*International Journal of Engineering and Science Invention (IJESI)*
*ISSN (Online): 2319-6734, ISSN (Print): 2319-6726*
*www.ijesi.org ||Volume 14 Issue 4 April 2025 || PP 160-167*

# Technology Assessment Model of Developing Geothermal Energy Resource

Jaswant Singh[1], Prof. Abhishek Kaushik [2]
*Scholar M.Tech(E.E) VGI[1] , HOD Dept. of EE, VGI[2]*
*jaswantacet@gmail.com [1], abhishek.kaushik@vgi.ac.in [2]*

***Abstract:-*** *Geothermal warmth is generated by heat of the earth. Water is normally employed as a heat transporter while extracting energy from the earth. Because the outer layer of stone is heavily broken and so permeable to fluids, surface water, often rainwater, reaches to depth & shares heat to the minerals. Within the crust, there are two primary types of heat transference: convection as well as conduction. Where rocks are heavily cracked and flowing fluids are plentiful, the ensuing convection of heat is extremely efficient and may be easily utilised by digging wells and releasing boiling waters to exterior.*
*Earth's plentiful thermal riches are potentially more than sufficient to meet people's energy requirements, but only a small percentage can be successfully mined. Mining out deep petroleum is quite costly. Assessments of future thermal power rely on expectations about the internet, energy pricing, incentives, border plate activity, and interest rates. Geothermal energy is a recognized and rationally matured kind of industrial clean liveliness with a high load influence, that designates that its present volume produces more electricity per year than other sources such as wind and solar power plants. Infrared control plants produce consistent output that is not affected by wind or environment, which causes substantial capacity coefficients that fluctuate between 60% to 90%, making the equipment perfect for base load energy supply.*

## I. INTRODUCTION

**Geothermal energy** is derived from natural heat stored within Earth. Beneath the Earth's surface lies a layer of intensely hot rock, often containing water trapped in porous areas. This underground water may sometimes rise to the surface as hot springs. In cases where it doesn't reach the surface naturally, it can be accessed through drilling techniques (Geothermal Energy, 2019). The extracted hot water and steam can then be harnessed for energy—either used directly for heating or rehabilitated into power.

This form of energy is typically low-cost, clean, and renewable, making it a highly attractive option for sustainable energy production in the future.

The term *geothermal* comes from Greek words *geo* (earth) and *therme* (heat). Heat within Earth's crust primarily invents from two sources: initial formation of planet and the ongoing dangerous decay of elements within its interior.

A temperature gradient known as geothermal gradient—representing difference amid Earth's hot core and its cooler surface—causes heat to flow outward. This internal heat is continually produced by harmful decline and residual warmth from Earth's formation. Infections at borderline between the Earth's mantle and core can exceed 4000°C (7,200°F).

Extreme pressure and heat beneath the surface can melt some rocks and cause solid mantle materials to move like a viscous fluid. These molten materials rise through the crust because they are less dense than surrounding rocks. Water and rock in the crust can be heated to temperatures as high as 370°C (700°F). Historically, geothermal hot springs have been used for bathing since the Stone Age and for heating spaces as early as the Roman Empire. Today, geothermal energy is increasingly recognized for its role in electricity production.

As of 2013, global geothermal electricity generation reached about 11,700 megawatts. Additionally, by 2010, around 28 gigawatts of geothermal heating volume had been installed worldwide for various uses, including space heating, industrial processes, agriculture, desalination, and spas.

Geothermal energy is considered a reliable, sustainable, and eco-friendly energy source (Glassley, 2010). Although traditionally limited to tectonically active regions, modern advancements in technology have broadened the scope of accessible geothermal sites, including residential heating systems. While geothermal wells can emit some greenhouse gases from deep within the Earth, their emissions are significantly lower than those from fossil fuel-based energy sources.

Earth possesses vast geothermal potential, far exceeding current human energy consumption needs. However, only a limited portion of this resource is economically viable with current technology. The future expansion of geothermal energy depends on factors such as technological improvements, market prices, government policies, geological activity, and financial considerations.

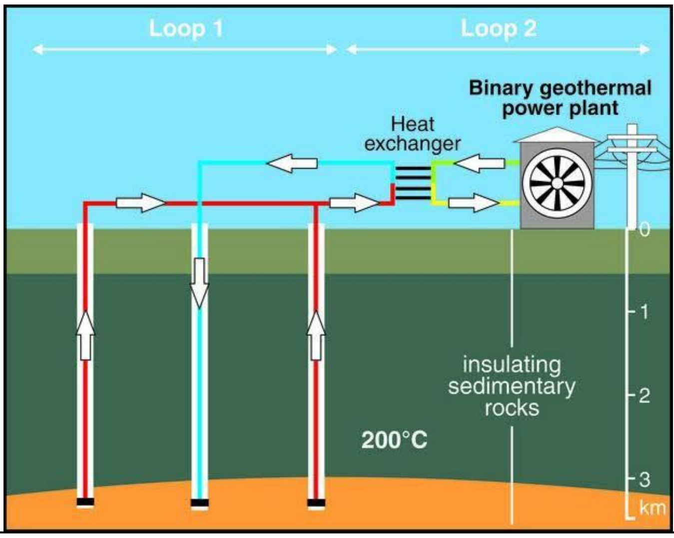


Fig 1: Working Processes of A Geothermal Power Plant

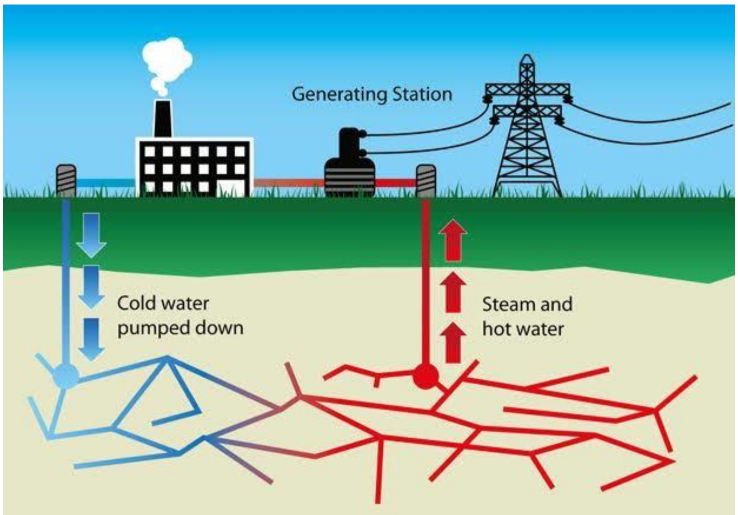


Fig 2: Geothermal Power Plant

## II. GEOTHERMAL ENERGY EXTRACTION:

As described by Manzella (2017), water is commonly utilized as a medium to transfer heat when harnessing energy from beneath the Earth's surface. Due to the fractured nature of the Earth's crust, it allows fluids—often rainwater—to seep down and absorb heat from the surrounding rocks. Within the crust, heat is transferred primarily through two mechanisms: conduction and convection. In regions where the rock is extensively fractured and fluid circulation is high, convective heat transfer becomes highly effective. This can be tapped by drilling wells to bring the heated fluids to the surface. These convective systems, known as hydrothermal resources, contain aquifers that serve as geothermal reservoirs. In some regions with extremely high thermal gradients, these fluids can reach temperatures above 300°C and may exist in the form of steam or liquid, depending on the pressure.

The geothermal fluids extracted can vary widely in both temperature and flow rate. They can be used either directly for heating purposes or to generate electricity. Even lower-temperature resources found at shallow depths are valuable, particularly when used with pulverized basis heat heart systems, which have become a prevalent method of utilizing geothermal energy today.

Rate at which heat is extracted from geothermal sources can vary, but to ensure long-term sustainability, the rate of energy withdrawal must not surpass the rate of natural replenishment. This helps maintain a thermal balance in the reservoir. Typically, geothermal plants operate at a consistent, reliable output level and are considered suitable for base-load power generation. Unlike other renewable sources that may fluctuate with weather or seasons, geothermal systems tend to produce a steady supply of energy, distinguishing them within the renewable energy sector.

Geothermal energy is harnessed through the following steps:

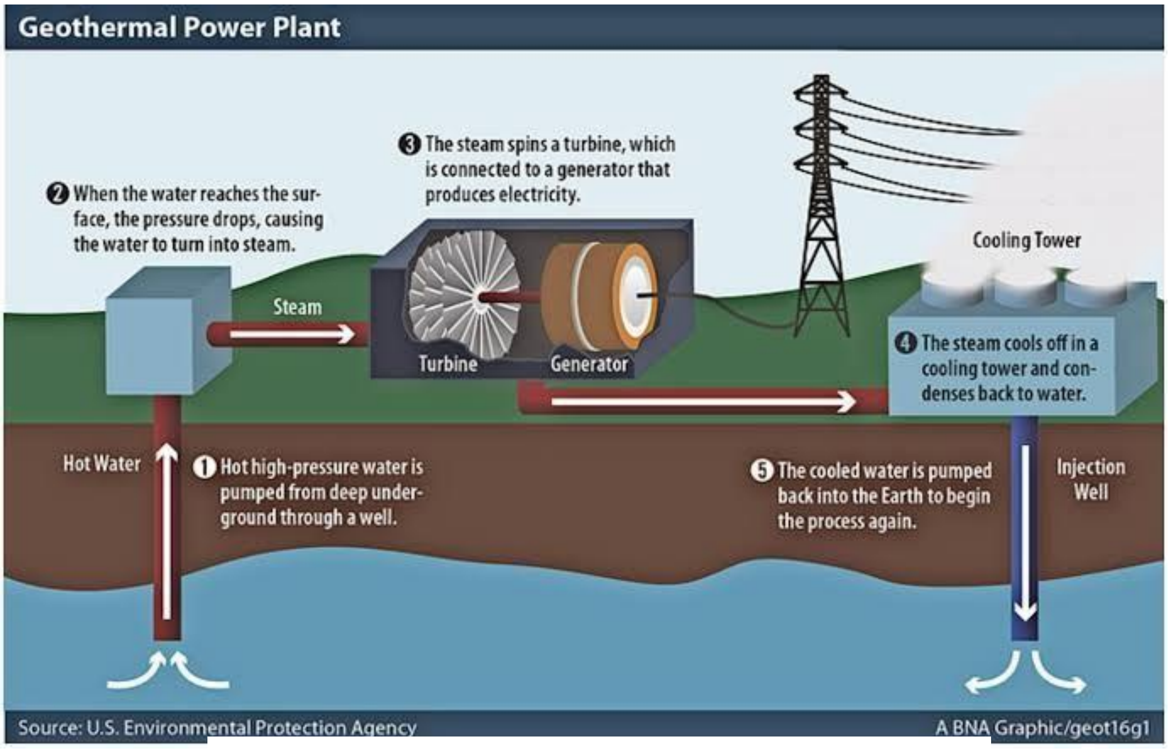


Fig 3: Operating Processes of A Geothermal Power Plant

• Heated, high-pressure water is extracted from deep beneath Earth's surface via a production well.
• As water ascends and reaches the surface, the drop in pressure causes it to convert into steam.
• This steam is directed to drive a turbine, which is linked to a generator that produces electricity.
• After powering the turbine, the steam is cooled in a cooling system and condenses back into water.
• The condensed water is then re-injected into the ground to sustain the cycle.

## III. TYPES OF GEOTHERMAL POWER PLANT

As outlined by Renewable Energy World (2K19), there are three main categories of geothermal control floras: dry vapor, showy steam, and binary sequence systems. Dry steam geothermal plants utilize naturally occurring subversive steam reservoirs. In these systems, steam is extracted directly from deep wells and transported through pipelines to a power facility, where it turns a turbine connected to a generator to produce electricity. The used steam is often condensed and either recycled back into the geothermal reservoir or employed for cooling processes. In the United States, there are only two known locations with natural underground steam sources: Geysers in Northern California and Yellowstone National Park in Wyoming. Due to environmental protections, Yellowstone cannot be developed for energy production, so The Geysers remains the only operational site for dry steam power plants in the country.

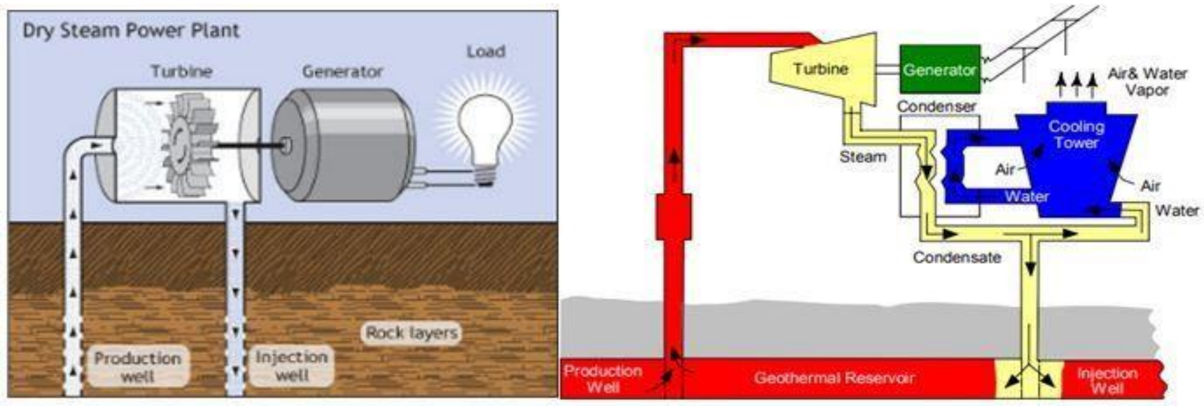


Fig 4: Schematic of A Dry Steam Power Plant (Geo-Heat Centre and U.S. Energy Department)

Flash steam power plants are most widely used type of geothermal energy systems. They operate using underground tanks containing aquatic at temperatures above 182°C. This highly pressurized hot water rises naturally through wells. As it moves toward the surface, the pressure drops, causing a portion of the water to rapidly vaporize, or "flash," into steam. Steam is then detached and directed to drive a turbine that generates electricity. Afterward, outstanding liquid water and any reduced steam are reinjected into reservoir to sustain cycle. In more advanced systems, this residual hot water can undergo a second or even third flashing process at lower pressures to extract additional steam, as seen in double or triple flash plants.

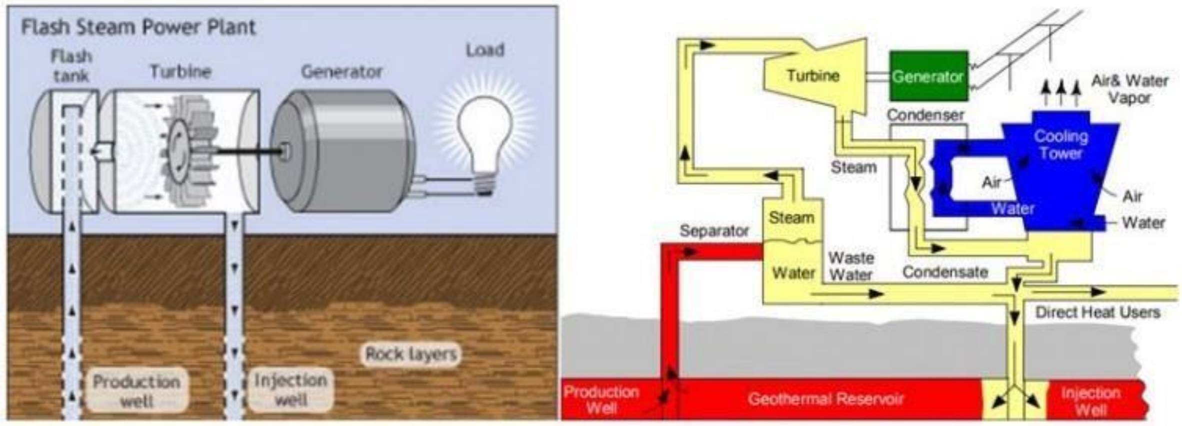


Fig 5: Schematic of A Flash Steam Power Plant (Geo-Heat Centre and U.S. Energy Department)

Binary cycle control plants function using geothermal aquatic with relatively low infections, typically ranging from 107°C to 182°C. Instead of using this water directly to produce steam, these systems transfer its heat to a secondary fluid—commonly an organic compound with a low scorching point. This secondary fluid vaporizes in a heat exchanger and drives a turbine to generate electricity. Throughout the process, the geothermal water and the secondary fluid remain completely separate. After releasing its heat, the water is re-injected into Earth to be naturally warmed, resulting in minimal or no emissions to the atmosphere.

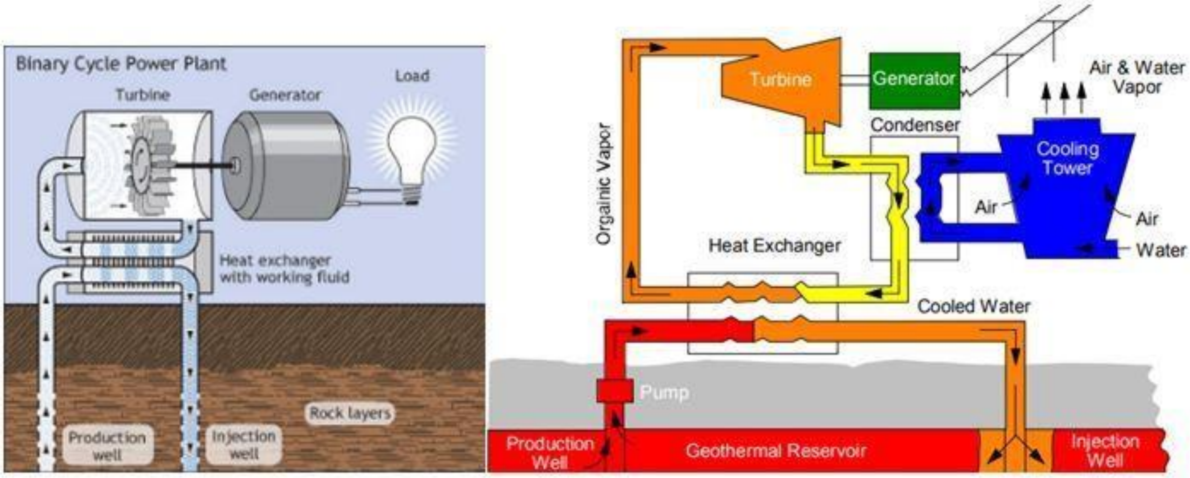


Fig 6: Schematic of A Binary Cycle Steam Power Plant (Geo-Heat Centre and U.S. Energy Department)

Geothermal energy resources can be categorized into two main types: vapor-dominated and liquid-dominated systems.Vapor-dominated reservoirs generate superheated steam at high temperatures, typically between 240°C and 300°C, which is ideal for electricity production.

Liquid-dominated systems, which are more prevalent, generally exist in areas with underground temperatures above 200°C. These systems are commonly located near active volcanic regions along the Pacific Ring of Fire, as well as in rift zones and geothermal hot spots. Electricity from these sources is typically generated using flash steam plants. These systems rely on the natural pressure of the hot water to convert it into steam, eliminating the need for external pumping mechanisms.

Low-temperature, liquid-dominated geothermal reservoirs—typically ranging amid 120°C and 200°C—require mechanical pumping to extract the fluids. These reservoirs are frequently found in regions with extensional geological settings, where heat is transferred through deep fault-driven circulation, such as in areas of the western United States and Turkey. In binary cycle power plants that use the Rankine process, geothermal water is routed through a heat exchanger, where it heats an organic working fluid. This fluid then vaporizes and drives a turbine to generate electricity.

## IV. ENHANCED GEOTHERMAL SYSTEM

Enhanced geothermal systems (EGS) function by injecting water into deep underground wells, where it is naturally heated by the Earth's internal heat before being extracted back to the surface. High-pressure water is used to widen pre-existing fractures in the rock, allowing for improved circulation. This approach is adapted from techniques originally developed in oil and gas business. However, unlike those methods, EGS involves accessing much deeper geological layers and avoids the use of harmful chemicals, thereby minimizing environmental risks.

Geothermal heat pumps are versatile systems that can be installed in nearly any location around the globe. Unlike traditional geothermal systems, they do not depend on the presence of fractured rock formations or underground water reservoirs. As outlined by the Oil & Gas Portal (2017), a standard geothermal heat pump setup includes three key components:

1. Reervoir
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

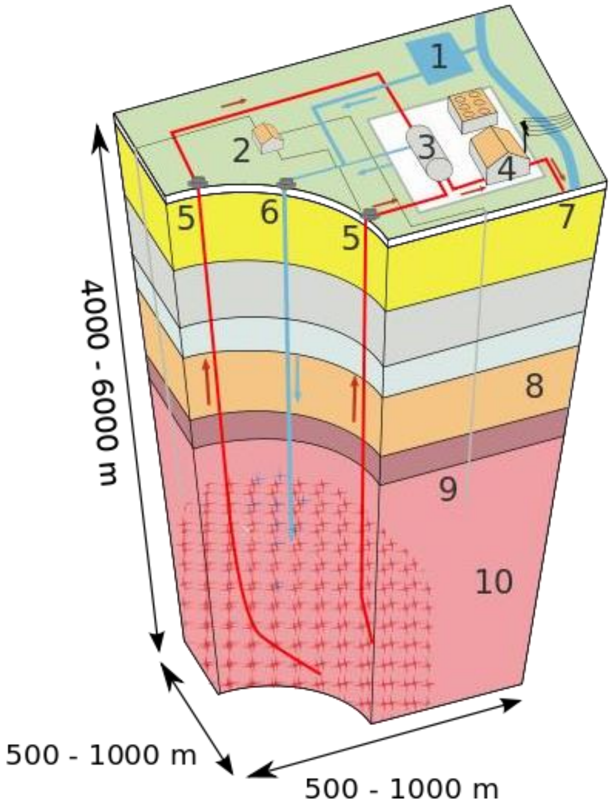


Fig 7: Enhanced Geothermal System

- A ground heat money changer
- Heat pump unit itself
- A duct system for air distribution within the building

A heat exchanger consists of a network of pipes arranged in a loop that is buried just below the surface near a building. A fluid—typically water or a water and antifreeze mixture—flows through these pipes, absorbing heat from the earth.

During colder months, the heat pump extracts heat from the fluid circulating in the heat exchanger and distributes it through the building's indoor air system. In warmer months, this process is reversed, with the heat pump transferring heat from the indoor air to the heat exchanger buried underground.

Additionally, the heat removed from the indoor air in the summer can be repurposed to warm water, offering a cost-free supply of hot water.

Geothermal heat pumps utilize four different loop configurations to transfer heat between the ground and the building. Three of these—horizontal, vertical, and pond/lake loops—are closed-loop systems, while the fourth option is an open-loop system. The selection of the most suitable system depends on factors such as climate, soil characteristics, available land area, and local installation costs.

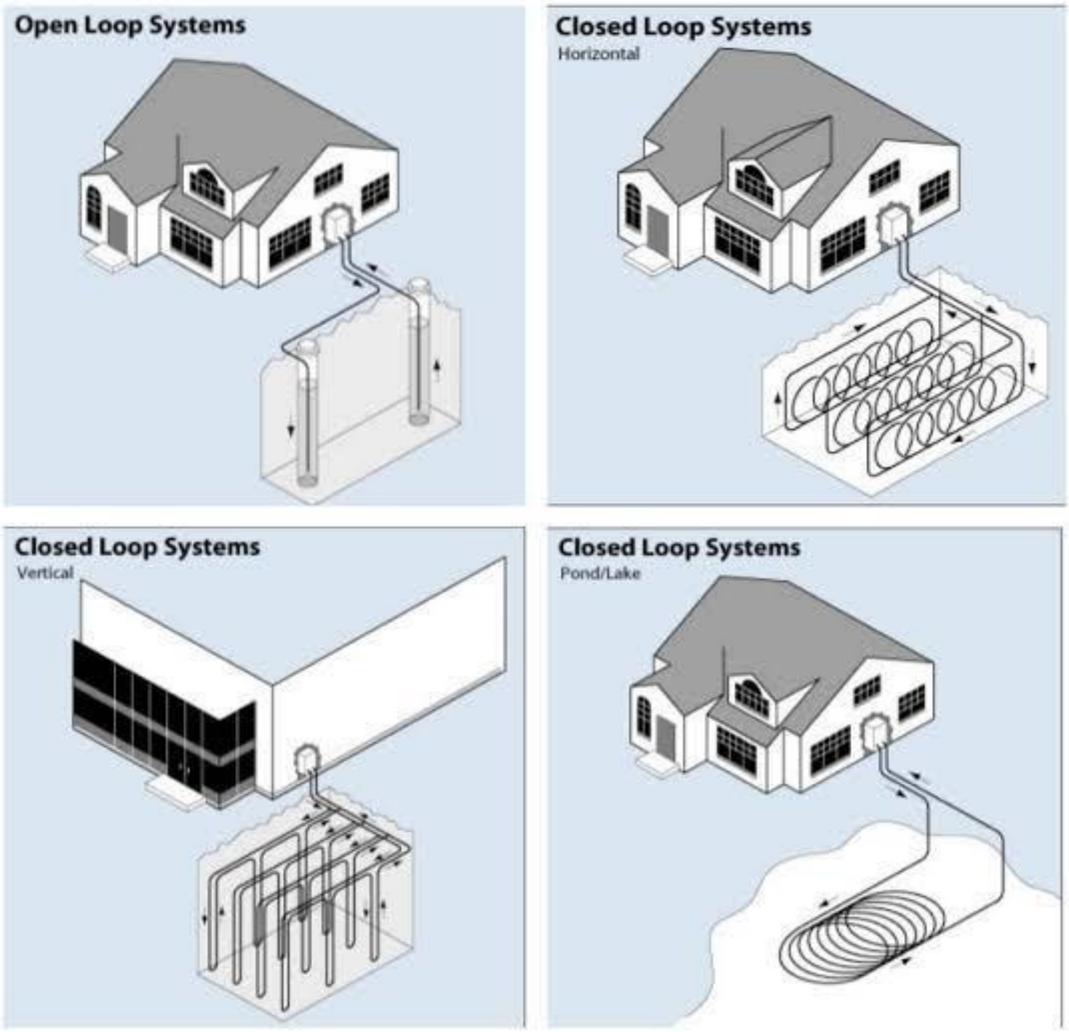


Fig 8: Schematics of Open and Closed-Loop Systems of Geothermal Heat Pumps

## V. GEOTHERMAL ENERGY PROS AND CONS

Based on Energy Informative (2020), the key benefits of geothermal energy include:

- **Eco-Friendly:** Geothermal energy is widely recognized as an environmentally sustainable power source. While its extraction involves some minor pollutants, these are significantly less harmful compared to emissions from traditional fossil fuels. The carbon emissions from a geothermal plant are very low. For instance, a typical geothermal facility emits about 122 kg of CO2 per megawatt-hour (MWh) of electricity, which is only about one-eighth of the carbon output from a standard coal-fired power plant.
- **Renewable:** Geothermal energy comes from naturally occurring reservoirs that are continuously replenished by the Earth's heat, making it a renewable resource. It is often described as sustainable, meaning it can maintain its output over time without depletion, unlike finite energy sources such as coal and oil. Experts suggest that the energy contained in geothermal sources could last for billions of years.

**Significant Potential:** Although global energy use is around 15 terawatts (TW), the energy stored within the Earth far exceeds this demand. However, the majority of geothermal reserves are currently not economically viable, so only a fraction of this potential can be tapped. Realistic projections for geothermal power capacity range from 0.035 to 2 TW. Presently, geothermal plants worldwide generate roughly 10,715 megawatts (MW) of electricity, which is considerably less than the approximately 28,000 MW of geothermal heating capacity installed globally.

**Advantages of Geothermal Energy**

- **Reliable Energy Source:** Geothermal energy offers consistent and dependable power generation. Unlike solar or wind power, which are heavily influenced by weather conditions, geothermal plants provide a predictable power output. This reliability makes geothermal energy an excellent choice for fulfilling the continuous base load demand of electricity. These power plants typically operate at a high capacity factor, meaning their actual electricity generation closely matches their maximum installed capacity. For instance, in 2005, the global average capacity factor for geothermal plants was around 73%, with some plants achieving up to 96%.

- **Efficient for Heating and Cooling:** To generate electricity efficiently, geothermal turbines require water temperatures exceeding 150°C. Alternatively, geothermal systems can exploit the modest temperature differences between the ground and surface air. Because the earth's temperature remains relatively stable throughout the year, just a few meters below the surface the ground serves as a natural heat reservoir. This characteristic enables geothermal heat pumps to provide heating and cooling in a manner similar to electric heat pumps.

**Drawbacks of Geothermal Energy (Based on Energy Informative, 2020)**

- **Environmental Concerns:** The earth's subsurface contains various greenhouse gases, some of which can escape during geothermal energy extraction and enter the atmosphere. Emissions such as sulfur dioxide and silica are commonly associated with geothermal power plants, and the geothermal reservoirs may contain toxic elements like mercury, arsenic, and boron. Despite these emissions, geothermal energy's overall environmental impact is much lower than that of fossil fuels like coal.
- **Land Stability Issues (Seismic Activity):** Building geothermal plants can sometimes lead to ground movement. There have been instances of land subsidence in countries such as Germany and New Zealand due to geothermal development. Additionally, techniques like hydraulic fracturing used in enhanced geothermal systems (EGS) can induce earthquakes. For example, in January 1997, the construction of a geothermal plant in Switzerland caused a 3.4-magnitude earthquake.
- **High Costs:** Developing geothermal power plants involves significant expenses. Exploration and drilling typically account for about half of the total investment. Building a plant with a 1-megawatt capacity can cost between $2 million and $7 million. Many geothermal resources remain economically unviable under current technology, energy prices, and subsidy levels.
- **Geographical Limitations:** Suitable geothermal reservoirs are not widespread. Certain countries, such as Iceland and the Philippines, benefit greatly from geothermal energy, meeting almost a third of their electricity needs through this source. However, geothermal reservoirs with sufficient heat flow exist only in specific regions where they can be economically accessed with current technologies.
- **Sustainability Challenges:** Geothermal reservoirs are naturally replenished by rainwater seeping into the ground over thousands of years. If geothermal fluids are extracted faster than they can be replaced, reservoirs may become depleted. To prevent this, some operations reinject fluid back into the reservoir after energy extraction. With careful management, geothermal energy can be a sustainable power source.

**Summary:** Geothermal energy is widely viewed as a clean, sustainable, and reliable form of energy. While it represents a smart choice in many areas, the high initial costs hinder its widespread adoption. The future role of geothermal energy in the global energy mix will depend on advances in technology, market energy prices, and governmental policies such as subsidies.

## REFERENCES


[1] Dye S. T. (2012). Geoneutrinos and the radioactive power of the Earth. Reviews of Geophysics. 50(3): RG3007

[2] Energy Informative (2020). Geothermal energy pros and cons. Retrieved from https://energyinformative.org/geothermal-energy-pros-and-cons/ on January 02, 2020

[3] Fridleifsson Ingvar B., Bertani Ruggero, Huenges Ernst, Lund John W., Ragnarsson Arni, Rybach Ladislaus (2008). Hohmeyer O., and Trittin T. The possible role and contribution of geothermal energy to the mitigation of climate change. Page 59-80

[4] Gando A., Dwyer D. A., McKeown R. D., Zhang C. (2011). Partial radiogenic heat model for Earth revealed by geoneutrino measurements. Nature Geoscience. 4(9): 647

[5] Geothermal Energy. December 14, 2019. Retrieved from https://www.encyclopedia.com/science-and-technology/technology/technology-terms-and-concepts/geothermal-energy on December 20, 2019.

[6] Glassley William E. (2010). Geothermal Energy: Renewable Energy and the Environment

[7] Lay Thorne, Hernlund John, Buffett Bruce A. (2008). Core-mantle boundary heat flow. Nature Geoscience, 1: 25-32.

[8] Manzella A. (2017). Geothermal Energy. Institute of Geosciences and Earth Resources - Pisa, Italy. EPJ Web of Conferences 148, 00012.

[9] Oil & Gas Portal (2017). Geothermal exploration process and production technologies. Retrieved from www.oil-gasportal.com/geothermal- exploration-process-and-production-plants/

[10] Renewable Energy World (2019). Geothermal Electricity Production. Retrieved from https://www.renewableenergyworld.com/types-of-renewable- energy/tech-3/geoelectricity/#gref on December 29, 2019.

[11] Turcotte D. L., Schubert G. (2002). Geodynamics, second edition. Cambridge, England, UK: Cambridge University Press, pp. 136-137.