ENERGY STORAGE

Definition

Energy storage systems are the set of methods and technologies used to store various forms of energy. There are many different forms of energy storage.

- *Solid State Batteries:* a range of electrochemical storage solutions, including advanced chemistry batteries and capacitors
- *Flow Batteries:* batteries where the energy is stored directly in the electrolyte solution enabling longer charge/discharge cycles, usually four hours each.
- *Flywheels:* mechanical devices that harness rotational energy to deliver instantaneous electricity
- *Compressed Air:* utilize compressed air to create energy reserves
- *Pumped hydro-power*: creates energy reserves by using gravity and the manipulation of water elevation
- *Thermal:* capturing heat or cold to create energy

Energy storage has many benefits. It is particularly important for the development and integration of renewable energy technologies. Some renewable energy sources have intermittent generation profiles, which means that electricity is only produced when the sun is shining or when the wind is blowing, for example. This creates supply and demand discrepancies because consumers may still require electricity when renewables sources are not producing.
Currently, grids deliver electricity in real-time, meaning electricity is being consistently produced to meet consumer demand. As a result, electricity generation systems are built to meet peak demand (the hours when most electricity consumption occurs, for example during the afternoon of a hot summer day when everyone is operating their air conditioning). Energy storage enables a lower-cost generating source to produce electricity at a different point in time to be stored and then used to meet times of peak demand. This 'flexibility' has the potential to transform how we produce and consume electricity.

Energy storage is also commonly used to smooth out the minor fluctuations in energy output for small and large electricity generation sources. Storage also provides increased reliability and strengthens system resilience at large and small substation levels.

Energy storage is also commonly used in transport, like in electric vehicles, trains and bikes.

Energy storage systems have traditionally been very expensive and not economically viable on a commercial scale. However, drastic improvements in energy storage technologies have led to decreases in costs and improved technology applications.

Energy storage is also a vital part of all the natural processes here on Earth. The storage of energy in one form or another for later use has been extremely important not only to mankind but also to virtually every other form of life. As humans we store energy in the form of chemical structures, such as carbohydrates and sugars in our bodies when we eat. This energy once stored, is slowly released over time which enables us to survive and function for long periods between meals. Without this energy storage, life would not be possible.

But as well as life, energy storage is a key component in any sustainable energy system. Fossil fuel resources such as coal and petroleum are becoming not only more scarce in some areas but also increasingly inaccessible and costly to extract. But luckily for us, the Earth has been blessed with an abundant supply of natural resources and we have developed many different types of renewable energy system to convert the abundant energy from the sun, the wind, rivers and the oceans into electrical power.

But what happens when the sun does not shine, the wind does not blow or the oceans tides reach their highs and lows, and this free energy is not available, then we have to find ways to economically save the generated power for later use. Although energy cannot be created or destroyed, it can be saved in various forms, for example, chemical storage in a battery. This is referred to as stored energy, and it is energy storage that will play a critical role in an efficient and renewable energy future.

When the term “energy storage” is used, most people think about the storage of electricity in batteries, but the ability to store energy from a primary source for later use is important in many situations, especially when that primary source of energy is from an uncontrollable and variable source such as solar or wind. The term “storage medium” is the energy reservoir that retains the potential energy within a energy storage device for later use.

There are many ways in which we can store energy, such as: electrochemically (batteries, fuel cells), electrically (capacitors, magnetic energy storage), mechanically (flywheels, springs, hydraulic accumulators), potential gravity (hydroelectric dams, river flows), and thermally (molten salt, steam, bodies of water) to name a few, and each with its own set of energy storage advantages and disadvantages.

There are two main reasons why energy storage is important and why it will grow with the increased development of renewable energy sources are:

- Many important renewable energy sources are intermittent, and only generate when the weather dictates, such as wind and solar, so the storage of energy provides a way of adjusting to variations in the energy demand
- Many transportation systems require energy to be stored and carried with the vehicle either in the form of a battery to start the engine, battery banks for electric vehicles or fuel cells to propel a vehicle in its different modes of operation.

Energy storage is an important component in any sustainable energy system with the types of energy storage media that can take and release energy in the form of electricity have the most universal value, because electricity can efficiently be converted either to mechanical or heat energy. The most common way of energy storage for later use is by using batteries.

Energy Storage Batteries

Energy Storage Battery

Electrochemical batteries are the most common energy storage device in use and still the predominant means of energy storage in many off-grid and sustainable energy systems. That’s because batteries by definition are portable sealed systems that store electrical energy in the form of chemical energy, and when electricity is needed, the chemical energy is converted back to electrical energy. Batteries are capable of having high energy conversion efficiencies making them ideal for use in not only transportation but also in home based alternative energy systems.

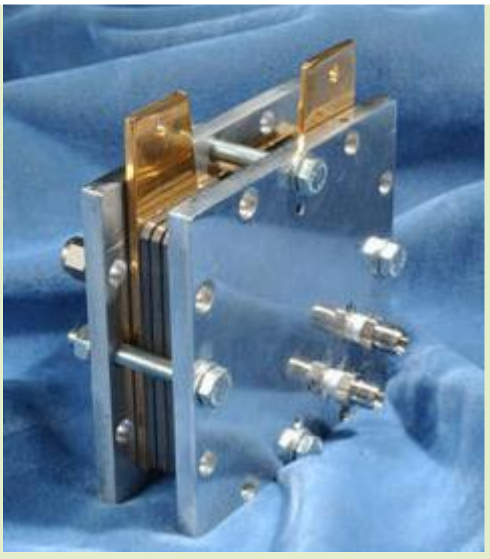
The lead–acid battery is one of the oldest and most mature battery based energy storage technologies. In its basic form, the lead–acid battery consists of a lead (Pb) negative electrode, a lead dioxide (PbO_2) positive electrode and a separator to electrically isolate them. The liquid electrolyte is usually dilute sulphuric acid (H_2SO_4), which provides the sulphate ions for the discharge reactions, but improved maintenance free gel-type batteries with a solid silica electrolyte are now becoming popular.

In the battery charging process, DC electric power either from conventional or renewable energy sources is stored in the active chemicals of the battery system to their high-energy, charged state under the influence of some form of charge controller. Both the power and energy capacities of lead-acid batteries are based on the size and geometry of the electrodes and proper recharging is important to obtain optimum life from any lead-acid battery under any conditions of use.

But keeping energy storage batteries fully charged day in and day out to ensure a ready supply of electricity is available when needed is a high priority that requires a fair amount of electricity. That's because batteries self-discharge when sitting idly by. To overcome some of these problems in electric vehicles, a kind of "super battery", called a fuel cell was developed.

Energy Storage Fuel Cell

A fuel cell is another electrochemical energy storage device that converts the stored chemical energy of a fuel (Hydrogen Energy), an oxidant (Oxygen), and an electrolyte sandwiched between them within a single cell directly into electrical energy. When the demand for electricity arises, the stored hydrogen is is passed over the anode (negative) and oxygen from air is passed over the cathode (positive), and with the use of a catalyst (platinum, nano iron powders, palladium), a chemical reaction takes place and electrons flow through an external circuit to produce electricity. Hydrogen Fuel Cells are now being used to power vehicles.



Energy Storage Fuel Cell

A fuel cell does not produce any pollutants when supplying energy, only heat and water as a by-product, and being similar to batteries have no moving parts making it a very clean energy storage solution. Therefore, theoretically it should be possible to obtain a reliability of over 99% in ideal conditions which is good as the cost of a fuel cell compared to a battery is very high.

Although energy storage fuel cells can produce DC power, fuel cells are mostly associated with providing the fuel for cars and other forms of transportation by using the electrolyser to separates water into oxygen and hydrogen using electricity as a way of storing energy. Then the fuel cell uses two different processes for the cycle of energy storage, production and use.

The advantage that fuel cells have over batteries for transportation is that the process is completely clean because when you burn the hydrogen directly in a vehicle engine, the only waste you get out is heat and water, no carbon dioxide, or other harmful emissions. Thus, feeding hydrogen into specially designed engines can power a clean-burning vehicle.

Fuel cells produce a constant power source through chemical reactions, like a conventional battery, but from a stream of fuel and many different fuels can be used, including natural gas and gasified biomass as well as hydrogen. However, where does the hydrogen fuel come from. Producing, storing, liquefying and transporting the hydrogen gas to where it is needed all requires energy to do so. Also, while the hydrogen gas can be burned in an engine, it is not as efficient as running it on gasoline.

Energy Storage is a key component in any sustainable energy system and the need for energy storage is evident by the intermittent ability to produce electricity from certain renewable energy devices. Of course, renewable energy systems such as wind, solar (solar photovoltaic (PV) and solar thermal), biomass, hydroelectric, ocean and river currents, waves, and tides, do not have to be grid-tied, but going off-grid means additional costs for battery backup because some of these are considered to be intermittent sources, when energy storage is absent.

Although electricity cannot be directly stored, it can be easily stored in other forms, for example, chemical energy and converted back to electricity when needed and as such there are a wide range of different technologies available that can be used for electrical energy storage, from batteries, to fuel cells, to super capacitors.

Batteries of different chemical compositions provide flexible options that can be used at scales from a few watts to power mobile phones up to several kilo-watts (kW) to drive electric vehicles, making them suitable for a wide range of off-grid and transportation applications. Also, electric vehicle batteries that are no longer suitable for use in vehicles may provide a low cost source of small-scale renewable energy storage.

Fuel cells are a relatively new energy storage technology with high capital costs. However, with characteristics such as no moving parts, no emissions, lightweight, versatility and reliability, makes them a new type of technology with a lot of future energy storage potential.

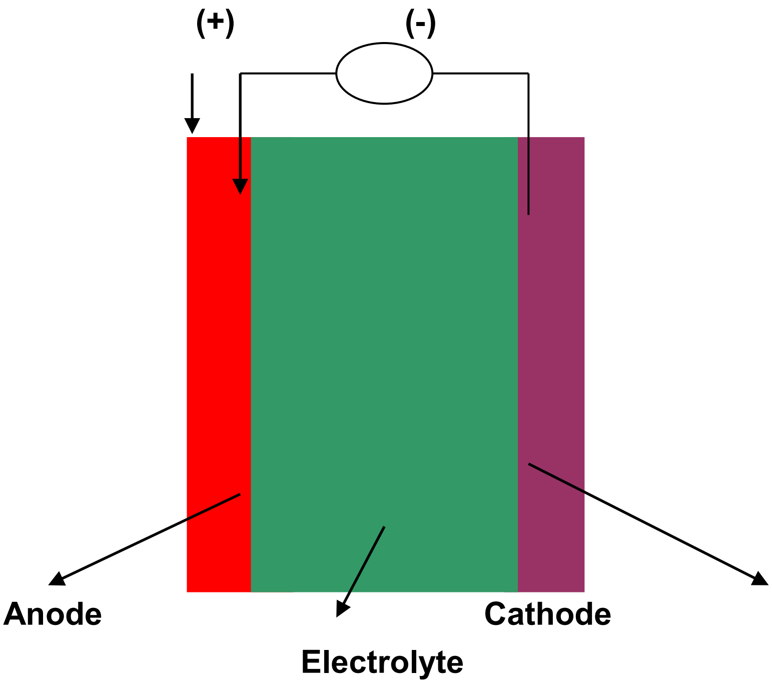
Fuel Cell

What is fuel cell?

A Fuel cell is a electrochemical device that converts chemical energy into electrical energy.
Every fuel cell has two electrodes, one positive and one negative, called, respectively, the cathode and anode. The reactions that produce electricity take place at the electrodes
In all types of fuel cell, hydrogen is used as fuel and can be obtained from any source of hydrocarbon.
The fuel cell transform hydrogen and oxygen into electric power, emitting water as their only waste product.
Every fuel cell also has an electrolyte, which carries electrically charged particles from one electrode to the other, and a catalyst, which speeds the reactions at the electrodes.
A single fuel cell generates a tiny amount of direct current (DC) electricity.
A converter is used to produce AC current.
In practice, many fuel cells are usually assembled into a stack. Cell or stack, the principles are the same.
In 1932, Francis Bacon developed the first successful FC. He used hydrogen, oxygen, an alkaline electrolyte, and nickel electrodes.

A fuel cell configuration

A fuel cell consists of two electrodes namely an anode and a cathode and sandwiched around an electrolyte. An electrolyte is a substance, solid or liquid, capable of conducting oving ions from one electrode to other.



Types of fuel cells

There are different types of fuel cells, differentiated by the type of electrolyte separating the hydrogen from the oxygen. The types of fuel cells are:

- Alkaline fuel cells (AFC)
- Direct methanol fuel cells (DMFC)
- Molten carbonate fuel cell (MFFC)
- Phosphoric acid fuel cells (PAFC)
- Polymer electrolyte membrane fuel cells (PEMFC)
- Solid oxide fuel cells (SOFC)

Principle, construction and working of H2-O2 fuel cell

Principle :The fuel is oxidized on the anode and oxidant reduced on the cathode. One species of ions are transported from one electrode to the other through the electrolyte to combine there with their counterparts, while electrons travel through the external circuit producing the electrical current.

Working

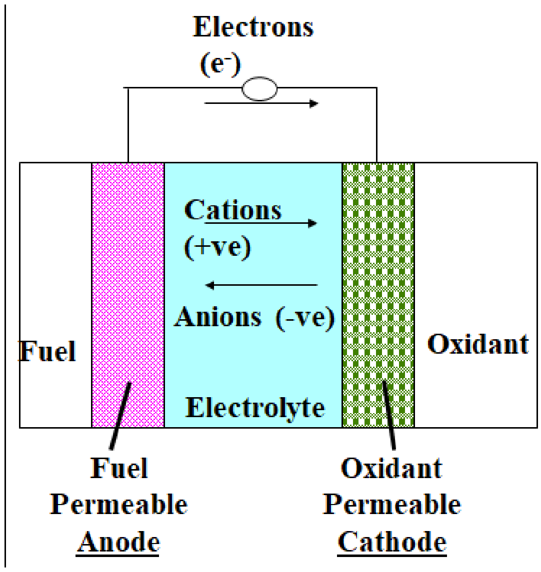
The Fuel gas (hydrogen rich) is passed towards the anode where the following oxidation reaction occurs:

$$H_2 (g) = 2H^+ + 2e^-$$

The liberated electrons from hydrogen in anode side do not migrate through electrolyte.

Therefore, they passes through the external circuit where work is performed, then finally goes into the cathode.

On the other hand, the positive hydrogen ions (H+) migrate across the electrolyte towards the cathode.



At the cathode side the hydrogen atom reacts with oxygen gas (from air) and electrons to form water as byproduct according to:

The overall cell reaction is

$$\text{fuel} + \text{oxidant} \qquad \text{product} +$$

$$H_2 + 1/2\ O_2 + 2e \qquad H_2O + \text{Heat}$$

The liberated electrons from the hydrogen are responsible for the production of electricity.

The water is produced by the combination of hydrogen, oxygen and liberated electrons and is sent out from the cell.

The DC current produced by fuel cell is later converted into AC current using an inverter for practical application.

The voltage developed in a single fuel cell various from 0.7 to 1.4 volt.

More power can be obtained by arranging the individual fuel cell as a stack. In this case, each single cell is sandwiched with one another by a interconnect.

Therefore, electricity power ranging from 1 kW to 200 kW can be obtained for domestic as well as industrial application.

Advantage, disadvantage and applications

Advantages

- **Zero Emissions**: a fuel cell vehicle only emits water vapour. Therefore, no air pollution occurs.
- **High efficiency:** Fuel cells convert chemical energy directly into electricity without the combustion process. As a result, Fuel cells can achieve high efficiencies in energy conversion.
- **High power density:** A high power density allows fuel cells to be relatively compact source of electric power, beneficial in application with space constraints.
- **Quiet operation**: Fuel cells can be used in residential or built-up areas where the noise pollution can be avoided.
- **No recharge:** Fuel cell systems do not require recharging.

Disadvantages

- It is difficult to manufacture and stores a high pure hydrogen
- It is very expense as compared to battery

Applications

1. **Portable applications**

- They used in portable appliances and power tools
- They can be used in small personal vehicles
- They are used Consumer electronics like laptops, cell phones can be operated
- They can be used in Backup power

2. **Transportation applications**

- They can be used for transport application in the following areas,
- Industrial transportation
- Public transportation
- Commercial transportation (truck, tractors)

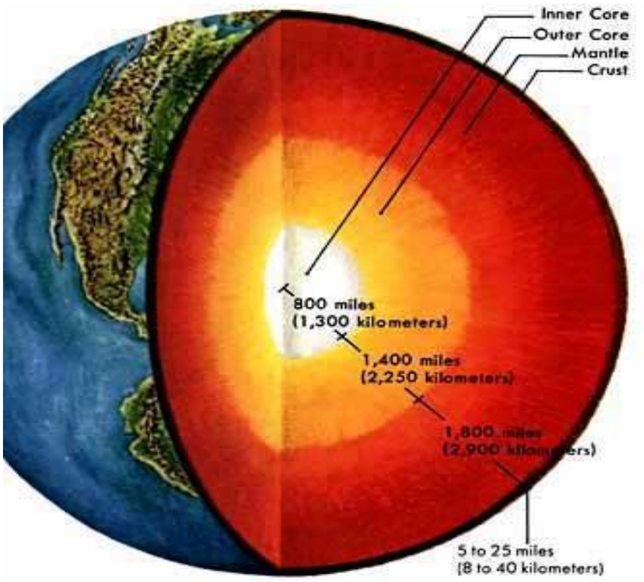
- Marine and Military transportation

3. **Power distribution application**

- Fuel cells can be used for the distribution of power in various fields such as,
- Homes and small businesses
- Commercial and industrial sites
- Remote, off-grid locations (telecom towers, weather stations)

What is geothermal energy?

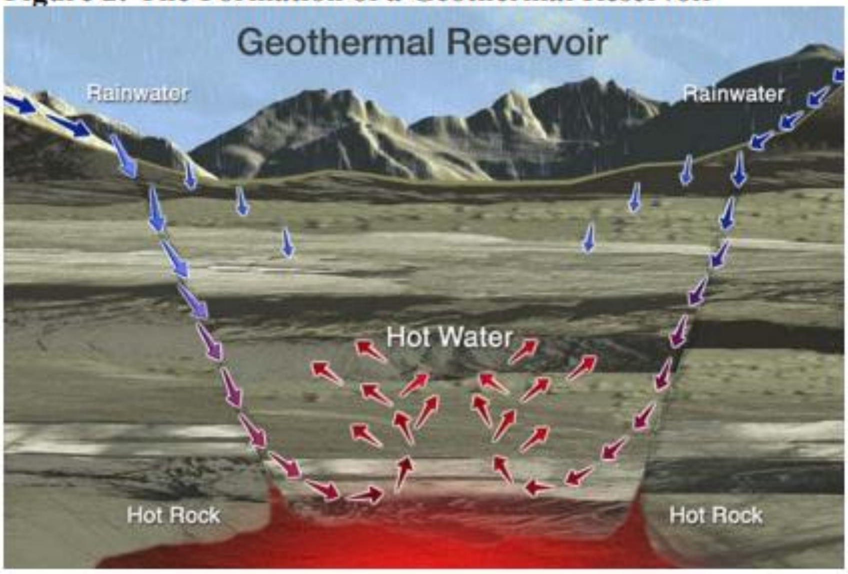
Geothermal energy is defined as heat from the Earth. It is a clean, renewable resource that provides energy in the U.S. and around the world in a variety of applications and resources. Although areas with telltale signs like hot springs are more obvious and are often the first places geothermal resources are used, the heat of the earth is available everywhere, and we are learning to use it in a broader diversity of circumstances. It is considered a renewable resource because the heat emanating from the interior of the Earth is essentially limitless. The heat continuously flowing from the Earth's interior, which travels primarily by conduction, is estimated to be equivalent to 42 million megawatts (MW) of power, and is expected to remain so for billions of years to come, ensuring an inexhaustible supply of energy.



How does a conventional geothermal reservoir work?

A geothermal system requires heat, permeability, and water. The heat from the Earth's core continuously flows outward. Sometimes the heat, as magma, reaches the surface as lava, but it usually remains below the Earth's crust, heating nearby rock and water ó sometimes to levels as hot as 700°F. When water is heated by the earthís heat, hot water or steam can be trapped in permeable and porous rocks under a layer of impermeable rock and a geothermal reservoir can form. This hot geothermal water can manifest itself on the surface as hot springs or geysers, but most of it staysdeep underground, trapped in cracks and porous rock. This natural collection of hot water is called a geothermal reservoir.

Figure 2: The Formation of a Geothermal Reservoir



What are the different ways in which geothermal energy can be used?

Geothermal energy can be used for electricity production, for commercial, industrial, and residential direct heating purposes, and for efficient home heating and cooling through geothermal heat pumps.

• Geothermal Electricity: To develop electricity from geothermal resources, wells are drilled into a geothermal reservoir. The wells bring the geothermal water to the surface, where its heat energy is converted into electricity at a geothermal power plant

. • Heating Uses: Geothermal heat is used directly, without involving a power plant or a heat pump, for a variety of applications such as space heating and cooling, food preparation, hot spring bathing and spas (balneology), agriculture, aquaculture, greenhouses, and industrial processes. Uses for heating and bathing are traced back to ancient Roman times. Currently, geothermal is used for direct heating purposes at sites across the United States. U.S. installed capacity of direct use systems totals 470 MW or enough to heat 40,000 average-sized houses, according to the Geo Heat Centre The Romans used geothermal water to treat eye and skin disease and, at Pompeii, to heat buildings. Medieval wars were even fought over lands with hot springs. The first known "health spa" was established in 1326 in Belgium at natural hot springs. And for hundreds of years, Tuscany in Central Italy has produced vegetables in the winter from fields heated by natural steam.

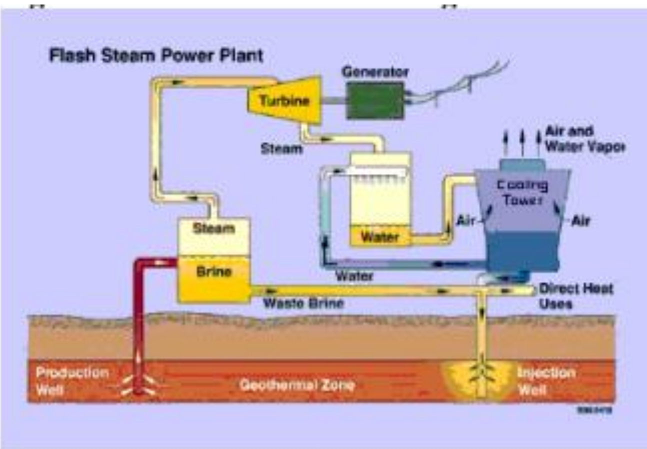
Geothermal Heat Pumps (GHPs): Geothermal heat pumps take advantage of the Earthís relatively constant temperature at depths of about 10 ft to 300 ft. GHPs can be used almost everywhere in the world, as they do not share the requirements of fractured rock and water as are needed for a conventional geothermal reservoir. GHPs circulate water or other liquids through pipes buried in a continuous loop, either horizontally or vertically, under a landscaped area, parking lot, or any number of areas around the building. The Environmental Protection Agency considers them to be one of the most efficient heating and cooling systems available. Animals burrow underground for warmth in the winter and to escape the heat of the summer. The same idea is applied to GHPs, which provide both heating and cooling solutions. To supply heat, the system pulls heat from the

Earth through the loop and distributes it through a conventional duct system. For cooling, the process is reversed; the system extracts heat from the building and moves it back into the earth loop. It can also direct the heat to a hot water tank, providing another advantage ó free hot water. GHPs reduce electricity use 30ñ60% compared with traditional heating and cooling systems, because the electricity which powers them is used only to collect, concentrate, and deliver heat, not to produce it.

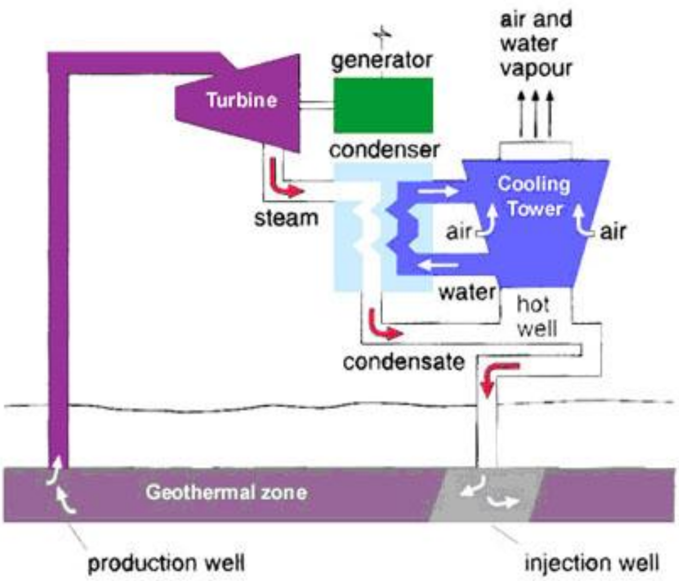
How does a geothermal power plant work?

There are four commercial types of geothermal power plants: a. flash power plants, b. dry steam power plants, c. binary power plants, and d. flash/binary combined power plants.

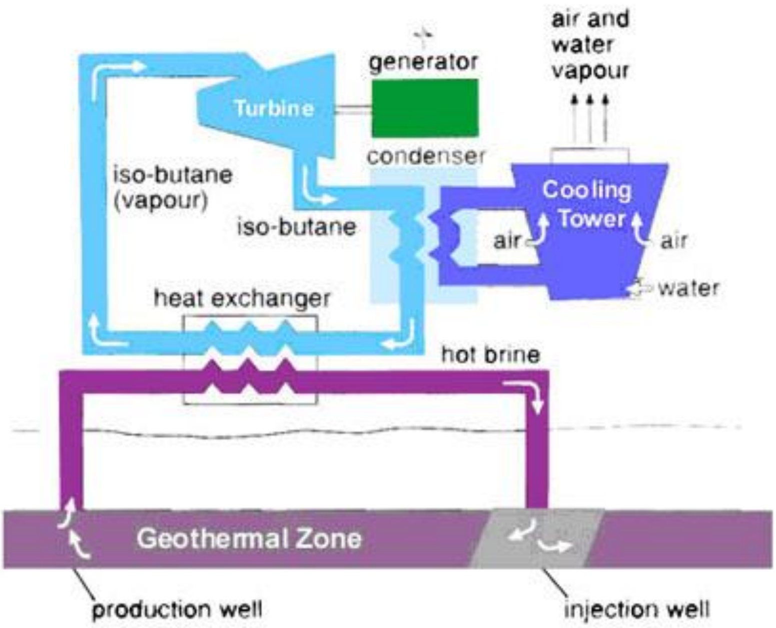
a. Flash Power Plant: Geothermally heated water under pressure is separated in a surface vessel (called a steam separator) into steam and hot water (called ìbrineî in the accompanying image). The steam is delivered to the turbine, and the turbine powers a generator. The liquid is injected back into the reservoir.



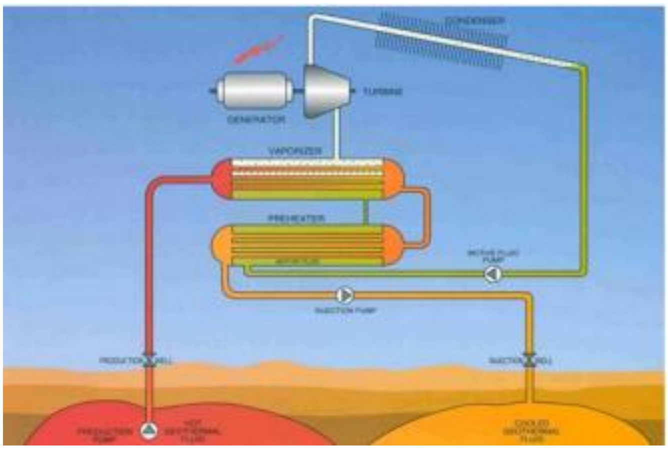
b. Dry Steam Power Plant: Steam is produced directly from the geothermal reservoir to run the turbines that power the generator, and no separation is necessary because wells only produce steam. The image below is a more simplified version of the process.



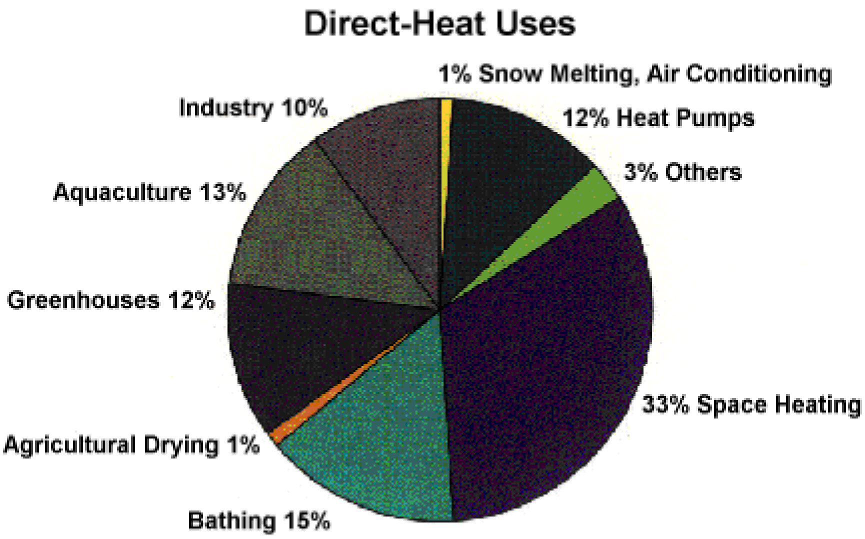
c. Binary Power Plant: Recent advances in geothermal technology have made possible the economic production of electricity from geothermal resources lower than 150°C (302°F). Known as binary geothermal plants, the facilities that make this possible reduce geothermal energy ís already low emission rate to zero. Binary plants typically use an Organic Rankine Cycle system. The geothermal water heats another liquid, such as isobutane or other organic fluids such as pentafluoropropane, which boils at a lower temperature than water. The two liquids are kept completely separate through the use of a heat exchanger, which transfers the heat energy from the geothermal water to the working fluid. The secondary fluid expands into gaseous vapor. The force of the expanding vapor, like steam, turns the turbines that power the generators. All of the produced geothermal water is injected back into the reservoir



d. Flash/Binary Combined Cycle: This type of plant, which uses a combination of flash and binary technology, has been used effectively to take advantage of the benefits of both technologies. In this type of plant, the portion of the geothermal water which flashes to 12 steam under reduced pressure is first converted to electricity with a backpressure steam turbine and the low-pressure steam exiting the backpressure turbine is condensed in a binary system.



Applications of Geothermal Energy



1. Space/District Heating: Schemes utilizing geothermal heat provide over 80% of the central heating needs of Reykjavik city in Iceland and are employed in many towns in USA, Poland and Hungary. The World Bank is currently supporting a program in Poland for using hot water from unsuccessful oil wells to displace the use of coal for district heating .

2. Agriculture and Aquaculture: In temperate and colder climates, greatly improved plant and fish growth can be achieved by heating soils, greenhouses and fish ponds using geothermal heat. One example of this is the largely successful Osearian Farm, Kenya (World Flowers, 2005).

3. Power Generation: With over 8000 MW of installed capacity, geothermal electric power generation is a well-proven technology that has been especially successful in countries and islands that have a high reliance on imported fossil fuels .

Other Benefits of Geothermal Energy

1. Minimize air pollution: Current geothermal fields produce only about one-sixth of the carbon dioxide that a natural gas fueled electrical generating power plant produces and none of the nitrous oxide (NOx) or sulfur bearing (SOx) gases. New state of the art geothermal binary and combined cycle plants produce virtually no air emissions. Each 1,000 MW of new geothermal power will offset 1.9 million pounds per year of noxious and toxic air pollution emissions in Western skies and offset about 7.8 billion pounds per year of climate affecting CO2 emissions from gas fired plants or much larger amounts from coal fired plants

2. Renewable energy source: All types of geothermal energy are renewable as long as the rate of heat extraction from the earth does not exceed the rate at which the thermal reservoir it depends upon is recharged by the earthâs heat. A geothermal reservoir that has been used for electricity generation may take several hundred years to recharge after it has been completely depleted. District heating system reservoir recovery may take 100-200 years, and geothermal heat pump reservoir recovery may take30 years or so.

3. Reduces dependence on imported energy: Geothermal energy is generated with indigenous resouces, thereby reducing trade deficits. Reducting trade deficits keeps wealth at home and promotes healthier economies. Nearly half of the U.S. annual trade deficit would be erased if imported oil were displaces with domestic energy resources