Module-5

Hydrogen Energy

- Hydrogen energy is a form of clean energy derived from hydrogen, the most existing element in the universe. It is primarily used as a fuel in two main ways: through combustion or in fuel cells. When hydrogen reacts with oxygen, it produces electricity, with water as the only by product, making it an environmentally friendly alternative to traditional fossil fuels.
- Hydrogen can be produced through various methods, including electrolysis (splitting water into hydrogen and oxygen using electricity), steam reforming of natural gas, or from renewable sources like biomass.

➢ Properties of Hydrogen:

1. Abundance (Available in very large quantity)

- Hydrogen is the most abundant element in the universe, primarily found in water (H_2O) and various organic compounds.

2. Energy Density (Per Mass)

- Hydrogen has a high energy density by mass, about 33.6 kWh per kilogram, which is much higher than gasoline or natural gas.

3. Clean Emissions

- When hydrogen is used in fuel cells or combusted, the only byproduct is water vapor (H2O).

4. Storage and Transport Challenges

- Hydrogen is a very light gas with a low volumetric energy density, requiring high-pressure tanks or liquefaction for storage and transportation.

5. Storage Versatility (capable of or adapted for many different uses)

- Hydrogen can be stored as a gas, liquid, or in chemical forms (such as ammonia or metal hydrides).

6. Renewable Production Methods

- Hydrogen can be produced through renewable processes like **electrolysis** (splitting water using electricity from renewable sources such as wind or solar).

7. High Temperature Reactions

- Hydrogen burns at a higher temperature than many conventional fuels.

8. **Fuel Cell Efficiency**

- Hydrogen fuel cells are highly efficient, with energy conversion efficiencies of around 40-60%, and up to 85% when used in combined heat and power systems.

9. **Non-Toxic and Non-Polluting**

- Hydrogen is non-toxic, non-polluting, and safe for humans to handle in appropriate conditions.

10. **Fuelling Flexibility**

- Hydrogen can be used in a variety of applications, including power generation (through fuel cells), transportation (fuel cell vehicles), and even industrial processes (like refining and ammonia production).

➢ Sources of Hydrogen:

- Hydrogen can be produced from a variety of sources using different methods. These sources can be classified into two main categories: **renewable (green) sources** and **non-renewable (Gray and blue) sources**.

❖ Renewable Hydrogen (Green Hydrogen)

- Renewable hydrogen is produced using renewable energy sources, ensuring minimum environmental impact and sustainability (ability to maintain or continue over a long period of time).

▪ **Electrolysis of Water (Water Splitting)**

- Electrolysis involves using electricity to split water (H2O) into hydrogen (H2) and oxygen (O2). When the electricity comes from renewable sources like wind, solar, or hydroelectric power, this process is considered carbon-free and is known as **green hydrogen**.

▪ **Biomass Gasification**

- Biomass (organic material such as wood, agricultural waste, and other plant-based materials) can be heated in a low-oxygen environment to produce hydrogen, carbon monoxide, and carbon dioxide. The hydrogen is then separated from the other gases.

▪ **Photobiological and Photoelectrochemical Processes**

- These are emerging methods where certain microorganisms (algae and bacteria) or materials absorb sunlight and convert water into hydrogen.

❖ Non-Renewable Hydrogen (Gray and Blue Hydrogen)

- Non-renewable hydrogen is produced from fossil fuels, typically natural gas, and involves higher carbon emissions unless coupled with carbon capture technology.

- **Steam Methane Reforming (SMR)**

- This is the most common method of hydrogen production, where natural gas (primarily methane, CH_4) is reacted with steam to produce hydrogen and carbon dioxide (CO_2).

- **Coal Gasification**

- In this method, coal is heated with steam and oxygen at high temperatures to produce a synthetic gas composed of hydrogen, carbon monoxide, and CO_2. Hydrogen is then separated from the synthetic gas.

- **Autothermal Reforming (ATR)**

- ATR is similar to steam methane reforming, but it uses both steam and oxygen to convert natural gas into hydrogen and carbon monoxide.

- **Partial Oxidation (POX)**

- This method involves partially oxidizing hydrocarbons (like methane) with oxygen to produce hydrogen and carbon monoxide, which can later be processed to extract more hydrogen.

❖ Other Emerging Sources of Hydrogen

- Several newer methods and technologies are being explored for hydrogen production:

- **Thermochemical Water Splitting**

- This involves using high temperatures (from nuclear reactors or concentrated solar power) to split water molecules into hydrogen and oxygen.

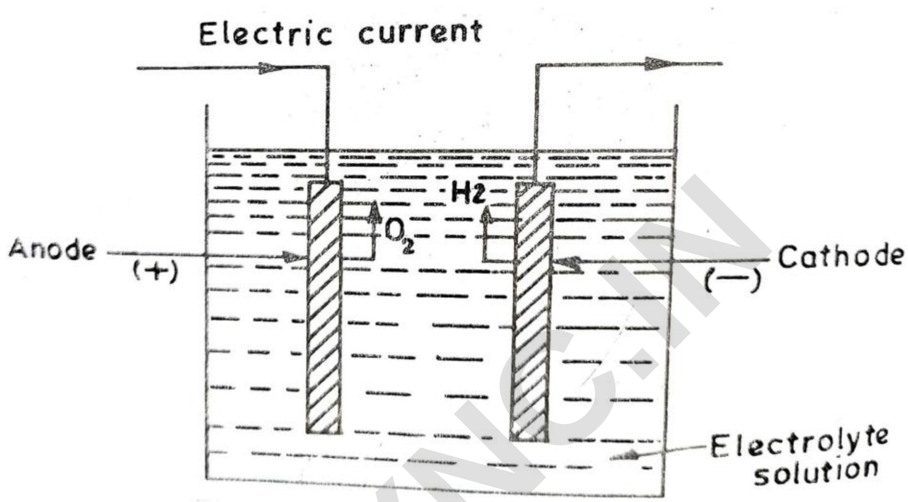
- **Hydrogen from Waste**

- Hydrogen can be produced by converting various types of waste (such as municipal solid waste or plastic waste) into hydrogen through gasification, pyrolysis, or other chemical processes.

➢ Production of Hydrogen:

❖ Electrolysis of Water:

- The process of splitting water into hydrogen and oxygen by means of a direct electric current is known as electrolysis.



- In principle, an electrolysis cell consists of two electrodes, commonly flat metal or carbon plates, immersed in an aqueous conducting solution called the electrolyte.
- A source of direct current voltage is connected to the electrodes so that an electric current flows through the electrolyte from the positive electrode (or anode) to the negative electrode (or cathode).
- As a result, the electrolyte (water) solution is decomposed into hydrogen gas (H2) which is released at the cathode, and oxygen gas (O2); released at the anode
- Electrolysis occurs in an electrolytic cell consisting of a positively charged anode and a negatively charged cathode, typically made of platinum.
- The chemical reaction for water electrolysis can be split into two half-reactions occurring at the cathode and anode.
- A **reduction reaction** occurs at the cathode when hydrogen ions acquire electrons and are converted into hydrogen gas.

$$2\,H^{+}\,(aq.) + 2\,e^{-} \rightarrow H_2\,(g)$$

- An **oxidation reaction** occurs when water molecules give electrons to the anode and liberate oxygen gas at the anode.

$$2\,H_2O\,(l) \rightarrow O_2\,(g) + 4\,H^{+}\,(aq.) + 4\,e^{-}$$

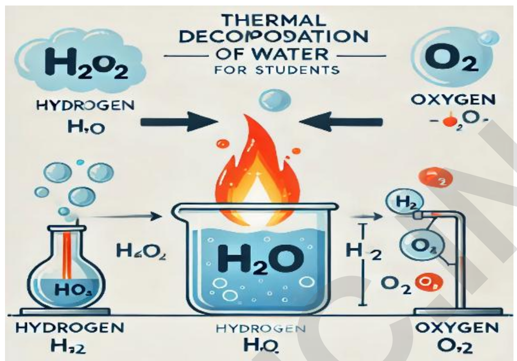
- The overall chemical reaction is

$$2\,H_2O\,(l) + \text{electrical energy} \rightarrow 2\,H_2\,(g) + O_2\,(g)$$

❖ Thermal Decomposition of Water:

- The **thermal decomposition of water** (also called **thermolysis** or **high-temperature water splitting**) is a process where water (H_2O) is heated to high temperatures (typically above 700°C) to break it down into hydrogen (H_2) and oxygen (O_2) through thermal energy. This method uses heat instead of electricity to drive the chemical reaction.

▪ Working Principle:



- When water is subjected to extremely high temperatures, the molecular bonds between hydrogen and oxygen atoms break. The required energy to decompose water increases as the temperature rises. Generally, the reaction requires temperatures of around **2000°C or higher** to be thermodynamically efficient.
- The reaction that occurs during thermal decomposition of water is:

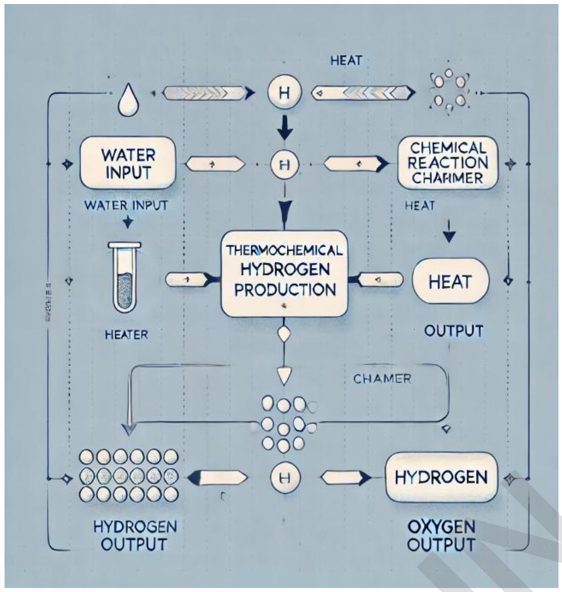
$$2H2O \rightarrow 2H2+O2$$

- At high temperatures, water molecules split into hydrogen and oxygen gases.

▪ Steps of the Process:

- **Heating Water**: The water is heated using an external heat source such as a nuclear reactor, concentrated solar power, or other high-temperature sources.
- **Thermal Decomposition**: At high temperatures (above 2000°C), the heat provides enough energy to overcome the bond energy between hydrogen and oxygen atoms in the water molecules, leading to the breaking of the H-O bonds.
- **Hydrogen and Oxygen Formation**: The decomposition reaction results in the formation of hydrogen gas (H_2) and oxygen gas (O_2).

➢ Thermos Chemical Production:



- The process follows a **cyclic reaction mechanism**, where water is split into hydrogen and oxygen through a series of chemical steps, using intermediate compounds that are continuously recycled.

- <u>**Steps of the Process**</u>

1. **Water Input & Heating**

   - Water (H_2O) is introduced into the system and heated to a very high temperature, typically between 500°C to 1000°C.
   - The heat source can be nuclear reactors, concentrated solar power, or industrial waste heat.

2. **Chemical Reactions in the Reaction Chamber**

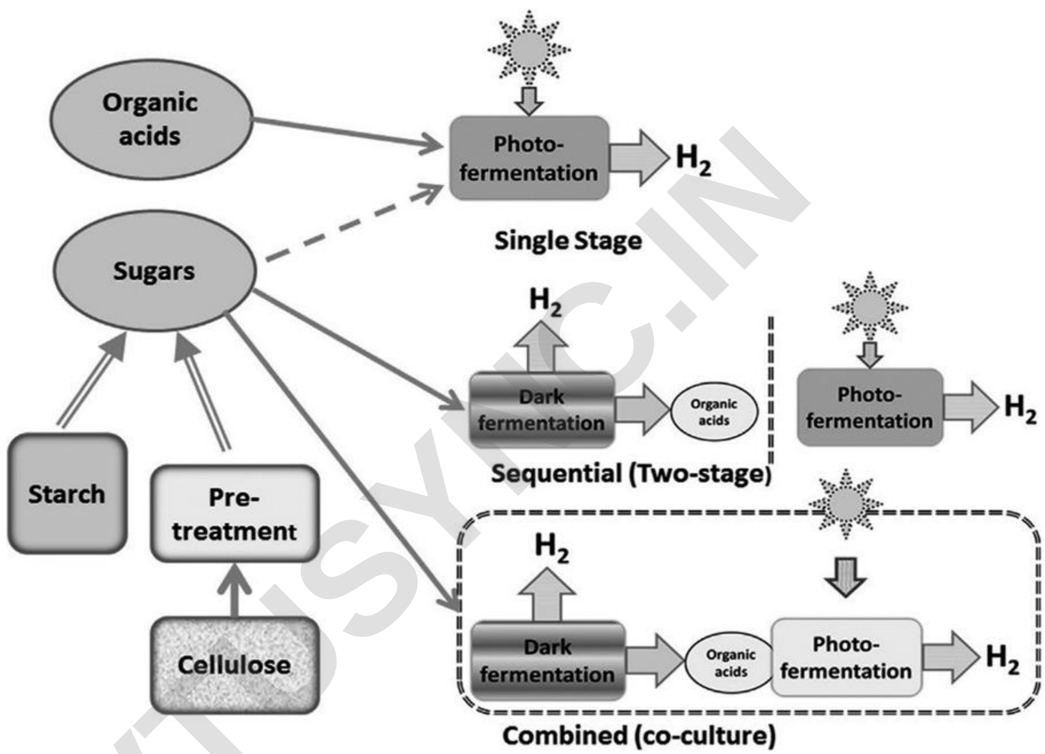
   - Water undergoes chemical reactions with specific compounds (like sulphur, iodine, or copper-chlorine) in a closed cycle.
   - These reactions help break the bonds in water molecules (H_2O) at lower energy levels than direct water splitting.

3. **Hydrogen & Oxygen Separation**

   - The reactions produce hydrogen gas (H_2) and oxygen gas (O_2) in different stages.
   - Hydrogen is collected for storage and use, while oxygen is released or used in industrial applications.

➢ **Biochemical Production:**

- Biochemical hydrogen production uses **microorganisms** (bacteria, algae, or enzymes) to break down organic matter and generate hydrogen (H_2) through biological reactions. This method is eco-friendly and can use **waste biomass** as a raw material.



- Microorganisms such as bacteria or algae are selected based on their ability to produce hydrogen.
- Organic materials like food waste, agricultural waste, or water are prepared as input for the process.
- A bioreactor is set up to provide suitable conditions such as temperature, pH, and light availability for microbial activity.
- The microorganisms break down the organic material or water to produce hydrogen gas.
- In dark fermentation, bacteria break down organic waste without oxygen, releasing hydrogen and byproducts like carbon dioxide and organic acids.
- In photo fermentation, photosynthetic bacteria use sunlight to convert organic acids into hydrogen gas.
- In bio photolysis, algae or cyanobacteria use sunlight to split water molecules into hydrogen and oxygen.
- The produced hydrogen gas is collected from the bioreactor using a gas collection system.
- Byproducts such as carbon dioxide, organic acids, or oxygen are separated and removed.
- The collected hydrogen gas is stored, compressed, or directly used for applications like fuel cells, electricity generation, or hydrogen-powered vehicles.

❖ Methods of Hydrogen Energy Storage

➢ Compressed Gas

- In this method, hydrogen is stored in its gaseous form by compressing it to high pressures, typically in the range of **200–700 bar**, inside specially designed strong cylinders or tanks.
- These tanks are often made of steel or lightweight composite materials with safety valves and pressure regulators to prevent accidents.
- This method is relatively simple and widely used because it does not require extremely low temperatures like cryogenic storage. However, the main limitation is that hydrogen has **low energy density per unit volume**, even at high pressures, which means large and heavy tanks are needed to store sufficient fuel.

➢ Cryogenic Liquid Storage

- In the cryogenic liquid storage method, hydrogen is stored in its liquid state at extremely low temperatures. Hydrogen becomes liquid at –253 °C (20 K) under atmospheric pressure. To maintain it in this state, special double-walled, vacuum-insulated cryogenic tanks are used to minimize heat transfer and evaporation.
- **Process**: Hydrogen gas is cooled and liquefied using cryogenic refrigeration.

➢ Metal Hybrides

- In this method, hydrogen is stored by forming a chemical bond with certain metals or metal alloys, creating metal hydrides. When hydrogen gas is passed over these metals under suitable pressure and temperature, the metal absorbs the hydrogen atoms into its crystal lattice, forming a stable compound. Later, when heat is supplied, the hydrogen is released back in gaseous form.

❖ Methods of Hydrogen Transportation

➢ **Compressed Gas Cylinders**

- Hydrogen gas is compressed to high pressures (350–700 bar) and stored in strong steel or composite cylinders.
- Suitable for small to medium quantities and short distances.
- Commonly used in laboratories, refuelling stations, and industries.

➢ **Liquid Hydrogen Transport**

- Hydrogen is cooled to cryogenic temperatures (-253°C) to become a liquid.
- Transported in insulated cryogenic tanks or tankers.
- Allows high energy density but requires energy-intensive liquefaction and advanced insulation.

➢ **Hydrogen Pipelines**

- Hydrogen can be delivered through dedicated underground pipelines similar to natural gas.
- Best suited for continuous, large-scale industrial supply over long distances.
- Requires leak-proof systems and materials resistant to hydrogen embrittlement.

➢ **Metal Hydrides**

- Hydrogen is absorbed into special metal alloys and later released by heating.
- Safe and compact method but adds weight and cost.
- Useful for portable applications and military use.

➢ **Liquid Organic Hydrogen Carriers (LOHCs)**

- Hydrogen is chemically bonded with organic liquids like toluene or ammonia.
- These liquids can be transported safely using conventional tankers.
- Hydrogen is later extracted via chemical processes at the destination.

➢ **Tube Trailers**

- Large trailers fitted with high-pressure gas cylinders (tubes) transport hydrogen gas.
- Common for over-the-road transport of hydrogen to refuelling stations and factories.
- Offers flexible delivery but limited by road weight and volume regulations.

❖ Applications of Hydrogen Energy

- Hydrogen can be used in fuel cells to generate electricity, or power and heat.
- Petroleum refining
- Glass purification
- Semiconductor manufacturing
- Aerospace applications
- Fertilizer production
- Welding, annealing and heat-treating metals
- Pharmaceuticals

❖ Problem associated with Hydrogen Energy

- **Hydrogen Storage** - Storage and transportation of hydrogen is more complex than that required for fossil fuels. This implies additional costs to consider for hydrogen fuel cells as a source of energy.
- **Hydrogen Extraction**- Despite being the most abundant element in the Universe, hydrogen does not exist on its own so needs to be extracted from water via electrolysis or separated from carbon fossil fuels. Both of these processes require a significant amount of energy to achieve. This energy can be more than that gained from the hydrogen itself as well as being expensive.
- **Overall Cost** - The cost for a unit of power from hydrogen fuel cells is currently greater than other energy sources.

Energy from Biomass

➢ Introduction:

- The energy obtained from organic matter, derived from biological organisms like Plants and animals is known as Biomass energy.
- Animals feed on plants, and plants grow through the photosynthesis process using solar energy Thus, photosynthesis process is primarily responsible for the generation of biomass energy.
- A small portion of the solar radiation is captured and stored in the plants during photosynthesis process. Therefore, it is an indirect form of solar energy.

Solar Energy ⟶ Photosynthesis ⟶ Biomass ⟶ Energy generation

➢ Photosynthesis

- Photosynthesis in the plant is an example of biological conversion of solar energy into sugars and starches which are energy rich compounds.
- Radiant energy of sun is absorbed by the green pigment chlorophyll in the plant and stored with in the plant in the form of chemical bund energy.

▪ **The process of photosynthesis has two main steps:**

- **Splitting of H2O** molecule into H2 and O2 under the influence of chlorophyll and sun light this phase of reaction called **light-dependent reaction.**
- Photolysis of H2O

o In the second phase, oxygen molecule escapes to atmosphere, hydrogen transferred from this unknown compound **H2CO** to **CO2** to form sugar or starch. Formation of starch or sugar are **dark reaction not requiring sunlight.**

o This reaction doesn't require sunlight hence called dark reaction.

o Photosynthesis is a complex process. It involves several successive stages, but the overall basic reaction is the formation of (glucose, fructose, etc.) as represented by:

$$CO_2 + H_2O + \text{light} + \text{Chlorophyll} \longrightarrow \underset{\text{(Sugar)}}{(H_2CO)_6} + O_2 + \text{Chlorophyll}$$

or

$$6CO_2 + 12H_2O \longrightarrow C_6H_{12}O_6 + 6H_2O + 6O_2$$

$$H_2CO + O_2 \longrightarrow CO_2 + H_2O + 112\ \text{kcal/mole.}$$

➢ **Photosynthetic Oxygen Production**

- In green plants, both photosynthesis and respiration occur during the day and only respiration at night.
- The energy produced in the plants by respiration is used in several processes such as to draw moisture and nutrients through its roots.
- The process of photosynthesis and respiration can be represented in the following diagram.

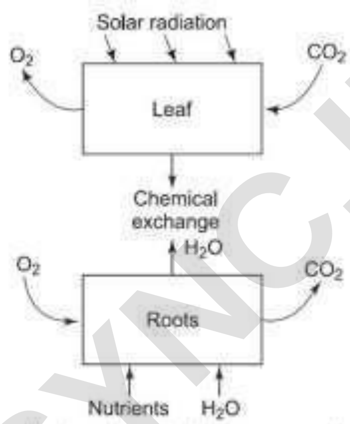


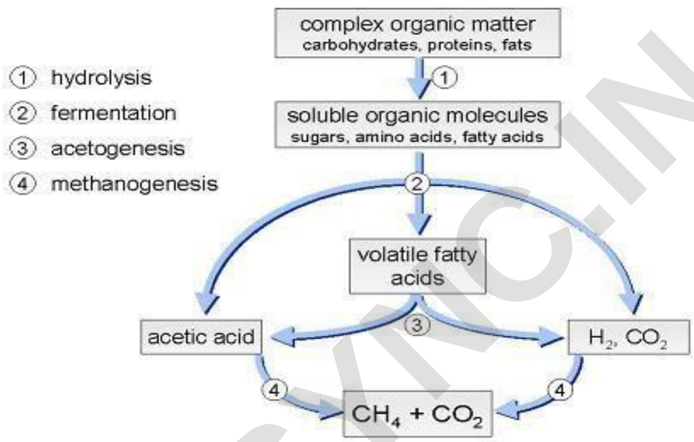
Photo synthesis and respiration processes in a plant

- The uptake of CO2 by a plant leaf is a function of many factors, especially temperature, CO2 concentration and the intensity of solar light.
- Solar radiation incident on a leaf is reflected, transmitted and absorbed. Part of the absorbed radiation provides the energy, it's stored during the photosynthesis and produces oxygen and carbohydrate.

❖ Anaerobic Digestion (Fermentation)

- Anaerobic Digestion is a biochemical degradation process that converts complex organic material, such as biomass & animal manure, into methane and other by products in the absence of oxygen.
- It is widely used for waste management, renewable energy production, and environmental protection. The process converts biodegradable materials such as food waste, animal manure, sewage sludge, and agricultural residues into biogas and digestate.

Steps Involved in Anaerobic Digestion (Fermentation)



1. **Hydrolysis:**
   - Biomass is normally comprised of very large organic polymers, which are unusable.
   - Through hydrolysis, these large polymers, namely proteins, fats and carbohydrates, are broken down into smaller molecules such as amino acids, fatty acids, and simple sugar.

2. **Fermentation (Acidogenesis):**
   - It is the next step of anaerobic digestion process in which acid forming bacteria further break down the Biomass products and produce an acidic environment in the digestive tank while creating ammonia, **H_2, CO_2, shorter volatile fatty acids, carbonic acids, alcohols,** as well as trace amounts of other by products.
   - While organic product, it is still too large and unusable so the biomass must next undergo the process of acetogenesis for the ultimate goal of methane production.

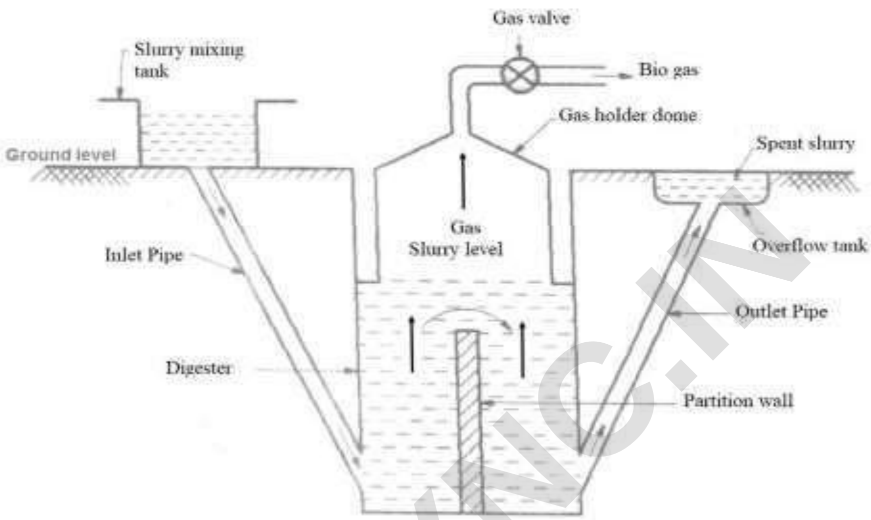
3. **Acetogenesis**
   - Acetogens break down the Biomass further to a point to which Methanogens can utilize much of the remaining material to create Methane as a Biofuel.

4. **Methanogenesis:**
   - Methanogenesis constitutes the final stage of anaerobic digestion process in which methanogens create methane from the final products of acetogenesis as well as from some of the intermediate products from hydrolysis and acidogenesis.

❖ Biogas Plants

➢ KVIC (Khadi and Village Industries Commission) - (Floating Dome) Type Biogas Plant

- It is used in India is known as KVIC plant - This mainly consists of a digester or pit for fermentation and a floating drum for the collection of gas.



➢ Construction:

- The digester is a deep circular pit or a well, built of bricks of 3.5-6.5 m in depth and 1.2 to 1.6 m in diameter and there is a partition wall in the centre, which divides the digester vertically and submerges in the slurry when it is full.
- In the inlet slurry mixing tank dung mixed with water (4:5) and loaded into the digester through inlet pipe.
- The digester is connected to the outlet tank through outlet pipe for removal of spent slurry.
- Gas holder dome is an inverted steel drum resting above the digester, the drum can move up and down i.e., float over the digester and it has an outlet at the top which could be connected to the storage tank.

➢ Working:

- Initially slurry is prepared in the mixing tank and it's fed into the inlet chamber of the digester through the inlet pipe.
- The plant is left unused for about two months and introduction of more slurry is also stopped.
- During this period, anaerobic fermentation of biomass takes place in the presence of water and produces biogas in the digester.
- Biogas being lighter rises up and starts collecting in the gas holder dome and this dome now starts moving up and starts floats freely on the surface of the slurry.
- Gas holder dome after reaching a certain level it cannot rises up as more & more gas starts collecting, more pressure begins to be exerted on the slurry.

❖ Janata (Fixed Doom) Type Biogas Plant:

➢ Construction:

- Figure represents the schematic diagram of a fixed dome type biogas plant called as Janta model or Chinese model of biogas plant.
- It is similar to KVIC model except that both the digester and gas holder are constructed in a fixed dome usually below the ground surface.
- In the slurry mixing tank dung mixed with water (4:5) and loaded into the digester through inlet pipe.
- Digester is a huge tank with a dome like ceiling which has an outlet with a valve for the supply of biogas.
- The digester is connected to the outlet tank through outlet pipe for removal of spent slurry or sludge.

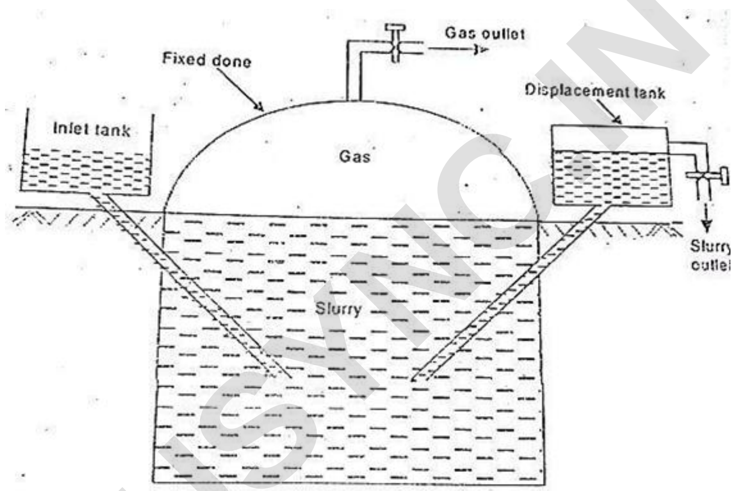


Fig. 8-7. Chinese design biogas plant

➢ Working:

- Initially slurry is prepared in the mixing tank and it's fed into the inlet chamber of the digester through the inlet pipe.
- When digester is partially filled with the slurry, the introduction of slurry stopped and plant is left unused for about two months.
- During this period, anaerobic fermentation of biomass takes place in the presence of water and produces biogas which starts collecting in the dome of the digester.
- As more and more biogas starts collecting, the pressure exerted by the biogas forces the spent slurry into the outlet chamber.
- From the outlet chamber, the spent slurry overflows into the overflow tank which is manually removed and used as manure for plants.
- The gas valve connected to a system of pipelines is opened when a supply of gas is required.

❖ Transportation of Biogas

- Biogas, mainly composed of methane (CH_4) and carbon dioxide (CO_2), can be transported from the production site (like a biogas plant) to the point of use using the following methods:

➢ **Pipeline Transportation**

- Biogas can be transported through pipelines for short distances, usually within a radius of 5 to 10 km. After purification to remove moisture, hydrogen sulphide, and carbon dioxide, the gas is slightly pressurized and distributed through underground or above-ground pipelines.

➢ **Compressed Biogas (CBG) in Cylinders**

- In this method, biogas is cleaned and then compressed to high pressure (200–250 bar) and stored in steel cylinders. These cylinders are then transported by trucks or small vehicles to areas where the biogas will be used, such as in vehicles, generators, or rural households.

➢ **Liquefied Biogas (LBG)**

- Liquefied Biogas is created by upgrading and cooling biogas to cryogenic temperatures (around -160°C) to convert it into liquid form. The liquefied gas is then transported in insulated cryogenic tankers over long distances.

➢ **4. Biogas Bags (Flexible Balloons)**

- For small-scale or local uses, biogas can be stored in low-pressure flexible rubber or PVC bags. These are easy to handle and transport manually or on carts for very short distances.

❖ Problems Involved with Biogas Production:

➢ **Irregular Feedstock Supply:**

- Availability of raw materials like dung or organic waste can be seasonal or insufficient.

➢ **Lack of Technical Knowledge:**

- Many users lack proper training to operate and maintain biogas plants efficiently.

➢ **Gas Impurities:**

- Biogas often contains hydrogen sulphide and moisture, which can corrode equipment and reduce gas quality.

➢ **High Initial Cost:**

- Setting up a biogas plant requires significant investment, which may not be affordable for small users.

➢ **Maintenance Issues:**

- Poor construction and lack of regular maintenance can lead to leakages and reduced gas output.

➢ **Low Public Awareness:**

- Social acceptance and awareness about the benefits of biogas are still limited in many areas

❖ Applications of Biogas

➢ **Cooking and Heating:**

- Biogas is commonly used as a clean fuel for cooking and heating in homes, hotels, and institutions, replacing firewood or LPG.

➢ **Electricity Generation:**

- It can be used to run biogas engines or generators to produce electricity for local or grid supply.

➢ **Transportation Fuel:**

- After purification (to remove CO_2 and H_2S), biogas becomes **bio-CNG**, which can be used as an alternative to petrol or diesel in vehicles.

➢ **Industrial Use:**

- Industries use biogas for steam generation, drying, or as a replacement for furnace oil in boilers.

➢ **Agricultural Use:**

- The **digestate** (slurry left after biogas production) is a nutrient-rich organic fertilizer for crops.

➢ **Waste Management:**

- Biogas plants help manage organic waste from households, farms, and industries, reducing pollution and odors.

❖ Applications of Biogas in Engines

- **Power Generation:** Biogas is used in internal combustion engines to generate electricity in biogas power plants.
- **Pumping Water:** Biogas-powered engines are used in agriculture for running water pumps in rural areas.
- **Vehicle Fuel:** Upgraded and compressed biogas (CBG) can be used as an alternative fuel in vehicles (similar to CNG).
- **Industrial Engines:** Biogas is used to run engines that drive equipment and machinery in small industries.
- **Backup Power Systems:** Biogas engines serve as a reliable backup power source during grid failures or in off-grid locations.

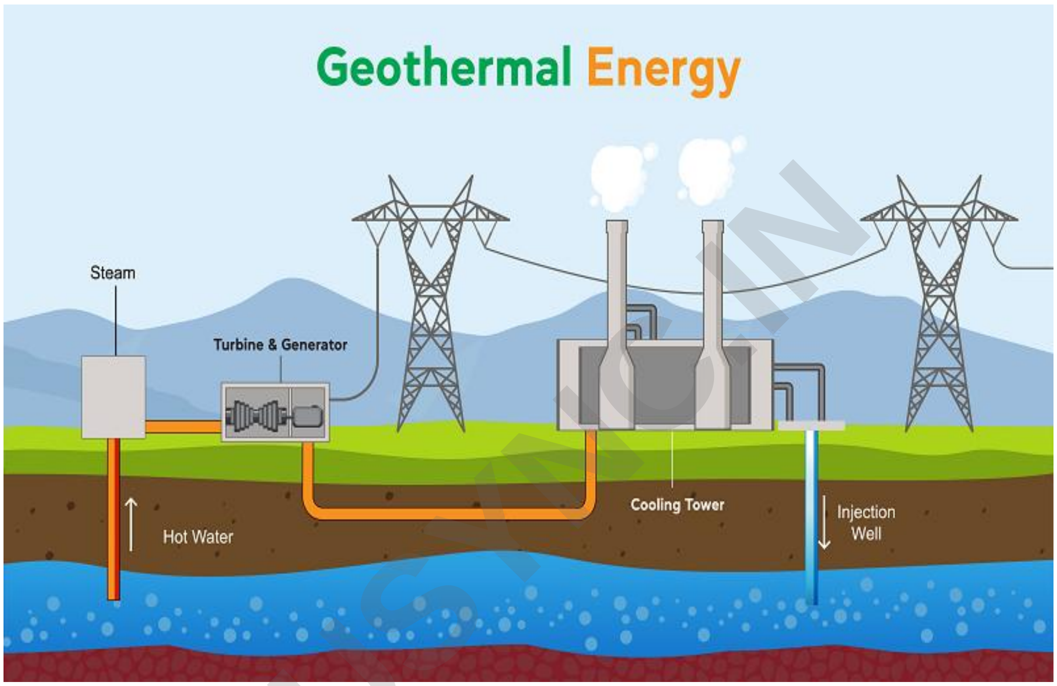
❖ Advantages of Biogas

- **Renewable Energy Source:** Biogas is produced from organic waste, making it a sustainable and eco-friendly fuel.
- **Reduces Waste:** It helps in managing agricultural, animal, and kitchen waste by converting it into useful energy.
- **Produces Organic Fertilizer:** The by-product (slurry) from biogas plants is a nutrient-rich organic manure.
- **Reduces Greenhouse Gases:** Biogas reduces methane emissions from waste and lowers dependence on fossil fuels.
- **Low Operational Cost:** Once installed, biogas plants have minimal running costs and require low maintenance.
- **Improves Rural Energy Access:** Biogas provides clean fuel for cooking, lighting, and power in rural areas.

Geothermal Energy Conversion

- Geothermal comes from the Greek word, where ‘Geo’ refers to Earth, and ‘Thermo’ refers to Heat. The heat procures from inside the earth’s crust. Generally, it is found distantly far below the earth’s burning molten rock ‘Magma’ and stored in the rocks and vapour in the earth's centre.

➢ Principle of Working:



- Geothermal energy is heating energy that comes from inside the Earth's surface. The Earth's internal heat is stored in the form of hot water and steam, which can be harnessed for generating electricity or for direct heating purposes.

❖ **Working Principle**:

- **Heat Extraction**: Geothermal power plants use the Earth's natural heat from inside the surface. The heat is contained in hot water or steam reservoirs deep underground. Wells (deep hole) are drilled into these reservoirs to access the hot water or steam.
- **Conversion to Mechanical Energy**: The extracted steam is directed to a turbine. The high-pressure steam rotates the turbine blades, converting thermal energy into mechanical energy.
- **Electricity Generation**: The turbine is connected to a generator. As the turbine rotates, the generator converts the mechanical energy into electrical energy.
- **Cooling**: After the steam has passed through the turbine, it is condensed back into water using a cooling tower or heat exchanger. The cooled water is then reinjected back into the ground to be reheated, ensuring sustainability.
- **Distribution**: The generated electricity is sent through power lines to homes and industries.

➢ Types of Geothermal Station (Plant)

- A geothermal power plant uses steam obtained from these geothermal reservoirs to generate electricity. Wells are drilled at the appropriate locations to bring this geothermal energy up to the surface. A mixture of steam and water is collected from the production well. Steam separators are employed to separate the steam and use it to operate tur steam turbines run the generators and, hence, electricity is generated. The condensed steam and the water collected from the production well are injected back into the reservoir through the injection well.

❖ Dry Steam dominated systems

- In this type of geothermal system, water is vaporised into steam at the lower level in the earth's crust. The steam rises to the earth's surface in a dry state (about 200°C and more than 2 MPa pressure). This dry steam can be used conveniently and directly to run steam turbines and generate electric power. The schematic of such a system is illustrated in Fig.

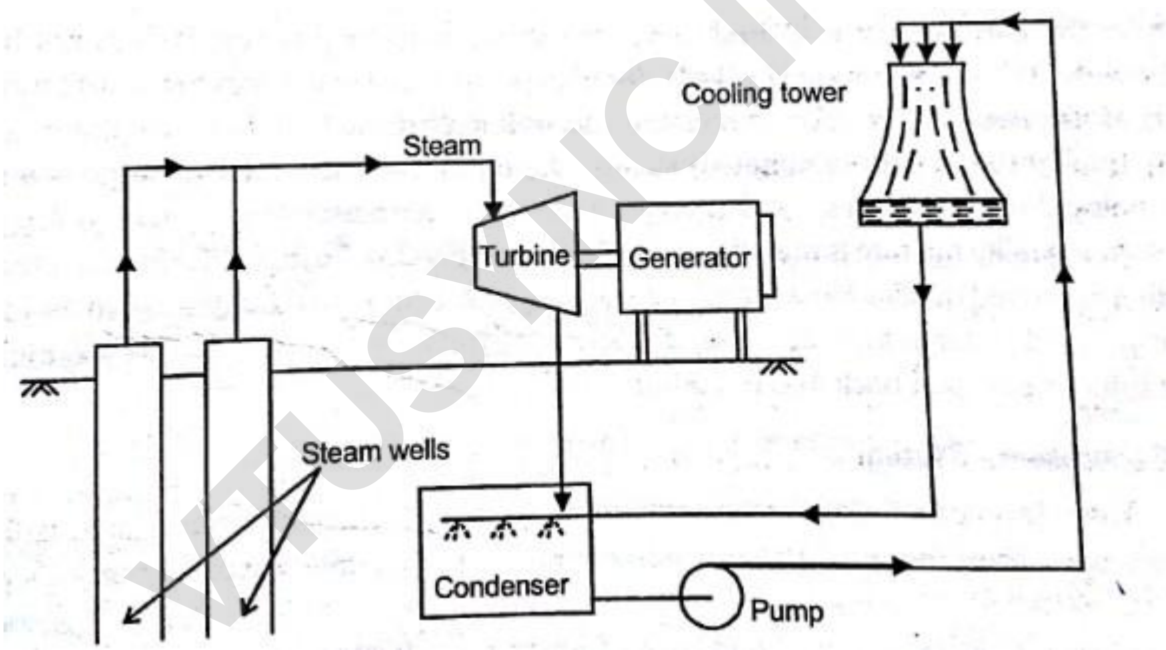


Fig: Dry Steam dominated geothermal energy system

❖ Liquid Dominated Systems – Flash (Wet) Steam Open System

- This is a major geothermal energy source, which is liquid dominated (hot water), and steam is obtained by the use of a flash separator. The schematic arrangement of a flash steam open geothermal system is illustrated in fig

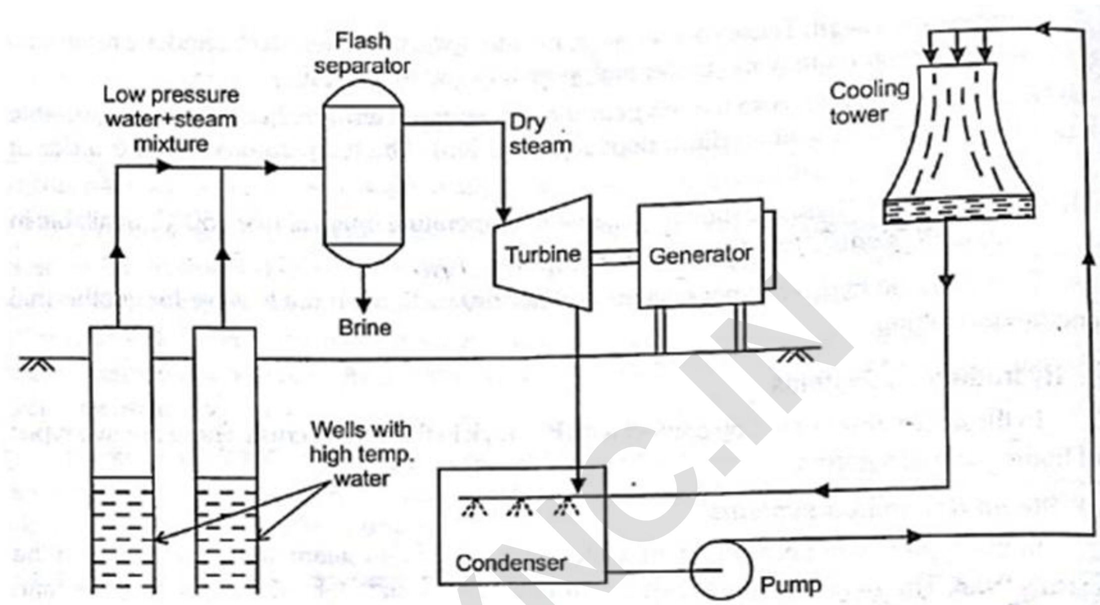
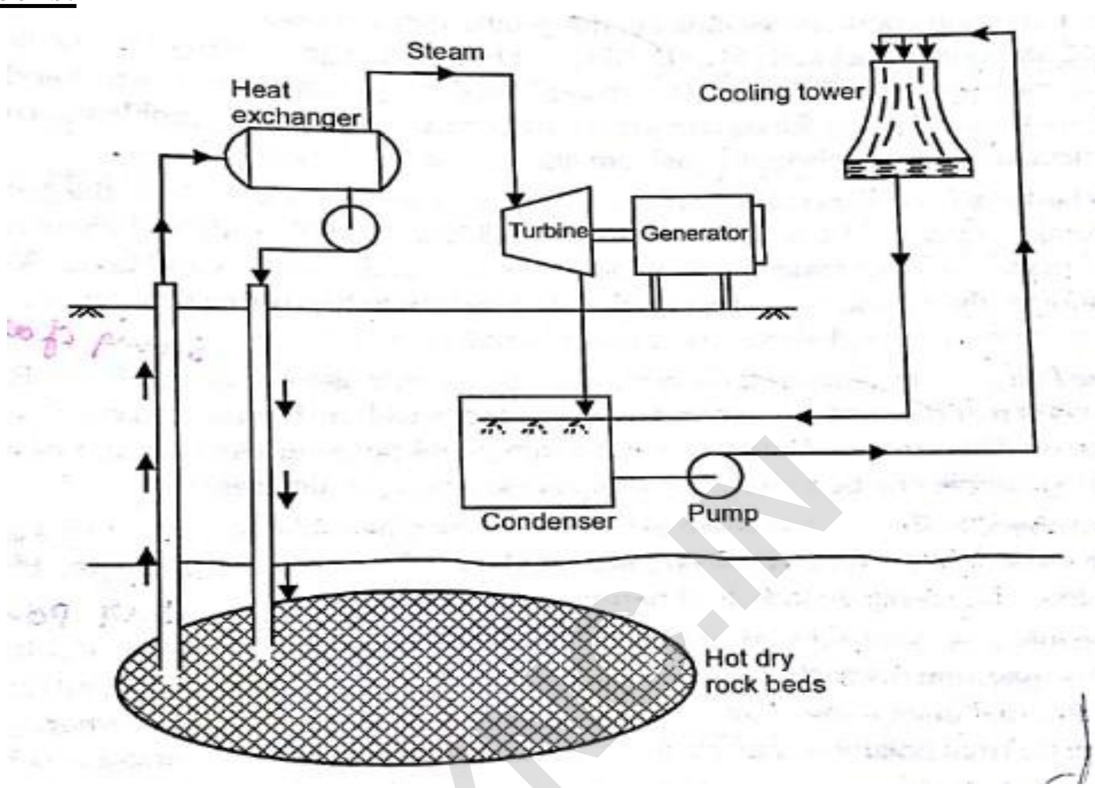


Fig: Liquid dominated (flash steam) geothermal energy system

- In this type of geothermal system, hot water at about 150°C under high pressure available under the earth's crust is utilized. Since the water is under pressure, it does not boil even above 100°C. When trapped by wells, the high-pressure hot water rises to the well surface and loses its pressure. The drop in pressure causes it to partially flash to a two-phase mixture of low quality (i.e., water dominated) steam. This low-quality mixture is then throttled in a flash separator, further reducing the pressure but with a improved quality. Here the mixture gets separated into dry saturated steam and saturated brine. The dry steam from the separator is used to run turbines and generate electricity, while the brine is pumped back into the ground.

❖ **Hot Dry Rocks:**



- Hot dry rocks are also termed Petro thermal systems. These are very hot solid rocks available in the earth's crust at medium depths (2 to 5 km). The temperature of the dry rocks is of the order of 300°C, which is quite sufficient to produce steam. These dry rocks in real hot condition, as there is no water contact. To exploit this hot energy source, cold water is pumped into the hot rocks, which becomes hot and get evaporated. The hot water or steam so produced is passed through a suitable heat exchanger, to produce steam and run a steam turbine, for power generation. The schematic of such a system is illustrated in Fig.

❖ Problems Associated with Geothermal Energy Conversion System:

- There are a number problems associated with the operation of geothermal systems. Some of the major problems are discussed here.

1. Solid particles and non-condensable Gases:

- The steam/water from hydrothermal reservoirs contain solid particles and non-condensable gases. The solid particles are removed using centrifugal separators at the well exit and by strainers before the turbine entry. This leads to pressure and temperature loss and hence loss of the thermal efficiency of the complete system.
- The main non-condensable gases in geothermal sources are CO_2 (70 to 80%) and small amounts of methane, H_2, N_2, NH_3 and H_2S. These gases along with the fluid enter equipment's and also escape to the atmosphere through condenser, ejectors and cooling towers. These gases in the equipment's cause corrosion and scaling problems.

2. Discharge of Used Water:

- Discharging large quantities of used water from the geothermal systems to rivers and seas will cause water pollution (both thermal and chemical). This may make the water toxic and becomes hazardous to the animals and users.

3. Noise Pollution:

- In geothermal systems noise pollution is also a major problem. Exhausts, blow down and centrifugal separators work always with high noise, which is hazardous to the working people. The noise can be minimized by using silencers and its effect on working people can be reduced by using noise protective devices.

4. Atmospheric Pollution:

- The harmful gases in the geothermal water after use will escape, (from the cooling tower, separator, etc.) and cause atmospheric pollution. Hydrogen Sulphide (H_2S} is highly toxic and harmful to the living beings.

5. Subsidence:

- The removal of huge quantities of underground water causes land subsidence (collapse of ground layers and fall in the ground level). Subsidence causes stressing of pipelines and damage to the structures/foundations. This problem can be greatly reduced by reinjection of the used water.

6. Sand & other solid particles:

- The high-pressure water from the geothermal system usually carries sand and other solid particles. These cause separation problem, erosion and scaling problems in the equipment's. This-Causes a lot of maintenance problems for the plant and loss of efficiency.

❖ Scope (Range of View, Application) of Geothermal Energy:

- The scope of geothermal energy is vast, as it offers a sustainable and renewable source of power with a variety of applications. Geothermal energy can be used for:

1. **Electricity Generation**: It provides a reliable and consistent power source, especially in regions with geothermal hotspots (e.g., Iceland, the Philippines, and the U.S.), with the potential to supply up to 10% of global electricity by 2050.
2. **Direct Heating**: It's used for space heating in buildings and agricultural applications, like greenhouses, and can also support industrial processes that require heat.
3. **Geothermal Heat Pumps (GHPs)**: These systems exploit the Earth's stable temperature to heat and cool buildings, offering an efficient and energy-saving solution for residential and commercial uses.
4. **Environmental Benefits**: Geothermal energy has a low carbon footprint, making it a clean and sustainable alternative to fossil fuels.