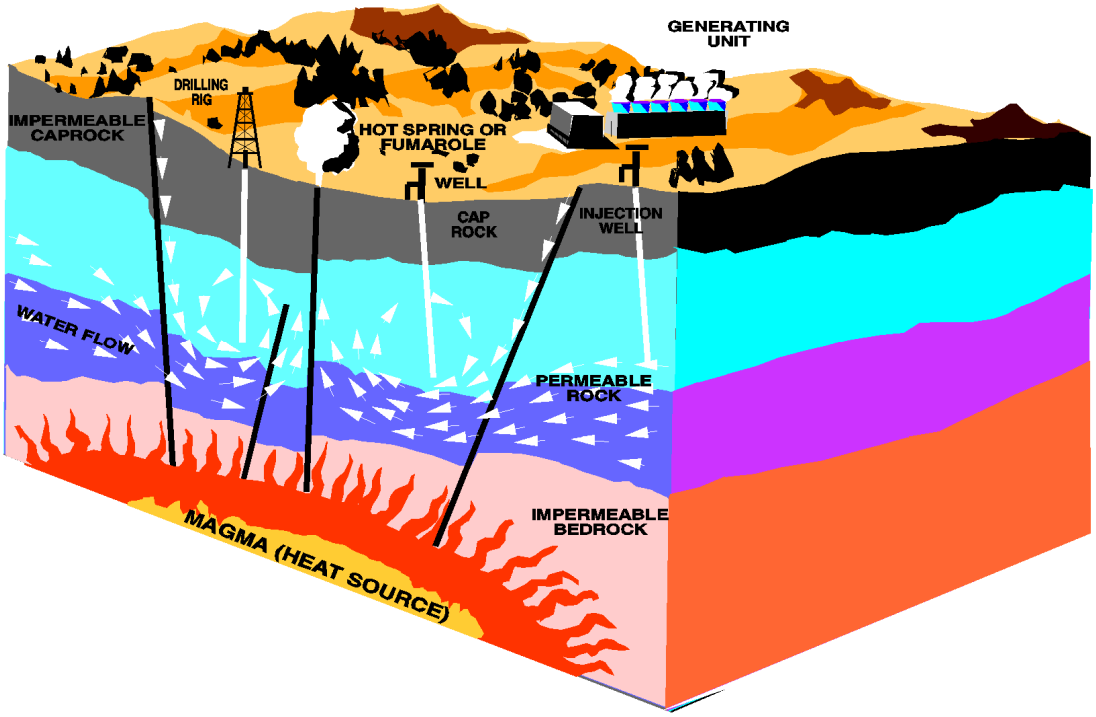
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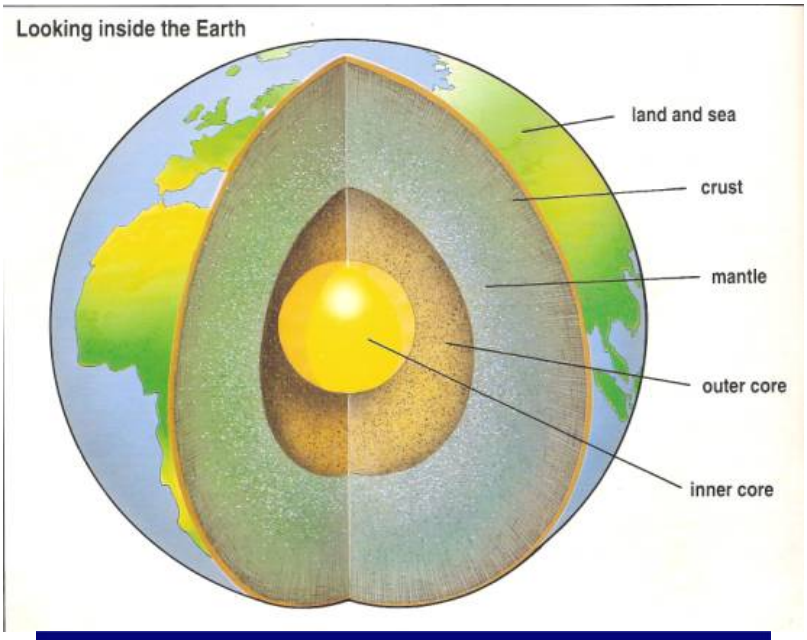
Geo-Thermal Energy

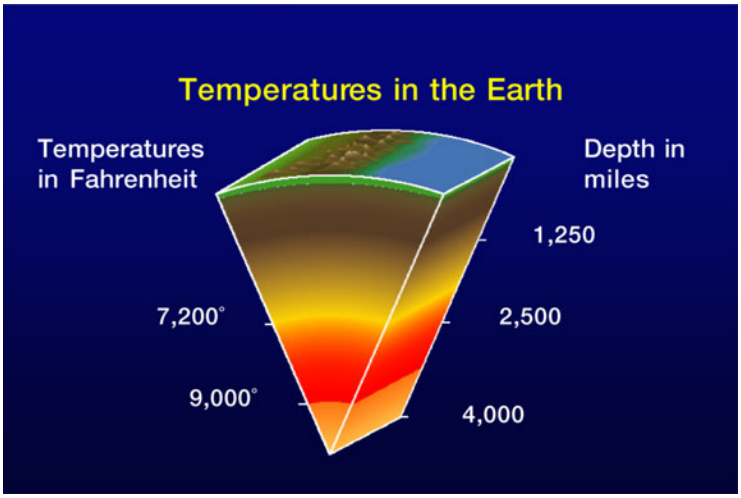
What is Geo-Thermal Energy: Geothermal energy is thermal energy generated and stored in the Earth. Thermal energy is the energy that determines the temperature of matter. The geothermal energy of the Earth's crust originates from the original formation of the planet (20%) and from radioactive decay of minerals (80%). The geothermal gradient, which is the difference in temperature between the core of the planet and its surface, drives a continuous conduction of thermal energy in the form of heatfrom the core to the surface. The adjective *geothermal* originates from the Greek roots *γη (ge)*, meaning earth, and *θερμος (thermos)*, meaning hot.At the core of the Earth, thermal energy is created by radioactive decay and temperatures may reach over 5000 °C (9,000 °F). Heat conducts from the core to surrounding cooler rock. The high temperature and pressure cause some rock to melt, creating magma convection upward since it is lighter than the solid rock. The magma heats rock and water in the crust, sometimes up to 370 °C (700 °F). Sources of Geo Thermal Energy:From hot springs, geothermal energy has been used for bathing since Paleolithic times and for space since ancient Roman times, but it is now better known for electricity generation. Worldwide, 11,400 megawatts (MW) of geothermal power is online in 24 countries in 2012. An additional 28 giga watts of direct geothermal heating capacity is installed for district heating, space heating, spas, industrial processes, desalination and agricultural applications in 2010.Geothermal power is cost effective, reliable, sustainable, and environmentally friendly, but has historically been limited to areas near tectonic plate boundaries. Recent technological advances have dramatically expanded the range and size of viable resources, especially for applications such as home heating, opening a potential for widespread exploitation. Geothermal wells release greenhouse gases trapped deep within the earth, but these emissions are much lower per energy unit than those of fossil fuels. As a result, geothermal power has the potential to help mitigate global warming if widely deployed in place of fossil fuels.The Earth's geothermal resources are theoretically more than adequate to supply humanity's energy needs, but only a very small fraction may be profitably exploited. Drilling and exploration for deep resources is very expensive. Forecasts for the future of geothermal power depend on assumptions about technology, energy prices, subsidies, and interest rates. Pilot programs like EWEB's customer opt in Green Power Program show that customers would be willing to pay a little more for a renewable energy source like geothermal. But as a result of government assisted research and industry experience, the cost of generating geothermal power has decreased by 25% over the past two decades. In 2001, geothermal energy cost between two and ten US cents per kWh.

Energy inside the Earth: Geothermal energy is generated in the earth's core, about4,000 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 anouter 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 thecontinents.
- 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.


GENERATING UNIT
DRILLING RIG
IMPERMEABLE CAPROCK
HOT SPRING OR FUMAROLE
WELL
CAP ROCK
INJECTION WELL
WATER FLOW
PERMEABLE ROCK
IMPERMEABLE BEDROCK
MAGMA (HEAT SOURCE)


Looking inside the Earth
land and sea
crust
mantle
outer core
inner core


Temperatures in the Earth
Temperatures in Fahrenheit
Depth in miles
1,250
7,200°
2,500
9,000°
4,000

Where Geo Thermal Energy is found: Most geothermal reservoirs are deep underground with no visible clues showing above ground Geothermal energy can sometimes find its way to the surface in the form of:

- 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. When magma comes close to the surface it heats ground water found trapped in porous rock or water running along fractured rock surfaces and faults. Such hydrothermal resources have two common ingredients: water (hydro) and heat (thermal). Naturally occurring large areas of hydrothermal resources are called geothermal reservoirs. Geologists use different methods to look for geothermal reservoirs. Drilling a well and testing the temperature deep underground is the only way to be sure a geothermal reservoir really exists.Most of the geothermal reservoirs in the United States are located in the western states,Alaska, and Hawaii. California is the state that generates the most electricity from geothermal energy. The Geysers dry steam reservoir in northern California is the largest known dry steam field in the world. The field has been producing electricity since 1960.



Advantages & Disadvantages of Geo Thermal Energy:

Advantages:

- Geothermal energy is renewable energy source. Geothermal energy is renewable energy source because earth's heat is being constantly replenished by the radioactive decay of minerals at a rate of 30 TW.
- Geothermal energy is clean source of energy because geothermal power plants are connected with minimum carbon emissions, with most of them are equipped with emission-control systems to reduce the exhaust of greenhouse gases carried by drawn fluids.
- Geothermal energy belongs to energy sources that can be directly used. Hot springs have been used for bathing since ancient times and in modern times geothermal energy is directly used to heat homes via geothermal heat pumps.
- Geothermal energy is reliable source of energy that does not suffer from intermittency issue like this is the case with some other renewable energy sources, most notably solar and wind. Geothermal heat is available 24-7 and is therefore one of the most reliable renewable energy sources, a one that does not require energy storage solution in order to work reliably.

- Geothermal power plants have minimal land and freshwater requirements unlike for instance solar energy which needs large area and plenty of water for cooling. Geothermal plants use only 3.5 square kilometers (1.4 sq mi) per gigawatt of electrical production and require just 20 liters of freshwater per MW/h.

Disadvantages:

- The biggest disadvantage of geothermal energy are high upfront costs, most of which refer to exploitation and drilling. Geothermal power plant construction and well drilling currently cost about €2-5 million per generated MW of electricity.
- Small number of countries that currently harness geothermal energy. Geothermal energy is currently being harnessed in only 24 countries of the world. The main reason why there aren't more countries involved is because geothermal power plants are currently cost-effective only in areas near tectonic plate boundaries though the recent technological advances such as EGS (enhanced geothermal systems) should significantly expand the range of viable geothermal resources in years to come.
- The lack of qualified personnel needed to install geothermal systems. Geothermal energy use isn't widely spread or as popular as this is the case with solar and wind, which means that there is less qualified personnel available to hire and they also cost more.
- Local depletion of geothermal resources. This has been the case in several well known geothermal sites such as Geysers. In order to avoid local depletion of geothermal resources extraction of geothermal energy must be closely monitored.
- Enhanced geothermal systems can trigger earthquakes therefore severely affecting land stability if not done carefully.

Uses of Geo thermal energy: Application of geothermal energy is to 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 Heat Systems: The direct use of hot water as an energy source has been happening from the ancient times like hot springs which are said to be mineral rich waters having natural healing powers. The most common use direct use of geothermal energy is for heating building through DISTRICT HEATING SYSTEM in which hot water near the earth surface can be piped into buildings and industries for heat.

2. Industrial uses: Dying of cloth, Washing wool, and piping under sidewalks to keep from freezing, manufacturing paper, Greenhouses, Spas Aquaculture: Fish, Shrimp, Abalone, and Alligators.

3. Electricity Generation: In a power plant requires water or steam at very high temperature (300 to 700 Fahrenheit). Geothermal power plants are generally built where geothermal reservoirs are located .A geothermal power station can provide a large amount of electricity

Geothermal Wells:A geothermal production well produces fluid heated by the natural heat of the earth. Geothermal fluids may be steam or hot water and in California have total dissolved solid concentrations of up to 250,000 parts per million (about seven times above sea water). Very hot geothermal fluids may be used for electrical power generation. Cooler (but still quite hot) geothermal fluids are used for projects such as space heating, aquaculture, snow melting, food processing, dehydration, and hot tubs and spas.

Harnessing Geothermal Energy

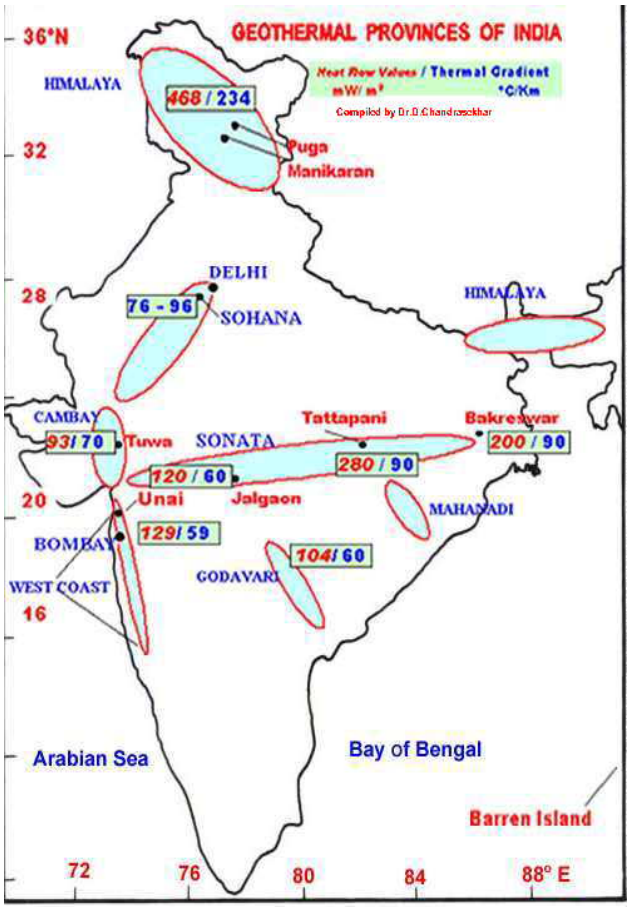
As society becomes more and more interested in the use of clean and renewable energy sources, convenient and affordable options are starting to surface. Clean, renewable sources come in many forms, through solar power, wind power, and even geothermal power. Geothermal power is a natural source that initially came from the origination of the earth. There are other

contributing factors to the inner earth's power, such as the shifting of tectonic plates, the decay of radioactive minerals and elements, as well as the energy generated from solar rays continuously striking the earth's crust. It is important to differentiate between geothermal energy and thermal energy. Geothermal energy is power that is generated within the earth, while thermal energy is generated through the heating and acceleration of molecules.Geothermal energy can be harnessed in many ways. The most popular are geothermal heat pumps, geothermal hot water, and geothermal hot dry rock. All of these things can be harnessed with the use of geothermal plants. The plants themselves, though, are not necessarily cost efficient yet. The plants themselves emit some pollution. Any drilling that is done can release noxious gases such as carbon dioxide and greenhouse gases. This is a contributing factor to the diminishing atmosphere as well as to acid rains.

While geothermal energy is not 100 percent clean, it is 100 percent renewable. The release of some greenhouse gases is still less than those emitted through the burning of fossil fuels, which are not renewable and extremely harsh on the environment. Many geothermal power plants do use extra processes to minimize the emission of pollutants. It has also been theorized that any toxic fluids emitted during the process of harnessing geothermal energy can be injected back into the earth's core, so they will not come in contact with the atmosphere. Geothermal hot water (hot springs are considered to be geothermal hot water) can be found underground and can be used many ways. It can be pumped directly into an application for hot water or it can be used to heat buildings, grow greenhouse plants, fish farming, and pasteurizing. For instance, water issued from hot springs is heated by the geothermal heat from the interior of the earth. The temperature of the earth's rocks increase with depth (known as a geothermal gradient.) If water reaches into the crust it comes in contact with these very hot rocks. The water from hot springs in non-volcanic areas is heated in this manner. Geothermal hot dry rock can also be used to generate electricity. Cracks and pores in the rock release geothermal energy which can be captured. If the rate of geothermal energy released is not sufficient for power generation, high-pressure cold water is pumped into the rock. The water captures the heat of the rock until it is forced out of the ground in the form of hot water. The water is then converted into electricity with either a steam turbine or a binary power plant system. While geothermal energy itself is renewable, geothermal sites are not necessarily. An overworked site, or one with an excessively large energy plant, can quickly be depleted. Geothermal power sites also need to be actively managed to minimize the release of greenhouse gases and toxic elements so as to limit the impact to the surrounding environment.

Potential in India: It has been estimated from geological, geochemical, shallow geophysical and shallow drilling data it is estimated that India has about 10,000 MWe of geothermal power potential that can be harnessed for various purposes. Rocks covered on the surface of India ranging in age from more than 4500 million years to the present day and distributed in different geographical units. The rocks comprise of Archean, Proterozoic, the marine and continental Palaeozoic, Mesozoic, Teritary, Quaternary etc., More than 300 hot spring locations have been identified by Geological survey of India (Thussu, 2000). The surface temperature of the hot springs ranges from 35 C to as much as 98 C. These hot springs have been grouped together and termed as different geothermal provinces based on their occurrence in specific geotectonic regions, geological and strutural regions such as occurrence in orogenic belt regions, structural grabens, deep fault zones, active volcanic regions etc., Different orogenic regions are – Himalayan geothermal province, Naga-Lushai geothermal province, Andaman-Nicobar Islands geothermal province and non-orogenic regions are – Cambay graben, Son-Narmada-Tapi graben, west coast, Damodar valley, Mahanadi valley, Godavari valley etc.

- Puga Valley (J&K)
- Tatapani (Chhattisgarh)
- Godavari Basin Manikaran (Himachal Pradesh)
- Bakreshwar (West Bengal)
- Tuwa (Gujarat)
- Unai (Maharashtra)
- Jalgaon (Maharashtra)



TYPES OF GEOTHERMAL HEAT PUMP SYSTEMS

There are four basic types of ground loop systems. Three of these -- horizontal, vertical, and pond/lake -- are closed-loop systems. The fourth type of system is the open-loop option. Which one of these is best depends on the climate, soil conditions, available land, and local installation costs at the site. All of these approaches can be used for residential and commercial building applications.

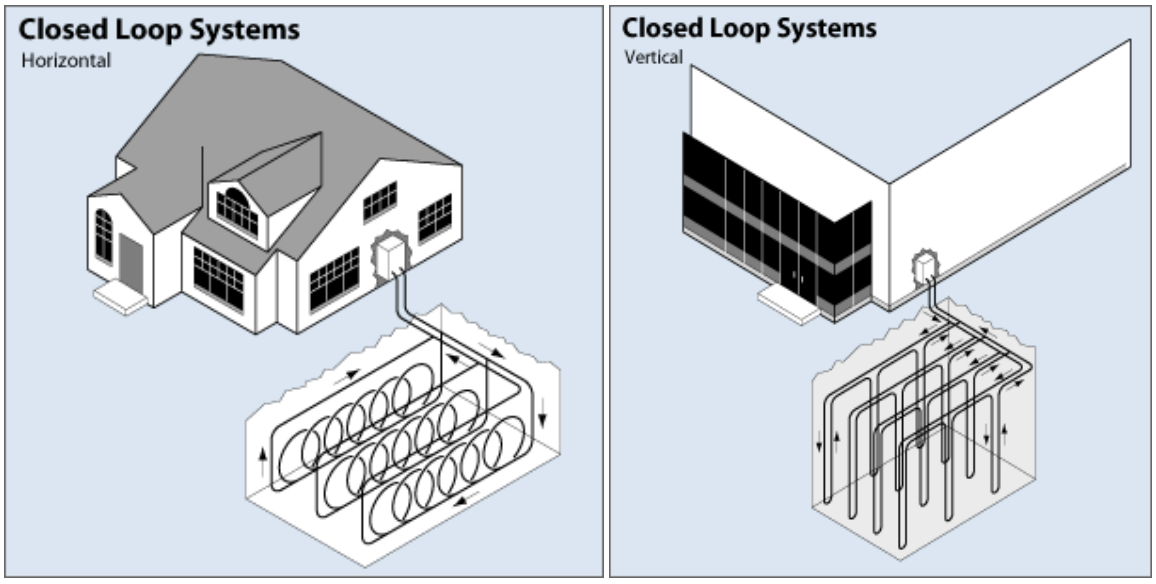
CLOSED-LOOP SYSTEMS

Most closed-loop geothermal heat pumps circulate an antifreeze solution through a closed loop -- usually made of plastic tubing -- that is buried in the ground or submerged in water. A heat exchanger transfers heat between the refrigerant in the heat pump and the antifreeze solution in the closed loop. The loop can be in a horizontal, vertical, or pond/lake configuration.One variant of this approach, called direct exchange, does not use a heat exchanger and instead pumps the refrigerant through copper tubing that is buried in the ground in a horizontal or vertical configuration. Direct exchange systems require a larger compressor and work best in moist soils (sometimes requiring additional irrigation to keep the soil moist), but you should avoid installing in soils corrosive to the copper tubing. Because these systems circulate refrigerant through the ground, local environmental regulations may prohibit their use in some locations.

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. The most common layouts either use two pipes, one buried at six feet, and the other at four feet, or two pipes placed side-by-side at five feet in the ground in a two-foot wide trench. The Slinky™ method of looping pipe allows more pipe in a shorter trench, which cuts down on installation costs

and makes horizontal installation possible in areas it would not be with conventional horizontal applications.

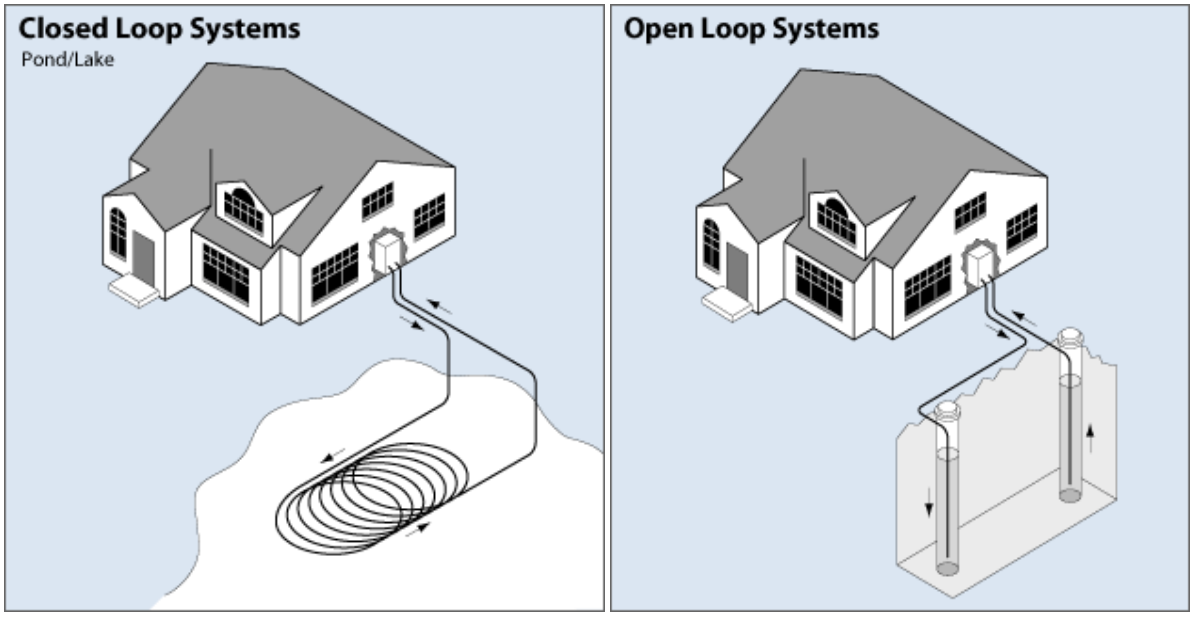


VERTICAL

Large commercial buildings and schools often use vertical systems because the land area required for horizontal loops would be prohibitive. Vertical loops are also used where the soil is too shallow for trenching, and they minimize the disturbance to existing landscaping. For a vertical system, holes (approximately four inches in diameter) are drilled about 20 feet apart and 100 to 400 feet deep. Into these holes go two pipes that are connected at the bottom with a U-bend to form a loop. The vertical loops are connected with horizontal pipe (i.e., manifold), placed in trenches, and connected to the heat pump in the building.

POND / LAKE

If the site has an adequate water body, this may be the lowest cost option. A supply line pipe is run underground from the building to the water and coiled 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 GHP 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 obviously practical only where there is an adequate supply of relatively clean water, and all local codes and regulations regarding groundwater discharge are met.

HYBRID SYSTEMS

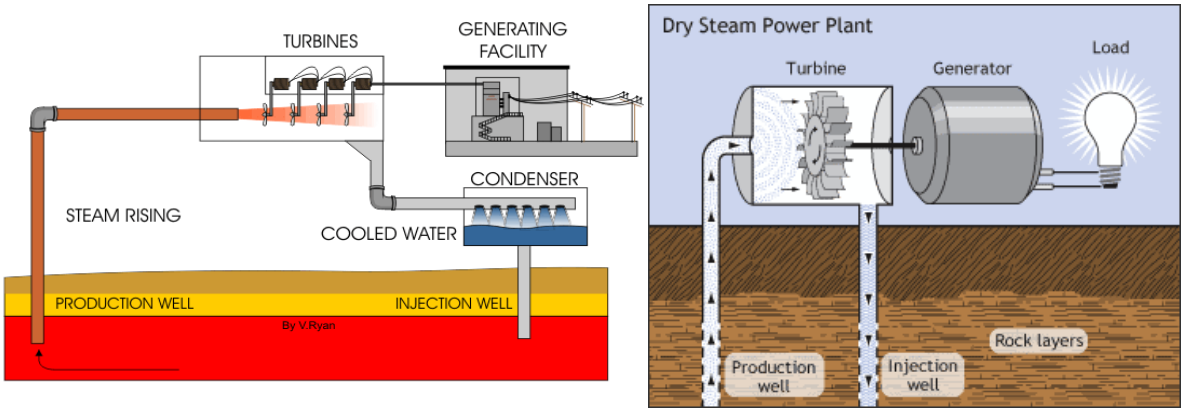
Hybrid systems using several different geothermal resources, or a combination of a geothermal resource with outdoor air (i.e., a cooling tower), are another technology option. Hybrid approaches are particularly effective where cooling needs are significantly larger than heating needs. Where local geology permits, the "standing column well" is another option. In this variation of an open-loop system, one or more deep vertical wells is drilled. Water is drawn from the bottom of a standing column and returned to the top. During periods of peak heating and cooling, the system can bleed a portion of the return water rather than reinjection it all, causing water inflow to the column from the surrounding aquifer. The bleed cycle cools the column during heat rejection, heats it during heat extraction, and reduces the required bore depth.

Types of Geo thermal Power Plants:

Dry Steam Power Plants:

Steam plants use hydrothermal fluids that are primarily steam. The steam goes 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!)

This is the oldest type of geothermal power plant. It was first used at Lardarello in Italy in 1904. Steam technology is used today at The Geysers in northern California, the world's largest single source of geothermal electricity. These plants emit only excess steam and very minor amounts of gases.

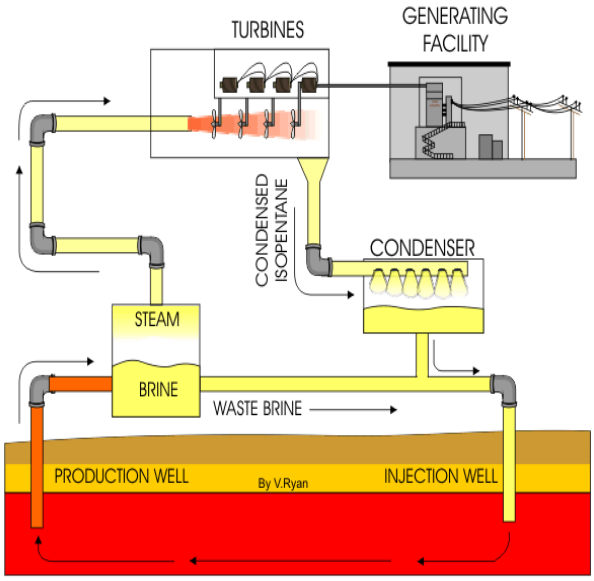


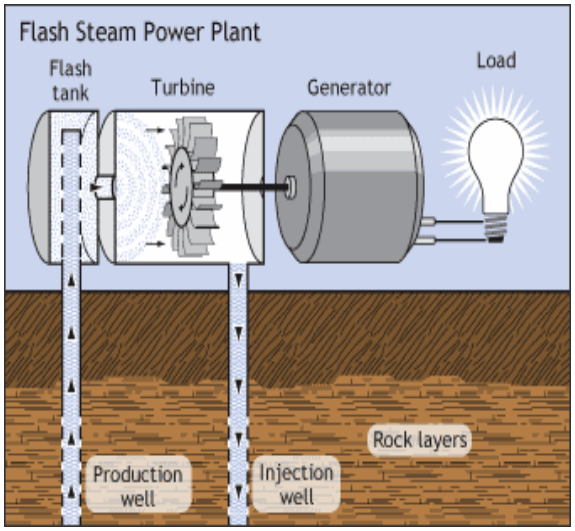
2.Flash and Double Flash Cycle

Hydrothermal fluids above 360°F (182°C) can be used in flash plants to make electricity.

Fluid is sprayed into a tank held at a much lower pressure than the fluid, causing some of the fluid to rapidly vaporize, or "flash." The vapor then drives a turbine, which drives a generator.

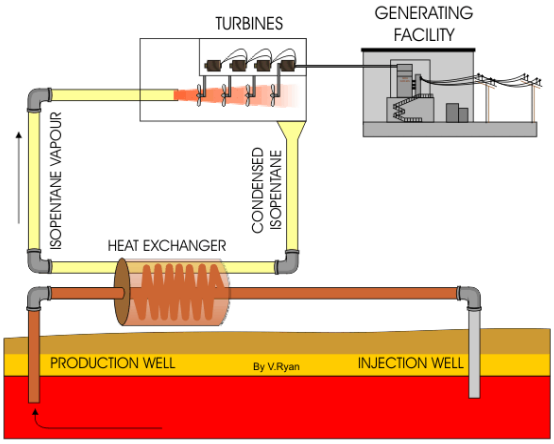
If any liquid remains in the tank, it can be flashed again in a second tank (double flash) to extract even more energy.

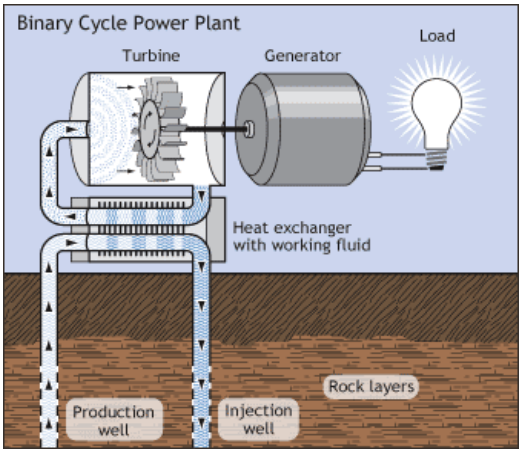




3.Binary Cycle power Plant

Most geothermal areas contain moderate-temperature water (below 400°F). Energy is extracted from these fluids in binary-cycle power plants. Hot geothermal fluid and a secondary (hence, "binary") fluid with a much lower boiling point than water pass through a heat exchanger. Heat from the geothermal fluid causes the secondary fluid to flash to vapor, which then drives the turbines.Because this is a closed-loop system, virtually nothing is emitted to the atmosphere. Moderate-temperature water is by far the more common geothermal resource, and most geothermal power plants in the future will be binary-cycle plants.





Biomass

Biomass Energy

The term "biomass" refers to organic matter that has stored energy through the process of photosynthesis. It exists in one form as plants and may be transferred through the food chain to animals' bodies and their wastes, all of which can be converted for everyday human use through processes such as combustion, which releases the carbon dioxide stored in the plant material. Many of the biomass fuels used today come in the form of wood products, dried vegetation, crop residues, and aquatic plants. Biomass has become one of the most commonly used renewable sources of energy in the last two decades, second only to hydropower in the generation of electricity. It is such a widely utilized source of energy, probably due to its low cost and indigenous nature, that it accounts for almost 15% of the world's total energy supply and as much as 35% in developing countries, mostly for cooking and heating.

Biomass is one of the most plentiful and well-utilised sources of renewable energy in the world. Broadly speaking, it is organic material produced by the photosynthesis of light. The chemical material (organic compounds of carbons) is stored and can then be used to generate energy. The most common biomass used for energy is wood from trees. Wood has been used by humans for producing energy for heating and cooking for a very long time.

Biomass has been converted by partial-pyrolisis to charcoal for thousands of years. Charcoal, in turn has been used for forging metals and for light industry for millennia. Both wood and charcoal formed part of the backbone of the early Industrial Revolution (much northern England, Scotland and Ireland were deforested to produce charcoal) prior to the discovery of coal for energy.

Wood is still used extensively for energy in both household situations, and in industry, particularly in the timber, paper and pulp and other forestry-related industries. Woody biomass accounts for over 10% of the primary energy consumed in Austria, and it accounts for much more of the primary energy consumed in most of the developing world, primarily for cooking and space heating.

It is used to raise steam, which, in turn, is used as a by-product to generate electricity. Considerable research and development work is currently underway to develop smaller gasifiers that would produce electricity on a small-scale. For the moment, however, biomass is used for off-grid electricity generation, but almost exclusively on a large-, industrial-scale.

For the production of energy from biomass, the term feedstock is used to refer to whatever type of organic material will be used to produce a form of energy. The feedstock must then be converted to a usable energy form through one of many processes.

Feedstock + Process -> Usable Energy Form

Some common biomass conversion processes include:

- **Combustion**: the process by which flammable materials are burned in the presence of air or oxygen to release heat. It is the simplest method by which biomass can be used for energy. In its rudimentary form, combustion is used for space heating (i.e. a fire for warmth) but can also be used to heat steam for electricity generation.

- **Gasification**: is the conversion of biomass into a combustible gas mixture referred to as Producer Gas (CO+H2+CH4) or Syngas. The gasification process uses heat, pressure and partial combustion to create syngas, which can then be used in place of natural gas.

- **Pyrolysis**: Consists of thermal decomposition in the absence of oxygen. It is the precursor to gasification, and takes place as part of both gasification and combustion [3]. The products of pyrolysis include gas, liquid and a sold char, with the proportions of each depending upon the parameters of the process.

- **Anaerobic digestion (or bio digestion**): is the process whereby bacteria break down organic material in the absence of air, yielding a biogas containing methane and a solid residue. The methane can then be captured to produce energy. Similarly, the solid residue can also be burned to produce energy.

- **Fermentation**: 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 (an alcohol) 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 can be used as a fuel for boilers or for subsequent gasification.

Some feedstocks are more conducive for certain biomass conversion processes than others. The determination of which feedstocks and processes will be used is determined largely by the availability of resources and the desired end form of energy.

Types of Biomass Fuels

Biomass fuels are organic materials produced in a renewable manner. Two categories of biomass fuels, woody fuels and animal wastes, comprise the vast majority of available biomass fuels. Municipal solid waste (MSW) is also a source of biomass fuel. Biomass fuels have low energy densities compared to fossil fuels. In other words, a significantly larger volume of biomass fuel is required to generate the same energy as a smaller volume of fossil fuel.

The low energy density means that the costs of fuel collection and transportation can quickly outweigh the value of the fuel. Biomass fuels are typically consumed on-site or transported short distances only (e.g., less than 50 miles). Biomass fuels tend to have a high moisture content, which adds weight and increases the cost of transportation. The moisture content also decreases combustion performance.

There are two primary factors to be considered in the evaluation of biomass fuels: Fuel supply, including the total quantities available, the stability of the supply or of the industry generating the fuel, and competitive uses or markets for the fuel. Cost of biomass fuel collection, processing, and transportation, and who pays these costs.

This section discusses three sources of biomass fuel: woody fuels, animal waste, and MSW. These discussions include the issues of fuel supply and costs. These fuels are summarized, along with their respective benefits and barriers, in Table 2 at the end of this section.

1. Woody Fuels

Wood wastes of all types make excellent biomass fuels and can be used in a wide variety of biomass technologies. Combustion of woody fuels to generate steam or electricity is a proven technology and is the most common biomass-to-energy process. Different types of woody fuels can typically be mixed together as a common fuel, although differing moisture content and chemical makeup can affect the overall conversion rate or efficiency of a biomass project. There are at least six subgroups of woody fuels. The differentiators between these subgroups mainly have to do with availability and cost. Forestry residues—in-forest woody debris and slash from logging and forest management activities. Mill residues—by-products such as sawdust, hog fuel, and wood chips from lumber mills, plywood manufacturing, and other wood processing facilities. Agricultural residues—by-products of agricultural activities including crop wastes, vineyard and orchard pruning's or turnings, and rejected agricultural products. Urban wood and yard wastes—residential organics collected by municipal programs or recycling centres and construction wood wastes. Dedicated biomass crops—trees, corn, oilseed rape, and other crops grown as dedicated feedstocks for a biomass project. Chemical recovery fuels (black liquor)—woody residues recovered out of the chemicals used to separate fiber for the pulp and paper industry.

2. Forestry Residues

Forestry residues have been the focus of many recent biomass studies and feasibility assessments due to increasing forest management and wildfire prevention activities under the National Fire Plan. The USDA Forest Service and the Bureau of Land Management have been tasked with reducing the hazardous fuel loading within the forests and the urban-wild land interface.

Forestry residues are typically disposed of by on-site (in-forest) stacking and burning. This results in substantial air emissions that affect not only the forest lands and nearby populations, but the overall regional air quality as well. Open burning can also cause water quality and erosion concerns. The Forest Service and other public and private land management entities would like to have viable alternatives for disposing of their forestry residues in a more environmentally benign manner.

3. Mill Residues

Mill residues are a much more economically attractive fuel than forestry residues, since the in-forest collection and chipping are already included as part of the commercial mill operations. Biomass facilities collocated with and integral to the mill operation have the advantage of eliminating transportation altogether and thus truly achieve a no-cost fuel. Mill residues have long been used to generate steam and electricity.

4. Agricultural Residues

Agricultural residues can provide a substantial amount of biomass fuel. Similar to the way mill residues provide a significant portion of the overall biomass consumption in the Pacific Northwest, agricultural residues from sugar cane harvesting and processing provide a significant portion of the total biomass consumption in other parts of the world. One significant issue with agricultural residues is the seasonal variation of the supply.

Large residue volumes follow harvests, but residues throughout the rest of the year are minimal. Biomass facilities that depend significantly on agricultural residues must either be able to adjust output to follow the seasonal variation, or have the capacity to stockpile a significant amount of fuel.

5. Urban Wood and Yard Wastes

Urban wood and yard wastes are similar in nature to agricultural residues in many regards. A biomass facility will rarely need to purchase urban wood and yard wastes, and most likely can charge a tipping fee to accept the fuel.

Many landfills are already sorting waste material by isolating wood waste. This waste could be diverted to a biomass project, and although the volume currently accepted at the landfills would not be enough on its own to fuel a biomass project, it could be an important supplemental fuel and could provide more value to the community in which the landfill resides through a biomass project than it currently does as daily landfill cover.

6. Dedicated Biomass Crops

Dedicated biomass crops are grown specifically to fuel a biomass project. The most prevalent example of dedicated biomass crops are corn varieties grown for ethanol production. Fast-growing poplar trees have also been farm-raised for a biomass fuel, but this has not proven to be economically sustainable. Another dedicated crop example is soybean oils used in the production of biodiesel.

7. Chemical Recovery Fuels

Chemical recovery fuels are responsible for over 60 percent of the total biomass energy consumption of the United States, and therefore must be mentioned in any analysis of biomass. By and large, the chemical recovery facilities are owned by pulp and paper facilities and are an integral part of the facility operation.

8. Animal Wastes

Animal wastes include manures, renderings, and other wastes from livestock finishing operations. Although animal wastes contain energy, the primary motivation for biomass processing of animal wastes is mitigation of a disposal issue rather than generation of energy. This is especially true for animal manures. Animal manures are typically disposed of through land application to farmlands. Tightening regulations on nutrient management, surface and groundwater contamination, and odour control are beginning to force new manure management and disposal practices. Biomass technologies present attractive options for mitigating many of the environmental challenges of manure wastes. The most common biomass technologies for animal manures are combustion, anaerobic digestion, and composting. Moisture content of the manure and the amount of contaminants, such as bedding, determine which technology is most appropriate.

9. Dry Animal Manure

Dry animal manure is produced by feedlots and livestock corrals, where the manure is collected and removed only once or twice a year. Manure that is scraped or flushed on a more frequent schedule can also be separated,

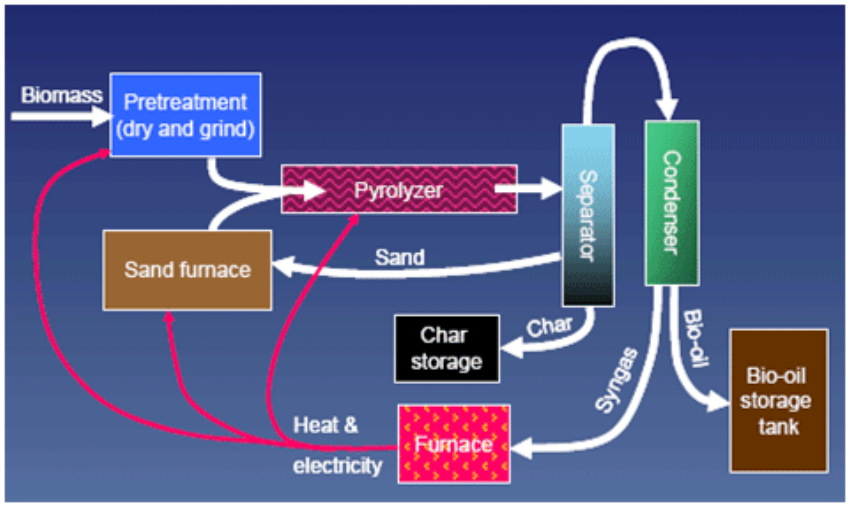
stacked, and allowed to dry. Dry manure is typically defined as having moisture content less than 30 percent. Dry manure can be composted or can fuel a biomass-to-energy combustion project.

Animal manure does have value to farmers as fertilizer, and a biomass-to-energy project would need to compete for the manure. However, the total volume of manure produced in many livestock operations exceeds the amount of fertilizer required for the farmlands, and Nutrient Management Plans are beginning to limit the over-fertilization of farmlands. Therefore, although there are competitive uses for the manure and low-cost disposal options at this time, manure disposal is going to become more costly over time, and the demand for alternative disposal options, including biomass-to-energy, will only increase.

10. Wet Animal Manure (Dairy Manure Slurry)

Wet animal manure is typically associated with larger and more modern dairy operations that house their milking cows in free-stall barns and use a flush system for manure collection. The combination of free-stall barns and manure flushing collects all of the milking cow manure with every milking cycle, two or three times a day. The manure is significantly diluted through the addition of the flush water, but after separation of some of the flush water, the slurry is an excellent fuel.

Biomass Pyrolysis



Biomass 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.

The pyrolysis process consists of both simultaneous and successive reactions when organic material is heated in a non-reactive atmosphere. Thermal decomposition of organic components in biomass starts at 350 °C–550 °C and goes up to 700 °C–800 °C in the absence of air/oxygen. The long chains of carbon, hydrogen and oxygen compounds in biomass break down into smaller molecules in the form of gases, condensable vapours (tars and oils) and solid charcoal under pyrolysis conditions. Rate and extent of

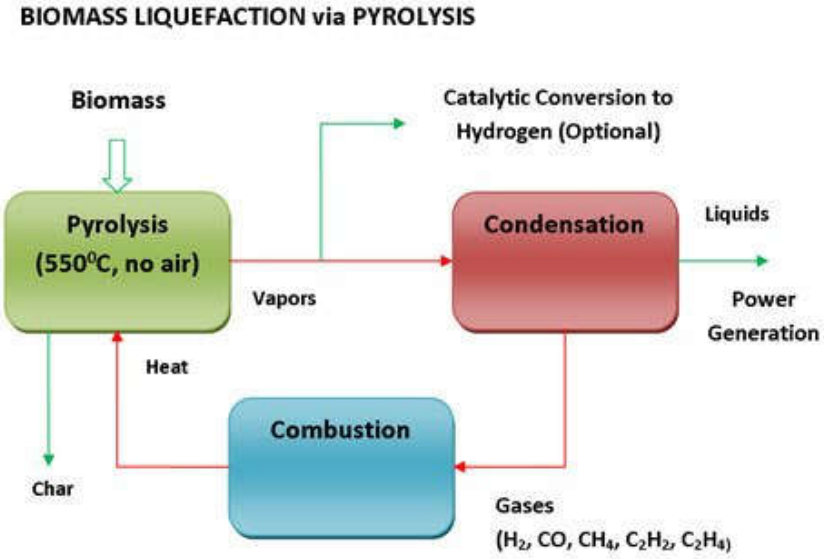
decomposition of each of these components depends on the process parameters of the reactor temperature, biomass heating rate, pressure, reactor configuration, feedstock etc

Depending on the thermal environment and the final temperature, pyrolysis will yield mainly biochar at low temperatures, less than 450 ^{0}C, when the heating rate is quite slow, and mainly gases at high temperatures, greater than 800 ^{0}C, with rapid heating rates. At an intermediate temperature and under relatively high heating rates, the main product is bio-oil.

Slow and Fast Pyrolysis

Pyrolysis processes can be categorized as slow or fast. 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 is currently the most widely used pyrolysis system.
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 500^{o}C 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.



Advantages of Biomass Pyrolysis

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. Biomass pyrolysis offers a flexible

and attractive way of converting organic matter into energy products which can be successfully used for the production of heat, power and chemicals.

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.

Biomass pyrolysis has been garnering 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.

Biomass Combustion Technologies

Direct combustion is the best established and most commonly used technology for converting biomass to heat. During combustion, biomass fuel is burnt in excess air to produce heat. The first stage of combustion involves the evolution of combustible vapours from the biomass, which burn as flames. The residual material, in the form of charcoal, is burnt in a forced air supply to give more heat. The hot combustion gases are sometimes used directly for product drying, but more usually they are passed through a heat exchanger to produce hot air, hot water or steam.

The combustion efficiency depends primarily on good contact between the oxygen in the air and the biomass fuel. The main products of efficient biomass combustion are carbon dioxide and water vapor, however tars, smoke and alkaline ash particles are also emitted. Minimization of these emissions and accommodation of their possible effects are important concerns in the design of environmentally acceptable biomass combustion systems.

Underfeed Stokers Biomass is fed into the combustion zone from underneath a firing grate. These stoker designs are only suitable for small scale systems up to a nominal boiler capacity of 6 MW_{th} and for biomass fuels with low ash content, such as wood chips and sawdust. High ash content fuels such as bark, straw and cereals need more efficient ash removal systems. Sintered or molten ash particles covering the upper surface of the fuel bed can cause problems in underfeed stokers due to unstable combustion conditions when the fuel and the air are breaking through the ash covered surface.

Grate Stokers The most common type of biomass boiler is based on a grate to support a bed of fuel and to mix a controlled amount of combustion air, which often enters from beneath the grate. Biomass fuel is added at one end of the grate and is burned in a fuel bed which moves progressively down the grate, either via gravity or with mechanical assistance, to an ash removal system at the other end. In more sophisticated designs this allows the overall combustion process to be separated into its three main activities:

- Initial fuel drying
- Ignition and combustion of volatile constituents
- Burning out of the char.

Grate stokers are well proven and reliable and can tolerate wide variations in fuel quality (i.e. variations in moisture content and particle size) as well as fuels with high ash content. They are also controllable and efficient.

Fluidized Bed Boilers The basis for a fluidized bed combustion system is a bed of an inert mineral such as sand or limestone through which air is blown from below. The air is pumped through the bed in sufficient volume and at a high enough pressure to entrain the small particles of the bed material so that they behave much like a fluid. The combustion chamber of a fluidized bed plant is shaped so that above a certain height the air velocity drops below that necessary to entrain the particles. This helps retain the bulk of the entrained bed material towards the bottom of the chamber. Once the bed becomes hot, combustible material introduced into it will burn, generating heat as in a more conventional furnace. The proportion of combustible material such as biomass within the bed is normally only around 5%. The primary driving force for development of fluidized bed combustion is reduced SO2 and NOx emissions from coal combustion.

Bubbling fluidized bed (BFB) combustors are of interest for plants with a nominal boiler capacity greater than 10 MW_{th}. Circulating fluidized bed (CFB) combustors are more suitable for plants larger than 30 MW_{th}. The minimum plant size below which CFB and BFB technologies are not economically competitive is considered to be around 5-10 MW_e.

BIOGAS:

Biogas is methane produced by the process of anaerobic digestion of organic material by anaerobes. It can be produced either from biodegradable waste materials or by the use of energy crops fed into anaerobic digesters to supplement gas yields. The solid byproduct, digestate, can be used as a biofuel or a fertilizer. Engineered to produce butanol by hijacking their amino acid metabolism. Biogas can be recovered from mechanical biological treatment waste processing systems. Note: Landfill gas, a less clean form of biogas, is produced in landfills through naturally occurring anaerobic digestion. If it escapes into the atmosphere, it is a potential greenhouse gas. Farmers can produce biogas from manure from their cattle by using anaerobic digesters

Factors affecting Biogas production:
1. Substrate temperature 2. pH level 3. Mixing Ratio 4. Loading Rate 5. Hydraulic Retention time 6. Nitrogen inhibition 7. C/N ratio 8. Agitation 9. Toxicity 10. Solid concentration 11. Seeding 12. Metal Cations 13. Particle size 14. Additives 15. Heating

Benefits Of Biogas Technology:

- ✓ Production of energy.
- ✓ Transformation of organic wastes to very high quality fertilizer.
- ✓ Improvement of hygienic conditions through reduction of pathogens.
- ✓ Environmental advantages through protection of soil, water, air etc. Micro-economical benefits by energy and fertilizer substitutes. Macro-economical benefits through decentralizes energy generation and environmental protection.

Main types of simple biogas plants:

- ❖ balloon plants,
- ❖ fixed-dome plants,
- ❖ floating-drum plants

Balloon Plants:

A balloon plant consists of a plastic or rubber digester bag, in the upper part of which the gas is stored. The inlet and outlet are attached direct to the skin of the balloon. When the gas space is full,the plant works like a fixed-dome plant - i.e., the balloon is not inflated; it is not very elastic. The fermentation slurry is agitated slightly by the movement of the balloon skin. This is favorable to the digestion process. Even difficult feed materials, such as water hyacinths, can be used in a balloon plant. The balloon material must be UV-resistant.

Materials which have been used successfully include RMP (red mud plastic), Trevira and buty.

Advantages:

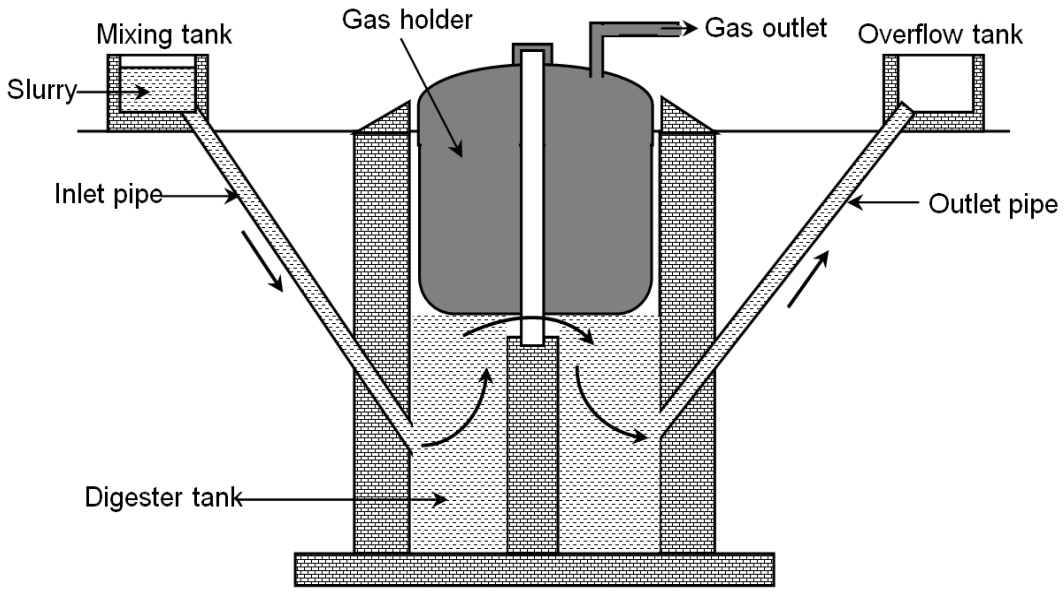
Low cost, ease of transportation, low construction (important if the water table is high), high digester temperatures, uncomplicated cleaning, emptying and maintenance.

Disadvantages:

Short life (about five years), easily damaged, and does not create employment locally, little scope for self-help. Balloon plants can be recommended wherever the balloon skin is not likely to be damaged and where the temperature is even and high. One variant of the balloon plant is the channel-type digester with folia and sunshade.

FLOATING GAS HOLDER TYPE BIOGAS PLANT

The floating gas holder type bio gas plant consists of a dome shaped gas holder made of steel for collecting bio gas. The dome shaped gas holder is not fixed but is moveable and floats over the slurry present in the digester tank. Due to this reason, this biogas plant is called floating gas holder type biogas plant.



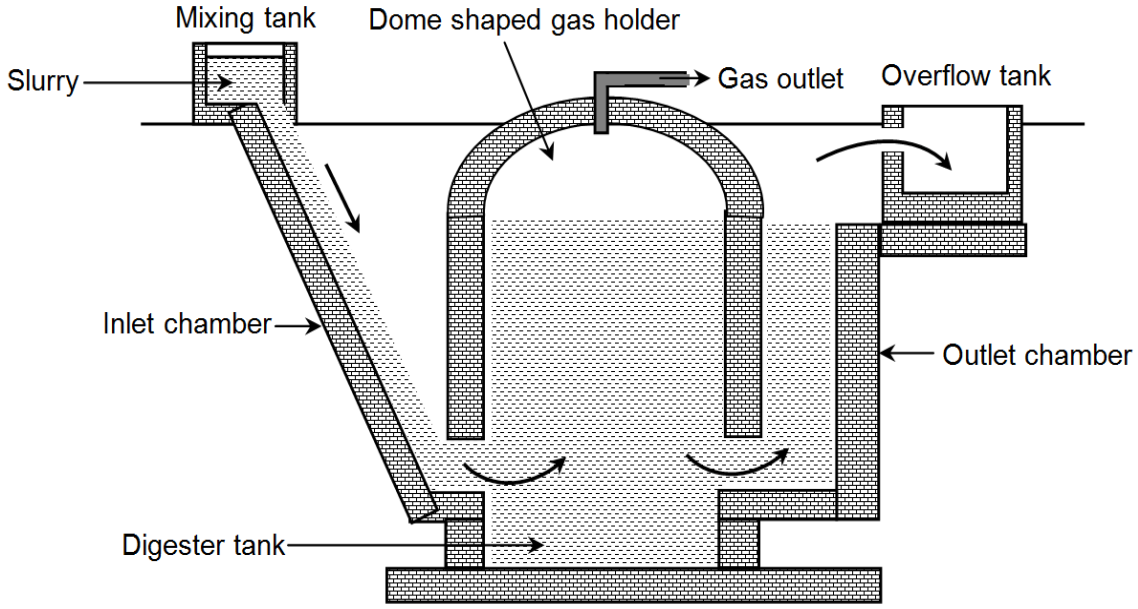
Slurry is prepared by mixing water in cattle dung in equal proportion in mixing tank. The slurry is then injected into a digester tank with the help of inlet pipe. The digester tank is a closed underground tank made up of bricks. Inside the digester tank, the complex carbon compounds present in the cattle dung breaks into simpler substances by the action of anaerobic microorganisms in the presence of water. This anaerobic decomposition of complex carbon compounds present in cattle dung produces bio gas and gets completed in about 60 days. The bio gas so produced starts to collect in floating gas holder and is supplied to homes through pipes. And the spent

slurry is replaced from time to time with fresh slurry to continue the production of bio gas.

FIXED DOME TYPE BIOGAS PLANT

The fixed dome type bio gas plant consists of a closed underground digester tank made up of bricks which has a dome shaped roof also made up of bricks. This dome shape roof of the digester tank functions as gas holder and has an outlet pipe at the top to supply gas to homes.

Slurry is prepared by mixing water in cattle dung in equal proportion in mixing tank. The slurry is then sent into the digester tank with the help of inlet chamber. It should be noted that slurry is fed into the digester tank up to the point where the dome of the roof starts. Inside the digester tank, the complex carbon compounds present in the cattle dung breaks into simpler substances by the action of anaerobic microorganisms in the presence of water. This anaerobic decomposition of complex carbon compounds present in cattle dung produces bio gas and gets completed in about 60 days. The bio gas so produced starts to collect in dome shaped roof of bio gas plant and is supplied to homes through pipes. The spent slurry is replaced from time to time with fresh slurry to continue the production of bio gas.



Size and Site Selection for Biogas plant

Sizing of biogas plant follows based on three parameters namely

- **Daily feed, Retention time and Digester volume**

The biogas plant size is dependent on the average daily feed stock and expected hydraulic retention time of the material in the biogas system. Capacity of the plant should be designed based on the availability of raw materials. Capacity of the plant indicates the quantity of gas produced in a day. Based on the study, 1 kg of cow dung along with equal quantity of water (1:1) under anaerobic conditions in a day produces 0.04 m^3 or 40 litres of biogas. Based on the availability of cow dung, the capacity of biogas plant to be constructed can be calculated as follows

Example

i. 1 cow will yield an average of 10 kg of cow dung in a day. Assume a house is having 3 cows. Our objective is to calculate the capacity of the plant to be constructed.

ii. 3 cow x 10 kg/cow/day = 30 kg of cow dung/day 1 kg of cow dung will yield 0.04 m^3 or 40 litres of biogas. So 30 kg will produce 30x 40 = 1200 litres or 1.2 m^3 of gas in a day. So the capacity of the plant to be constructed will be 1 m^3.

Example

To produced 1 m^3 of gas in a day, quantity of cow dung required can be calculated as

1 m^3/ (0.04 m^3/kg of cow dung) = 25 kg of dung.

When a biogas plant is underfed the gas production will be low; in this case, the pressure of the gas might not be sufficient to fully displace the slurry in the outlet chamber. If too much material is fed into the digester and the volume of gas is consumed, the slurry may enter the gas pipe and to the appliances.

Table shows the quantity of cow dung required for different plant capacities.

Plant Size (m^3)	Daily dung required/day (kg)	Quantity of water required (litres)
1	25	25
2	50	50
3	75	75
4	100	100
6	150	150
8	200	200
10	250	250

Scaling of the digester

The size of the digester i.e. the digester volume is determined by the length of the retention time and by the amount of fermentation slurry supplied daily.

The amount of fermentation slurry consists of the feed material (e.g., cattle dung) and the mixing water. ***Example***

25 kg of cow dung + 25 l water = 50 l fermentation slurry The digester volume is calculated by the formula

Digester volume (l) = Daily feed (l/day) x Retention time (days)

Assuming the Retention time to be 40 days, then the digester volume can be calculated by

Digester volume = 50 (l/day) x 40 (days) = 2000 l or 2 m^3

Selection of construction site

Selection of construction sites are mainly governed by the following factors:

- The site should facilitate easy construction works.
- The selected site should be such that the construction cost is minimized
- The selected site should ensure easy operation and maintenance activities like feeding of plant, use of main gas valve, composing and use of slurry, checking of gas leakage, draining condensed water from pipeline etc.
- The site should guarantee plant safety.
- To make plant easier to operate and avoid wastage of raw materials, especially the dung/swine manure, plant must be as close as possible to the cattle shed.
- The site should be in slightly higher elevation than the surrounding. This helps in avoiding water logging. This also ensures free flow of slurry from overflow outlet to the composting pit.
- For effective functioning of bio-digesters, right temperature (20-35°C) has to be maintained inside the digester. Therefore it is better to avoid damp and cool place

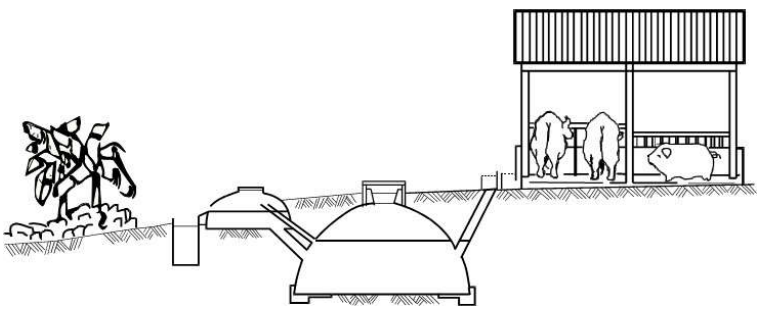
– Sunny site is preferable.

- To mix dung and water or flush swine manure to the digester, considerable quantity of water is required. If water source is far, the burden of fetching water becomes more.
- The well or ground water source should be at least 10 meter away from the biodigester especially the slurry pit to avoid the ground water pollution.
- If longer gas pipe is used the cost will be increased as the conveyance system becomes costly. Furthermore, longer pipeline increases the risk of gas leakage. The main gas valve which is fitted just above the gas holder should be opened

and closed before and after the use of biogas. Therefore the plant should be as near to the point of application as possible.

- The site should be at sufficient distance from trees to avoid damage of bio-digester from roots.
- Type of soil should have enough bearing capacity to avoid the possibility of sinking of structure.

Location of biogas plant



A biogas plant should not be located further than 5 meters from the field. The digester chamber must be in an open area and should not be near any water source or natural water as animal excrement may seep into underground water. The plant should also be situated on a slope and not on the low land to avoid the danger of floods. The excess manure from expansion chamber should flow into the farmer's field or the storage tank and not into natural water bodies such as rivers to avoid the risk of pollution

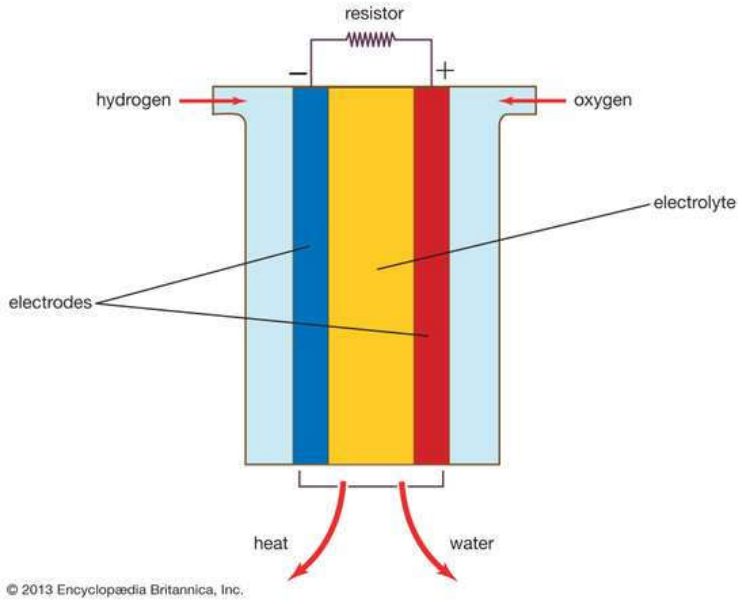
Fuel cells:

Fuel cell, any of a class of devices that convert the chemical energy of a fuel directly into electricity by electrochemical reactions. A fuel cell resembles a battery in many respects, but it can supply electrical energy over a much longer period of time. This is because a fuel cell is continuously supplied with fuel and air (or oxygen) from an external source, whereas a battery contains only a limited amount of fuel material and oxidant that are depleted with use. For this reason fuel cells have been used for decades in space probes, satellites, and manned spacecraft. Around the world thousands of stationary fuel cell systems have been installed in utility power plants, hospitals, schools, hotels, and office buildings for both primary and backup power; many waste-treatment plants use fuel cell technology to generate power from the methane gas produced by decomposing garbage. Numerous municipalities in Japan, Europe, and the United States lease fuel cell vehicles for public transportation and for use by service personnel. Personal fuel cell vehicles were first sold in Germany in 2004.

The United States government and several state governments, most notably California, have launched programs to encourage the development and use of hydrogen fuel cells in transportation and other applications. While the technology has proven to be workable, efforts to make it commercially competitive have been less successful because of concern with the explosive power of hydrogen, the relatively low energy density of hydrogen, and the high cost of platinum catalysts used to create an electric current by separating electrons from hydrogen atoms.

Principles Of Operation : From chemical energy to electrical energy

A fuel cell (actually a group of cells) has essentially the same kinds of components as a battery. As in the latter, each cell of a fuel cell system has a matching pair of electrodes. These are the anode, which supplies electrons, and the cathode, which absorbs electrons. Both electrodes must be immersed in and separated by an electrolyte, which may be a liquid or a solid but which must in either case conduct ions between the electrodes in order to complete the chemistry of the system. A fuel, such as hydrogen, is supplied to the anode, where it is oxidized, producing hydrogen ions and electrons. An oxidizer, such as oxygen, is supplied to the cathode, where the hydrogen ions from the anode absorb electrons from the latter and react with the oxygen to produce water. The difference between the respective energy levels at the electrodes (electromotive force) is the voltage per unit cell. The amount of electric current available to the external circuit depends on the chemical activity and amount of the substances supplied as fuels. The current-producing process continues for as long as there is a supply of reactants, for the electrodes and electrolyte of a fuel cell, unlike those in a regular battery, are designed to remain unchanged by chemical reaction.



A typical fuel cell.

A practical fuel cell is necessarily a complex system. It must have features to boost the activity of the fuel, pumps and blowers, fuel-storage containers, and a variety of sophisticated sensors and controls with which to monitor and adjust the operation of the system. The operating capability and lifetime of each of these system design features may limit the performance of the fuel cell.

As in the case of other electrochemical systems, fuel cell operation is dependent on temperature. The chemical activity of the fuels and the value of the activity promoters, or catalysts, are reduced by low temperatures (e.g., 0 °C, or 32 °F). Very high temperatures, on the other hand, improve the activity factors but may reduce the functioning lifetime of the electrodes, blowers, construction materials, and sensors. Each type of fuel cell thus has an operating-temperature design range, and a significant departure from this range is likely to diminish both capacity and lifetime.

A fuel cell, like a battery, is inherently a high-efficiency device. Unlike internal-combustion machines, in which a fuel is burned and gas is expanded to do work, the fuel cell converts chemical energy directly into electrical energy. Because of this fundamental characteristic, fuel cells may convert fuels to useful energy at an efficiency as high as 60 percent, whereas the internal-combustion engine is limited to efficiencies near 40 percent or less. The high efficiency means that much less fuel and a smaller storage container are needed for a fixed energy requirement. For this reason, fuel cells are an attractive power supply for space missions of limited duration and for other situations where fuel is very expensive and difficult to supply. They also emit no noxious gases such as nitrogen dioxide and produce virtually no noise during operation, making them contenders for local municipal power-generation stations.

A fuel cell can be designed to operate reversibly. In other words, a hydrogen-oxygen cell that produces water as a product can be made to regenerate hydrogen and oxygen. Such a regenerative fuel cell entails not only a revision of electrode design but also the introduction of special means for separating the product gases. Eventually, power modules comprising this type of high-efficiency fuel cell, used in conjunction with large arrays of thermal collectors for solar heating or other solar energy systems, may be utilized to keep energy-cycle costs lower in longer-lived equipment. Major automobile companies and electrical-machinery manufacturing companies worldwide have announced their intention to produce or use fuel cells commercially in the next few years.

Types Of Fuel Cells

Various types of fuel cells have been developed. They are generally classified on the basis of the electrolyte used, because the electrolyte determines the operating temperature of a system and in part the kind of fuel that can be employed.

Alkaline fuel cells

These are devices that, by definition, have an aqueous solution of sodium hydroxide or potassium hydroxide as the electrolyte. The fuel is almost always hydrogen gas, with oxygen (or oxygen in air) as the oxidizer. However, zinc or aluminum could be used as an anode if the by-product oxides were efficiently removed and the metal fed continuously as a strip or as a powder. Fuel cells generally operate at less than 100 °C (212 °F) and are constructed of metal and certain plastics. Electrodes are made of carbon and a metal such as nickel. Water, as a reaction product, must be removed from the system, usually by evaporation from the electrolyte either through the electrodes or in a separate evaporator. The operating support system presents a significant design problem. The strong, hot alkaline electrolyte attacks most plastics and tends to penetrate structural seams and joints. This problem has been overcome, however, and alkaline fuel cells are used on the U.S. space shuttle orbiters. Overall efficiencies range from 30 to 80 percent, depending on the fuel and oxidizer and on the basis for the calculation.

Phosphoric acid fuel cells

Such cells have an orthophosphoric acid electrolyte that allows operation up to about 200 °C (400 °F). They can use a hydrogen fuel contaminated with carbon dioxide and an oxidizer of air or oxygen. The electrodes consist of catalyzed carbon and are arranged in pairs set back-to-back to create a series generation circuit. The framing structure for this assembly of cells is made of graphite, which markedly raises the cost. The higher temperature and aggressive hot phosphate create structural design problems, particularly for joints, supporting pumps, and sensors. Phosphoric acid fuel cells have been proposed and tested on a limited scale for local municipal power stations and for remote-site generators.

Molten carbonate fuel cells

Fuel cells of this type operate quite differently from those so far discussed. The fuel consists of a mixture of hydrogen and carbon monoxide generated from water and a fossil fuel. The electrolyte is molten potassium lithium carbonate, which requires an operating temperature of about 650 °C (1,200 °F). Warming up to operational temperatures may take several hours, making these cells unsuitable for vehicles. In most cases, the electrodes are metallic-based, and the containment system is made of metals and special engineering plastics. Such combinations of materials are anticipated to be relatively inexpensive, perhaps only three times that of the alkaline fuel cell and less than that of the phosphoric acid variety. The cells combine the hydrogen and carbon monoxide first with the carbonate electrolyte and then with oxidizing oxygen to produce a reaction product of water vapour and carbon dioxide.

Molten carbonate fuel cells are expected to be useful in both local and larger power stations. Efficiencies of 45 percent may be attained where fossil fuels are already used. Operation at high temperatures creates a design problem for long-lived system parts and joints, especially if the cells must be heated and cooled frequently. The toxic fuel and high temperature together make power plant safety an area of special concern in engineering design and testing as well as in commercial operation.

Solid oxide fuel cells

In some ways solid oxide fuel cells are similar to molten carbonate devices. Most of the cell materials, however, are special ceramics with some nickel. The electrolyte is an ion-conducting oxide such as zirconia treated with yttria. The fuel for these experimental cells is expected to be hydrogen combined with carbon monoxide, just as for molten carbonate cells. While internal reactions would be different in terms of path, the cell products would be water vapour and carbon dioxide. Because of the high operating temperatures (900 to 1,000 °C, or 1,600 to 1,800 °F),

the electrode reactions proceed very readily. As in the case of the molten carbonate fuel cell, there are many engineering challenges involved in creating a long-lived containment system for cells that operate at such a high-temperature range.

Solid oxide fuel cells would be designed for use in central power-generation stations where temperature variation could be controlled efficiently and where fossil fuels would be available. The system would in most cases be associated with the so-called bottoming steam (turbine) cycle—i.e., the hot gas product (at 1,000 °C) of the fuel cell could be used to generate steam to run a turbine and extract more power from heat energy. Overall efficiencies of 60 percent might be possible.

Solid polymer electrolyte fuel cells

A cell of this sort is built around an ion-conducting membrane such as Nafion (trademark for a perfluorosulfonic acid membrane). The electrodes are catalyzed carbon, and several construction alignments are feasible. Solid polymer electrolyte cells function well (as attested to by their performance in Gemini spacecraft), but cost estimates are high for the total system compared with the types described above. Engineering or electrode design improvements could change this disadvantage.

Characteristics of Fuel Cells

Reversible fuel cells will deliver to a load a voltage, VL = Vrev, which is independent of the current generated. Their V-I characteristic is a horizontal line. Such ideal cells require reaction kinetics fast enough to supply electrons at the rate demanded by the current drawn. Clearly, reversible cells cannot be realized. In practical fuel cells, two major deviations from the ideal are observed:

1. The open-circuit voltage, Voc, is smaller than Vrev.

2. The load voltage, VL, decreases as the load current, IL, increases.

Frequently, the V-I characteristics approaches a straight line with some curvature at low currents as, for example, those of Figure 9.26 (left), while other cells exhibit characteristics in which the linearity can be seen only in a limited region (right).

To facilitate fuel cell performance calculations, it is useful to express the cell's characteristics in a mathematical form, that is, to describe the load voltage, VL, as an analytical function of the load current, IL,

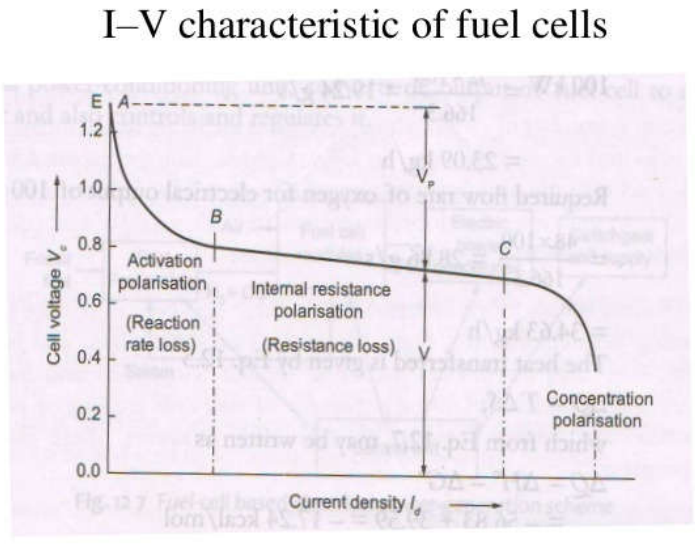


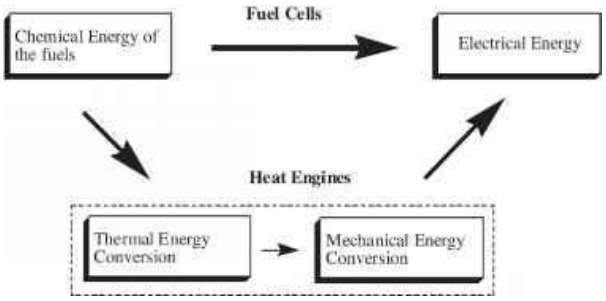
Figure 9.26 The typical modern fuel cell tends to have V-I characteristics consisting of a long stretch of apparently linear relationship between current and voltage, with a small curvature at the low current end (left, above). The small Engelhard liquid-electrolyte

demonstration cell had a limited region in which voltage decreases linearly with current. At both lower and higher currents, the V-I characteristic exhibited marked curvature (right, above).

The typical modern fuel cell tends to have V-I characteristics consisting of a long stretch of apparently linear relationship between current and voltage, with a small curvature at the low current end (left, above). The small Engelhard liquid-electrolyte demonstration cell had a limited region in which voltage decreases linearly with current. At both lower and higher currents, the V-I characteristic exhibited marked curvature (right, above).

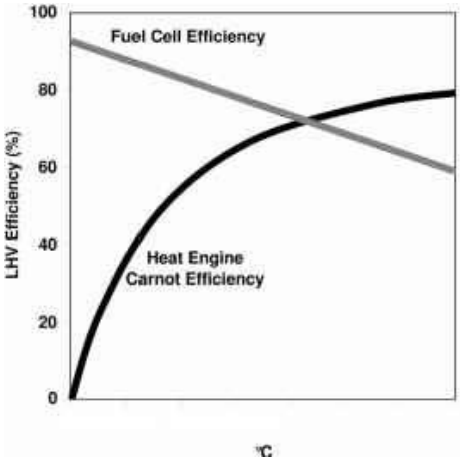
One way to accomplish this is to fit, empirically, a curve to the observed data, that is, to treat the cell as a black box without inquiring what is happening internally. It turns out that good fits can, in general, be achieved. They describe accurately what the load voltage is for a given load current, as long as such parameters as temperatures and pressures are the same as those used in obtaining the data. However, such empirically obtained mathematical expressions fail to provide adequate insight on the workings of the fuel cell, and, thus, they provided limited guidance as how to improve its design. For that, one must be able to interpret the relationship between the empirical parameters and the physical processes inside the cell.

Fuel Cell Efficiency



In contrast to heat engines (gasoline and diesel engines), the fuel cell does not involve conversion of heat to mechanical energy and the overall thermodynamic efficiencies can be very high.

Fuel cells, therefore, are considered as very efficient electrical energy-producing devices with high power densities at relatively low temperatures. The possible applications of fuel cells are numerous, from micro fuel cells producing only a few.



Since fuel cells use materials that are typically burnt to release their energy, y the fuel cell efficiency is described as the ratio of the electrical energy produced to the heat that is produced by burning the fuel (its enthalpy of formation or Δhf). From the basic definition of efficiency: η = W / Qin where W is given by ΔG (or NFE) Qin is the enthalpy of formation of the reaction taking place. Since two values can often be computed depending on the state of the reactant, the larger of the two values (higher "higher heating value) ") is used (HHV).

$$\eta = \frac{\Delta G}{HHV} = \frac{NFE}{HHV}$$

Maximum Fuel Cell Efficiency

The maximum efficiency occurs under open circuit conditions (reversible) when the highest cell voltage is obtained

$$\eta_{\max} = \frac{\Delta G^o}{HHV} = \frac{NFE^o}{HHV}$$