up through the fuel pile. The syngas, also known as producer gas in biomass circles, exits the top of the chamber. In downdraftor crossdraft gasifiers, the air and syngas may enter and exit at different locations

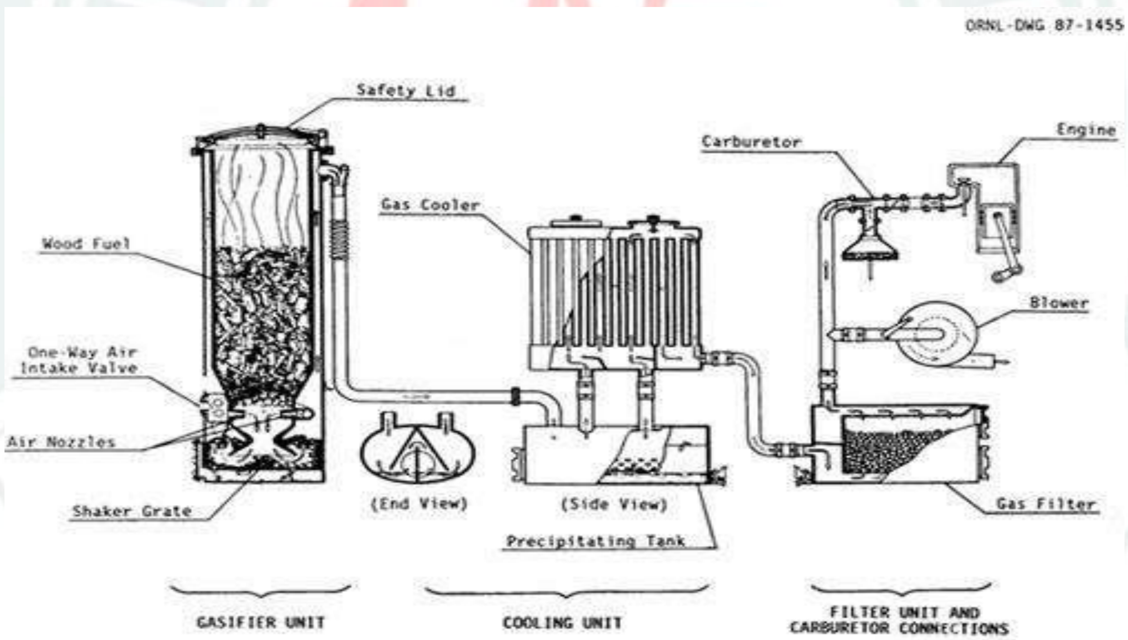


Fig. 1-2. Schematic view of the World War II, Imbert gasifier.

DESIGN

- There is a rich literature on gas-works, town-gas, gas-generation, wood-gas, and producer gas, that is now in the public domain due to its age.
- . Wood gas generators often use wood; however, charcoal can also be used as a fuel. It is denser and produces a cleaner gas without the tarry volatiles and excessive water content of wood.
- The FEMA wood gas generator is (by definition of the FEMA manual) an emergency gasifier. It is designed to be rapidly assembled in a true fuel crisis.
- This simplified design has distinct benefits over the earlier European units such as easier

oxidization zone to creep to a larger area, causing a drop in temperature; a lower operating temperature leads to tar production and it lacks a true reduction zone further increasing this design's propensity to produce tar.

- Tar in the wood gas stream is considered a dirty gas and tar will gum up a motor quickly, possibly leading to stuck valves and rings.
- A new design known as the Keith gasifier improves on the FEMA unit, incorporating extensive heat recovery and eliminating the tar problem. Testing at Auburn University has shown it to be 37% more efficient than running gasoline.[9]
- This system set the world speed record for biomass powered vehicles[10] and has made several cross country tours.
- Wood gasifiers of proven design and thoroughly tested construction are considered safe to use outdoors, or in a partially enclosed space, for example, under a shelter open to the air on two sides; they may also be considered relatively safe to use in an extremely well ventilated (e.g. negative pressure) indoor area not connected to any indoor area used for sleeping, equipped with redundant (more than 1), completely independent, battery-powered, regularly tested carbon-monoxide gas detectors.

Advantages

Wood gas generators have a number of advantages over use of petroleum fuels:

- They can be used to run internal combustion engines (or gas turbines, for maximal efficiency) using wood, a renewable resource, and in the absence of petroleum or natural gas, for example, during a fuel shortage.
- They have a closed carbon cycle, contribute less to global warming, and are sustainable in nature.
- They can be relatively easily fabricated in a crisis using materials on hand.
- They are far cleaner burning than a wood fire or a gasoline-powered engine (without emissions controls), producing little, if any soot.
- When used in a stationary design, they reach their true potential, as they are feasible to use in small combined heat and power scenarios (with heat recovery from the wood gas producer, and possibly the engine/generator, for example, to heat water for hydronic heating), even in industrialized countries, even during good economic times, provided that a sufficient supply of wood is attainable. Larger-scale installations can reap even better efficiencies, and are useful for district heating as well.

Disadvantages

The disadvantages of wood gas generators are:

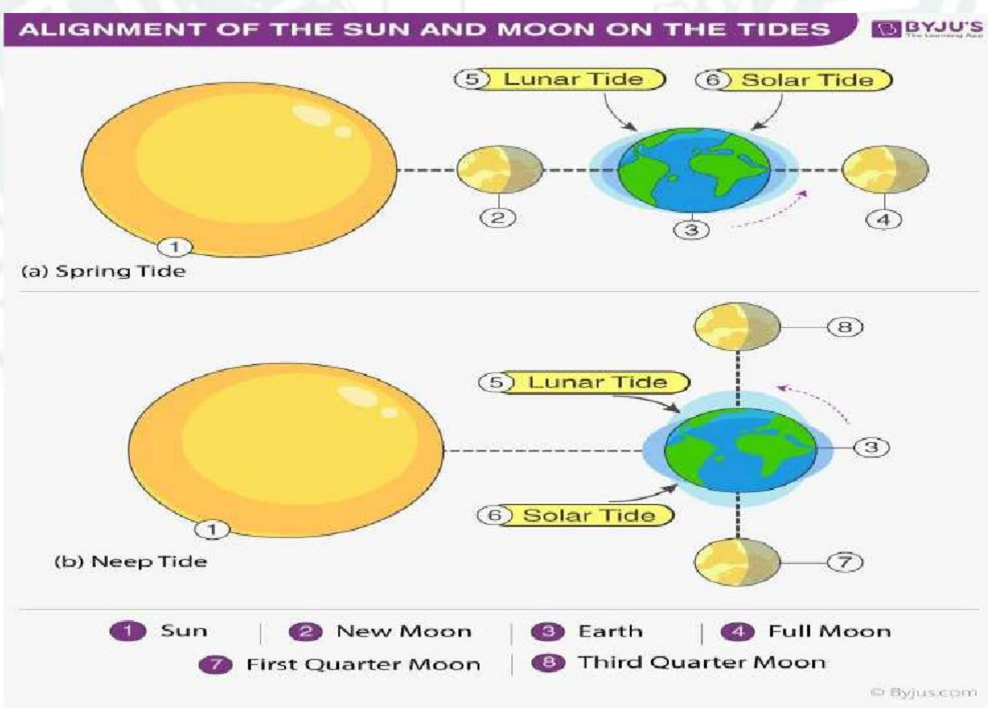
- the large specific sizea
- the relatively slow starting speed; the time to heat the initially cold batch of wood to the necessary temperature level can take many minutes and in bigger plants even hours until the designed power is reached.
- a batch burning operation, that some designs feature, and that regularly interrupts the gas producing process.
- the stop operation out of a high load level is difficult (for example the stop of the engine using the gas): the residual heat still produces gas, which for a certain time leaves the gasifier either without control, or has to be used in a burner
- the primary combustible fuel-gas produced during gasification is carbon monoxide: it is an intentional fuel-product, and is subsequently burned to safe carbon dioxide in the engine (or other application) along with the other fuel-gases; however, continuous exposure to carbon monoxide can be fatal to humans even in small to moderate concentrations.
- the humidity of the wood (usually 15 to 20%) and the water vapor created by the O- and H-atoms of the dry wood itself condenses during the gas cooling and filtering procedure and yields a liquiD, which needs specific waste water treatment. This treatment requires about 25 to

CHAPTER-5
OTHER ENERGY SOURCES

TIDAL ENERGY

Tides

- Tides are the rise and fall of sea levels caused by the combined effects of the gravitational forces exerted by the Moon and the Sun, and the rotation of the Earth.
- The gravitational forces of the sun and the moon combined with the rotation of the earth result in an alternate rise and fall of the sea levels.
- At one particular place, it usually occurs twice on a lunar day. The rise of the sea level is called the high tide, whereas the fall is called the low tide.
- When the earth and moon's gravitational field are in a straight line, the influences of these two fields become very strong and causing millions of gallons of the water flow towards the shore resulting in the high tide condition. Likewise, when the moon and earth's gravitational fields are perpendicular to each other, the influences of these fields become weak, causing the water to flow away from the shore resulting in a low tide condition.
- When the moon is perfectly aligned with the earth and the sun, the gravitational pull of the sun and the moon on the earth becomes much stronger and the high tides much higher and the low tides much lower during each tidal cycle. This condition occurs during the full or new moon phase. Such tides are known as spring tides.
- Similarly, another tidal situation emerges when the gravitational pull of the moon and sun are against each other cancelling their effects. This results in a smaller difference between the low and high tides due to the smaller pulling action on the seawater, thereby resulting in weak tides. These weak tides are known as neap tides. Neap tides occur during the quarter moon phase.



Tidal energy is a form of hydropower that works by harnessing the kinetic energy created from the rise and fall of ocean tides and currents, also called tidal flows, and turns it into usable electricity.
The larger the tidal range, or the height difference between sea level at high and low tide, the more power can be produced.
Tides fluctuate thanks to the gravitational pull of the sun and moon. Tidal power is a clean and renewable energy source - it emits no greenhouse gases as it produces electricity. Tidal power is only practical for large, commercial-scale projects.
Tidal Energy is Convertion

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

1. Tidal Turbines

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). Tidal turbines utilize the same technology as wind turbines. The only difference is that the blades of tidal turbines are way stronger and shorter. So, the best way to compare tidal turbines is underwater windmills. 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. Ideally, the water currents turn the turbine. The turbine is connected to a generator through a shaft. So, when the turbine turns, the shaft also turns.The turning shaft activates a generator, which generates 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 initial cost of setting up this tidal stream system is quite on the higher side, not to mention the difficulty in maintenance. However, it remains a cheaper alternative and doesn't cause environmental degradation compared to other tidal technologies. The world's first tidal power station was constructed in 2007 at Strangford Lough in Northern Ireland.

2. 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. For the barrage to be able to produce power, the tidal range, which is the difference between low and high tide, has to be more than 5 meters. As the tide enters the system, ocean or seawater flows via the dam into the basin. When the tides subside, the system's gates close, trapping the water in the estuary or basin. When the tides start to move out, the gates in the dam that consist of turbines open up, and water begins to flow out, hitting the turbines, which eventually turn to produce energy. Construction of tidal barrages

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.

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.

Advantages of Tidal Energy

1. It's environmentally friendly

The fact that tidal energy technologies are installed on the coastlines and offshore makes them good for the environment since the land will not be interfered with. Also, tidal energy is a clean source of energy, meaning it doesn't release any greenhouses gasses to the atmosphere.

2. It's a renewable energy source

Tides harnessed to produce tidal energy result from the combined gravitational pull of the sun, moon, and earth in conjunction with the rotation of the planet around its axis. This is a natural process that occurs every single day. This means that tides will continue to occur, and production of tidal energy will continue until the end of time.

3. It's highly predictable

The development of tides is a well-understood cycle. This makes it a lot easier to develop tidal energy systems with the right dimensions. Why? Because the level of power the system will be exposed to is already determined. Which explains why the capacity of the installed equipment and the entire physical size has completely no energy generation limitations, even though stream generators and tidal turbines used resemble those of wind turbines.

4. Cost-competitive

Tidal energy technologies, once constructed, have the potential to generate electricity for many years, which means they are long-lasting. Although the upfront costs of setting up a tidal power plant are relatively high, the return on investment will be realized in the long run. A typical example is the La Rance tidal barrage, which is still producing electricity since 1966.

5. Minimizes over-dependence on fossil fuels

Fossil-based sources of energy such as oil, coal and natural gas emit greenhouse gasses that lead to climate change and global warming. Tidal energy offers a green and renewable alternative to cut back on greenhouse gas emissions.

6. Offers a sense of protection

Barrages and dams that are utilized to tap tidal energy for the generation of electricity could insulate coastal areas and ship ports from high impact and dangerous tides in the course of bad weather and storms.

7. It's quite effective than wind even at low speeds

Oceans currents have the capacity to produce more energy than air currents because ocean water is 832 times denser than air. This means ocean currents applies greater force on the turbines to generate more energy.

Disadvantages of Tidal Energy

1. High upfront capital costs

Tidal energy technologies are considerably new. Meaning the costs of infrastructure are relatively high at the moment. Experts also project that tidal energy will only start to be commercially beneficial in 2020 with enhancements of innovative technologies.

2. It's not completely environmentally friendly

Tidal energy generation systems are thought to harbor some environmental impacts, but they have not been quantified. In addition, these tidal plants produce electricity using tidal barrages that depend on the manipulation of sea levels. This means that they have the same environmental impacts as hydroelectric dams.

3. Problems of efficiency

The generation of tidal electricity wholly depends on tidal surges, which happen twice a day. This means when tides are not happening, there is no production of energy, which is why extra costs must be incurred to set up energy storage systems.

4. Tidal energy needs a long gestation period

Tidal power plants need a lot of time to be able to produce electricity efficiently. This aspect, combined with the cost of installation, can be unsustainable. A typical example of a tidal power plant that was closed due to time and cost overruns is the UK's Severn Barrage.

5. Impact on marine life

The greatest fear among tidal energy systems developers is the impact the plants and turbines will have on the surrounding marine ecosystem. The rotation of turbines and vibrations of the tidal plant could significantly interrupt the marine ecosystem and inhibit the natural movement of marine life.

Although tidal energy technology is still in its infancy stage, the grave impacts of fossil fuels and the fear of them running out someday means a lot of time and resources will be dedicated towards sun, wind and geothermal are way ahead, tidal is fast catching up with the pack. Tidal energy is seen as the next big thing once its technology becomes a lot better.

Examples of Tidal Energy Projects

1. LaRance Tidal Power Station, France

Capacity: 240MW

The world's first tidal barrage, in Brittany, built between 1961 and 1966, was the world's largest tidal energy generator until 2011, when it was overtaken by South Korea's Sihwa Lake. Currently, this is world's oldest and second-biggest renewable tidal power plant operated by Électricité de France (EDF), which has an annual generation capacity of 540GWh.

2. Sihwa Lake Tidal Power Station, South Korea

Capacity: 254MW

South Korea's Sihwa Lake Tidal Power Station on Lake Sihwais the world's biggest tidal power plant with an installed capacity of 254MW. The project, owned by Korea Water Resources Corporation, opened in August 2011. Situated about 60 kilometers southwest of Seoul, the project utilizes a 12.5km long seawall set up in 1994 for flood control and agriculture.

Conclusion.

Tidal power is not a widely used energy source just yet. There are only nine tidal power stations in operation globally.

However, there are more being planned as tidal power technologies become more fine-tuned.

Many of the proposed tidal power plants are solely for research purposes, but the number of commercial energy power plants is increasing.

Testing sites for tidal power generation have been popping up in places in order to learn more about how tidal energy systems work. One of the most notable testing sites is in the Bay of Fundy in Canada.

From what we know now, it seems that tidal power holds a lot of potential to help us move away from fossil fuels in the future.

OCEAN THERMAL ENERGY CONVERSION (OTEC)

- Ocean Thermal Energy Conversion (OTEC) is a process that can produce electricity by using the temperature difference between deep cold ocean water and warm tropical surface water.
- In 1881 The world's first conceptual invention OTEC was formed by a French Physicist Mr. J. D'Arsonval .
- OTEC is an energy technology that converts solar radiation to electric power .
- OTEC utilizes the world's largest solar radiation collector.
- OTEC technology is easily applicable in many industrial fields for recovery and saving of energy in lower temperature range and small thermal head.
- Some of temperature distribution of ocean seawater measured in vertical direction in tropical and subtropical zones are shown in Fig.1.
- Greater the temperature difference , greater will be the efficiency. Greater the depth , lesser will be the temperature

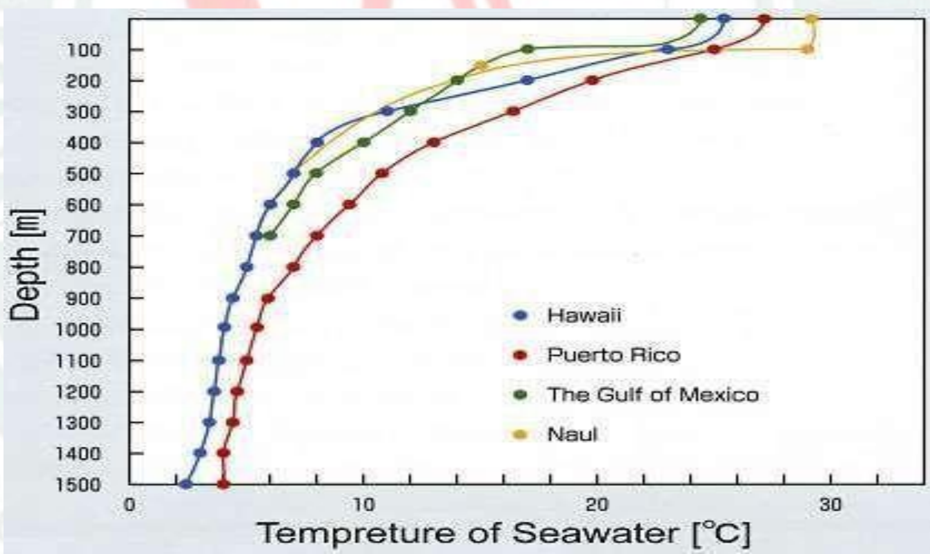


Figure 1. Distribution of Seawater Temperature

TYPES OF ELECTRICITY CONVERSION SYSTEM

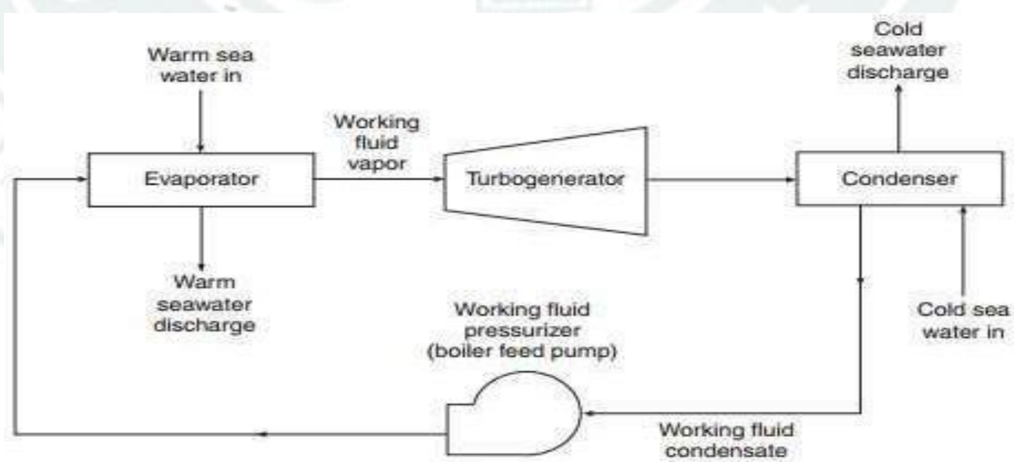
- There are three types of electricity conversion systems:

1. Closed OTEC Cycle Power Plant
2. Open OTEC Cycle Power Plant

3. Hybrid Cycle OTEC Power Plant

1. **<u>Closed Loop OTEC Cycle</u>**

- In the closed-cycle OTEC system, warm sea water vaporizes a working fluid, such as ammonia, flowing through a heat exchanger (evaporator).
- The vapor expands at moderate pressures and turns a turbine coupled to a generator that produces electricity.
- The vapor is then condensed in heat exchanger (condenser) using cold seawater pumped from the ocean's depths through a cold-water pipe.
- The condensed working fluid is pumped back to the evaporator to repeat the cycle.
- The working fluid remains in a closed system and circulates continuously.
- The heat exchangers (evaporator and condenser) are a large and crucial component of the closed-cycle power plant, both in terms of actual size and capital cost.
- The working fluid is vaporized by heat transfer from the warm sea water in the evaporator. The vapor expands through the turbogenerator and is condensed by heat transfer to cold sea water in the condenser. Closed-cycle OTEC power systems, which operate at elevated pressures, require smaller turbines than open-cycle systems.



<u>Figure 2. Schematic diagram of a closed-cycle OTEC system</u>

2. Open Loop OTEC Cycle

- In an open-cycle OTEC, the sea water is itself used to generate heat without any kind ofintermediate fluid.
- Open-cycle OTEC uses the tropical oceans' warm surface water to make electricity.
- The open cycle consists of the following steps:

• Flash evaporation of a fraction of the warm seawater by reduction of pressure below the saturation value corresponding to its temperature.
• Expansion of the vapour through a turbine to generate power.
• Heat transfer to the cold seawater thermal sink resulting in condensation of the workingfluid.
• Compression of the non-condensable gases (air released from the seawater streams at thelow operating pressure) to pressures required to discharge them from the system.

- In open-cycle OTEC, warm sea water is used directly as the working fluid. Warm sea water is flash evaporated in a partial vacuum in the evaporator. The vapor expands through the turbine and is condensed with cold sea water. The principal disadvantage ofopen-cycle OTEC is the low system operating pressures, which necessitate large components to accommodate the high volumetric flow rates of steam.

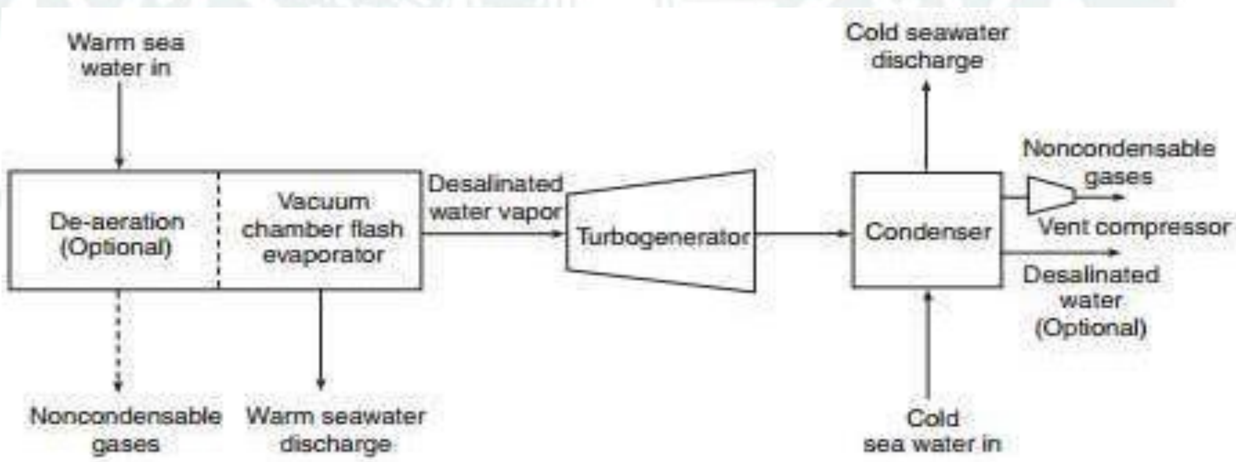


Figure 3. Schematic diagram of an open-cycle OTEC system

3. **Hybrid OTEC Cycle**

- A hybrid cycle combines the features of both the closed-cycle and open-cycle systems.
- In a hybrid OTEC system, warm seawater enters a vacuum chamber where it is flash-evaporated into steam, which is similar to the open-cycle evaporation process.
- The steam vaporizes the working fluid of a closed-cycle loop on the other side of an ammonia vaporizer.
- The vaporized fluid then drives a turbine that produces electricity. The steam condenses within the heat exchanger and provides desalinated water.

APPLICATIONS

- Ocean thermal energy conversion (OTEC) systems have many applications.
- OTEC can be used to generate electricity, desalinate water and provide refrigeration and air-conditioning.

1. **Electricity Production**
   - Two basic OTEC system designs have been demonstrated to generate electricity: closed cycle and open cycle.
   - The details are discussed in the above slide.
2. **Desalinated Water**
   - Desalinated water can be produced in open- or hybrid-cycle plants using surface condensers.
   - By this system around 1% of raw seawater quantity is to be distilled to pure fresh water.
   - In a hybrid system, desalinated water is produced by vacuum flash distillation and power is produced by a closed cycle loop.
   - The obtainable distilled water capacity is approx. 10,000 m3 /day with 1MW OTEC.
3. **Refrigeration and Air-Conditioning**
   - The cold 5°C seawater made available by an OTEC system creates an opportunity to provide large amounts of cooling to operations that are related to or close to the plant.
   - The low-cost refrigeration provided by the cold seawater can be used to upgrade or maintain the quality of fish.
   - The cold seawater delivered to an OTEC plant can be used in chilled-water coils to provide airconditioning for buildings.
   - In the tropical area there is a need for cooling AC for office, hotel, etc. For that purpose OTEC is useful .

ADVANTAGES

- Helps in producing fuels such as hydrogen, ammonia, and methanol .
- Produces base load electrical energy .
- Produces desalinated water for industrial, agricultural, and residential uses .
- Is a resource for on-shore and near-shore Mari culture operations .
- Provides air-conditioning for buildings .
- Provides moderate-temperature refrigeration .
- Has significant potential to provide clean, cost-effective electricity for the future.
- Food Aquaculture products can be cultivated in discharge water.
- Eco- friendly .
- Minimal maintenance costs compared to other power production plants.

OTEC helps in mining .Specially beneficial for small islands as they can become self-sufficient

DISADVANTAGES

- OTEC produced electricity at present would cost more than electricity generated from fossils fuels at their current costs.
- No energy company put money in this project because it only had been tested in a very small scale.
- Construction of OTEC plants and lying of pipes in coastal waters may cause localized damage to reefs and near-shore marine ecosystem.
- OTEC plant construction and operation may affect commercial and recreational fishing.

CONCLUSION

- Ocean thermal energy conversion is a potential source of renewable energy that creates no emissions i.e. it is fuel free.
- It has a low environmental impact, can supply pure water for both drinking and agriculture purposes.
- Can supply refrigeration and cooling and can provide a coastal community with reliable energy.
- Amount of solar energy absorbed by oceans is 4000 times presently consumed by humans. We would need less than 1% of that renewable energy to satisfy our desires.

GEOTHERMAL ENERGY

WHAT IS GEOTHERMAL ENERGY

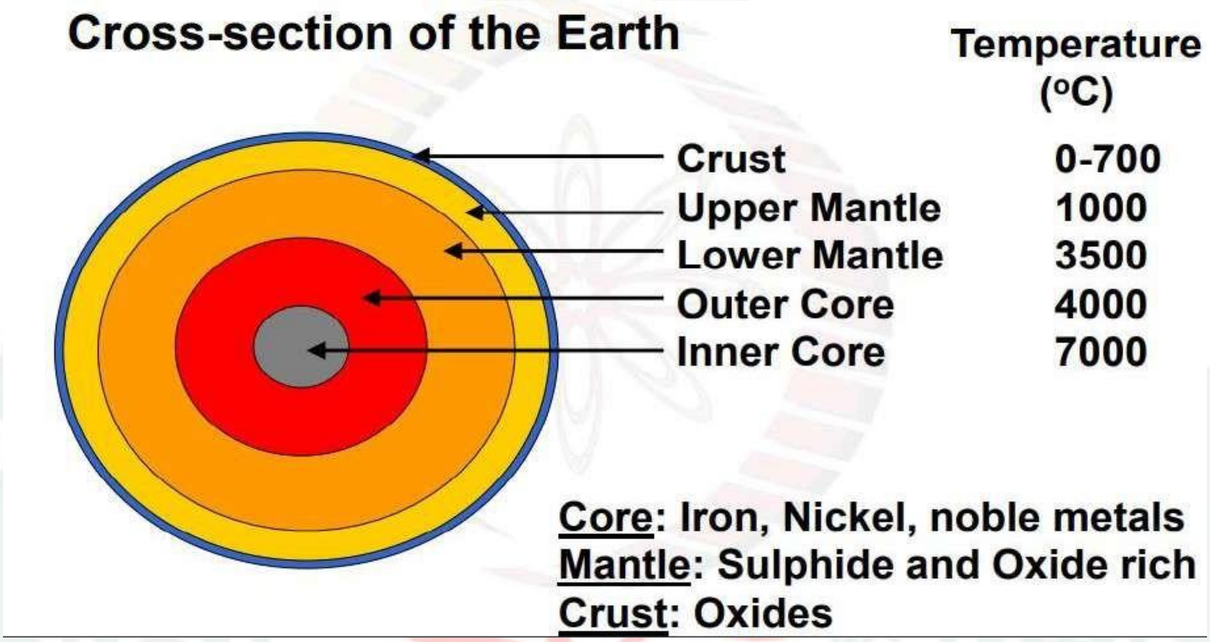
- The word Geothermal comes from the Greek word geo means (Earth) and thermal means (heat).
- It's simply the heat energy of the earth, generated by various natural processes, such as:
    1. heat from when the planet formed and accreted, which has not yet been lost.
    2. Decay of radioactive elements.
    3. Friction etc……
- The Geothermal energy is enormous and last for several millions of years. Hence it is called renewable energy. There is the large amount of heat lying in earth's interior in the form of Volcanoes, geysers and hot springs. This thermal energy contained in the interior of the earth is called geothermal energy.

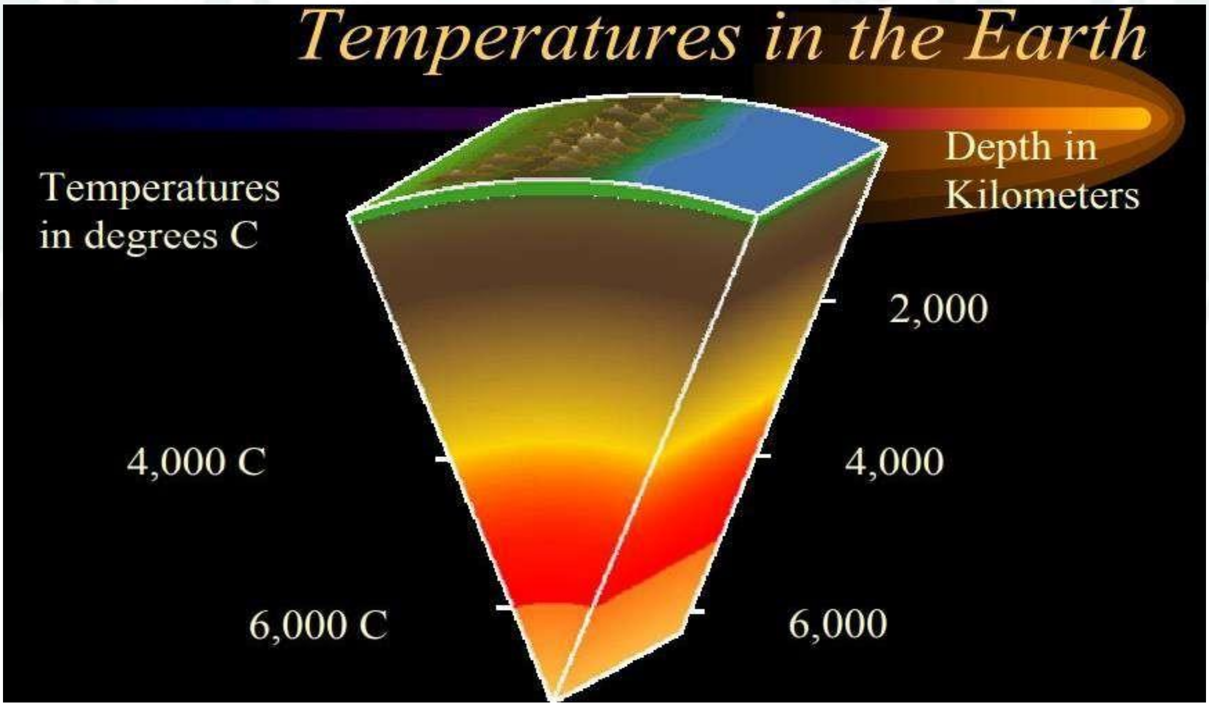
WHERE DOES IT COME FROM???

Geothermal energy is generated in the earth's core, about 4,000 miles below the surface. Temperatures hotter than the sun's surface are continuously produced inside the earth by the slow decay of radioactive particles, a process that happens in all rocks. The earth has a number of different layers:

- The core itself has two layers: a solid iron core and an outer core made of very hot melted rock, called **magma**.
- The mantle which surrounds the core and is about 1,800 miles thick. It is made up of magma and rock.
- The crust is the outermost layer of the earth, the land that forms the continents and ocean floors. It can be three to five miles thick under the oceans and 15 to 35 miles thick on the continents.

The earth's crust is broken into pieces called **plates**. Magma comes close to the earth's surface near the edges of these plates. This is where volcanoes occur. The lava that erupts from volcanoes is partly magma. Deep underground, the rocks and water absorb the heat from this magma. The temperature of the rocks and water get hotter and hotter as you go deeper underground.





WHERE IS GEOTHERMAL ENERGY FOUND?

Most geothermal reservoirs are deep underground with no visible clues showing above ground.

- **Hydrothermal source:-**
  - Vapour dominated or dry steam fields
  - Liquid dominated system
  - Hot-water fields

  It contains superheated water, steam or both in fractures or porous rock but further trapped by a layer of impermeable rock. It may give dry and pure steam with the temperature above 240C.The majority of these resources have moderate temperature ranging from 100C to 180C while few resources have moderate temperature ranging from 150C to 200C.

- **Geopressured reservoirs:-**
  It is hot water trapped underground at the depth of about 4km to 9.1km with temperature about 150C stored under pressure of about 1000 bar from the weight of overlying rock. It is used for heat and natural gas having great heat potential for power generation but uneconomical.

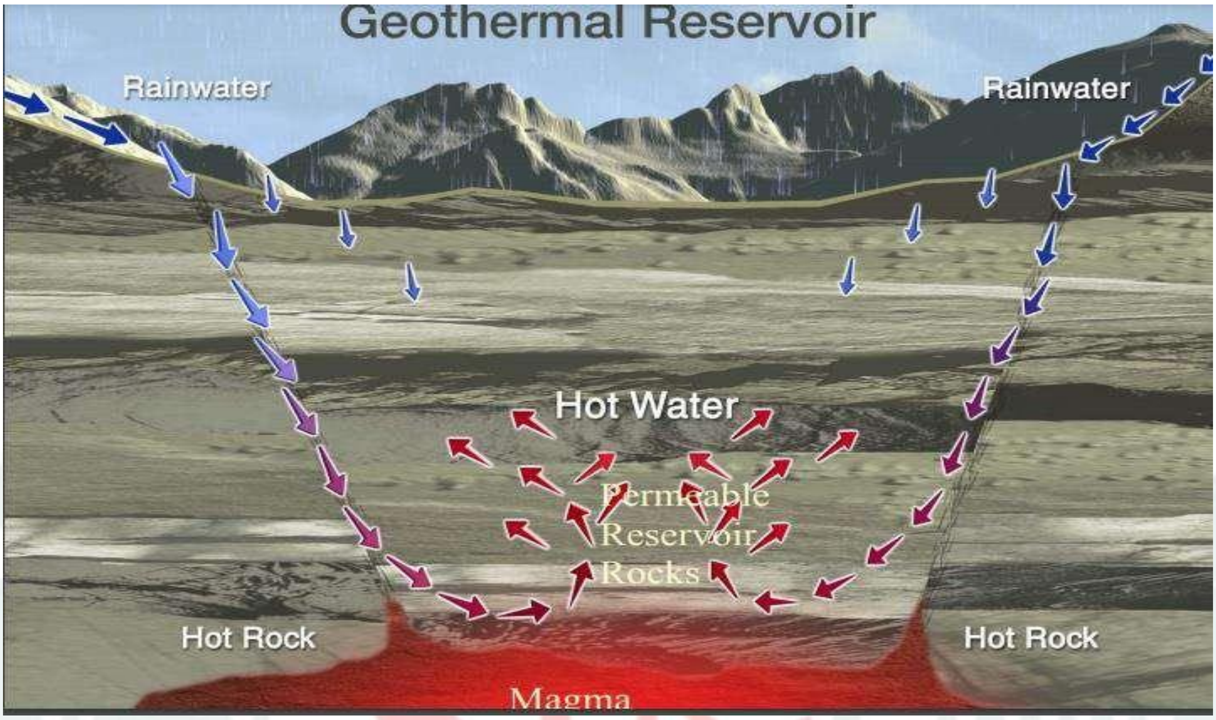
- **Hot dry rock or Petrothermal:-**
  It consist of high temperature rocks ranging from 90C to 650C.The rocks can be fractured and water may be circulated through the rocks to extract thermal energy.

- **Magma Resources:-**
  The molten rock or magma present in the volcanic vents at a temperature ranging from 700C to 1600C.

- **Volcanoes and fumaroles:-**
  (Holes where volcanic gases are released)

- **Hot springs and geysers:-**
  The most active geothermal resources are usually found along major plate boundaries where earthquakes and volcanoes are concentrated.

Most of the geothermal activity in the world occurs in an area called the **Ring of Fire**. This area rims the Pacific Ocean.



Main Components of a Geothermal Power Plant

- Production Well
- Separator
- Heat Exchanger
- Steam Turbine
- Condenser
- Generator
- Injection Well

Production Well

- Source of steam
- Depth 3 km to 10 km
- Similar to production well of an oil rig
- Wells may be located as far as 10 km to 14 km from power plant
- Steam can be moist or dry, Moist steam passes through separator
- Water or brine is re-injected through injection well

Separator

- Steam contains non condensable gases including Hydrogen sulphide
- Separator are used for the purpose to remove these gases
- 2 phase and 3 phase separators are used according to requirement
- Separators are vertically horizontally designed

Steam Turbine

- Specially designed steam turbine are used for geothermal power plants
- Steam can be corrosive due to many non condensable gases e.g. Hydrogen sulphide
- To protect rotor blades and nozzles from corrosion special coatings and materials are used
- The generation and transmission side of geothermal power plants is similar to conventional power plants

Condenser

- Steam condensed at a vacuum at the turbine exit
- Most plants use direct contact condensers that uses water itself as the cooling media.

Generator

- It uses to produce electricity. The steam comes from reservoirs of hot water found a few miles or more below the earth's surface. The steam rotates a turbine that activates a generator, which produces electricity.

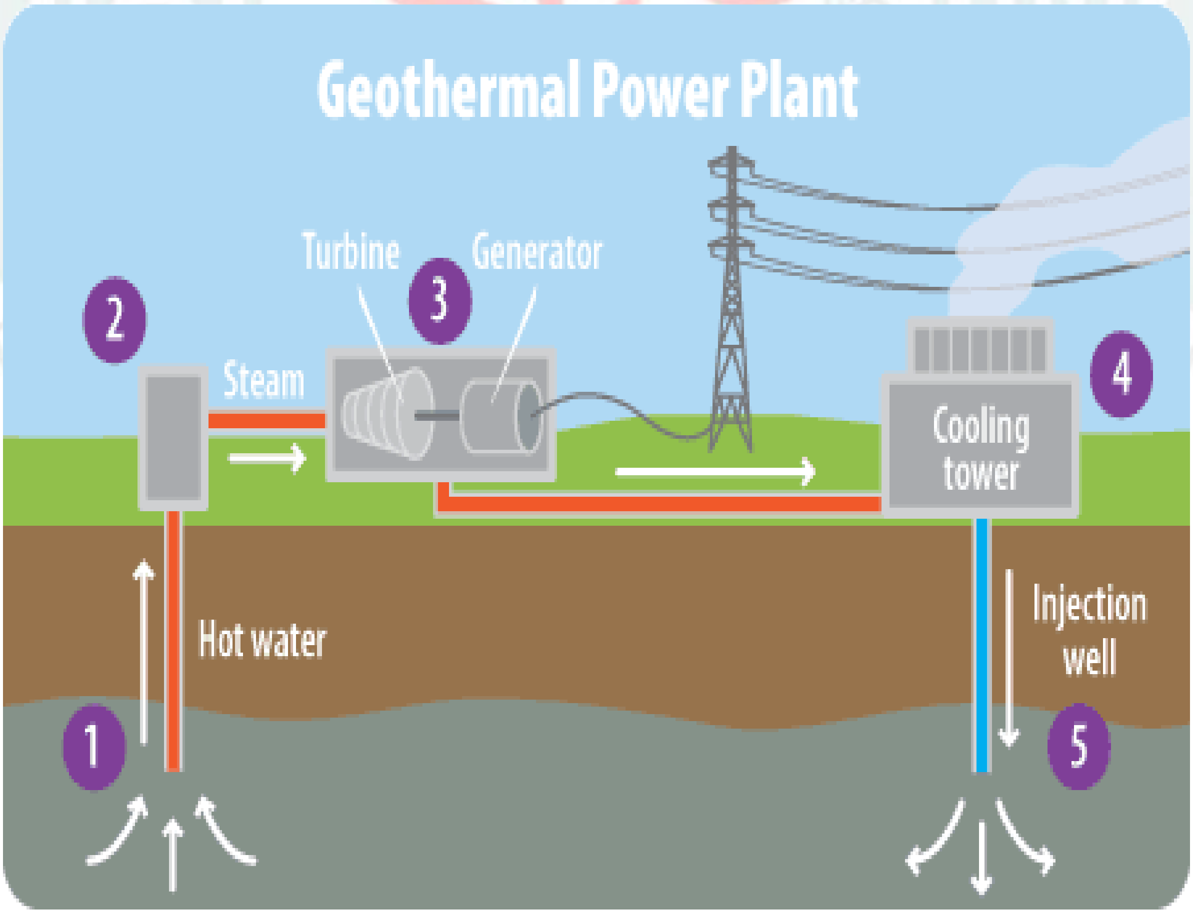
Injection Well

- The excess condensate and the brine from the separator returns back to the underground thermal reservoir,
- Reinjection wells are located in appropriate places
- Some reservoirs can give outputs for years without reinjection

Working of a Geothermal Power Plant

- Large holes have to be dug into the earth until a geothermal hotspot is found. Pipes are inserted inside these holes through which water is sent and steam output is obtained.

- The production involves two process
  1) Converting geothermal energy into Mechanical energy
  2) Converting Mechanical Energy into Electrical Energy
- The success of the energy production depends on the temperature of the plant which depends on the temperature of the rocks in earth.
- The water is sent through the injection well and reaches the rocks and then hot water comes from the production well.
- Due to the high pressure when it reaches the topmost of the earth surface it is converted into steam.
- The separator is the place where steam that comes from the earth is made clean by removing the brine and dirt so that they do not damage the turbine blades.
- The high pressure and low pressure steam runs the turbine.
- The generator is coupled with turbine to produce electricity.
- The condenser is a phase changer where the steam output of the turbine is given to the condenser and gets converted to hot water.
- This hot water is then sent to the cooling tower where it loses it heat and then sent to the geothermal reservoir for further production of steam.



POWER PLANTS

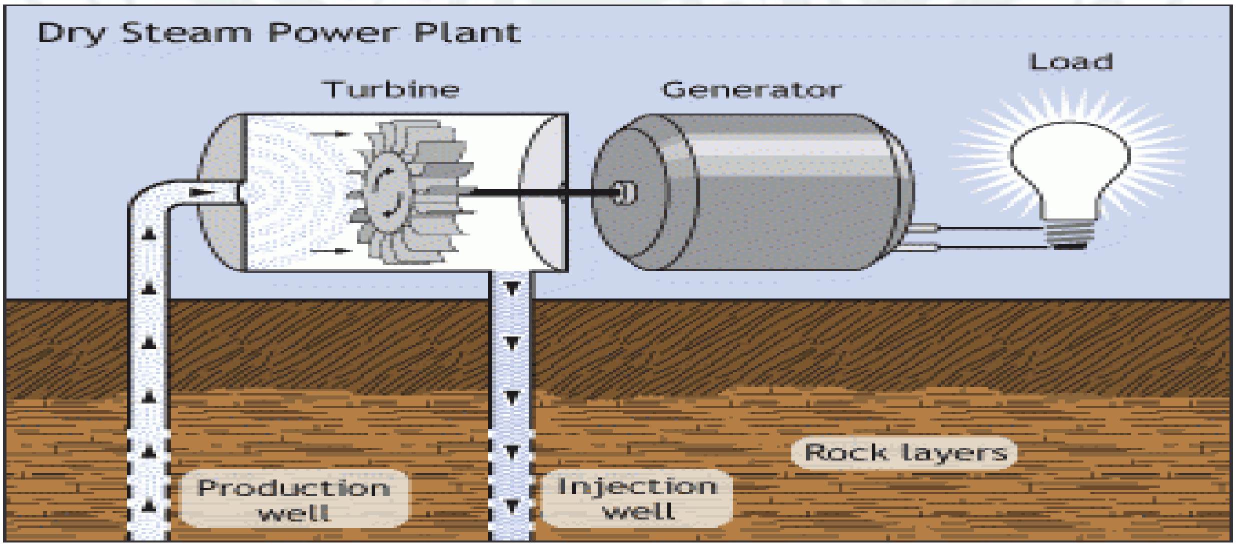
Power plants use steam produced from geothermal reservoirs to generate electricity. There are three geothermal power plant technologies being used to convert hydrothermal fluids to electricity—dry steam, flash steam and binary cycle. The type of conversion used (selected in development) depends on the state of the fluid (steam or water) and its temperature.

Types of a Geothermal Power Plant

- Dry steam plant
- Flashed steam plant
- Binary power plant
- Hybrid power plant

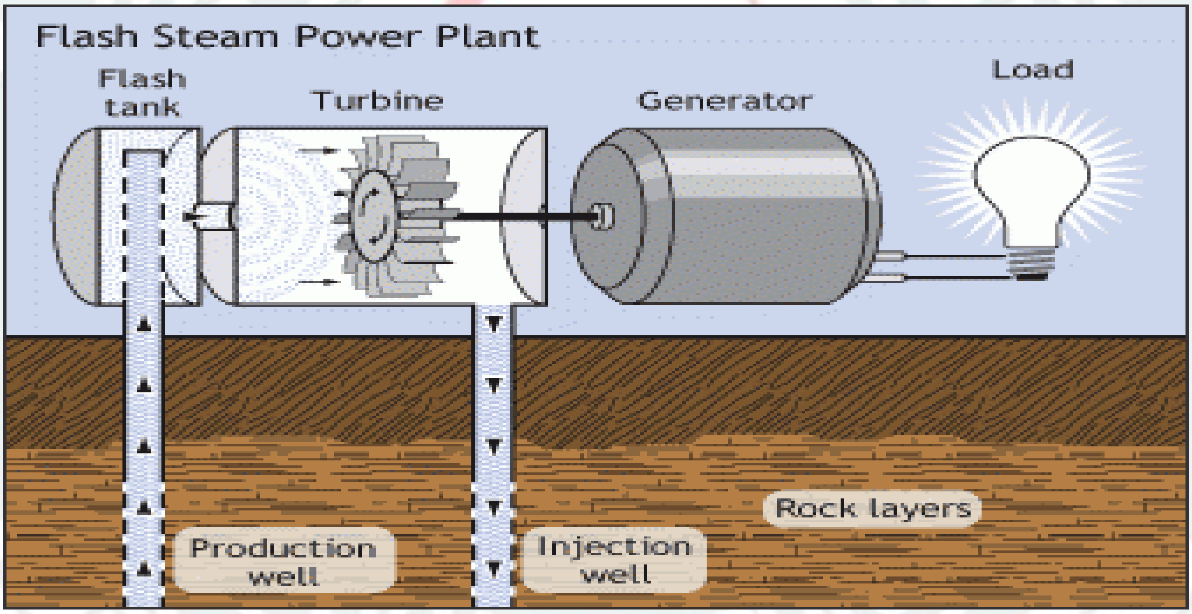
Dry steam plant:-

- A power plant where steam is released from the pressure of a deep reservoir, through a rock catcher, and then past the power generator turbines.
- "Dry" steam extracted from natural reservoir
- Steam is used to drive a turbo-generator
- Steam is condensed and pumped back into the ground
- Can achieve 1 kWh per 6.5 kg of steam (A 55 MW plant requires 100 kg/s of steam)
- Dry steam power plants systems were the first type of geothermal power generation plants built (they were first used at Lardarello in Italy in 1904).



Flashed steam plant:-

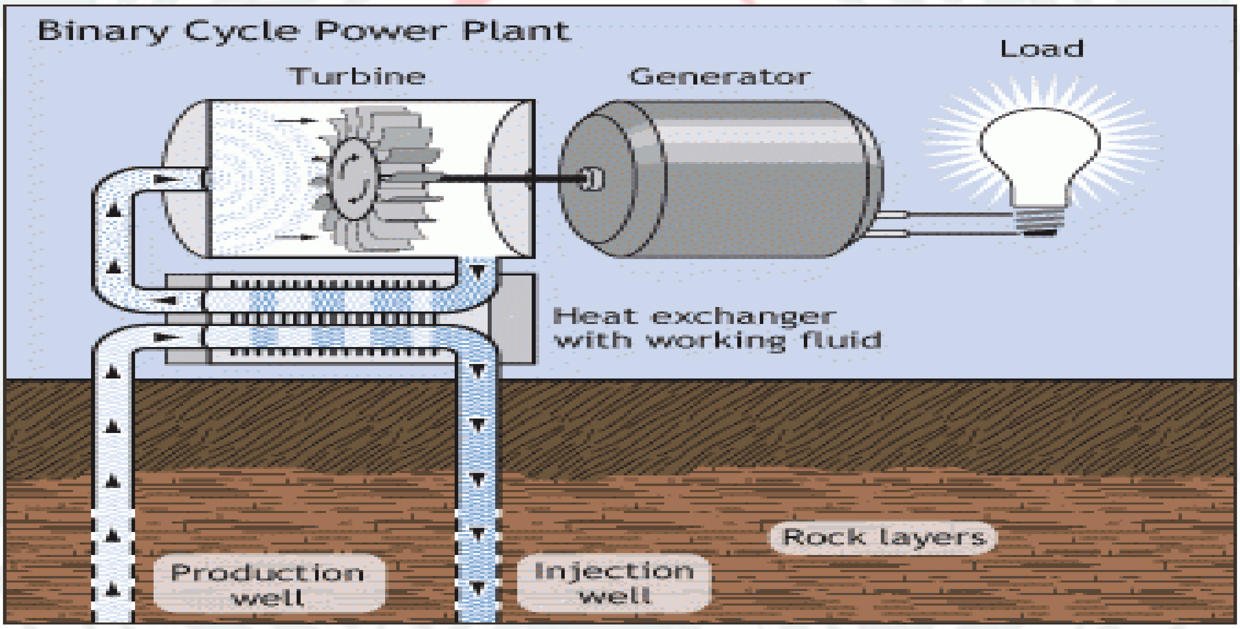
- A power plant where water is pumped under great pressure to the surface. When it surfaces, the pressure is reduced and as a result some of the water changes to steam. This creates a blast of steam. The water is then returned to the earth to be heated up by geothermal rocks again.
- Steam with water extracted from ground
- Pressure of mixture drops at surface and more water "flashes" to steam
- Steam separated from water
- Steam drives a turbine
- Turbine drives an electric generator
- Generate between 5 and 100 MW
- Use 6 to 9 tons of steam per hour



Binary power plant:-

- A power plant where warm geothermal water is pumped to the surface and passed through a heat exchanger that contains a special fluid that boils the water. The heat from the water makes this secondary fluid flash into vapour. The newly created vapour spins the turbines, while the cooled steam is injected back into the earth.
- Low temps – 100o and 150oC
- Use heat to vaporize organic liquid – E.g., iso-butane, iso-pentane

- Use vapour to drive turbine
  – Causes vapour to condense
  – Recycle continuously
- Typically 7 to 12 % efficient
- 40 MW units common
- It is basically a Rankine cycle with organic working fluid. To transfer a fraction of the brine enthalpy to vaporize the secondary working fluid. These plants are usually applied to low or medium enthalpy geothermal fields where the resource fluid is used, via heat exchanger, to heat a process fluid in a closed loop having boiling and condensation points that match the geothermal resource temperature. Binary plants range in size from less than 1MW to 50MW



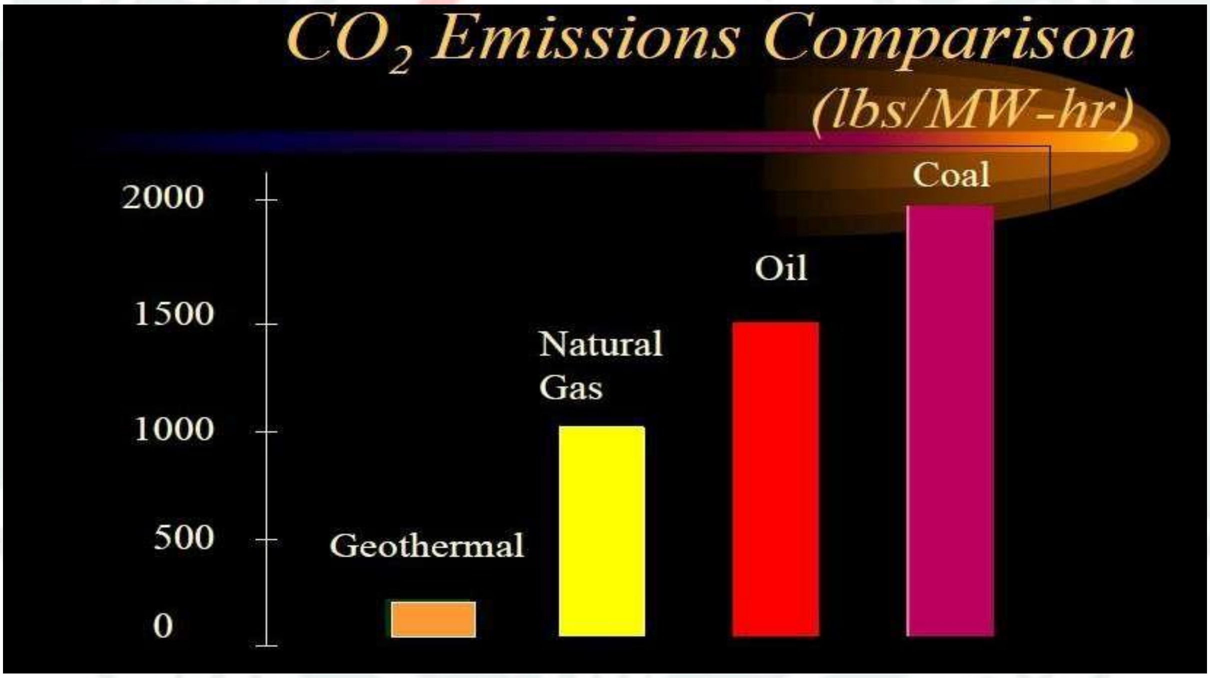
Hybrid power plant:-

- This type of power plants use combined cycle which adds a traditional Rankine cycle to produce electricity from what otherwise would become waste heat from a binary cycle. Using two cycle provides relatively high electric efficiency. The same basics are used by the Hybrid geothermal power plant as a standalone geothermal power plant but combine a different heat source into the process
- This type of plant, which uses a combination of flash and binary technology, has been used effectively to take advantage of the benefits

of both technologies. In this type of plant, the portion of the geothermal water which “flashes” to steam under reduced pressure is first converted to electricity with a back pressure steam turbine and the low-pressure steam exiting the backpressure turbine is condensed in a binary system.

Advantages

- It is versatile in its use and reliable source of energy.
- It delivers a greater amount of net energy from its system.
- Require little land area.
- Its availability is independent of weather.
- No extra storage systems are necessary.
- It leads a minimum pollution.



Disadvantages

- Drilling operation is noisy.
- Continuous extraction of heated ground water may lead to subsidence of land.
- Geothermal fluid reduces the life of plants.
- Overall efficiency is low about 15 percent comparing fossil fuel.

USES OF GEOTHERMAL ENERGY

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

1) **Direct Use and District Heating Systems**
   - Provides heat to industrial processes.
   - Raising plants in greenhouses, drying crops.
   - Provide heat for buildings.
   - Heating water at fish farms.

2) **Electricity generation**

   In a power plant requires water or steam at very high temperature (300 to 700 degrees Fahrenheit). Geothermal power plants are generally built where geothermal reservoirs are located within a mile or two of the surface.

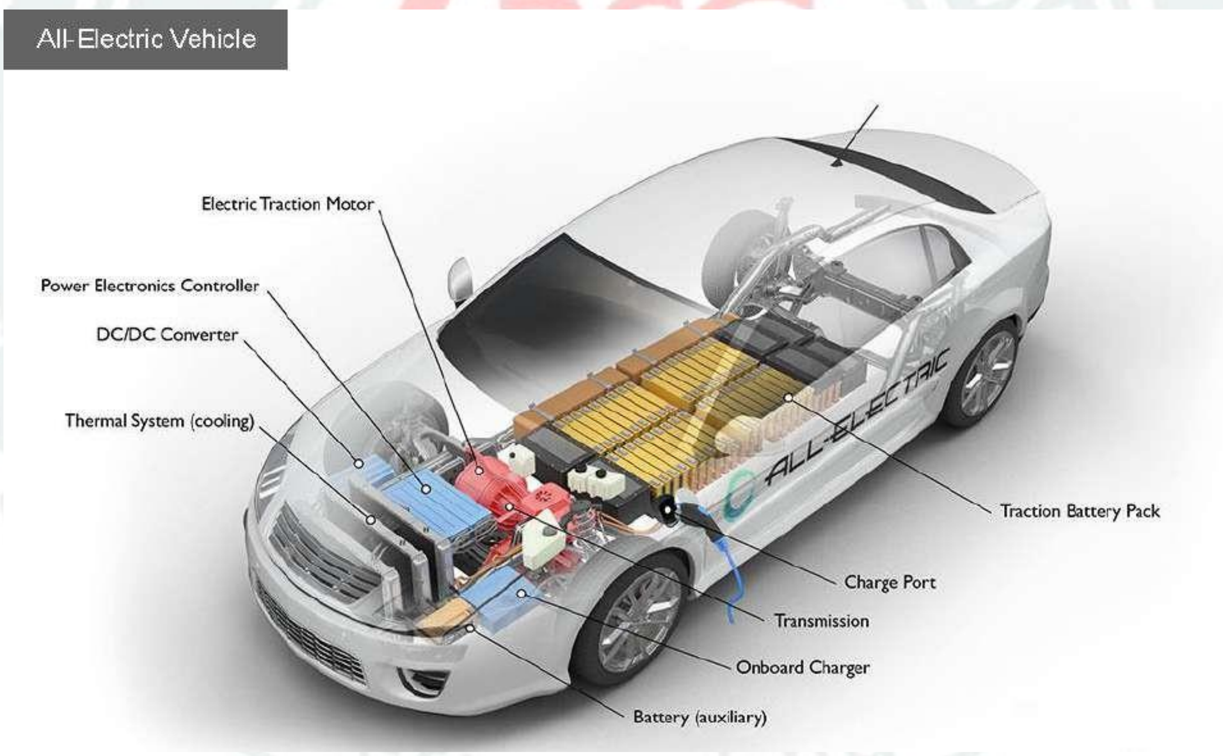
3) **Geothermal heat pumps**

   Use stable ground or water temperatures near the earth's surface to control building temperatures above ground.

Electric Vehicle

An **electric vehicle** (**EV**) is a vehicle that uses one or more electric motors or traction motors for propulsion. An electric vehicle may be powered through a collector system by electricity from off-vehicle sources, or may be self-contained with a battery, solar panels, fuel cells or an electric generator to convert fuel to electricity.

All-electric vehicles (EVs), also referred to as battery electric vehicles, have an electric motor instead of an internal combustion engine. The vehicle uses a large traction battery pack to power the electric motor and must be plugged in to a wall outlet or charging equipment, also called electric vehicle supply equipment (EVSE). Because it runs on electricity, the vehicle emits no exhaust from a tailpipe and does not contain the typical liquid fuel components, such as a fuel pump, fuel line, or fuel tank.



How does the electric car engine work?

Electric cars function by plugging into a charge point and taking electricity from the grid. They store the electricity in rechargeable batteries that power an electric motor, which turns the wheels. Electric cars accelerate faster than vehicles with traditional fuel engines – so they feel lighter to drive.

Key Components of an All-Electric Car

1. **Battery (all-electric auxiliary):** In an electric drive vehicle, the auxiliary battery provides electricity to power vehicle accessories.

2. **Charge port:** The charge port allows the vehicle to connect to an external power supply in order to charge the traction battery pack.

3. **DC/DC converter:** This device converts higher-voltage DC power from the traction battery pack to the lower-voltage DC power needed to run vehicle accessories and recharge the auxiliary battery.

4. **Electric traction motor:** Using power from the traction battery pack, this motor drives the vehicle's wheels. Some vehicles use motor generators that perform both the drive and regeneration functions.

5. **Onboard charger:** Takes the incoming AC electricity supplied via the charge port and converts it to DC power for charging the traction battery. It also communicates with the charging equipment and monitors battery characteristics such as voltage, current, temperature, and state of charge while charging the pack.

6. **Power electronics controller:** This unit manages the flow of electrical energy delivered by the traction battery, controlling the speed of the electric traction motor and the torque it produces.

7. **Thermal system (cooling):** This system maintains a proper operating temperature range of the engine, electric motor, power electronics, and other components.

8. **Traction battery pack:** Stores electricity for use by the electric traction motor.

9. **Transmission (electric):** The transmission transfers mechanical power from the electric traction motor to drive the wheels.

EV batteries - capacity and kWh explained

Kilowatts (kW) is a unit of power (how much energy a device needs to work). A kilowatt-hour(kWh) is a unit of energy (it shows how much energy has been used), e.g. a **100 watt**

lightbulb uses 0.1 kilowatts each hour. An average home consumes 3,100 kWh of energy a year. An electric car consumes an average of 2,000 kWh of energy a year.

When braking in a traditional car, the kinetic energy caused usually goes to waste. However, in an electric car braking converts and stores thermal energy from brake pads and tyres heat friction and reuses it to power the car. This is called **regenerative braking** and it's pretty clever!

How to charge an EV?

You can charge an electric vehicle either by plugging it into a socket or by plugging into a charging unit. There are plenty of charging stations around the world to stay fully charged while you're out and about. There are three types of chargers:

Three-pin plug - a standard three-pin plug that you can connect to any 13 amp socket.

Socketed - a charge point where you can connect either a Type 1 or Type 2 cable.

Tethered - a charge point with a cable attached with either a Type 1 or Type 2 connector.

How long does it take to charge an electric car?

There are also three EV charging speeds:

Slow - typically rated up to 3kW. Often used to charge overnight or at the workplace. Charging time: 8-10 hours.

Fast - typically rated at either 7Kw or 22kW. Tend to be installed in car parks, supermarkets, leisure centres and houses with off-street parking. Charging time: 3-4 hours.

Rapid - typically rated from 43 kW. Only compatible with EVs that have rapid charging capability. Charging time: 30-60 minutes.

What types of electric cars are there?

Plug-in electric - This means the car runs purely on electricity and gets all its power when it's plugged in to charge. This type doesn't need petrol or diesel to run so doesn't produce any emissions like traditional cars.

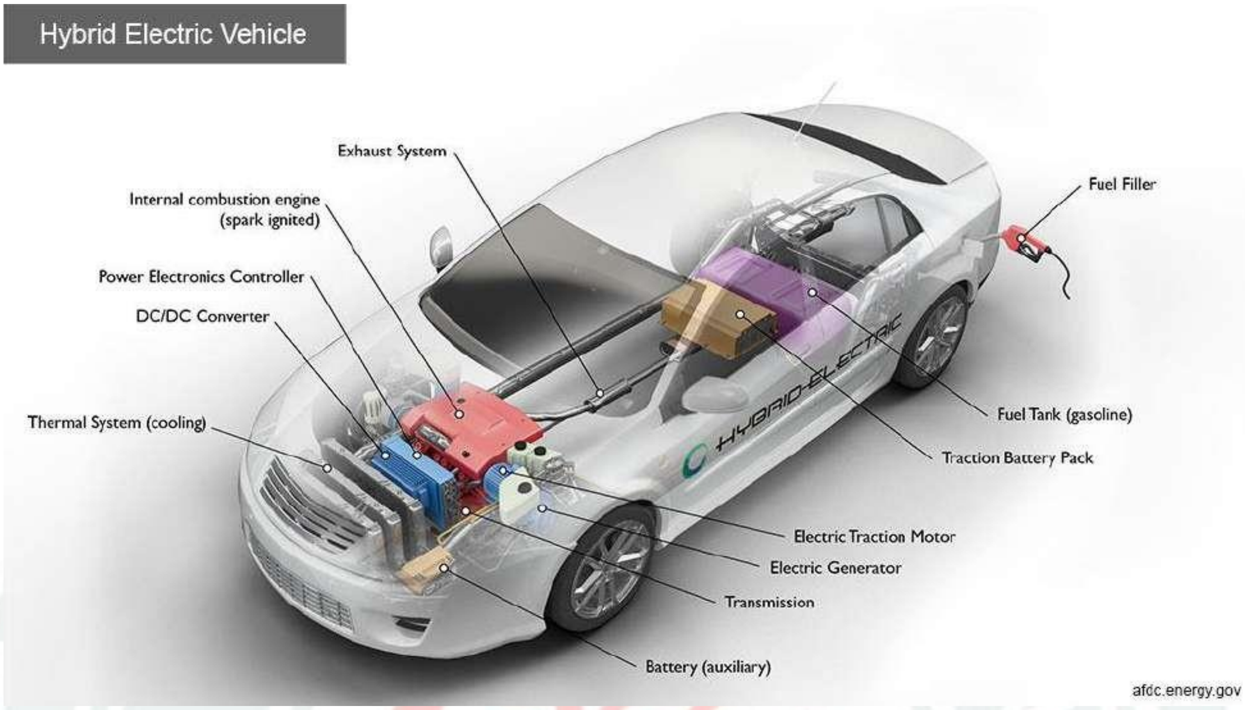
Plug-in hybrid - These cars mainly run on electricity but also have a traditional fuel engine so you can use petrol or diesel too if they run out of charge. When running on fuel, these cars will produce emissions but when they're running on electricity, they won't. Plug-in hybrids can be plugged into an electricity source to recharge their battery.

Hybrid-electric - These run mainly on fuel like petrol or diesel but also have an electric battery too, which is recharged through regenerative braking. These let you switch between using your fuel engine and using 'EV' mode at the touch of a button. These cars cannot be plugged into an electricity source and rely on petrol or diesel for energy.

Hybrid Electric Cars

A **hybrid electric vehicle** (**HEV**) is a type of hybrid vehicle that combines a conventional internal combustion engine (ICE) system with an electric propulsion system (hybrid vehicle drivetrain). The presence of the electric powertrain is intended to achieve either better fuel economy than a conventional vehicle or better performance. There is a variety of HEV types and the degree to which each function as an electric vehicle (EV) also varies. The most common form of HEV is the hybrid electric car, although hybrid electric trucks (pickups and tractors), buses, boats and aircraft also exist.

Modern HEVs make use of efficiency-improving technologies such as regenerative brakes which convert the vehicle's kinetic energy to electric energy, which is stored in a battery or super capacitor. Some varieties of HEV use an internal combustion engine to turn an electrical generator, which either recharges the vehicle's batteries or directly powers its electric drive motors; this combination is known as a motor–generator. Many HEVs reduce idle emissions by shutting down the engine at idle and restarting it when needed; this is known as a start-stop system. A hybrid-electric produces fewer tailpipe emissions than a comparably sized gasoline car since the hybrid's gasoline engine is usually smaller than that of a gasoline-powered vehicle. If the engine is not used to drive the car directly, it can be geared to run at maximum efficiency, further improving fuel economy.



How Do Hybrid Electric Cars Work?

Hybrid electric vehicles are powered by an internal combustion engine and an electric motor, which uses energy stored in batteries. A hybrid electric vehicle cannot be plugged in to charge the battery. Instead, the battery is charged through regenerative braking and by the internal combustion engine. The extra power provided by the electric motor can potentially allow for a smaller engine. The battery can also power auxiliary loads and reduce engine idling when stopped. Together, these features result in better fuel economy without sacrificing performance.

Key Components of a Hybrid Electric Car

1. **Battery (auxiliary):** In an electric drive vehicle, the auxiliary battery provides electricity to start the car before the traction battery is engaged and also powers vehicle accessories.

2. **DC/DC converter:** This device converts higher-voltage DC power from the traction battery pack to the lower-voltage DC power needed to run vehicle accessories and recharge the auxiliary battery.

3. **Electric generator:** Generates electricity from the rotating wheels while braking, transferring that energy back to the traction battery pack. Some vehicles use motor generators that perform both the drive and regeneration functions.

4. **Electric traction motor:** Using power from the traction battery pack, this motor drives the vehicle's wheels. Some vehicles use motor generators that perform both the drive and regeneration functions.

5. **Exhaust system:** The exhaust system channels the exhaust gases from the engine out through the tailpipe. A three-way catalyst is designed to reduce engine-out emissions within the exhaust system.

6. **Fuel filler:** A nozzle from a fuel dispenser attaches to the receptacle on the vehicle to fill the tank.

7. **Fuel tank (gasoline):** This tank stores gasoline on board the vehicle until it's needed by the engine.

8. **Internal combustion engine (spark-ignited):** In this configuration, fuel is injected into either the intake manifold or the combustion chamber, where it is combined with air, and the air/fuel mixture is ignited by the spark from a spark plug.

9. **Power electronics controller:** This unit manages the flow of electrical energy delivered by the traction battery, controlling the speed of the electric traction motor and the torque it produces.

10. **Thermal system (cooling):** This system maintains a proper operating temperature range of the engine, electric motor, power electronics, and other components.

11. **Traction battery pack:** Stores electricity for use by the electric traction motor.

12. **Transmission:** The transmission transfers mechanical power from the engine and/or electric traction motor to drive the wheels.

Types by degree of hybridization

1. **Full hybrid,** sometimes also called a strong hybrid, is a vehicle that can run only on a combustion engine, only on an electric motor, or a combination of both Ford's

hybrid system, Toyota's Hybrid Synergy Drive and General Motors/Chrysler's Two-Mode Hybrid technologies are full hybrid systems. The Toyota Prius, Ford Escape Hybrid, and Ford Fusion Hybrid are examples of full hybrids, as these cars can be moved forward on battery power alone. A large, high-capacity battery pack is needed for battery-only operation. These vehicles have a split power path allowing greater flexibility in the drivetrain by interconverting mechanical and electrical power, at some cost in complexity.

2. **Mild hybrid,** is a vehicle that cannot be driven solely on its electric motor, because the electric motor does not have enough power to propel the vehicle on its own. Mild hybrids include only some of the features found in hybrid technology, and usually achieve limited fuel consumption savings, up to 15 percent in urban driving and 8 to 10 percent overall cycle. A mild hybrid is essentially a conventional vehicle with oversize starter motor, allowing the engine to be turned off whenever the car is coasting, braking, or stopped, yet restart quickly and cleanly. The motor is often mounted between the engine and transmission, taking the place of the torque converter, and is used to supply additional propulsion energy when accelerating. Accessories can continue to run on electrical power while the gasoline engine is off, and as in other hybrid designs, the motor is used for regenerative braking to recapture energy. As compared to full hybrids, mild hybrids have smaller batteries and a smaller, weaker motor/generator, which allows manufacturers to reduce cost and weight.

Hybrid energy systems

Hybrid energy systems are combinations of two or more energy conversion devices (e.g., electricity generators or storage devices), or two or more fuels for the same device, that when integrated, overcome limitations that may be inherent in either.

For the purpose of comparison, it is useful to consider briefly the nature of conventional energy systems that are normally used where hybrid system might be used instead. There are basically three types of conventional systems of interest: (1) large utility networks, (2) isolated networks, and (3) small electrical load with dedicated generator.

Large utility networks consist of power plants, transmission lines, distribution lines and electrical consumers (loads). These networks are based on alternating current (AC) with constant frequency. Such networks are frequently assumed to have an infinite bus. This means that the voltage and frequency are unaffected by the presence of additional generators or loads.

Isolated electrical networks are found on many islands or other remote locations. They are similar in many ways to large networks, but they are normally supplied by one or more diesel generators. Generally, they do not have a transmission system distinct from the distribution system. Isolated networks do not behave as an infinite bus and may be affected by additional generators or loads.

For many small applications, it is common to supply an electrical load with a dedicated generator. This is the case, for example, at construction sites, highway signs, and vacation cabins. These systems are also normally AC but have no distribution system.

Applications for Hybrid Energy Systems

There are numerous possible applications for hybrid power systems. The most common examples are (1) remote AC network, (2) distributed generation applications in a conventional utility network, and (3) isolated or special purpose electrical loads.

The classic example of the hybrid energy system is the remote, diesel-powered AC network. The basic goal is to decrease the amount of fuel consumed by diesel generators and to decrease the number of hours that they operate. The first addition to ''hybridize'' the system is to add another type of generator, normally using a renewable source. These renewable generators are most commonly wind turbines or photovoltaic panels. Experience has shown, however, that simply adding another generator is not sufficient to produce the desired results. Accordingly, most hybrid systems also include one or more of the following: supervisory control system, short-term energy storage, and load management. Each of these will be described in more detail. An example of a typical hybrid energy system, in this case a wind/diesel system.

Characteristics of Hybrid Energy Systems

The characteristics and components of a hybrid system depend greatly on the application. The most important consideration is whether the system is isolated or connected to a central utility grid.

Central Grid Connected Hybrid Systems

If the hybrid system is connected to a central utility grid, as in a DG application, then the design is simplified to a certain degree and the number of components may be reduced.

This is because the voltage and frequency are set by the utility system and need not be controlled by the hybrid system. In addition, the grid normally provides the reactive power. When more energy is required than supplied by the hybrid system the deficit can be in general be provided by the utility. Similarly, any excess produced by the hybrid system can be absorbed by the utility. In some cases, the grid does not act as an infinite bus, however. It is then said to be ''weak.'' Additional components and control may need to be added. The grid connected hybrid system will then come to more closely resemble an isolated one.

Isolated Grid Hybrid Systems

Isolated grid hybrid systems differ in many ways from most of those connected to a central grid. First, they must be able to provide for all the energy that is required at any time on the grid or find a graceful way to shed load when they cannot. They must be able to set the grid frequency and control the voltage. The latter requirement implies that they must be able to provide reactive power as needed. Under certain conditions, renewable generators may produce energy in excess of what is needed. This energy must bedissipated in some way so as not to introduce instabilities into the system. There are basically two types of isolated grid hybrid systems which include a renewable energy generator among their components. These are known as low penetration or high penetration. In this context, ''penetration'' is defined as the instantaneous power from the renewable generator divided by the total electrical load being served. Low penetration, which is on the order of 20% or less, signifies that the impact of the renewable generator on the grid is minor, and little or no special equipment or control is required. High penetration, which is typically over 50% and may exceed 100%, signifies that the impact of the renewable generator on the grid is significant and special equipment or control is almost certainly required. High-penetration systems may incorporate supervisory control, so-called dump loads, shortterm storage, and load management systems.

Isolated or Special Purpose Hybrid Systems

Some hybrid systems are used for a dedicated purpose, without use of real distribution network. These special purposes could include water pumping, aerating, heating, desalination, or running grinders or other machinery. Design of these systems is usually such that system frequency and voltage control are not major issues, nor is excess power production. In those cases where energy may be required even when renewable source be temporarily unavailable, a more conventional generator may be provided. Renewable generators in small isolated systems typically do not run in parallel with a fossilfuel generator.

Technology used in Hybrid Energy Systems

Energy Consuming Devices

Hybrid energy systems typically use the same types of energy consuming devices that are found in conventional systems. These include lights, heaters, motors, and electronic devices. The combined energy requirement of all the devices is known as the total load, or just load. The load will typically vary significantly over the day and over the year. An example of a load varying over a year on an isolated island

Rotating Electrical Machinery

Rotating electrical machinery is found in many places in a hybrid energy system. Most such machines can function as either motors or generators, depending on the application. This section focuses on the generating function.

1. Induction Generators

2. Synchronous Generators

3. Renewable Energy Generators
   i) Wind Turbines
   ii) Photovoltaic Panels
   iii) Hydro Turbines
   iv) Biomass Fueled Generators
   v) Fuel Cells

4. Fossil Fuel Generators
   i) Diesel Engine/Generators
   ii) Gasoline Generators

5. Energy Storage
   i) Convertible Storage
   ii) End-Use Storage

6. Power Converters
   i) Electromechanical Power Converters
   ii) Electronic Power Converters
   iii) Maximum Power Point Trackers

7. Dump Loads

8. Dump Loads

Energy Loads

The energy supplied by a hybrid system can be categorized in a variety of ways. The first has to do whether the energy supplied is electricity or heat. Within the electrical category, electricity loads are often divided into primary and secondary loads. Primary loads are those that must be served immediately. Secondary loads are associated with load management.

Energy Resources Characteristics

Wind

The wind resource is ultimately generated by the sun, but it tends to be very dependent on location. Over most of the earth, the average wind speed varies from one season to another. It is also likely to be affected by general weather patterns and the time of day. It is not uncommon for a site to experience a number of days of relatively high winds and for those days to be followed by others of lower winds. The daily and monthly average wind speed for an island off the coast of Massachusetts, illustrating these variations, is illustrated in Fig. 10. The wind also exhibits shortterm variations in speed and direction. This is known as turbulence. Turbulent fluctuations take place over time periods of seconds to minutes.

Solar Radiation

The solar radiation resource is fundamentally determined by the location on the earth's surface, the date, and the time of day. Those factors will determine the maximum level of radiation. Other factors, such as height above sea level, water vapor or pollutants in the atmosphere, and cloud cover, decrease the radiation level below the maximum possible. Solar radiation does not experience the same type of turbulence that wind does, but there can be variations over the short term. Most often, these are related to the passage of clouds.

Hydropower

The hydropower resource at a site is a function of the amount of flowing water available (discharge) in a river or stream and the change in elevation (head). The head is usually relative constant (affected only by high water during storms), but the amount of water available can vary significantly over time. The average discharge is determined by rainfall and the drainage area upstream of the site on which the rain falls. Discharge will increase after storms and decrease during droughts. Soil conditions and nature of the terrain can also affect the discharge. Shortterm fluctuations are normally insignificant.

Biomass

Sources of biomass are forest or agricultural products. The resource is ultimately a function of such factors as solar radiation, rainfall, soil conditions, temperatures, and the plant species that can be grown.

Why We Need of Hybrid energy systems

Continuous power supply – The hybrid solar systems provide power continuously, without any interruption, as the batteries connected to them store the energy. So, when there is an electricity outage, the batteries work as inverter to provide you backup. This is also the case during the evening or night time when there is no sun and energy is not being generated; batteries provide the back-up and life goes on without any interruption.

Utilize the renewable sources in best way – Because the batteries are connected to the system to store the energy, there is no waste of the excess energy generated on bright sunny days. So, these systems make use of the renewable energy in best way, storing energy on a good day and utilize the stored power on a bad day. The balance is maintained.

Low maintenance cost – The maintenance cost of the hybrid solar energy systems is low as compared to the traditional generators which use diesel as fuel. No fuel is used and they do not require frequent servicing.

High efficiency – The hybrid solar energy systems work more efficiently than your traditional generators which waste the fuel under certain conditions. Hybrid solar systems work efficiently in all types of conditions without wasting the fuel.

Load management – Unlike traditional generators, which provide high power as soon as they turned on, most of hybrid solar power systems manage load accordingly. A hybrid solar system may have technology that adjusts the energy supply according to the devices they are connected towhether it's an air conditioner requiring high power or a fan which requires less.

Disadvantages

Complicated controlling process – With different types of energy sources in use, the systems require some knowledge. The operation of different energy sources, their interaction and co-ordination must be controlled and it can become complicated.

High installation cost – Although the maintenance cost is low, the initial investment for the installation of a hybrid solar energy systems is high as compared to a solar systems.

Less battery life – The batteries connected to the system may have a lower life as they are often exposed to natural elements like heat, rain, etc.

The number of instruments connectable is limited – The number of devices you can connect to a hybrid solar energy system is limited and vary from system to system.

Photovoltaic-Diesel Hybrid System

The PV-diesel hybrid system is the integration of photovoltaic system with diesel generator to supply the load. The purpose of this technology is providing electricity for 24 hours to the customers but reducing the operation hours of diesel generator in an optimal way. The systems consist of PV arrays, diesel generator, batteries and inverter. The basic operation is controlled by knowing the condition of load and battery.

The PV-Diesel hybrid system has to be completed with the control system with the capabilities to run the entire component in a certain conditions. The energy sources from photovoltaic arrays and diesel generator has to be optimum supplying the daily load energy.

The basic operation of photovoltaic hybrid system could be divided into 3 load conditions, which are low load, medium load and peak load.

Under low load conditions the diesel generator is off and the load energy supplied by the PV energy through the inverter. The diesel generator will operate at optimal loading to feed the load, and it will charge the battery if there is excess energy at medium load. At the peak load condition diesel generator running at optimal loading in parallel with inverter. Inverter is converting DC power from the battery into AC power.

What is a photovoltaic diesel hybrid system?

A "hybrid" is something that is formed by combining two kinds of components that produce the same or similar results. A photovoltaic diesel hybrid system ordinarily consists of a PV system, diesel gensets and intelligent management to ensure that the amount of solar energy fed into the system exactly matches the demand at that time. In contrast to conventional off-grid systems of up to 300 kW, in which a Sunny Island inverter serves as a master, the diesel gensets itself performs this function.

How does a photovoltaic diesel hybrid system work?

Basically, the PV system complements the diesel gensets. It can supply additional energy when loads are high or relieve the gensets to minimize its fuel consumption. In the future, excess energy could optionally be stored in batteries, making it possible for the hybrid system to use more solar power even at night. Intelligent management of various system components ensures optimal fuel economy and minimizes CO_2 emissions.

What are the components of this photovoltaic diesel hybrid system?

PV inverters

PV inverters are the central components of the Fuel Save Solution. Designed specifically to be used in weak utility grids, they are suitable for high voltage and frequency fluctuations. They also remain extremely productive in harsh ambient conditions such as heat, moisture, salty air, among others.

A centralized PV system contains only one string into a central point, where direct current is converted to alternating current. In a decentralized PV system, the PV power is divided into many strings, which are converted into alternating current by several inverters.

Fuel save Controller

Fuel Save Controller provides the perfect interface between the gensets, PV systems and loads, managing demand-based PV feed-in into the diesel-powered grid. As the central component of the Fuel Save Solution, it ensures maximum security with reduced fuel costs and minimizes CO2 emissions.

Diesel gensets

In grid-remote regions, pure diesel systems often provide the energy for industrial applications. They constitute the local grid, ensuring a constant power supply to all connected users. Because the gensets require a constant fuel supply, they are often the system's highest operating cost. In regions with weak utility grids, diesel gensets often serve as a backup during grid power outages.

Gensets system house

This includes the monitoring and control systems for the diesel gensets. The genset system house is the central terminal and point of common coupling.

Optional storage batteries

To boost the efficiency of the entire energy supply system, it is advisable to include a storage battery. When solar irradiation is insufficient or energy is needed after dark, the storage battery supplies the required energy, ensuring optimal hybrid system operation.

What are the advantages of a photovoltaic diesel hybrid system?

1) Lower fuel costs
2) Reduced risk of fuel price increases and supply shortages thanks to optimized planning
3) Minimal CO_2 emissions (protects the environment and facilitates CO_2 certificate trading)

PV Wind Hybrid Systems

It is type of hybrid energy system consist of 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.Solar Photovoltaic (PV) – Wind Turbine (WT) Hybrid System is the best way to utilize not just one local available RE resource but multiple renewable RE resources.

Specific site conditions

1. The PV-wind hybrid system suits to conditions where sun light and wind has seasonal shifts.
2. In summer the daytime is long and sun light is strong enough, while in winter the days are shorter and there are more clouds.

System Components

1. A photo-voltaic solar-cell array
2. A mast mounted wind generator
3. Lead-acid storage batteries
4. An inverter unit to convert DC power to AC power
5. Electrical lighting loads and electrical heating loads
6. Several fuse, junction boxes and associated wiring
7. Test instruments for measuring voltages, currents, power factors, and harmonic contamination data throughout the system.

Advantages

1. Best for Remote Area Power Systems (RAPS)
2. Two different energy sources provide a diversity of supply, reducing the risk of power outages. Can be used for 24-hrs power generation.
3. Operational in all weather.
4. Green Energy.

Disadvantages

1. Infrastructure cost may be high.
2. Too labor intensive.
3. Wind turbines can't operate in high or low wind speeds.
4. Not for Large scale production.

Micro hydel PV Hybrid System

Micro-Hydro power systems convert the potential energy in small streams and waterways into kinetic energy via a mechanical turbine, which drives a generator to produce electricity. The greater the drop and quantity of water there is flowing through the turbine, the more electricity can be generated.

Components

1. Micro Hydro Plant
2. Grid Network
3. Batteries
4. Energy Convertors
5. Voltage Controller
6. Power Invertors

Advantages

MHP is decentralized, renewable, robust, and simple technology.

It only takes a small amount of flow (as little as few litres per minute) or a drop as low as 1 m to generate electricity with micro hydro. Electricity can be delivered as far as 1 km away to the location where it is being used. If planned carefully and well adapted to the environmental conditions, micro hydropower schemes produce a continuous and predictable supply of electrical energy in comparison to other small-scale renewable technologies.

Disadvantages

1. It Has an Environmental Impact. Perhaps the largest disadvantage of hydroelectric energy is the impact it can have on the environment
2. There are Limited Reservoirs. ...
3. There are Droughts.
4. It's Not Always Safe.