

# Renewable Energy and Distributed Generations

## Lecture 14

### Geothermal Energy Resources

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## ***Lecture learning outcomes:***

At the end of this lecture, you will be able to:

- i. Understand the types of Geothermal Power Plant (GPP)
- ii. Knows motivation behind using Geothermal Power plant
- iii. Identify the component of GPP
- iv. Knows the Operation GPP
- v. Understand the operation and factors affecting GPP

# Outlines

- 1. Introduction**
- 2. Types of Geothermal Power Sources**
- 3. Motivation behind using Geothermal energy**
- 4. Geothermal Energy system components**
- 5. Operation of Geothermal Power Plant**
- 6. Advantage and Disadvantage of GPP**
- 7. Factors Affecting GPP Operation**

**Summary**

**References**

# 1. Introduction

- Geo (earth) + thermal (heat) equals geothermal energy, which is heat energy from the earth
- Hot water reservoirs at different temperatures and depths below the earth's surface that are naturally occurring or created by humans are known as geothermal resources[1].
- The fact that heat is constantly generated inside the earth makes geothermal energy a renewable energy source.
- Steam is used in geothermal power plants to generate energy.
- The steam originates from hot water reservoirs located several miles below the surface of the earth.
- Steam drives a turbine, which in turn turns on a generator to produce power as presented in Fig.1.

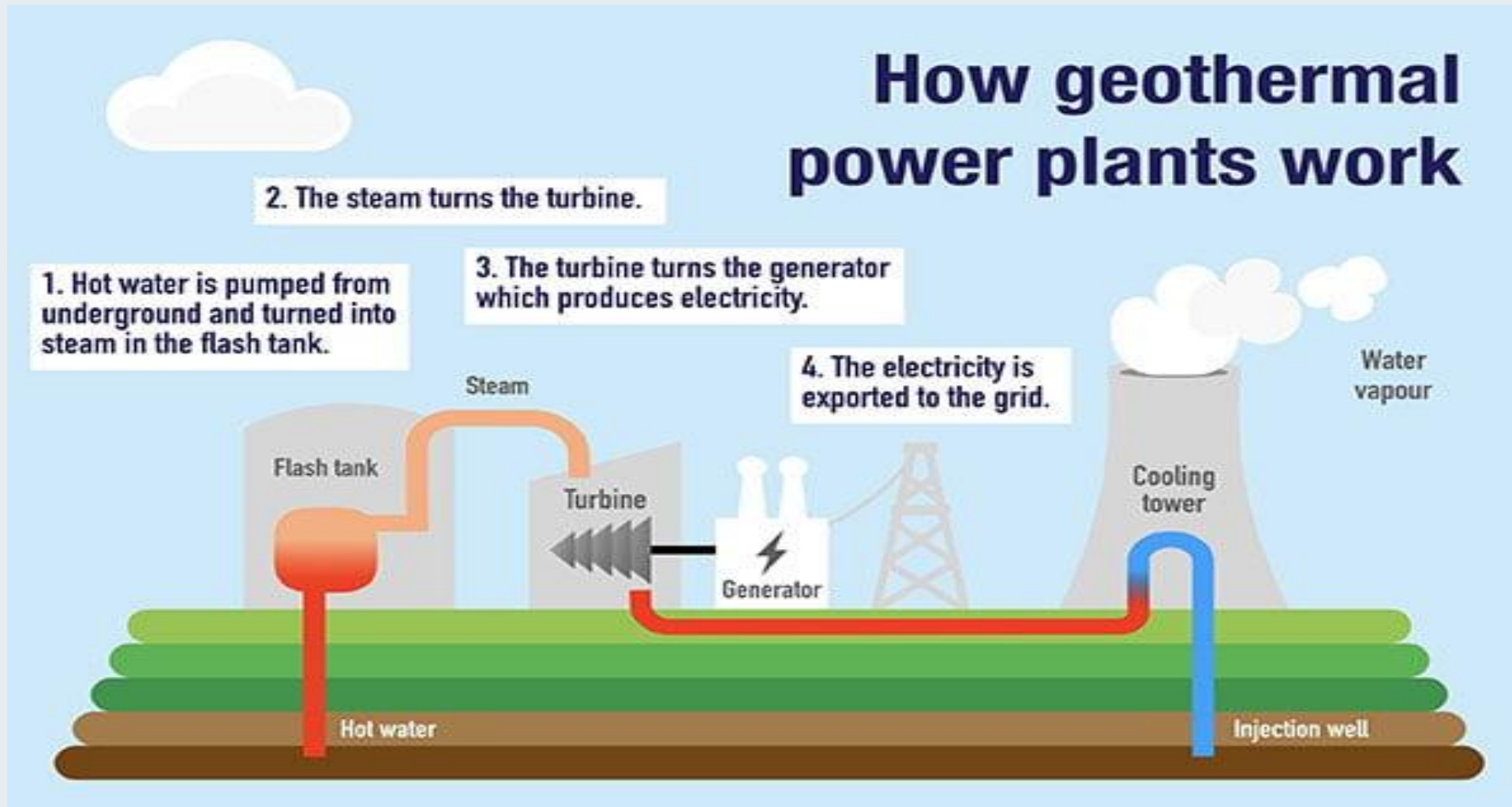


Figure 1. Geothermal power Plant working principle.

<https://amigoenergy.com/blog/understanding-geothermal-energy/>

# Introduction

- Earth has a heat content of  $10^{31}$  joules.
- This heat naturally flows to the surface by **conduction** at a rate of 44.2 terawatts, (TW,) and is replenished by radioactive decay at a rate of 30 TW.
- These power rates more than double the amount of energy that humans now use (15 TW ) from primary sources, however the majority of this power is too diffuse (on average  $0.1 \text{ W/m}^2$ ) to be retrieved.
- **To release** the heat underneath, the earth's crust needs to be punctured by fluid conduits, such as water or magma.
- The crust functions as a thick insulating blanket.

# Cont.....

# Introduction

# Cont.....

- Between 45 and 90 percent of the heat that leaves earth is thought to come from the radioactive decay of atoms, mostly found in the mantle
- Gravitational potential energy is further subdivided as follows:
  - a. release during earth's formation.
  - b. Heat produced as the numerous heavy metals like copper, nickel, and iron that sank to the earth's core during differentiation.
- Geothermal heat is naturally occurring heat that rises to higher levels of the earth's crust as a result of radioactive materials in the crust decaying.

# Introduction

# Cont.....

- Hydro-geothermal energy is the accumulation of interior earth energy in gasses and water
- whereas petro-thermal energy is the retention of that energy in solid rocks
- Petro-thermal energy has just lately been employed for building heating and cooling, but hydro-geothermal energy has been used for decades, either directly or to generate heat and electricity.
- The most common phrase used to describe the production of electricity from hydro-geothermal energy is geothermal energy.
- The global installed capacity of geothermal energy is a combined capacity of 16,318 MW in 2023[2].
- The installed capacity per country is given Fig.2

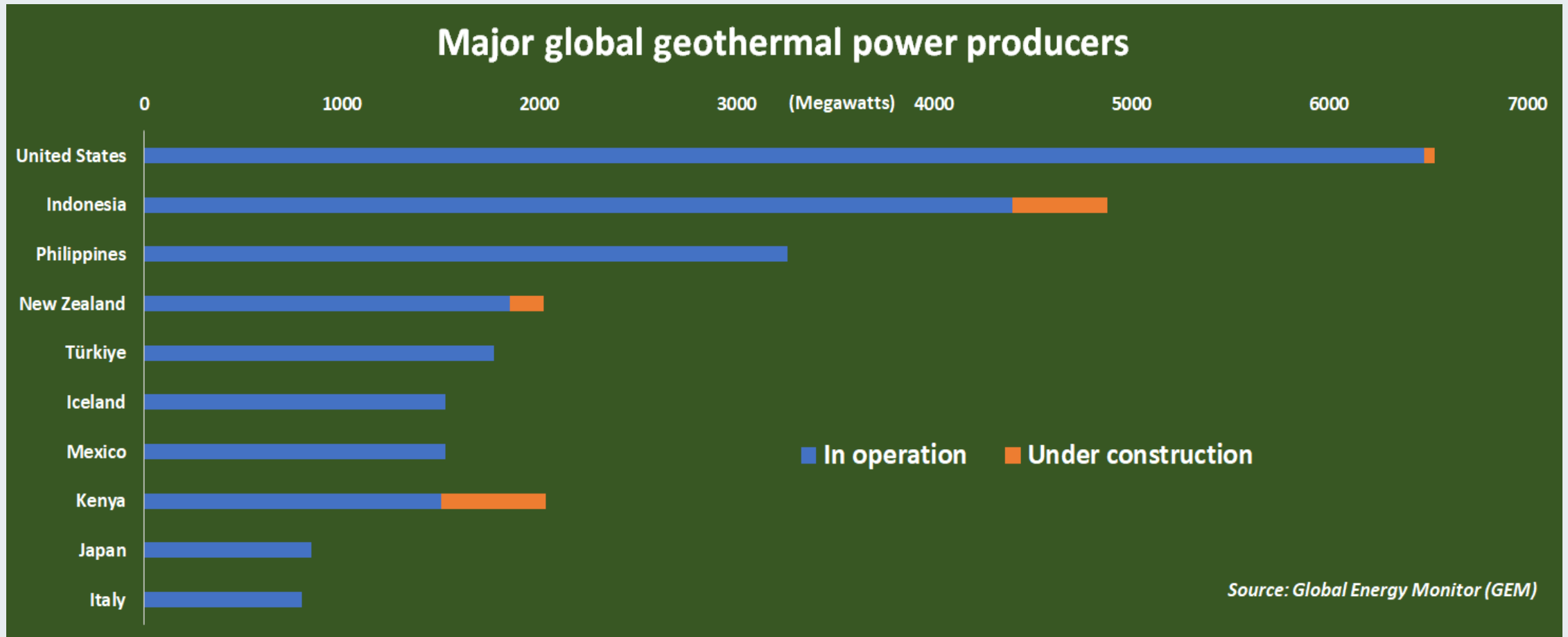


Figure 1. Global Geothermal Power producer[3]. <https://www.reuters.com/markets/commodities/kenya-steps-up-global-geothermal-powerhouse-2023-10-05/>

# Introduction

# Cont.....

- The majority of this hot geothermal water remains underground, locked in fissures and porous rock
- It can occasionally surface as hot springs or geysers.
- It's known that this naturally occurring hot water gathering as a geothermal reservoir.
- Accordingly, this naturally existing energy should be harnessed and different techniques should be applied to produce these energy
- Its efficient uses based on the types of resources is also needed

## 2. Types of Geothermal Power Sources

**Hot Water Reservoirs:** The hot underground water reservoir is used as input for producing energy

- The large number hot water reservoir exist in different regions

**Natural Steam Reservoirs:** this needs the deep dug-holes into the ground that can causes steam flow to the surface.

**Geo-pressured Reservoirs:** it uses the salt-water , which is completely saturated with different natural gas in stored under pressure from the weight of overlying rock.

- Can be used for different applications like heat **and natural gas.**

**Normal Geothermal Gradient**

**Molten Magma:**

### 3. Motivation behind using Geothermal energy

- Environmentally friendly
- Reliable and doesn't dependent on weather condition
- Easily integrated with the Grid
- Naturally abundant
- Possibility of generating in large Giga-watt
- It is an exceptionally constant source of energy , it is not dependent on neither wind nor sun , and available all year long

# Motivation

cont.....

- High efficiency : Geothermal heat pump systems uses 25% to 50% less electricity than conventional systems for heating or cooling, and
- Flexible design they can be adjusted to different situations, requiring less
- Little to No Geothermal System Maintenance
- Reliable and Long life span , 20-50 years as presented in Fig.2
- Minimal Land Use Compared to Other Energy Sources

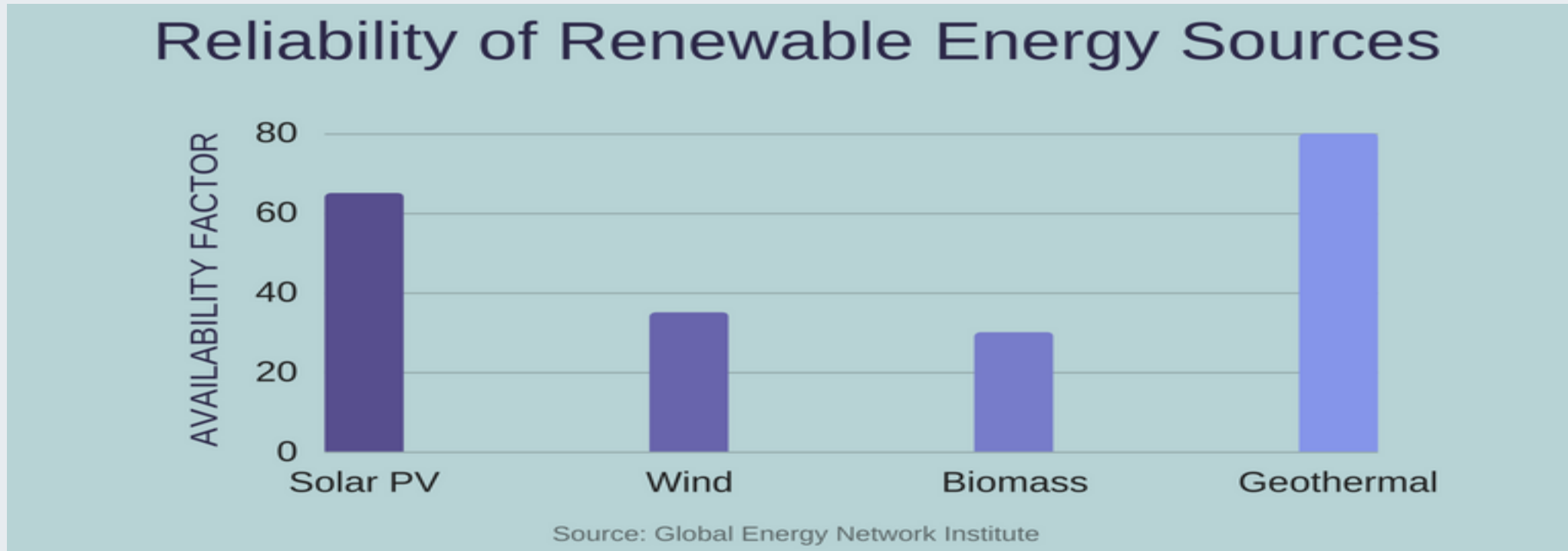


Figure 2. the Reliability of Geothermal energy Vs OTHER RE resources. <https://www.greenmatch.co.uk/blog/2014/04/advantages-and-disadvantages-of-geothermal-energy>

## Geothermal energy is used for:

- Used as electricity generations
- Work as direct uses for the commercial, industrial, and residential heating purposes
- For efficient home heating and cooling through geothermal heat pumps[4]:
- For indirect uses drilling wells are needed then hot water will flow into a geothermal reservoir.
- a temperature above  $150^{\circ}\text{C}$  is needed for indirect use and for the direct use it is generally around  $80^{\circ}\text{C}$ .
- Then, the water go to the surface through wells and then its heat energy will be converted into electricity at a geothermal power plant.

# 4. Geothermal Energy System Components(GESC)

- A geothermal system is composed of three main elements:
  - i. Heat Source
  - ii. Reservoir
  - iii. Fluid
- The geothermal energy is transferred from interior towards the surface by conduction as presented in Fig.4.
- It can be explained as follows: "convecting water in the earth's upper crust transfers heat from a heat source to a heat sink, usually the free surface, in a confined space"

- Three primary components comprise a geothermal system: a reservoir, a heat source, and a fluid that acts as a heat carrier.
- The heat source may be the earth's normal temperature, which rises with depth of a temperature (> 600 °C) magmatic incursion that has reached relatively shallow depths (5–10 km).
- The heated permeable rocks serve as the reservoir, where heat is extracted by the circulating fluids
- If the hot rocks are not permeable, it is necessary to fracture them

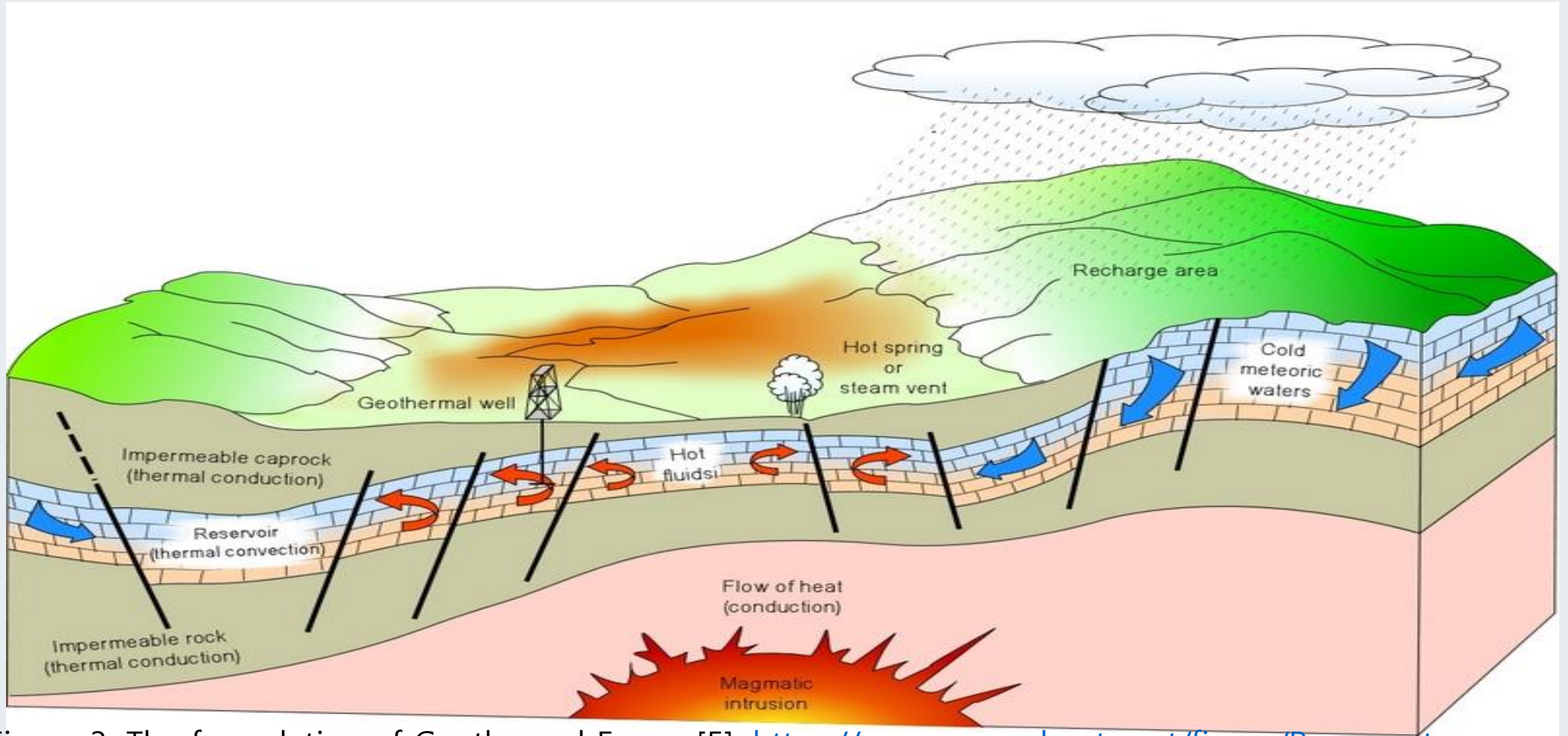


Figure 3. The formulation of Geothermal Energy[5]. [https://www.researchgate.net/figure/Representation-schematique-dun-systeme-geothermique-ideal-5\\_fig2\\_267724906](https://www.researchgate.net/figure/Representation-schematique-dun-systeme-geothermique-ideal-5_fig2_267724906)

# 5. Operation of Geothermal Power Plant(OGTPP)

- **There are four commercial types of geothermal power plants[6]:**
  - a. flash power plants
  - b. dry steam power plants
  - c. binary power plants
  - d. flash/binary combined power plants

## a. Flash Steam Power Plant

- Under intense pressure, the hot water is forced to the surface.
- Because the water contains contaminants like salt, it is frequently referred to as "brine."
- Some of the water turns into steam when it reaches the surface because of the drop in pressure as presented in Fig.4.
- This creates a steam blast, which rotates the turbine and then create electricity. Operates at higher temperature, greater than  $182^{\circ}\text{C}$
- The cooled water is put back into the reservoir so that geothermal rocks can warm it once more.

# OGTPP

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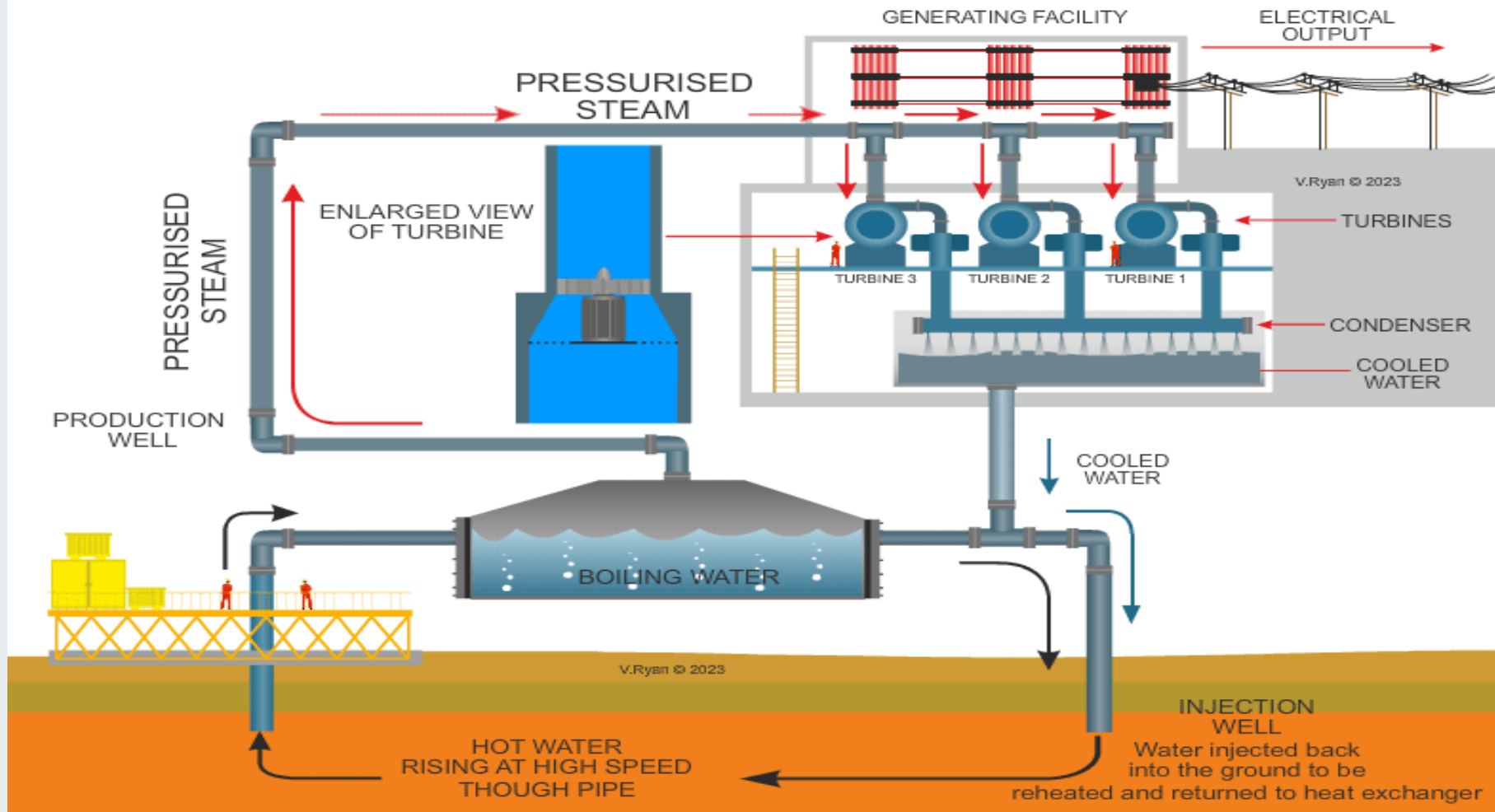


Figure 4. Flash Steam Power Plant operation. <https://technologystudent.com/energy1/geo4.htm>

b. **Dry Steam Power Plant:** Generator turbines in dry steam plants are powered by steam extracted directly from a geothermal reservoir[7].

- An electrical generator is powered by the steam, which is brought straight to a turbine, which is presented in Fig.5.

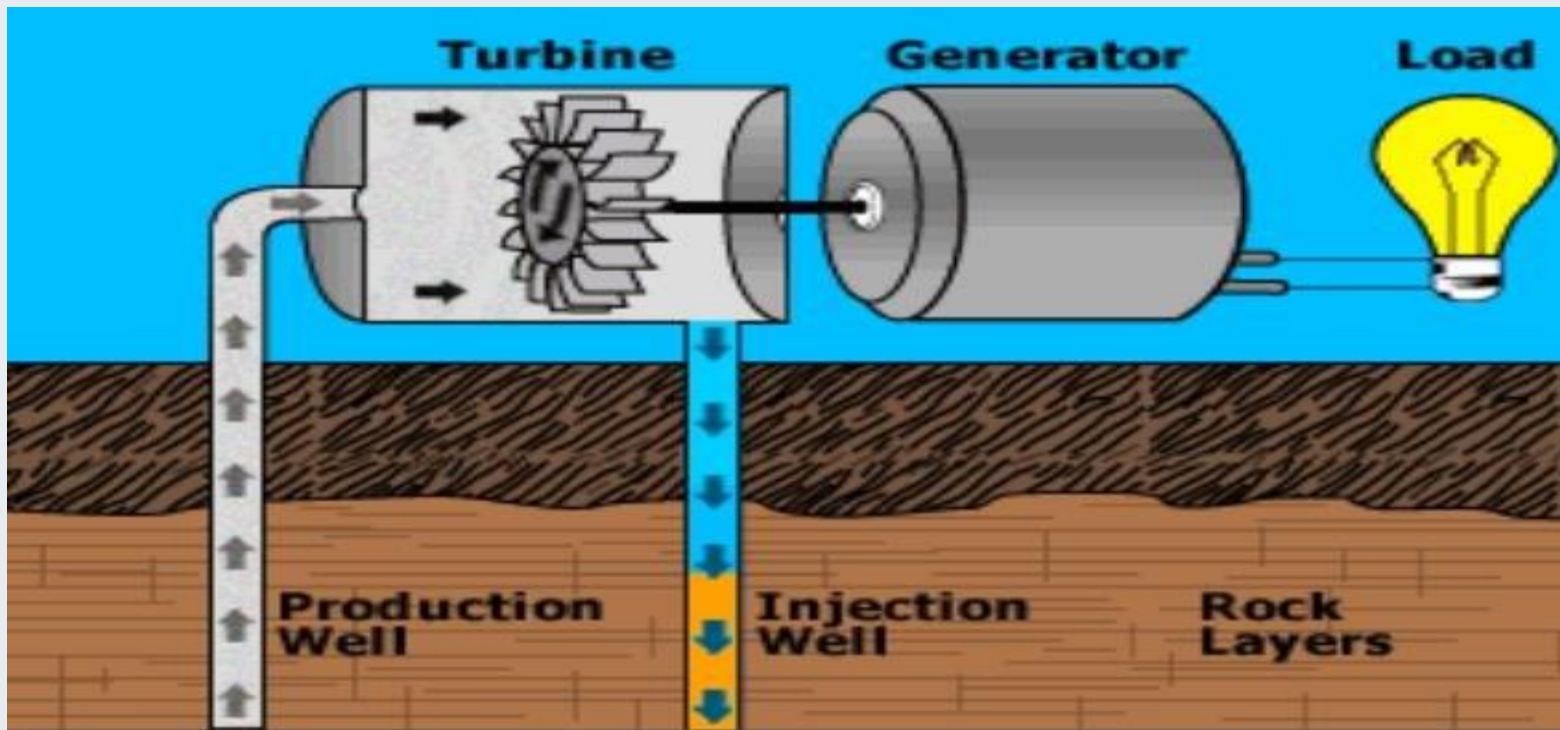


Figure 5. Dry Steam Power Plant operation.

[https://www.researchgate.net/figure/Dry-steam-power-plant\\_fig6\\_359577886](https://www.researchgate.net/figure/Dry-steam-power-plant_fig6_359577886)

- The purpose of the cooling tower is to make the steam exiting from the turbine as cool as possible, so that it has low pressure;
- This leads to make more energy or electricity to be extracted from the turbine.
- The cooling tower produces cool water by pushing evaporation of some of the water that is fed to it.
- Some of the water may lost through evaporation needs to be continuously replaced.
- Accordingly, the cooling towers are used in coal and nuclear power plants, which also have steam turbines

## C. Binary Power Plant:

- When the source contains minerals or chemicals, or when the geothermal resources are not hot enough to generate steam, a binary cycle power plant is utilized.
- In binary-cycle power plants, heat from geothermal hot water is transferred to **another** liquid.
- The heat causes the second liquid to become steamy, which drives a generator turbine.

# OGTTP

# Cont.....

- Typically, the Organic rankine Cycle like isobutane or other organic fluids like penta-fluoropropane, which boils at a lower temperature than water, is heated by the geothermal water.
- A heat exchanger is used to transport the heat energy from the geothermal water to the working fluid, keeping the two liquids entirely apart.
- There is a gaseous vaporization of the secondary fluid.
- Similar to steam, the force of the expanding vapor drives the turbines that run the generators as presented in Fig.6

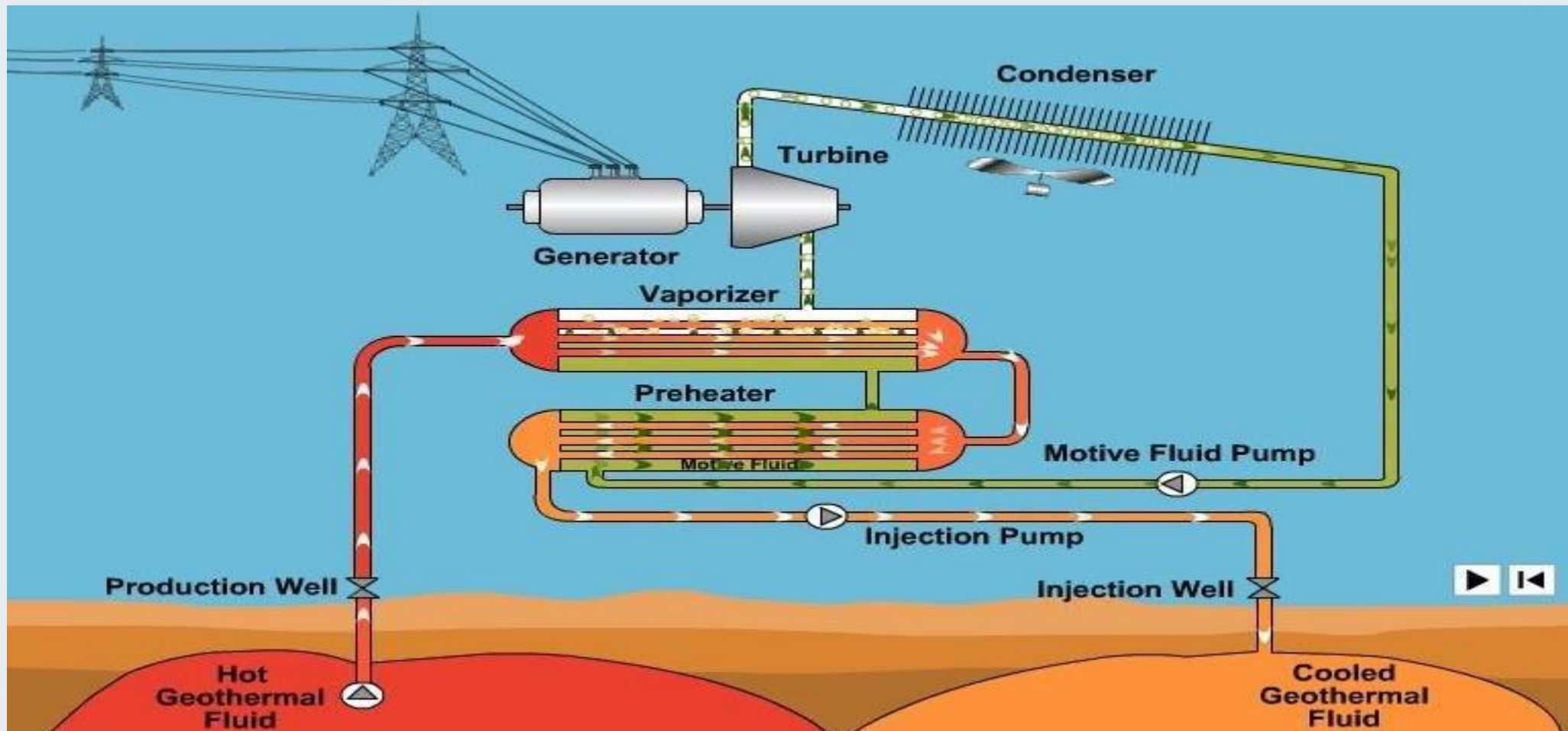


Figure 6. Binary Power Plant operation. [https://www.researchgate.net/figure/Binary-cycle-power-plant-fig7\\_359577886](https://www.researchgate.net/figure/Binary-cycle-power-plant-fig7_359577886)

## 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 steam under reduced pressure is first converted to electricity with a back pressure steam turbine and the low-pressure steam exiting the back pressure turbine is condensed in a binary system.
- In addition to different power plant technologies in use today, additional applications and technologies continue to emerge.

## 6. Factors Affecting GPP Operation

- Water must exist in an underground reservoir. Plenty of water that steadily recharges to prevent depletion of the reservoir.
- It must be really hot in the water. Warm enough to support the practical production of energy.
- Drilling must be done at an economical depth.
- Costs associated with the exploration, drilling wells, plants and equipment and costs of operation, and maintenance should be minimized
- A geothermal plant's price is highly site-specific.

# Factors Affecting GPP

# Cont....

- The average cost of a geothermal power plant is estimated to be between USD 1870 and USD 5050 per kW[8],[9].
- Generally speaking, **flash and direct dry** steam plants are less expensive than binary plants.
- While a depth of 10 km is feasible, the economical depth may only go as deep as 6 km.
- An additional aspect raising the overall price is the cost of exploration.
- There will be a trade-off: drilling deeper wells will be more expensive, but the deeper wells will draw hotter water, increasing the efficiency of producing power and, ultimately, lowering the cost per unit.

# 7. Advantage and Disadvantage of GPP

## Advantage

- Important minerals be extracted from the underground water.
- Creates jobs and reduce reliance on oil .
- Could be online for long time without failures, 90 to 100% of the time compared to others like coal and nuclear plants .
- coal and nuclear plants operates 75 % and 65%, respectively per their life time
- Flash and Dry Steam Power Plants emit 1000x to 2000x less carbon dioxide than fossil fuel plants, no nitrogen oxides and little SO<sub>2</sub>.
- Binary and Hot Dry Rock plants have no gaseous emission at all.
- Reduced land requirement for power plant
- Reduced carbon emission compared to others as presented in Fig.7

# Advantage and Disadvantage of GPP

Cont.....

- For geothermal power generation no need of burning fuel, but they may release small amounts of SO<sub>2</sub> and CO<sub>2</sub>
- Geothermal power plants emit 97% less acid and about 99% less carbon dioxide than fossil fuel power plants of similar size[10]

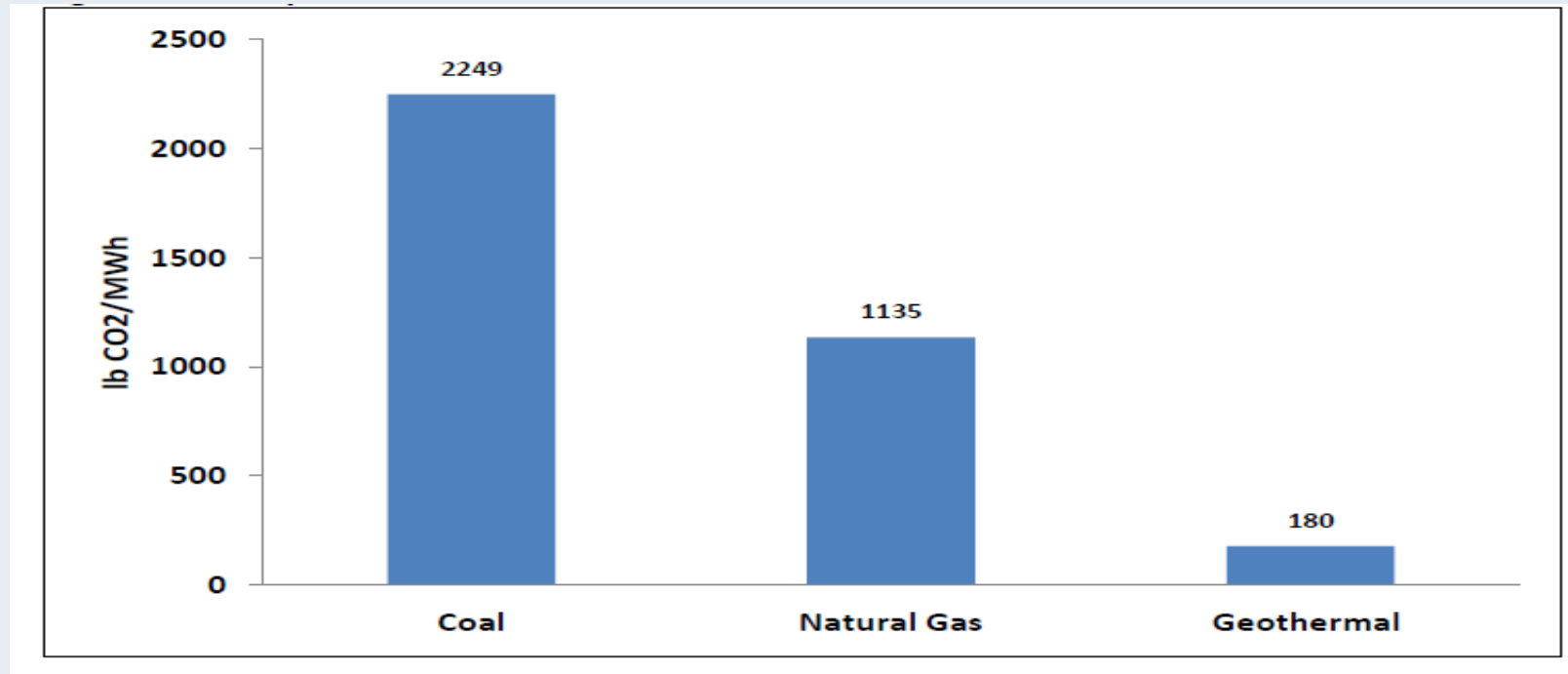


Figure 7. Emission Comparison GPP and others . [https://www.researchgate.net/figure/Comparison-of-coal-natural-gas-and-geothermal-CO2-emissions-GEA-2012\\_fig5\\_338384566](https://www.researchgate.net/figure/Comparison-of-coal-natural-gas-and-geothermal-CO2-emissions-GEA-2012_fig5_338384566)

# Advantage and Disadvantage of GPP

Cont.....

## Disadvantages

- High start-up cost
- Increased billing cost to consumer
- Water can be corrosive to plant pipes, equipment
- Mineral and solid waste can be produced
- Gasses are smelly, like ammonia
- Brine/salt-water can salient soil if the water is not properly injected back into the reserve after the heat is extracted.
- Noise pollution during drilling

# Summary

- In conclusion, the geothermal renewable energy is well discussed in this session.
- The three common operation of geothermal power generation like flash steam, dry steam and binary steam is well discussed.
- In line with this, the versatile advantage of geothermal energy in terms of environmental friendly, its efficiency and emission reduction compared other resources is also discussed.
- Besides this, the application of geothermal power plant is also discussed.
- The total installed capacity and potentials of geothermal power plant is also discussed.

## References

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Thank you !