UNIT III

BIO-MASS: Principles of bio-conversion, anaerobic/aerobic digestion, types of bio-gas digesters, gas yield, combustion characteristics of bio-gas, utilization for cooking, bio fuels, I.C. engine operation and economic aspects.
GEOTHERMAL ENERGY: Resources, types of wells, methods of harnessing the energy, potential in India.
OCEAN ENERGY: OTEC, Principles of utilization, setting of OTEC plants, thermodynamic cycles. Tidal and wave energy: Potential and conversion techniques, mini-hydel power plants, and their economics.

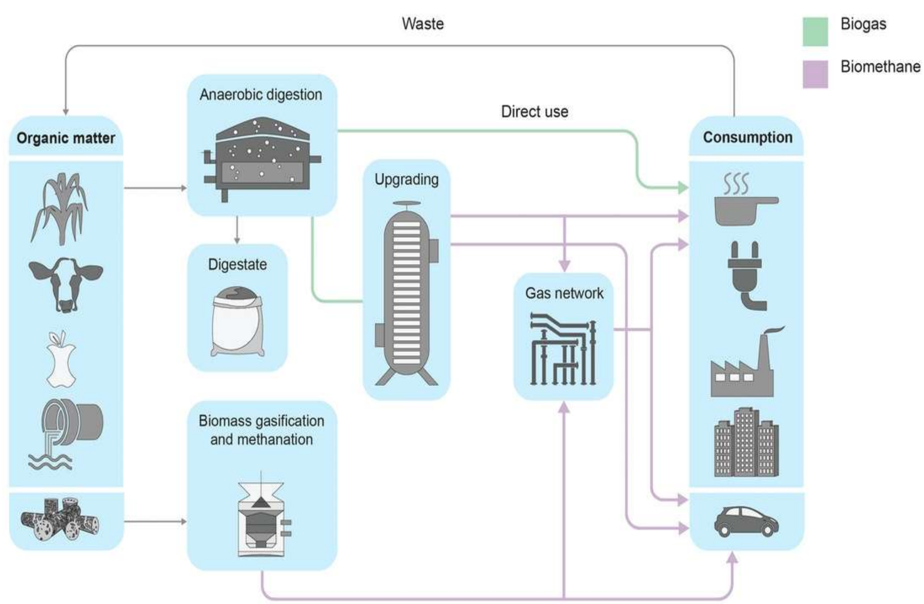
Biogas

Biogas is a mixture of methane, CO_2 and small quantities of other gases produced by anaerobic digestion of organic matter in an oxygen-free environment. The precise composition of biogas depends on the type of feedstock and the production pathway; these include the following main technologies:
Biodigesters: These are airtight systems (e.g. containers or tanks) in which organic material, diluted in water, is broken down by naturally occurring micro-organisms. Contaminants and moisture are usually removed prior to use of the biogas.
Landfill gas recovery systems: The decomposition of municipal solid waste (MSW) under anaerobic conditions at landfill sites produces biogas. This can be captured using pipes and extraction wells along with compressors to induce flow to a central collection point.
Wastewater treatment plants: These plants can be equipped to recover organic matter, solids, and nutrients such as nitrogen and phosphorus from sewage sludge. With further treatment, the sewage sludge can be used as an input to produce biogas in an anaerobic digester.
The methane content of biogas typically ranges from 45% to 75% by volume, with most of the remainder being CO_2. This variation means that the energy content of biogas can vary; the lower heating value (LHV) is between 16 megajoules per cubic metre (MJ/m^3) and 28 MJ/m^3. Biogas can be used directly to produce electricity and heat or as an energy source for cooking.
Biomethane (also known as “renewable natural gas”) is a near-pure source of methane produced either by “upgrading” biogas (a process that removes any CO_2 and other contaminants present in the biogas) or through the gasification of solid biomass followed by methanation:
Upgrading biogas: This accounts for around 90% of total biomethane produced worldwide today. Upgrading technologies make use of the different properties of the various gases contained within biogas to separate them, with water scrubbing and membrane separation accounting for almost 60% of biomethane production globally today (Cedigaz, 2019).
Thermal gasification of solid biomass followed by methanation: Woody biomass is first broken down at high temperature (between 700-800°C) and high pressure in a low-oxygen

environment. Under these conditions, the biomass is converted into a mixture of gases, mainly carbon monoxide, hydrogen and methane (sometimes collectively called syngas). To produce a pure stream of biomethane, this syngas is cleaned to remove any acidic and corrosive components. The methanation process then uses a catalyst to promote a reaction between the hydrogen and carbon monoxide or CO_2 to produce methane. Any remaining CO_2 or water is removed at the end of this process.
Biomethane has an LHV of around 36 MJ/m^3. It is indistinguishable from natural gas and so can be used without the need for any changes in transmission and distribution infrastructure or end-user equipment, and is fully compatible for use in natural gas vehicles.

What is biogas and biomethane?

There are multiple production pathways for biogas and biomethane



Note: Only biomethane is considered suitable for use in the transport sector.
A wide variety of feedstocks can be used to produce **biogas**. For this report, the different individual types of residue or waste were grouped into four broad feedstock categories: crop residues; animal manure; the organic fraction of MSW, including industrial waste; and wastewater sludge.

Crop residues: Residues from the harvest of wheat, maize, rice, other coarse grains, sugar beet, sugar cane, soybean and other oilseeds. This report included sequential crops, grown between two harvested crops as a soil management solution that helps to preserve the fertility of soil, retain soil carbon and avoid erosion; these do not compete for agricultural land with crops grown for food or feed.
Animal manure: From livestock including cattle, pigs, poultry and sheep.
Organic fraction of MSW: Food and green waste (e.g. leaves and grass), paper and cardboard and wood that is not otherwise utilised (e.g. for composting or recycling). MSW[1] also includes some industrial waste from the food-processing industry.
Wastewater sludge: Semi-solid organic matter recovered in the form of sewage gas from municipal wastewater treatment plants.
Specific energy crops, i.e. low-cost and low-maintenance crops grown solely for energy production rather than food, have played an important part in the rise of biogas production in some parts of the world, notably in Germany. However, they have also generated a vigorous debate about potential land-use impacts, so they are not considered in this report's assessment of the sustainable supply potential.

Using waste and residues as feedstocks avoids the land-use issues associated with energy crops. Energy crops also require fertiliser (typically produced from fossil fuels), which needs to be considered when assessing the life-cycle emissions from different biogas production pathways. Using waste and residues as feedstocks can capture methane that could otherwise escape to the atmosphere as they decompose.

Most **biomethane** production comes from upgrading biogas, so the feedstocks are the same as those described above. However, the gasification route to biomethane can use **woody biomass** (in addition to MSW and agricultural residues) as a feedstock, which consists of residues from forest management and wood processing.
The feedstocks described above were considered in this report's assessment of the sustainable biogas and biomethane supply potential, and are further discussed in Section 3 below.

A range of different feedstocks can be used to produce biogas and biomethane Biogas: Most production today comes from crops and animal manure

- Crops
- Animal manure
- Municipal solid waste
- Municipal wastewater

The development of biogas has been uneven across the world, as it depends not only on the availability of feedstocks but also on policies that encourage its production and use. Europe, the People's Republic of China (hereafter, "China") and the United States account for 90% of global production.

Europe is the largest producer of biogas today. Germany is by far the largest market, and home to two-thirds of Europe's biogas plant capacity. Energy crops were the primary choice of feedstock that underpinned the growth of Germany's biogas industry, but policy has recently shifted more towards the use of crop residues, sequential crops, livestock waste and the capture of methane from landfill sites. Other countries such as Denmark, France, Italy and the Netherlands have actively promoted biogas production.

In **China**, policies have supported the installation of household-scale digesters in rural areas with the aim of increasing access to modern energy and clean cooking fuels; these digesters account for around 70% of installed biogas capacity today. Different programmes have been announced to support the installation of larger-scale co-generation plants (i.e. plants producing both heat and power). Moreover, the Chinese National Development and Reform Commission issued a guidance document in late 2019 specifically on biogas industrialisation and upgrading to biomethane, supporting also the use of biomethane in the transport sector.

In the **United States**, the primary pathway for biogas has been through landfill gas collection, which today accounts for nearly 90% of its biogas production. There is also growing interest in biogas production from agricultural waste, since domestic livestock markets are responsible for almost one-third of methane emissions in the United States (USDA, 2016). The United States is also leading the way globally in the use of biomethane in the transport sector, as a result of both state and federal support.

Around half of the remaining production comes from developing countries in Asia, notably **Thailand** and **India**. Remuneration via the Clean Development Mechanism (CDM) was a key factor underpinning this growth, particularly between 2007 and 2011. The development of new biogas projects fell sharply after 2011 as the value of emission reduction credits awarded under the CDM dropped. Thailand produces biogas from the waste streams of its cassava starch sector, biofuel industry and pig farms. India aims to develop around 5 000 new compressed biogas plants over the next five years (GMI, 2019). **Argentina** and **Brazil** have also supported biogas through auctions; Brazil has seen the majority of production come from landfills, but there is also potential from vinasse, a by-product from the ethanol industry.

A clear picture of today's consumption of biogas in **Africa** is made more difficult by a lack of data, but its use has been concentrated in countries with specific support programmes. Some governments, such as Benin, Burkina Faso and Ethiopia, provide subsidies that can cover from half to all of the investment, while numerous projects promoted by non-governmental organisations provide practical know-how and subsidies to lower the net investment cost. In addition to these subsidies, credit facilities have made progress in a few countries, notably a recent lease-to-own arrangement in Kenya that financed almost half of the digester installations in 2018 (Ter Heegde, 2019)

The rise of biogas has been shaped by two main factors: Policy support and feedstock availability

Almost two-thirds of biogas production in 2018 was used to generate electricity and heat (with an approximately equal split between electricity-only facilities and co-generation facilities). Around 30% was consumed in buildings, mainly in the residential sector for cooking and heating, with the remainder upgraded to biomethane and blended into the gas networks or used as a transport fuel.

Today there is around 18 GW of installed power generation capacity running on biogas around the world, most of which is in Germany, the United States and the United Kingdom. Capacity increased on average by 4% per year between 2010 and 2018. In recent years, deployment in the United States and some European countries has slowed, mainly because of changes in policy support, although growth has started to pick up in other markets such as China and Turkey.

The levelised cost of generating electricity from biogas varies according to the feedstocks used and the sophistication of the plant, and ranges from USD 50 per megawatt-hour (MWh) to USD 190/MWh. A substantial part of this range lies above the cost of generation from wind and utility-scale solar photovoltaic (PV), which have come down sharply in recent years.

The relatively high costs of biogas power generation mean that the transition from feed-in tariffs to technology-neutral renewable electricity auction frameworks (such as power purchase agreements) in many countries could limit the future prospects for electricity-only biogas plants. However, unlike wind and solar PV, biogas plants can operate in a flexible manner and so provide balancing and other ancillary services to the electricity network. Recognising the value of these services would help to spur future deployment prospects for biogas plants.

Where local heat off-take is available, the economic case for biogas co-generation is stronger than for an electricity-only plant. This is because co-generation can provide a higher level of energy efficiency, with around 35% of the energy from biogas used to generate electricity and an additional 40-50% of the waste heat put to productive use.

Certain industrial subsectors, such as the food and drink and chemicals, produce wet waste with a high organic content, which is a suitable feedstock for anaerobic digestion. In such industries, biogas production can also have the co-benefit of providing treatment for waste while also supplying on-site heat and electricity.

For the moment, a relatively small but growing share of the biogas produced worldwide is upgraded to biomethane. This area has significant potential for further growth, although – as outlined in subsequent sections of this report – this is heavily contingent on the strength and design of policies aimed at decarbonising gas supply in different parts of the world.

Upgrading biogas to biomethane could be a major source of future growth Biomethane: Around 90% of today's production is from upgrading biogas:
The biomethane industry is currently very small, although it is generating growing amounts of interest in several countries for its potential to deliver clean energy to a wide array of end users, especially when this can be done using existing infrastructure.

Currently around 3.5 Mtoe of biomethane are produced worldwide. The vast majority of production lies in European and North American markets, with some countries such as Denmark and Sweden boasting more than 10% shares of biogas/biomethane in total gas sales. Countries outside Europe and North America are catching up quickly, with the number of upgrading facilities in Brazil, China and India tripling since 2015.

Biomethane represents about 0.1% of natural gas demand today; however, an increasing number of government policies are supporting its injection into natural gas grids and for decarbonising transport. For example, Germany, Italy, the Netherlands and the United Kingdom have all introduced support for biomethane in transport. Brazil's RenovaBio programme has a target of reducing the carbon intensity of fuels in the transport sector by 10% by 2028. Subnational schemes are also emerging, such as low-carbon fuel standards in the US state of California and in British Columbia, Canada.

The percentage of biogas produced that is upgraded varies widely between regions: in North America it is around 15% while in South America it is over 35%; in Europe, the region that produces the most biogas and biomethane, around 10% of biogas production is upgraded (although in countries such as Denmark and Sweden the percentages are much higher); in Asia, the figure is 2%.

The main co-product of biogas upgrading is CO_2, which is produced in a relatively concentrated form and therefore could be used for industrial or agricultural purposes or combined with hydrogen to yield an additional stream of methane. Another option would be to store it underground, in which case the biomethane would be a CO_2-negative source of energy.
As noted above, the alternative method to produce biomethane is through thermal gasification of biomass. There are several biomass gasification plants currently in operation, but these are mostly at demonstration scale producing relatively small volumes. Some of these plants have struggled to achieve stable operation, as a result of the variable quality and quantity of feedstock. Since this is a less mature technology than anaerobic digestion, thermal gasification arguably offers greater potential for technological innovation and cost reductions. Prospects would be enhanced if incumbent gas producers were to commit resources to its development, as it would appear a better fit with their knowledge and technical expertise.

The rising interest in biomethane means that the number of operating plants worldwide (both biogas upgrading and biomass gasification facilities) is expected to exceed 1 000 in the course of 2020. Around 60% of plants currently online and in development inject biomethane into the gas distribution network, with a further 20% providing vehicle fuel. The remainder provides methane for a variety of local end uses.

Most biomethane production today is in Europe and North America, although these regions upgrade only a small share of their overall biogas output

Solid biomass (traditional use)

Solid biomass (modern use)

Biofuels

Biogas (direct use + upgrading)

Bioenergy accounts for around 10% of the world's primary energy demand today. It can be consumed either in solid, liquid or gaseous form, and by far the most prevalent use of bioenergy today is solid biomass (around 90%).

The use of solid biomass is typically categorised as either "traditional" or "modern", and currently demand is split roughly equally between the two. Modern biomass relies on more advanced technologies, mainly in electricity generation and industrial applications, which use upgraded fuels such as woodchips and pellets. Traditional use refers to the burning of solid biomass, such as wood, charcoal, agricultural residues and animal dung, for cooking or heating using basic technologies such as three-stone fires. With low conversion efficiencies and significant negative health impacts from indoor air pollution, many developing economies are trying to shift consumption away from traditional use.

The differentiation between traditional and modern does not apply for liquid and gaseous bioenergy, since both are produced using advanced technologies. Liquid biofuels make up around 7% of total bioenergy demand today. Biofuels are the main renewable energy source used directly in the transport sector, with around 90 Mtoe or almost 2 million barrels of oil equivalent per day consumed in 2018. About 70% of biofuels consumed today is bioethanol, which is usually blended with gasoline; most of the remainder is biodiesel.

Biogas and biomethane today account for less than 3% of total bioenergy demand, and represent an even smaller 0.3% share of total primary energy. But there are reasons to believe that these low-carbon gases could gain a firmer foothold in the future.

They can provide the system benefits of natural gas (storage, flexibility, high-temperature heat) without the net carbon emissions. As economies decarbonise, this becomes a crucial attribute.

Biogas provides a sustainable supply of heat and power that can serve communities seeking local, decentralised sources of energy, as well as a valuable cooking fuel for developing countries.

The GHG reduction benefit is amplified by the processing and use of methane (a potent GHG) that could otherwise be released to the atmosphere from the decomposition of organic by-products and waste.

Biogas and biomethane can also play an important part in waste management, improving overall resource efficiency.

Where it displaces gas transported or imported over long distances, biogas and biomethane also yield energy security benefits.

There are also broader non-energy considerations, such as nutrient recycling, rural job creation or reductions in the time spent in low-income communities collecting firewood. Both biogas and biomethane can also be developed at scale through partnerships between the energy and agricultural industries. By transforming a range of organic wastes into higher-value products, biogas and biomethane fit well into the concept of the circular economy.

Policies can help to unlock these benefits, but much will depend on how much biogas and biomethane is available and at what cost. These are the questions addressed in the next section. **However, there is a strong potential role for biogas and biomethane in the transformation of the global energy system**

Fuel Cell

A fuel cell is an electrochemical device that produces electricity without combustion by combining hydrogen and oxygen to produce water and heat.

Advantages over conventional energy sources

They produce zero or very low emissions, especially Green House Gases (GHGs) depending on the fuel used. Have few moving parts and thus require minimal maintenance, reducing life cycle costs of energy production. Modular in design, offering flexibility in size and efficiencies in manufacturing Can be utilized for combined heat and power purposes, further increasing the efficiency of energy production

Working Principle

A fuel cell is a device that uses hydrogen (or hydrogen-rich fuel) and oxygen to create electricity by an electrochemical process. A single fuel cell consists of an electrolyte sandwiched between two thin electrodes (a porous anode and cathode) Hydrogen, or a hydrogen-rich fuel, is fed to the anode where a catalyst separates hydrogen's negatively charged electrons from positively charged ions (protons) At the cathode, oxygen combines with electrons and, in some cases, with species such as protons or water, resulting in water or hydroxide ions, respectively The electrons from the anode side of the cell cannot pass through the membrane to the positively charged cathode; they must travel around it via an electrical circuit to reach the other side of the cell. This movement of electrons is an electrical current. The amount of power produced by a fuel cell depends upon several factors, such as fuel cell type, cell size, the temperature at which it operates, and the pressure at which the gases are supplied to the cell Still, a single fuel cell produces enough electricity for only the smallest applications. Therefore, individual fuel cells are typically combined in series into a fuel cell stack. A typical fuel cell stack may consist of hundreds of fuel cells. Fuel cells are classified primarily by the kind of electrolyte they employ. This determines the kind of chemical reactions that take place in the cell, the kind of catalysts required, the temperature range in which the cell operates, the fuel required, and other factors. There are several types of fuel cells currently under development, each with its own advantages, limitations, and potential applications.

Classification of Fuel Cells

Based on the type of Electrolyte

1. Alkaline Fuel cell (AFC)
2. Phosphoric Acid Fuel cell (PAFC)
3. Polymer Electrolytic Membrane Fuel Cell (PEMFC) Solid Polymer Fuel Cell (SPFC) and Proton Exchange Membrane Fuel cell (PEMFC)
4. Molten Carbonate Fuel Cell (MCFC)
5. Solid Oxide Fuel Cell (SOFC)

Based on Types of Fuel and oxidant

6. Hydrogen (pure)-Oxygen (pure) fuel cell
7. Hydrogen rich gas-air fuel cell
8. Ammonia –air fuel cell
9. Synthesis gas- air fuel cell
10. Hydro carbon (gas)- air fuel cell Based on operating temperature

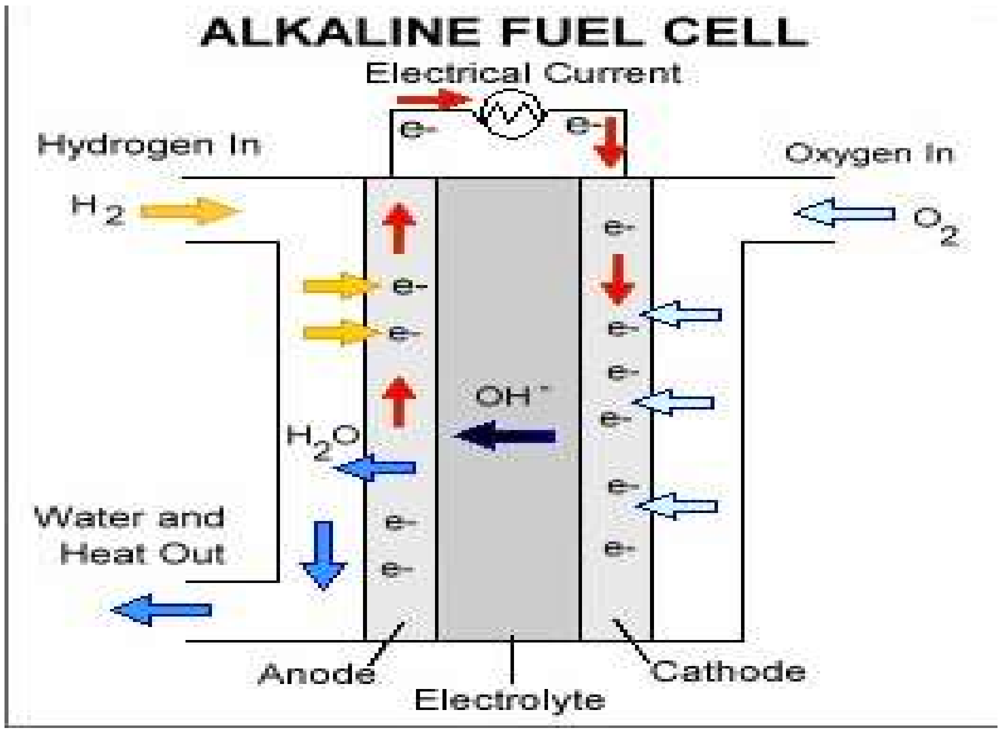
Alkaline Fuel Cells (AFC)

The alkaline fuel cell uses an alkaline electrolyte such as 40% aqueous potassium hydroxide. In alkaline fuel cells, negative ions travel through the electrolyte to the anode where they combine with hydrogen to generate water and electrons. It was originally used by NASA on space missions. NASA space shuttles use Alkaline Fuel Cells. Alkaline fuel cells (AFCs) were one of the first fuel cell technologies developed, and they were the first type widely used in the U.S. space program to produce electrical energy and water onboard spacecraft. These fuel cells use a solution of potassium hydroxide in water as the electrolyte and can use a variety of nonprecious metals as a catalyst at the anode and cathode. Hightemperature AFCs operate at temperatures between 100ºC and 250ºC (212ºF and 482ºF). However, more-recent AFC designs operate at lower temperatures of roughly 23ºC to 70ºC (74ºF to 158ºF). AFCs are high-performance fuel cells due to the rate at which chemical reactions take place in the cell. They are also very efficient, reaching efficiencies of 60 percent in space applications. The disadvantage of this fuel cell type is that it is easily poisoned by carbon dioxide (CO_2). In fact, even the small amount of CO_2 in the air can affect the cell's operation, making it necessary to purify both the hydrogen and oxygen used in the cell. CO_2 can combine with KOH to form potasium carbonate which will increase the resistance. This purification process is costly.

Susceptibility to poisoning also affects the cell's lifetime (the amount of time before it must be replaced), further adding to cost. Cost is less of a factor for remote locations such as space or under the sea. However, to effectively compete in most mainstream commercial markets, these fuel cells will have to become more cost effective. AFC stacks have been shown to maintain sufficiently stable operation for more than 8,000 operating hours.

Anode Reaction: $2H_2 + 4OH^-$ »» $4H_2O + 4e$

Cathode Reaction: $O_2 + 2H_2O + 4e^-$ »» $4OH^-$



Molten Carbonate Fuel Cells (MCFC):

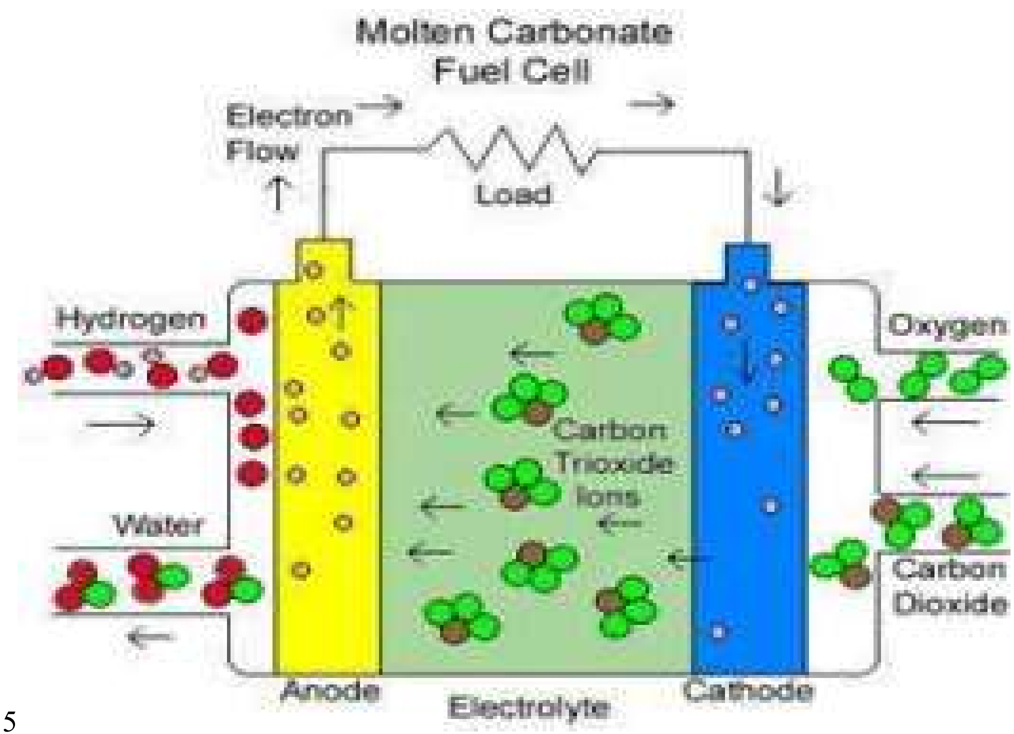
The molten carbonate fuel cell uses a molten carbonate salt as the electrolyte. It has the potential to be fuelled with coal- derived fuel gases, methane or natural gas. These fuel cells can work at up to 60% efficiency.

In molten carbonate fuel cells, negative ions travel through the electrolyte to the anode where they combine with hydrogen to generate water and electrons. Molten carbonate fuel cells (MCFCs) are currently being developed for natural gas and coal-based power plants for electrical utility, industrial, and military applications. MCFCs are high-temperature fuel cells that use an electrolyte composed of a molten carbonate salt mixture suspended in a porous, chemically inert ceramic lithium aluminum oxide (LiAlO2) matrix. Since they operate at extremely high temperatures of 650ºC and above, nonprecious metals can be used as catalysts at the anode and cathode, reducing costs. Unlike alkaline, phosphoric acid, and polymer electrolyte membrane fuel cells, MCFCs don't require an external reformer to convert more energy-dense fuels to hydrogen. Due to the high temperatures at which they operate, these fuels are converted to hydrogen within the fuel cell itself by a process called internal reforming, which also reduces cost. Although they are more resistant to impurities than other fuel cell types, scientists are looking for ways to make MCFCs resistant enough to impurities from coal, such as sulfur and particulates. The primary disadvantage of current MCFC technology is durability. The high temperatures at which these cells operate and the corrosive electrolyte used accelerate component breakdown and corrosion, decreasing cell life. Scientists are currently exploring corrosion-resistant materials for components as well as fuel cell designs that increase cell life without decreasing performance.

Anode Reaction: $CO_3^{-2} + H_2 \rightarrow H_2O + CO_2 + 2e^-$

Cathode Reaction: $CO_2 + ½O_2 + 2e^- \rightarrow CO_3^{-2}$

Overall Cell Reaction: $H_2 + ½O_2 \rightarrow H_2O$



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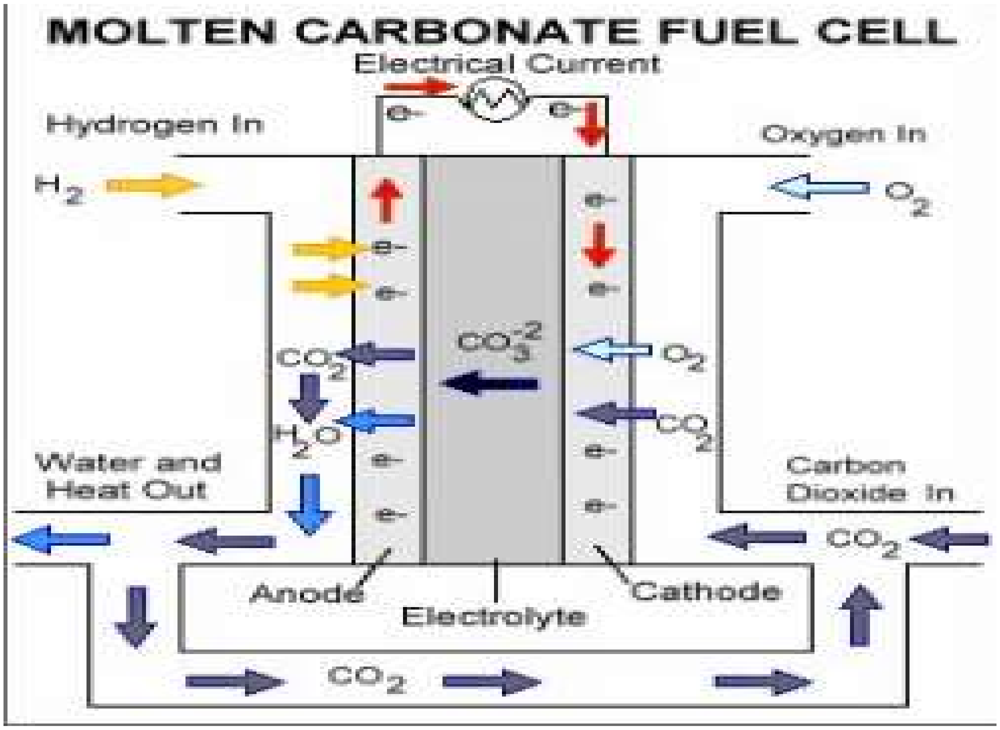
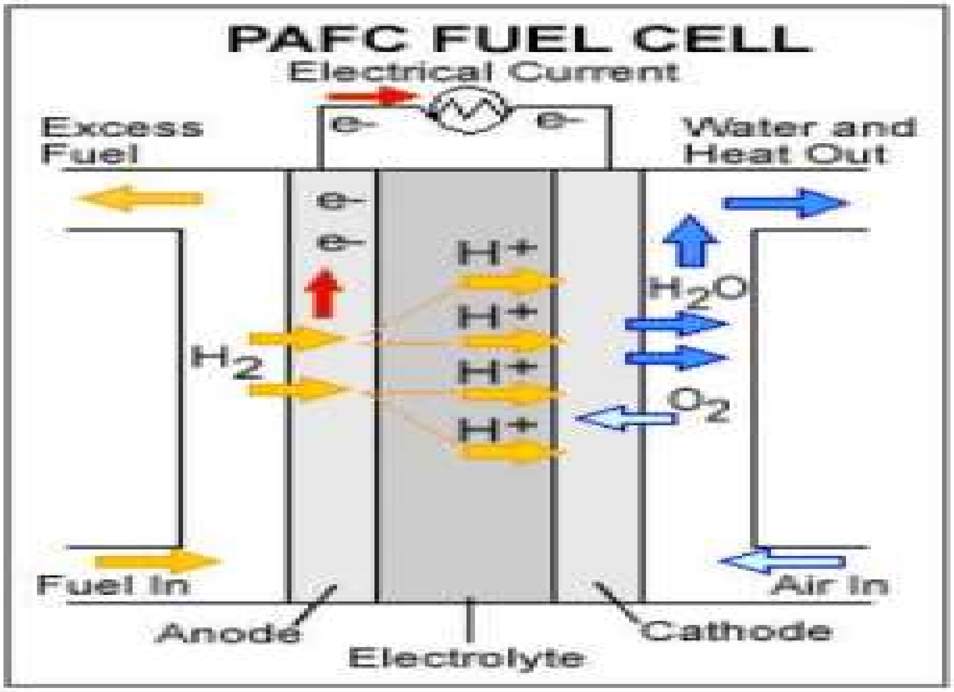
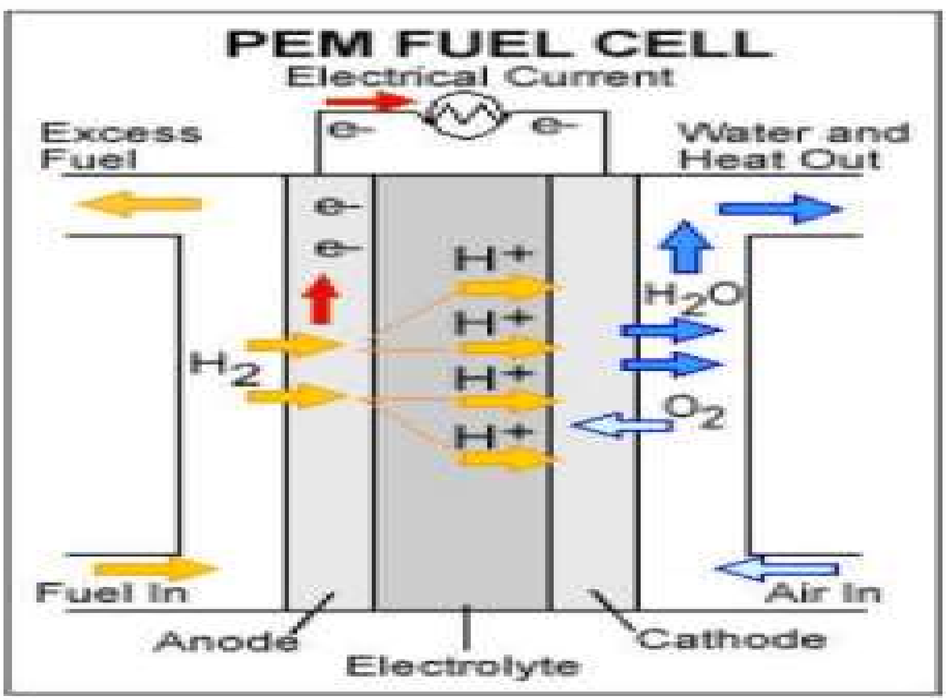


Phosphoric Acid Fuel Cells (PAFC):

A phosphoric acid fuel cell (PAFC) consists of an anode and a cathode made of a finely dispersed platinum catalyst on carbon and a silicon carbide structure that holds the phosphoric acid electrolyte. In phosphoric acid fuel cells, protons move through the electrolyte to the cathode to combine with oxygen and electrons, producing water and heat. This is the most commercially developed type of fuel cell and is being used to power many commercial premises


PAFC FUEL CELL
Electrical Current
e-
e-
Excess Fuel
Water and Heat Out
e-
e-
H+
H+
H+
H+
H2
H2O
O2
Fuel In
Air In
Anode
Electrolyte
Cathode


PEM FUEL CELL
Electrical Current
e-
e-
Excess Fuel
Water and Heat Out
e-
e-
H+
H+
H+
H+
H2
H2O
O2
Fuel In
Air In
Anode
Electrolyte
Cathode

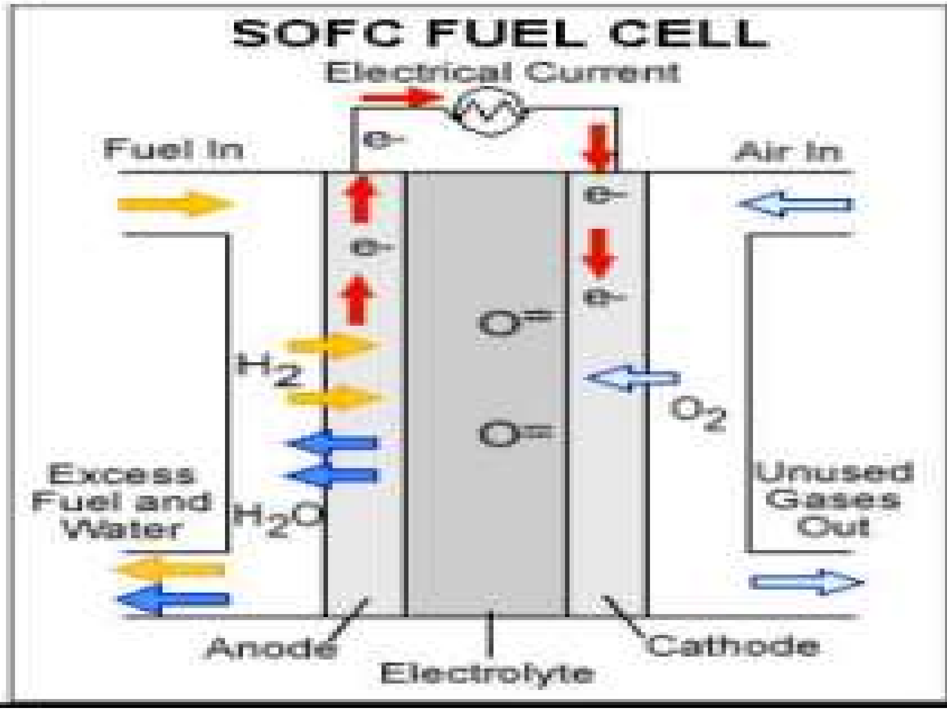
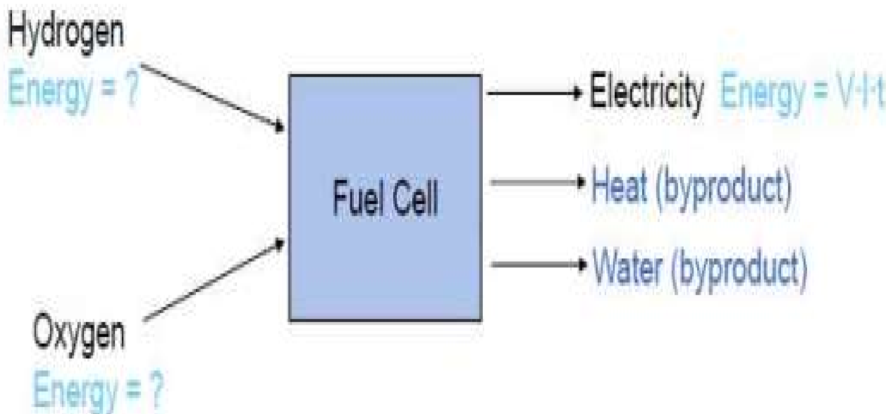
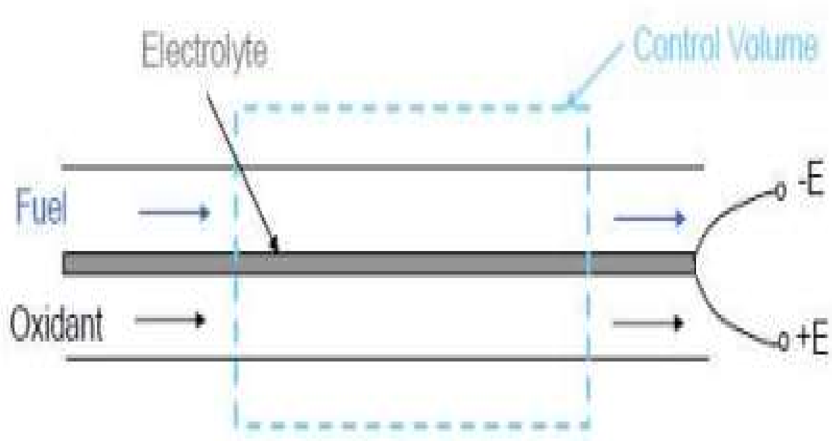


Table I. Classification of fuel cells

Fuel Cell Type	Electrolyte Used	Operating Temperarture		Electrode Reactions
Polymer Electrolyte	Polymer Membrane	60-140°C	Anode:	$H_2 = 2H^+ + 2e^-$
			Cathode:	$\frac{1}{2}O_2 + 2H^+ + 2e^- = H_2O$
Direct Methanol	Polymer Membrane	30-80°C	Anode:	$CH_3OH + H_2O = CO_2 + 6H^+ + 6e^-$
			Cathode:	$\frac{3}{2}O_2 + 6H^+ + 6e^- = 3H_2O$
Alkaline	Potassium Hydroxide	150-200°C	Anode:	$H_2 + 2\,OH^- = H_2O + 2e^-$
			Cathode:	$\frac{1}{2}O_2 + H_2O + 2e^- = 2\,OH^-$
Phosphoric Acid	Phosphoric Acid	180-200°C	Anode:	$H_2 = 2H^+ + 2e^-$
			Cathode:	$\frac{1}{2}O_2 + 2H^+ + 2e^- = H_2O$
Molten Carbonate	Lithium/Potassium Carbonate	650°C	Anode:	$H_2 + CO_3^{2-} = H_2O + CO_2 + 2e^-$
			Cathode:	$\frac{1}{2}O_2 + CO_2 + 2e^- = CO_3^{2-}$
Solid Oxide	Yittria Stablized Zirconia	1000°C	Anode:	$H_2 + O^{2-} = H_2O + 2e^-$
			Cathode:	$\frac{1}{2}O_2 + 2e^- = O^{2-}$





OCEAN THERMAL ENERGY CONVERSION (OTEC)

The ocean and seas constitute about 70% of the earth's surface area and hence they represent a large storage reservoir of the solar energy. In tropical waters, the surface water temperature is about 27 °C and at 1 km directly below, the temperature is about 4 °C. The reservoir of surface water may be considered a heat source and the reservoir of cold water (1 km below) is considered a heat sink. The concept of ocean thermal energy conversion is based on the utilization of temperature difference between the heat source and the sink in a heat engine to generate power.

The temperature gradient present in the ocean is utilized in a heat engine to generate power. This is called OTEC. Since the temperature gradient is very small, even in the tropical region, OTEC systems have very low efficiencies and very high capital costs. There are two basic designs for OTEC systems.

1. Open cycle or Claude cycle.
2. Closed cycle or Anderson cycle.

Open cycle or Claude cycle

In this cycle, the seawater plays a multiple role of a heat source, working fluid, coolant and heat sink. Warm surface water enters an evaporator where the water is flash evaporated to steam under particle vacuum. Low pressure is maintained in the evaporator by a vacuum pump. The low pressure so maintained removes the non-condensable gases from the evaporator. The steam and water mixture from evaporator then enters a turbine, driving it thus generating electricity. The exhaust from the turbine is mixed with cold water from deep ocean in a direct contact condenser and is discharged to the ocean. The cycle is then repeated. Since the condensate is discharged to the ocean, the cycle is called open.

Flash evaporation

In the evaporator the pressure is maintained at a value (0.0317 bar) slightly lower than the saturation pressure of warm surface water at 27°C (0.0356 bar). Hence, when the surface water enters the evaporator, it gets 'superheated'. This super heated water undergoes ‚volume boiling‛ causing the water to partially flash to steam.

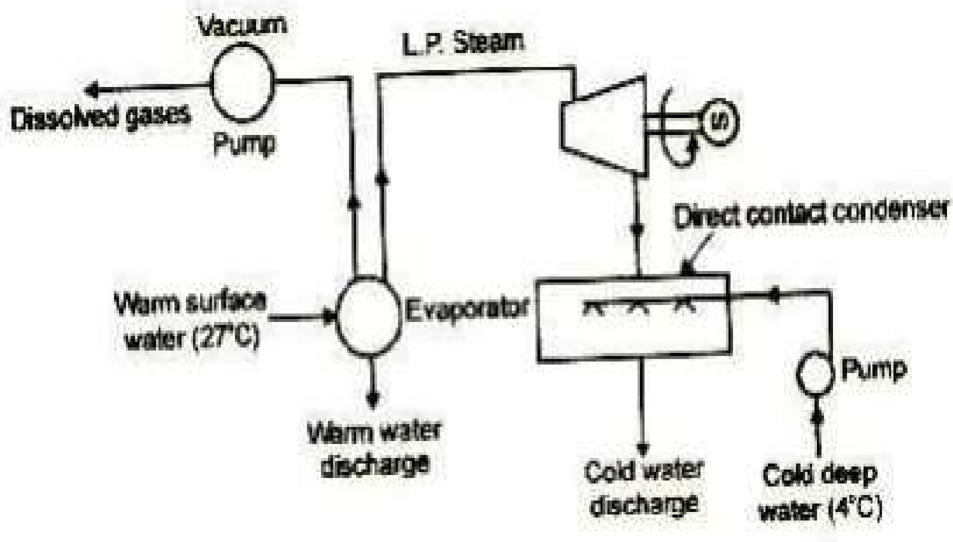


Figure: OTEC – open cycle.

Figure: OTEC –open cycle.

Closed OTEC cycle

Here, a separate working fluid such as ammonia, propane or Freon is used in addition to water. The warm surface water is pumped to a boiler by a pump. This warm water gives up its heat to the secondary working fluid thereby losing its energy and is discharged back to the surface of the ocean. The vapours of the secondary working fluid generated in the boiler, drive a turbine generating power. The exhaust from the turbine is cooled in a surface condenser by using cold deep seawater, and is then circulated back to the boiler by a pump.

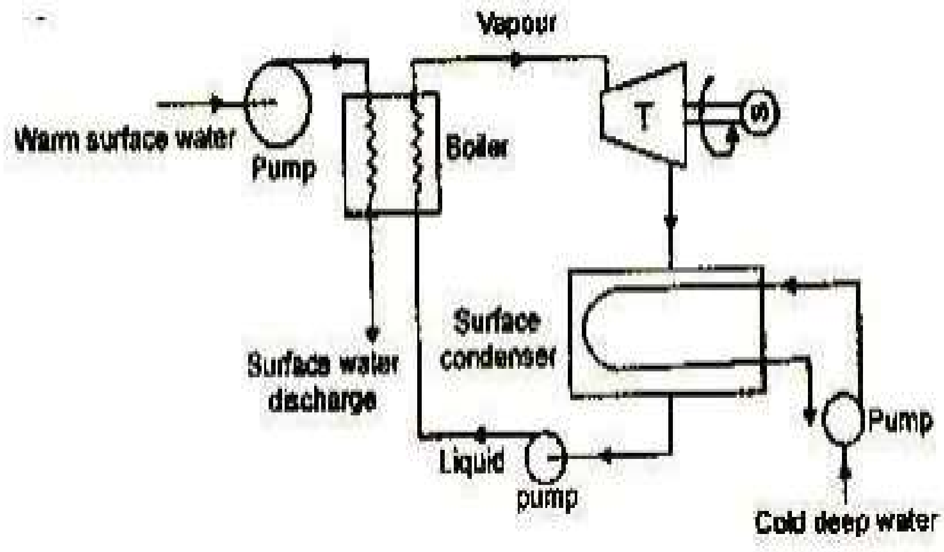


Figure: OTEC – closed cycle

Figure: OTEC –closed cycle

Advantages of OTEC

1. Ocean is an infinite heat reservoir which receives solar incidence throughout the year.
2. Energy is freely available.

Disadvantage of OTEC

1. Efficiency is very low, about 2.5%, as compared to 30-40% efficiency for conventional power plants.

2. Capital cost is very high.

GEOTHERMAL ENRGY

Geothermal energy—geo (earth) + thermal (heat)—is heat energy from the earth.

WHAT IS A GEOTHERMAL RESOURCE?

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

BENEFITS OF GEOTHERMAL ENERGY

Renewable—Through proper reservoir management, the rate of energy extraction can be balanced with a reservoir's natural heat recharge rate.

Baseload—Geothermal power plants produce electricity consistently, running 24 hours per day / 7 days per week, regardless of weather conditions.

Small Footprint—Geothermal power plants are compact; using less land per GWh (404 m^2) than coal (3642 m^2) wind (1335 m^2) or solar PV with center station (3237 m^2).

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

The Geothermal Technologies Office focuses on harnessing this clean, domestic natural resource to generate electricity by accelerating near-term hydrothermal and low-temperature adoption and boldly pursuing EGS as a transformative player by creating a commercial pathway to large-scale, reproducible systems.

HYDROTHERMAL SYSTEMS

ENHANCED GEOTHERMAL SYSTEMS (EGS)

The Energy Department's project portfolio continues to explore novel technologies in these areas in order to accelerate the adoption of geothermal energy production in America.

Geothermal Technologies Office

1. Electricity Generation

The United States of America continues to generate the most geothermal electricity in the world: more than 3.5 gigawatts, predominantly from the western United States. That's enough to power about three and half million homes! Pictured above, the Raft River geothermal plant is located in Idaho. Source: Geothermal Resources Council

Geothermal power plant in the Imperial Valley, California.

A geothermal resource requires fluid, heat and permeability in order to generate electricity:

Fluid—Sufficient fluid must exist naturally or be pumped into the reservoir.

Heat—The earth's temperature naturally increases with depth and varies based on geographic location.

Permeability—In order to access heat, the fluid must come into contact with the heated rock, either via natural fractures or through stimulating the rock.

Conventional hydrothermal resources contain all three elements naturally. Increasingly, however, geothermal systems where subsurface fluid and permeability are lacking are being engineered or enhanced to access the earth's heat by adding fluid to these hot subsurface resources. Known as enhanced geothermal systems (EGS), this technology could be a game-changer in the geothermal sector, tapping 100+ gigawatts of geothermal energy, roughly ten percent of domestic energy demand.

In addition, low-temperature and coproduced technologies are being explored for near-term power solutions.

POWER PLANTS

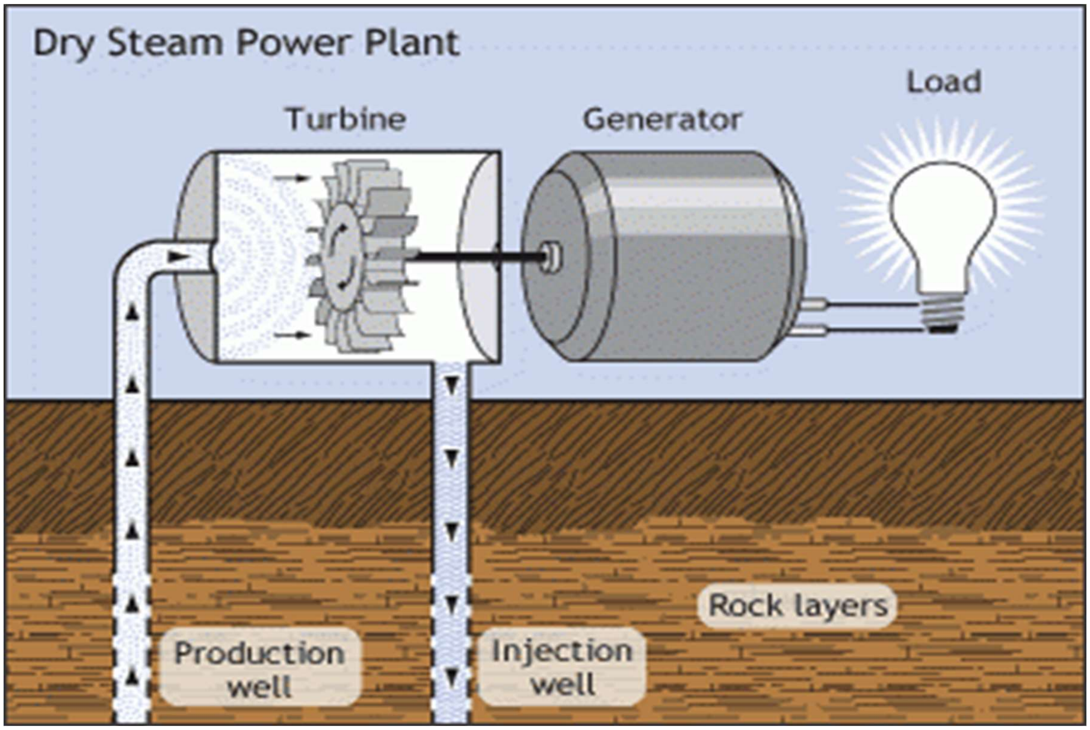
Power plants use steam produced from geothermal reservoirs to generate electricity. There are three geothermal power plant technologies being used to convert hydrothermal fluids to electricity—dry steam, flash steam and binary cycle. The type of conversion used (selected in development) depends on the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

Dry Steam Power Plant

Dry steam power plants at The Geysers in California.

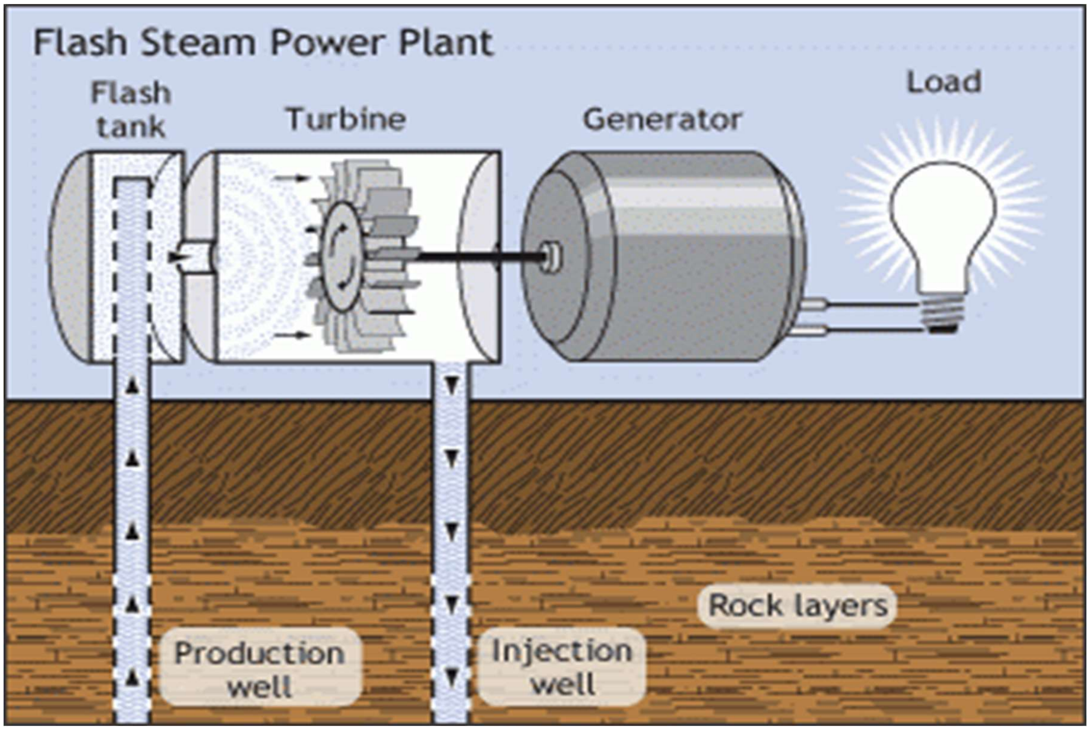
Dry steam plants use hydrothermal fluids that are primarily steam. The steam travels directly to a turbine, which drives a generator that produces electricity. The steam eliminates the need to burn fossil fuels to run the turbine (also eliminating the need to transport and store fuels). These plants emit only excess steam and very minor amounts of gases.

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). Steam technology is still effective today at currently in use at The Geysers in northern California, the world's largest single source of geothermal power.



Flash Steam Power Plant

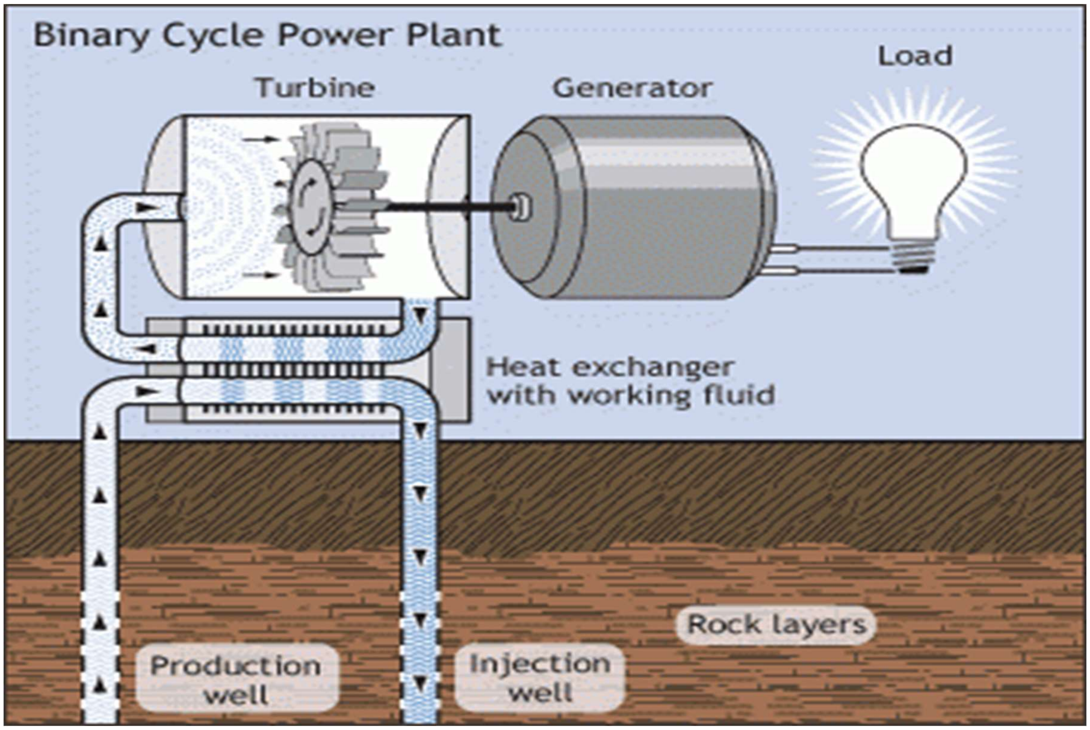
Flash steam plants are the most common type of geothermal power generation plants in operation today. Fluid at temperatures greater than 360°F (182°C) is pumped under high pressure into a tank at the surface held at a much lower pressure, causing some of the fluid to rapidly vaporize, or "flash." The vapor then drives a turbine, which drives a generator. If any liquid remains in the tank, it can be flashed again in a second tank to extract even more energy.



Binary Cycle Power Plant

Binary cycle geothermal power generation plants differ from Dry Steam and Flash Steam systems in that the water or steam from the geothermal reservoir never comes in contact with the turbine/generator units. Low to moderately heated (below 400°F) geothermal fluid and a secondary (hence, "binary") fluid with a much lower boiling point that water pass through a heat exchanger. Heat from the geothermal fluid causes the secondary fluid to flash to vapor, which then drives the turbines and subsequently, the generators.

Binary cycle power plants are closed-loop systems, and virtually nothing (except water vapor) is emitted to the atmosphere. Because resources below 300°F represent the most common geothermal resource, a significant proportion of geothermal electricity in the future could come from binary-cycle plants.



GEOTHERMAL HEAT PUMPS

The technology relies on the fact that the earth (beneath the surface) remains at a relatively constant temperature throughout the year, warmer than the air above it during the winter and cooler in the summer, very much like a cave. The geothermal heat pump takes advantage of this by transferring heat stored in the earth or in ground water into a building during the winter, and transferring it out of the building and back into the ground during the summer. The ground, in other words, acts as a heat source in winter and a heat sink in summer.

The system includes three principal components:

1. **Earth Connection Subsystem**

   Using the earth as a heat source/sink, a series of connected pipes, commonly called a "loop," is buried in the ground near the building to be conditioned. The loop can be buried either vertically or horizontally. It circulates a fluid (water, or a mixture of water and antifreeze) that absorbs heat from, or relinquishes heat to, the surrounding soil, depending on whether the ambient air is colder or warmer than the soil.

2. **Heat Pump Subsystem**

   For heating, a geothermal heat pump removes the heat from the fluid in the earth connection, concentrates it, and then transfers it to the building. For cooling, the process is reversed.

3. **Heat Distribution Subsystem**

   Conventional ductwork is generally used to distribute heated or cooled air from the geothermal heat pump throughout the building.

RESIDENTIAL HOT WATER

In addition to space conditioning, geothermal heat pumps can be used to provide domestic hot water when the system is operating. Many residential systems are now equipped with desuperheaters that transfer excess heat from the geothermal heat pump's compressor to the house's hot water tank. A desuperheater provides no hot water during the spring and fall when the geothermal heat pump system is not operating; however, because the geothermal heat pump is so much more efficient than other means of water heating, manufacturers are beginning to offer "full demand" systems that use a separate heat exchanger to meet all of a household's hot water needs. These units cost-effectively provide hot water as quickly as any competing system.

Fig: Heat exchanger left and heat pump right.

Types of Geothermal Heat Pumps

Geothermal heat pumps come in four types of loop systems that loop the heat to or from the ground and your house. Three of these – horizontal, vertical, and pond/lake – are closed-loop systems. The fourth type of system is the open-loop option. Choosing the one that is best for your site depends on the climate, soil conditions, available land, and local installation costs at the site.

Closed-Loop Systems.

Horizontal:

This type of installation is generally most cost-effective for residential installations, particularly for new construction where sufficient land is available. It requires trenches at least four feet deep.

Vertical:

This is often used for larger scale geothermal systems (such as in commercial buildings) where land is limited, or where the soil is too shallow to bury the horizontal loops in the trenches and some form of drilling into the bedrock is necessary. Vertical loop systems can be more expensive, but they use less land and also minimize disturbance to the existing landscape.

Pond/Lake:

If the site has an adequate water body, this may be the least expensive option. A supply line pipe runs underground from the building to the water and coils into circles at least eight feet under the surface to prevent freezing. The coils should only be placed in a water source that meets minimum volume, depth, and quality criteria.

Open-Loop System

This type of system uses well or surface body water as the heat exchange fluid that circulates directly through the geothermal heat pump system. Once it has circulated through the system, the water returns to the ground through the well, a recharge well, or surface discharge. This option is practical only with an adequate supply of relatively clean water, and if all local codes and regulations regarding groundwater discharge are met.

Energy-Efficient and CostEffective

Although installing a geothermal heat pump system is more expensive than installing an air source system of the same heating and cooling capacity, you can recoup the additional costs in energy savings in 5 to 10 years. An average geothermal heat pump system costs about $2,500 per ton of capacity. If a home requires a 3-ton unit, then it would cost about $7,500 (plus installation and drilling costs). A comparable ASHP system with air conditioning would cost about $4,000, but the energy costs could easily equate to the extra cost of installing a geothermal heat pump. Additionally, geothermal heat pump systems installed in new or existing homes by Dec. 31, 2016 are eligible for a 30% federal tax credit. See the Financial Incentives box for more information. Geothermal heat pump systems have an average 20+ year life expectancy for the heat pump itself and 25 to 50 years for the underground infrastructure. Additionally, they move between three and five times the energy they consume between a building's interior space and the ground.

Question Bank

Short

1. What are the main applications of geothermal energy?
2. Write a short note on tidal and wave energy.
3. Give classification of geothermal energy resources.
4. Mention the factors which affect the size of biomass plant
5. What is fermentation of biomass?
6. What are the relative advantages of biomass gasifiers?
7. Significance of bio-fouling in OTEC plants.
8. Enumerate the main applications of biogas.
9. What is bio-mass? How it is useful?
10. What are the different sources of geothermal energy?
11. How bio-energy may be useful for rural applications? Justify your answer.
12. Explain the principle of bio conversion

Long

1. Explain in detail aerobic digestion and different phases and the process involved in it.
2. Explain various methods to extract geothermal energy.
3. Explain the working of KVIC digester (Floating gas holder plant).
4. Explain the construction and working of open cycle OTEC plant.
5. Give the classification of Biomass plants? Explain them briefly
6. Explain the working of OTEC plant with the help of neat schematic diagram.
7. What are the advantages of anaerobic digestion, explain them in detail?
8. Explain with a schematic diagram, working of liquid dominated total flow geothermal system.
9. Briefly explain the factors which influence generation of gas from biomass.
10. Explain with a simple sketch the basic principle of tidal power generation.
11. What are the advantages and disadvantages of floating drum bioconversion plant?
12. Explain with relevant schematic diagram, working of hybrid OTEC cycle.
13. What are the different types of bio gas plants, explain them briefly?
14. Explain with simple sketch how wave energy conversion systems be used for power generation.
15. Discuss different systems used for generating the power using geothermal energy, in brief.
16. What are the factors, which affect the size of the bio-gas plants?
17. Explain the principle of open cycle OTEC system with suitable diagram
18. Explain the production of bio-gas. What are the factors which affect the generation of biogas?
19. State the limitations of OTEC system.

20. What is meant by anaerobic digestion? What are the factors, which affect bio digestion? Explain briefly.
21. Explain with the help of diagram, the principle of closed cycle OTEC system.
22. Explain the constructional detail and working of KVIC digester.
23. Explain the working of vapour dominant hydro thermal convection system.
24. Estimate the energy and power in simple single basin tidal system and also explain the working of any one tidal power generation system