Geothermal Energy: A Review

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***Abstract*:- Geothermal energy is energy created by the heat of the Earth. To extract energy from the underground, water is most times used as the heat carrier. As the crust is highly fractured and thus permeable to fluids, surface water, in most cases rainwater, penetrates at depth and exchanges heat with the rocks. Two main forms of heat transfer occur within the crust: conduction and convection. Where rocks are much fractured and circulating fluids are abundant, the resulting convective heat transfer is very efficient and can be easily exploited by drilling wells and discharge the hot fluids to the surface. 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, plate boundary movement and interest rates. Geothermal energy is a well-established and relatively mature form of commercial renewable energy characterized by a high load factor, which means that its installed capacity produces significantly more electricity during a year than other sources like wind and solar power plants. Geothermal power plants provide stable production output, unaffected by weather or climate, resulting in high capacity factors ranging from 60% to 90% which is ideal for making the technology suitable for base load electricity production.**

1.1 INTRODUCTION

Geothermal energy is energy created by the heat of the Earth. Under the Earth's crust lies a layer of thick, hot rock with most times, pockets of water, which sometimes seeps up to the surface in the form of hot springs. When the water does not travel naturally to the Earth's surface, it is sometimes possible to reach it by drilling (Geothermal Energy, 2019). This hot water can be used as a virtually free source of energy, either directly as hot water, steam or heat, or as a means of generating power.

This energy source, geothermal is nonpolluting, inexpensive and in most cases, renewable, which makes it a promising source of power for the future (Geothermal Energy, 2019).

The word "geothermal originates from the Greek words *geo*, which means *earth,* and *thermos*, which means *heat*."

The geothermal energy of the Earth's crust originates from the original formation of the planet and from radioactive decay of materials (Dye, 2012; Gando et al, 2011).

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 heat from the core to the surface. Earth's internal heat is thermal energy generated from radioactive decay and continual heat loss from Earth's formation (Turcotte D. L. & Schubert G., 2002). Temperatures at the core-mantle boundary may reach over 4000ºC (7,200ºF) (Lay et al, 2008).

The high temperature and pressure in Earth's interior cause some rock to melt and solid mantle to behave plastically, resulting in portions of the mantle convecting upward since it is lighter than the surrounding rock. Rock and water is heated in the crust, sometimes up to 370ºC (700ºF). With water from hot springs, geothermal energy has been used for bathing since Paleolithic times and for space heating since ancient Roman times, but it is now better known for electricity generation. Worldwide, 11,700 megawatts of geothermal power is available in 2013. An additional 28 gigawatts of direct geothermal heating capacity is installed for district heating, space heating, spas, industrial processes, desalination and agricultural applications as of 2010 (Fridleifsson et al, 2008).

Geothermal power is cost effective, reliable, sustainable, and environmentally friendly (Glassley, 2010), but has historically been limited to areas near tectonic plate boundaries. Recent technological advancements 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.

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, plate boundary movement and interest rates.

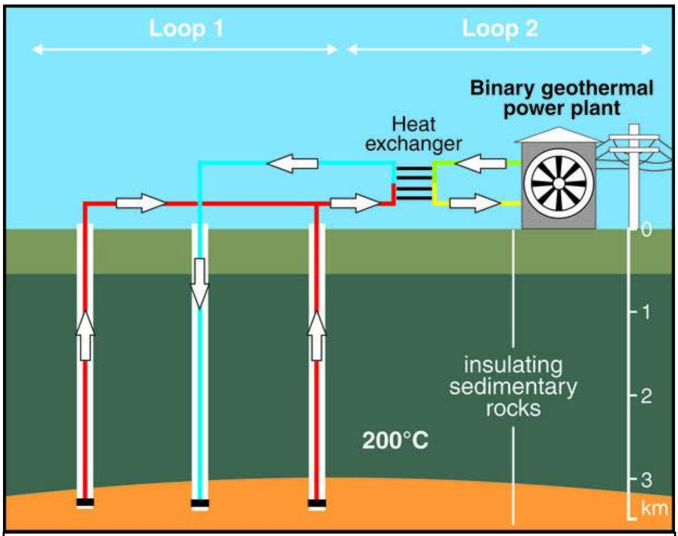

Fig 1: Working Processes of A Geothermal Power Plant

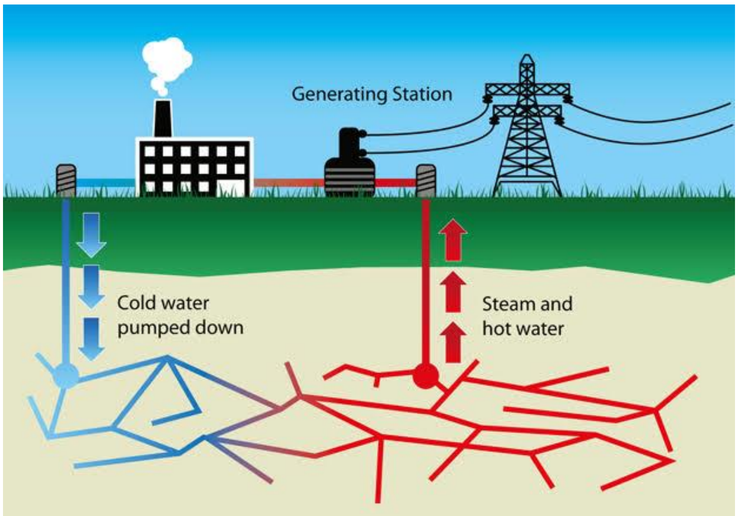

Fig 2: Geothermal Power Plant

1.2 GEOTHERMAL ENERGY EXTRACTION

According to Manzella (2017), to extract energy from the underground, water is most times used as the heat carrier. As the crust is highly fractured and thus permeable to fluids, surface water, in most cases rainwater, penetrates at depth and exchanges heat with the rocks. Two main forms of heat transfer occur within the crust: conduction and convection. Where rocks are much fractured and circulating fluids are abundant, the resulting convective heat transfer is very efficient and can be easily exploited by drilling wells and discharge the hot fluids to the surface. In these convective systems, named hydrothermal resources, the aquifers represent the geothermal reservoir. Occasionally, in areas of very high heat flow, the fluid has high temperature (up to above 300^{o}C) and, depending on the pressure, can be vapor (steam) or water. Warm and hot fluids can be extracted from the underground in a wide range of temperature and discharge rate, and used directly for their heat content or to produce electric power. Even the modest temperatures found at shallower depths can be used to extract or store heat by means of ground source heat pumps, which are nowadays a widespread application for geothermal energy.

Heat can be extracted at different rates. To guarantee a sustainable use of geothermal energy, the rate of consumption should not exceed the rate of generation, so that the heat removed from the resource is replaced on a similar time scale. Geothermal plants typically develop below a certain level of energy production. Geothermal typically provides base-load generation, since it is generally immune from weather and seasonal variation, therefore producing almost constantly and distinguishing it from several other renewable technologies that produce variable power or heat with time (Manzella, 2017).

Geothermal energy extraction processes can be summarized thus:

- Hot high-pressure water is pumped from deep underground through a well.
- When the water reaches the surface, the pressure drops, causing the water to turn into steam.
- The steam spins a turbine, which is connected to a generator that produces electricity.
- The steam cools off in a cooling tower and condenses back to water.
- The cooled water is pumped back into the Earth to begin the process again.

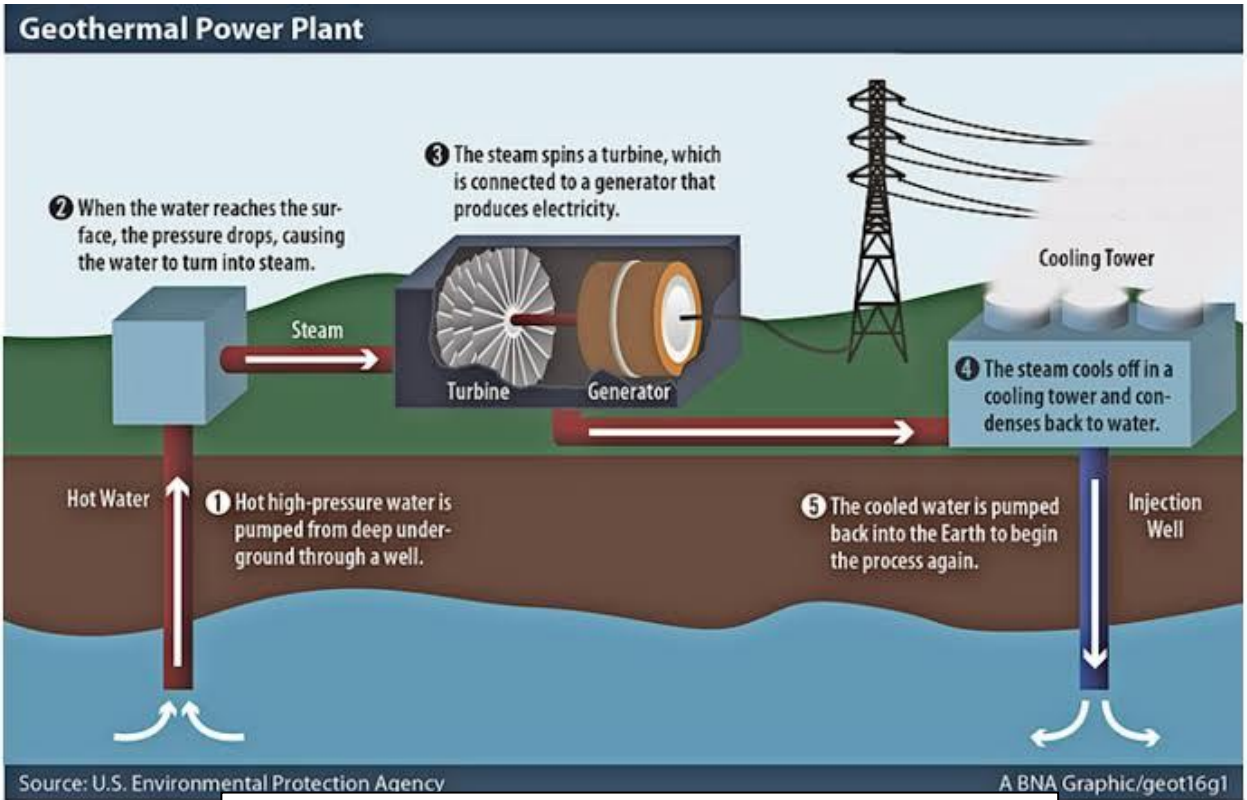

Fig 3: Operating Processes of A Geothermal Power Plant

1.3 TYPES OF GEOTHERMAL POWER PLANT

According to Renewable Energy World (2019), the three types of geothermal power plants are dry steam, flash steam and binary cycle.

DRY STEAM power plants draw from underground resources of steam. The steam piped directly from underground wells to the power plant, where it is directed into a turbine/generator unit. Here, the condensate is usually re-injected into the reservoir or used for cooling. There are only two known underground resources of steam in the United States: The Geysers in northern California and Yellowstone National Park in Wyoming, where there is a well-known geyser called Old Faithful. Since Yellowstone is protected from development, the only dry steam plants in the country are at The Geysers.

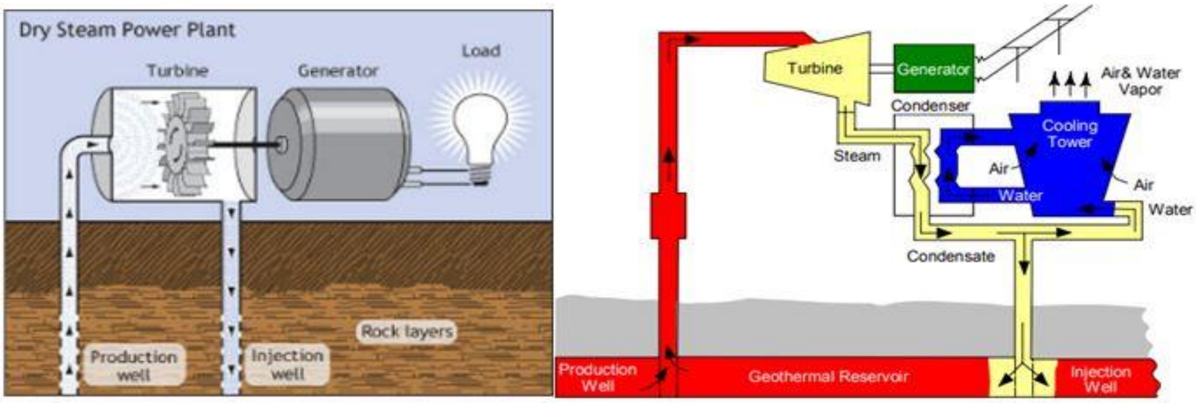

Fig 4: Schematic of A Dry Steam Power Plant (Geo-Heat Centre and U.S. Energy Department)

FLASH STEAM power plants are the most common. They use geothermal reservoirs of water with temperatures greater than 182ºC. This very hot water flows through wells in the ground under its own pressure. As it flows upward, the pressure decreases and some of the hot water boils or "flashes" into steam. The steam is then separated from the water and used to power a turbine. Any leftover water and condensed steam are injected back into the reservoir, making this a sustainable resource. The remaining hot water may be flashed again twice (double flash plant) or three times (triple flash) at progressively lower pressures and temperatures to obtain more steam.

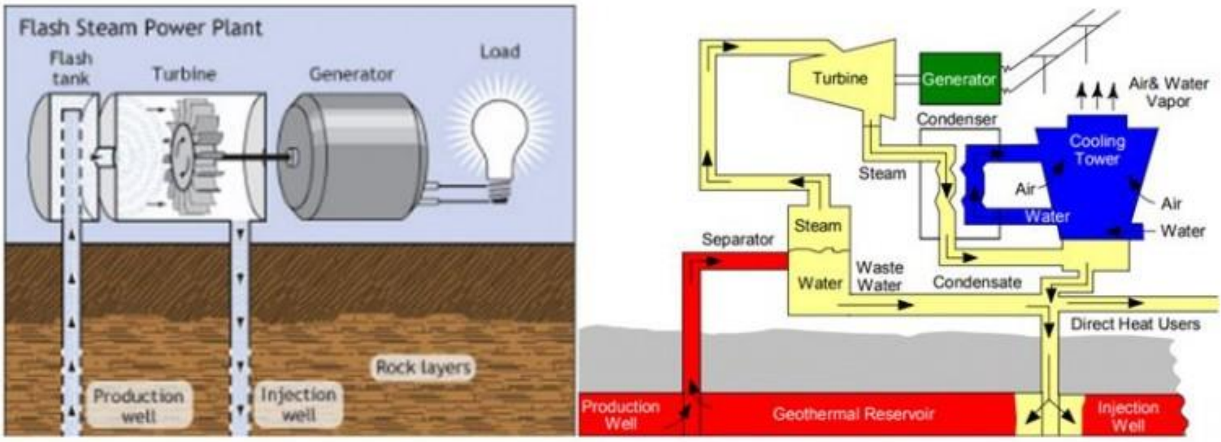

Fig 5: Schematic of A Flash Steam Power Plant (Geo-Heat Centre and U.S. Energy Department)

BINARY CYCLE power plants operate on water at lower temperatures of about 107ºC to 182ºC. These plants use the heat from the hot water to boil a working fluid, usually an organic compound with a low boiling point. The working fluid is vapourized in a heat exchanger and used to turn a turbine. The water is then injected back into the ground to be reheated. The water and the working fluid are kept separated during the whole process, so there are little or no air emissions.

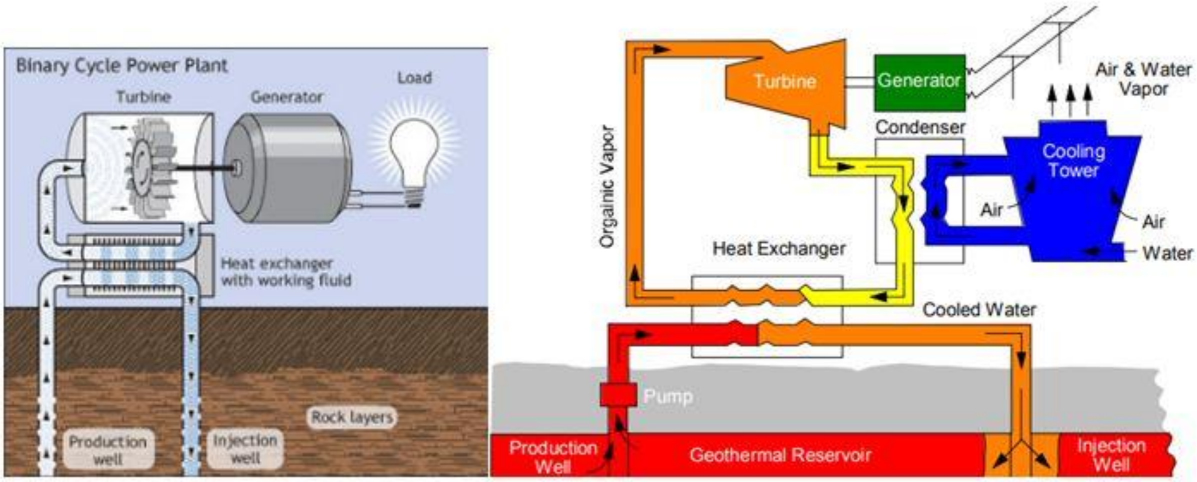

Fig 6: Schematic of A Binary Cycle Steam Power Plant (Geo-Heat Centre and U.S. Energy Department)

Geothermal energy comes in either Vapour-dominated or Liquid-dominated forms.

Vapour-dominated sites offer temperatures from 240ºC to 300ºC that produce superheated steam.

Liquid-Dominated Plants: These plants are more common with temperatures greater than 200ºC and are found near young volcanoes surrounding the Pacific Ocean and in rift zones and hot spots. Flash plants are the common means to generate electricity from these sources. Pumps are generally not required; they are instead powered when the water turns to steam.

However, lower temperature liquid-dominated reservoirs (120ºC to 200ºC) require pumping. They are common in extensional terrains, where heating takes place via deep circulation along faults, such as in the Western US and Turkey. Water passes through a heat exchanger in a Rankine cycle binary plant. The water vaporizes an organic working fluid that drives a turbine.

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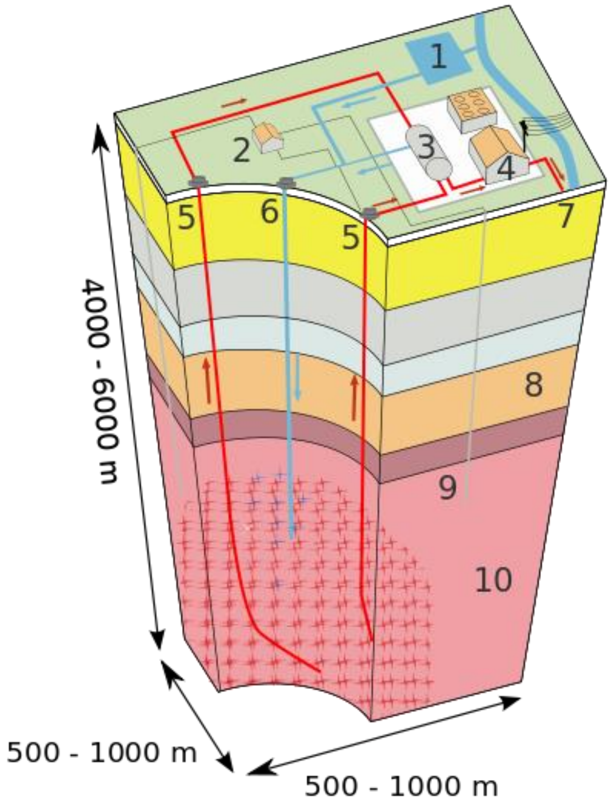
1.4 ENHANCED GEOTHERMAL SYSTEM

Enhanced geothermal systems basically operate on the principle of injecting water into wells to be heated and pumped back out. The water is injected under high pressure to expand existing rock fissures to enable the water to freely flow in and out.

The technique was adopted from oil and gas extraction techniques. However, the geologic formations are deeper and no toxic chemicals are used, reducing the possibility of environmental damage.



1. Reservoir
2. Pump House
3. Heat Exchanger
4. Turbine Hall
5. Production Well
6. Injection Well
7. Hot Water To District Heating
8. Porous Sediments
9. Observation Well
10. Crystalline Bedrock

Fig 7: Enhanced Geothermal System

1.5 GEOTHERMAL HEAT PUMPS

Geothermal heat pumps can be used almost everywhere in the world, as they not share requirements of fractured rock and water as are needed for a conventional geothermal reservoir.
According to Oil & gas portal (2017), geothermal heat pump systems consist of basically three parts:

- The ground heat exchanger
- The heat pump unit
- The air delivery system (ductwork)

The heat exchanger is basically a system of pipes called a loop, which is buried in the shallow ground near the building. A fluid (usually water or a mixture of water and anti-freeze) circulates through the pipes to absorb heat within the ground.

In the winter, the heat pump removes heat from the heat exchanger and pumps it into the indoor air delivery system. In the summer, the process is reversed, and the heat pump moves heat from the indoor air into the heat exchanger.

The heat removed from the indoor air during the summer can also be used to heat water, providing a free source of hot water.

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

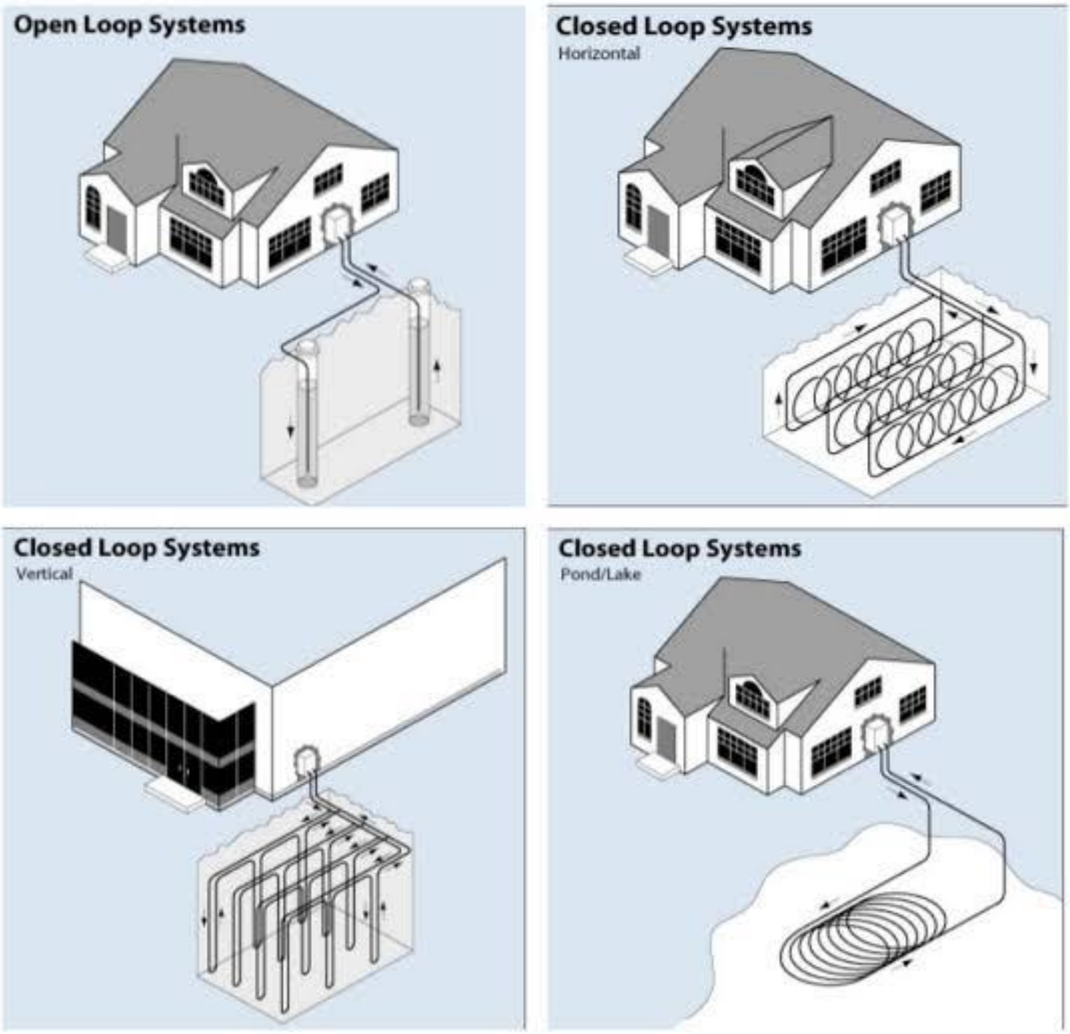


Fig 8: Schematics of Open and Closed-Loop Systems of Geothermal Heat Pumps

1.6 GEOTHERMAL ENERGY PROS AND CONS

According to Energy Informative (2020), some of the advantages of geothermal energy can be summarized as follows:

- Environmentally Friendly: Geothermal energy is generally considered environmentally friendly. There are a few polluting aspects of harnessing geothermal energy, but they are minor compared to the pollution associated with conventional fuel sources.
  The carbon footprint of a geothermal power plant is minimal.
  An average geothermal power plant releases the equivalent of 122Kg CO_2 every megawatt-hour (MWh) of electricity it generates – one eight of the carbon emissions associated with a typical coal power plant.
- Renewable: Geothermal reservoirs come from natural resources and are naturally replenished. Geothermal energy is therefore a renewable energy source.
  Sustainable is another label used for renewable sources of energy. In other words, geothermal energy is a resource that can sustain its own consumption rate, unlike conventional energy sources such as coal and fossil fuels. According to scientists, the energy in our geothermal reservoirs will literally last billions of years.
- Massive Potential: Worldwide energy consumption – about 15 terawatts (TW) – is not anywhere near the amount of energy stored in earth. However, most geothermal reservoirs are not profitable and we can only utilize a small portion of the total potential. Realistic estimates for the potential of geothermal power plants vary between 0.035 to 2 TW.
  Geothermal power plants across the world currently deliver about 10,715 megawatts (MW) of electricity, far less than installed geothermal heating capacity of about 28,000 MW.

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- Stable: Geothermal energy is a reliable source of energy. We can predict the power output of a geothermal power plant with remarkable accuracy. This is not the case with solar and wind, where weather plays a huge part in power production. Geothermal power plants are therefore excellent for meeting the base load energy demand.
  Geothermal power plants have a high capacity factor; actual power output is close to total installed capacity.
  The global average power output was 73% (capacity factor) of total installed capacity in 2005, but as much as 96% has been demonstrated.
- Great for Heating and Cooling: Water temperature of more than 150ºC or greater is needed in order to effectively turn turbines and generate electricity with geothermal energy. Another approach is to use the (relatively small) temperature difference between the surface and ground source.
  The earth is generally more resistant to seasonal temperature changes than air. Consequently, the ground only a couple of meters below the surface can act as a heat sink/source with a geothermal heat pump, much in the same way an electric heat pump works.

Disadvantages of geothermal energy, according to Energy Informative (2020):

- Environmental Issues: There is an abundance of greenhouse gases below the surface of the earth, some of which mitigates towards the surface and into the atmosphere. These emissions tend to be higher near geothermal power plants.
  Geothermal power plants are associated with sulfur dioxide and silica emissions, and the reservoir can contain traces of toxic heavy metals including mercury, arsenic and boron.
  However, it is needful to note that regardless of how it is being considered; the pollution associated with geothermal power is nowhere near that of coal power and fossil fuels.
- Surface Instability (Earthquakes): Construction of geothermal power plants can affect the stability of land. In fact, geothermal power plants have lead to subsidence (motion of the earth's surface) in both Germany and New Zealand.
  Earthquakes can be triggered due to hydraulic fracturing, which is an intrinsic part of developing enhanced geothermal system (EGS) power plants.
  In January 1997, the construction of a geothermal power plant in Switzerland triggered an earthquake with a magnitude of 3.4 on the Richter scale.
- Expensive: Commercial geothermal power projects are expensive. The exploration and drilling of new reservoirs come with a step price tag (typically half the costs). Total costs usually end up somewhere between 2 – 7 million dollars for a geothermal plant with a capacity of 1 megawatt (MW).
  Most geothermal resources cannot be utilized in a cost effective manner, at least not with current technology, level of subsidies and energy prices.
- Location Specific: Good geothermal reservoirs are hard to come by. Some countries have great reserves, Iceland and Philippines meet nearly one third of their electricity demand with geothermal energy. However, some parts of the crust have significantly high heat flow rates and these can provide heat energy at depths that can be economically exploited using several existing technologies.
- Sustainability Issues: Rainwater seeps through the earth's surface and into the geothermal reservoirs over thousands of years. Studies show that the reservoirs can be depleted if the fluid is removed faster than replaced. Efforts can be made to inject fluid back into the geothermal reservoir after the thermal energy has been utilized (the turbine has generated electricity).
  Geothermal power is sustainable if reservoirs are properly managed.

In summary, geothermal energy is generally regarded as environmentally friendly, sustainable and reliable. This makes geothermal energy a no-brainer in some places, but heavy upfront costs stops us from realizing the full potential.
The level of influence geothermal power will have on the energy system in the future will be dependent on technological advancements, energy prices and politics (subsidies).

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