University Mohamed Boudiaf - M’sila

Faculty of Technology

Department of Electrical Engineering

Specialty : Renewable energies and the environment

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Course Title:

Geothermal and other forms of renewable energy

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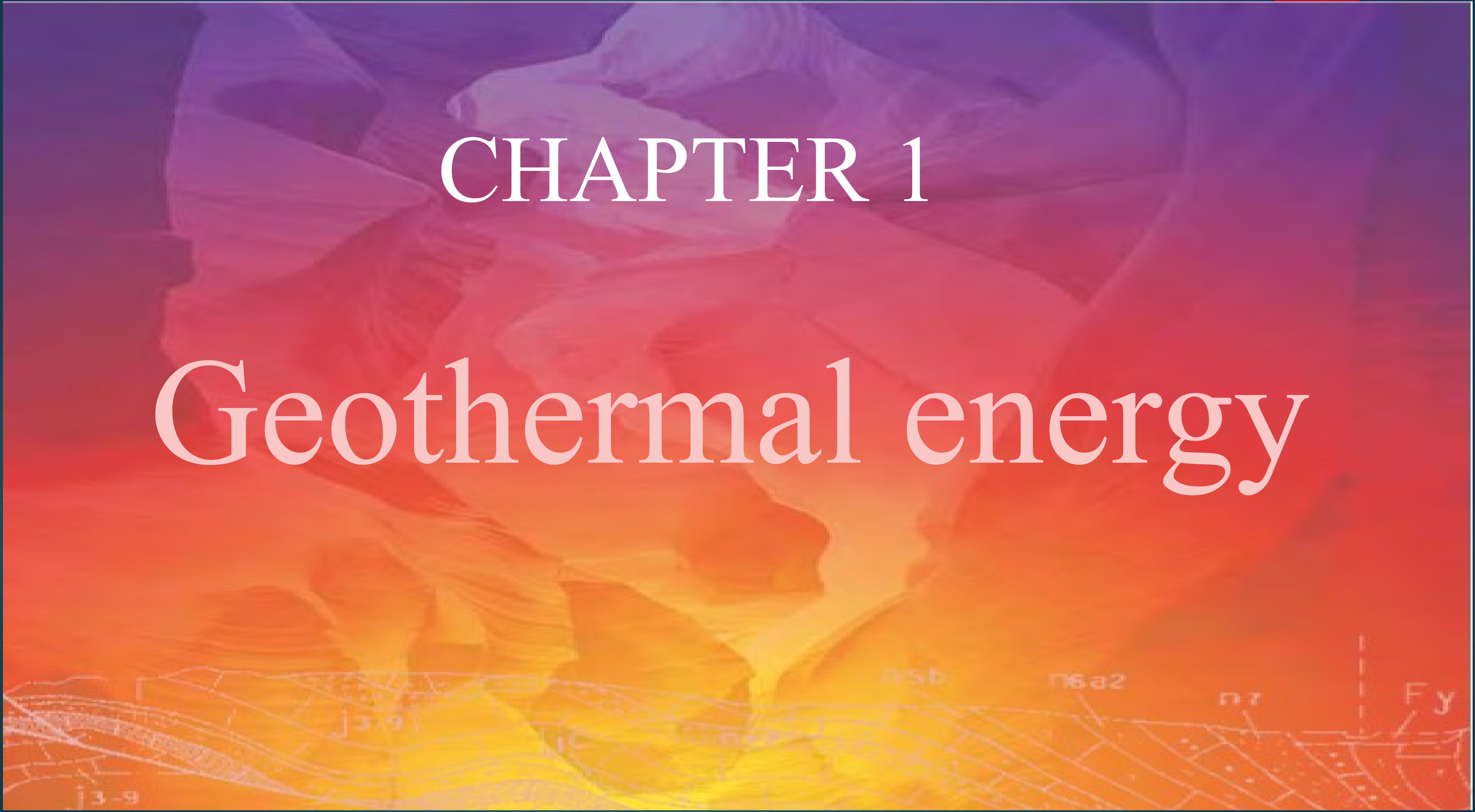

CHAPTER 1

Geothermal energy

Geothermal energy

Geothermal energy

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Geothermal energy

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Geothermal energy

1. Geothermal energy:

1.1.Definition:

Geothermal energy is energy created by the heat of the Earth. The word “geothermal originates from the Greek words :

Geo **→ which means** ***the Earth*****.**
Thermal **→ which means** ***the heat*****.**

So, ***Geothermal energy*** **literally means** ***“heat from the Earth.”***

1.2.Geothermal Reservoir

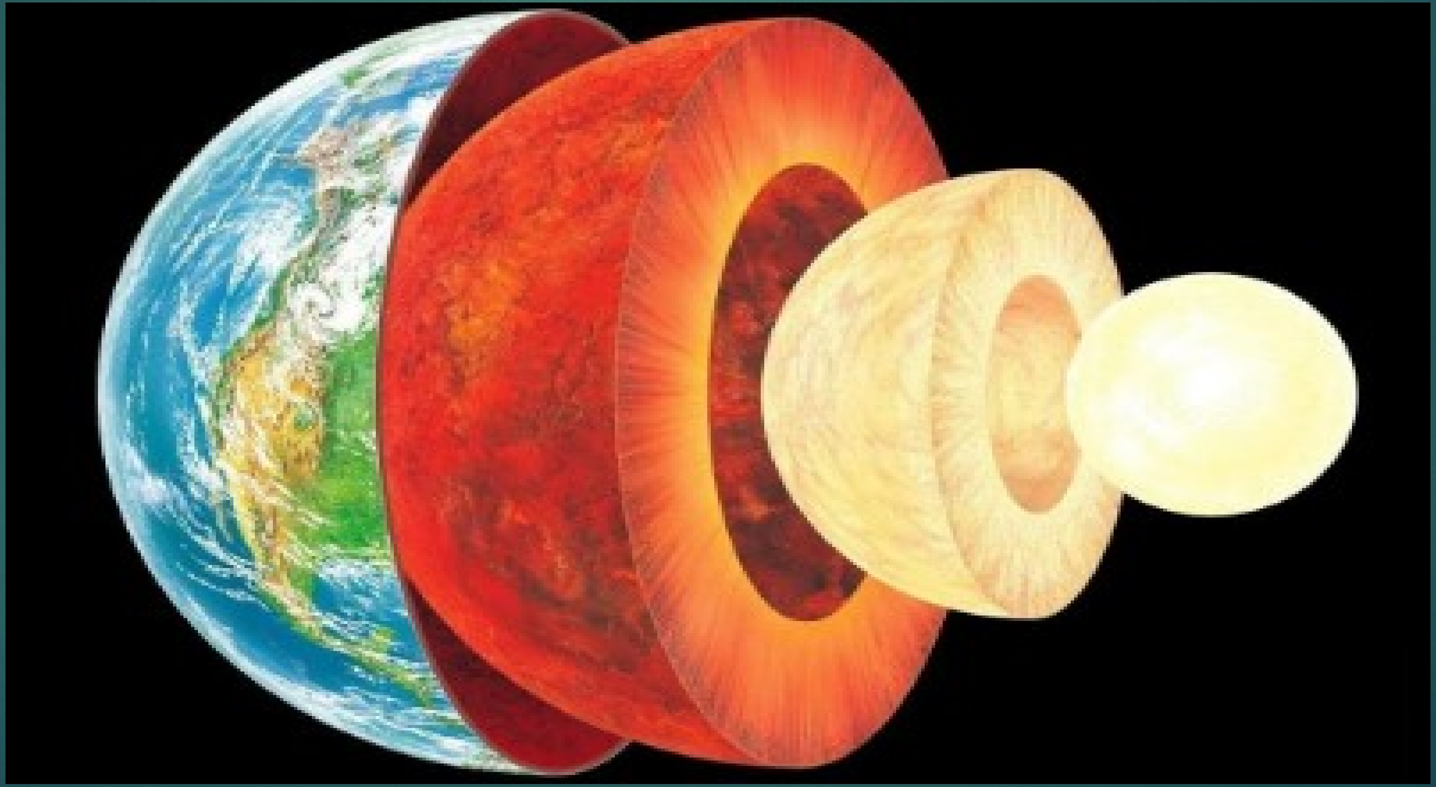
- Geysers
- Volcanoes

- Boiling mud pot
- Hot Springs

- Geothermal energy is considered a renewable energy resource because the heat emanating from the interior of the earth is essentially limitless.

- Geothermal energy is the thermal energy found in the earth's crust which originates from the formation of the planet and from the decay of the naturally radioactive isotopes of uranium , thorium and potassium.

2. Structure of the earth and temperature distribution



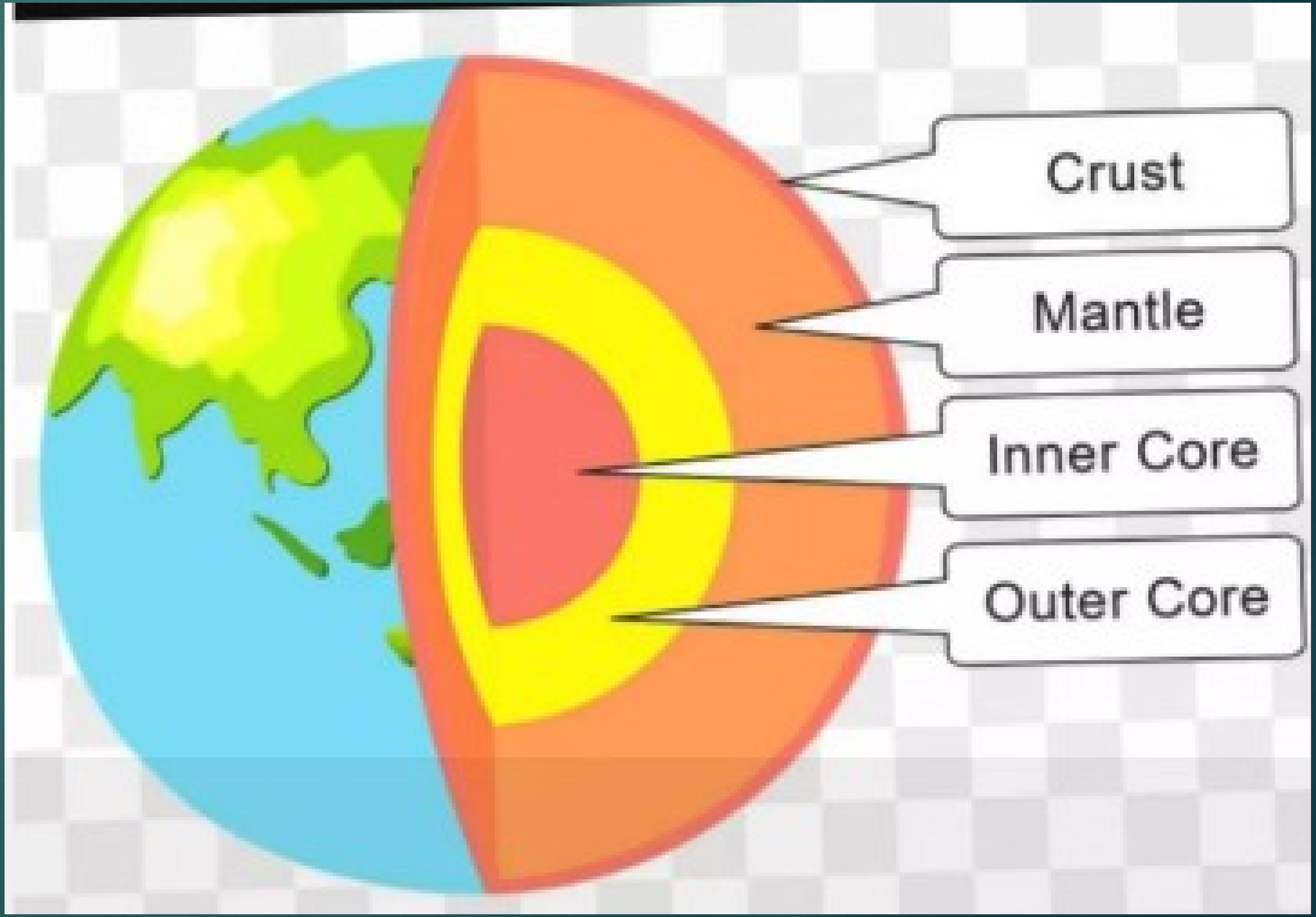
On the basis of relative position, density, and composition of the Earth, there are three different types of layers that identify the structure of the earth

These three layers are:

1. **Crust**
2. **Mantle**
3. **Core**

The core is further divided into:

- **Outer Core**
- **Inner Core**



2.1.Crust:

- The outermost layer of the Earth is the crust. It is also the surface of the Earth.

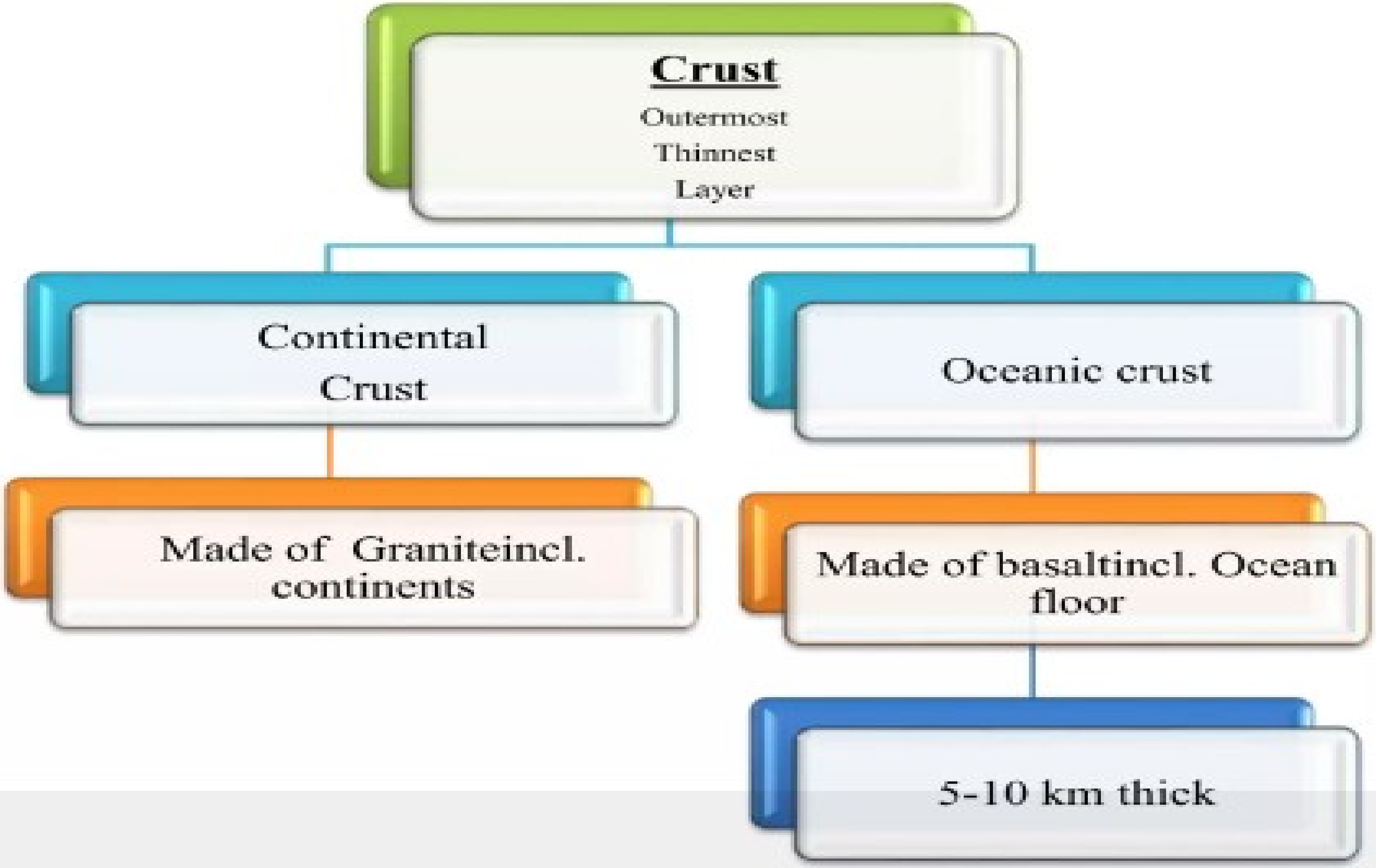
- It comprises the continents and ocean basins and is therefore classified into continental crust and oceanic crust.

- The oceanic crust extends to an average thickness of 5–10 km, whereas the continental crust extends to an average thickness of 20–70 km.

- The oceanic crust is mainly composed of basaltic igneous rocks, rich in silica and magnesium, and is therefore also called the **SIMA layer**.

- The continental crust is mainly composed of crystalline and granitic rocks, rich in silica and aluminum, and is therefore also called the **SIAL layer**

CRUST



Crust
Outermost
Thinnest
Layer

Continental Crust

Made of Graniteincl. continents

Oceanic crust

Made of basaltincl. Ocean floor

5-10 km thick

2.2.Mantle:

- The next layer is the mantle, which is composed mainly of iron and magnesium silicates. It is been referred as FaMa layer.

- Mantle is also where most of the internal heat of the Earth is located. It is about 2900 km thick.

- It can be subdivided into four layers namely

(1) Lithosphere (70-100 km)
(2) Asthenosphere (100-350km)
(3) Upper Mantle (350 -670km)
(4) Lower Mantle (670-2900km)

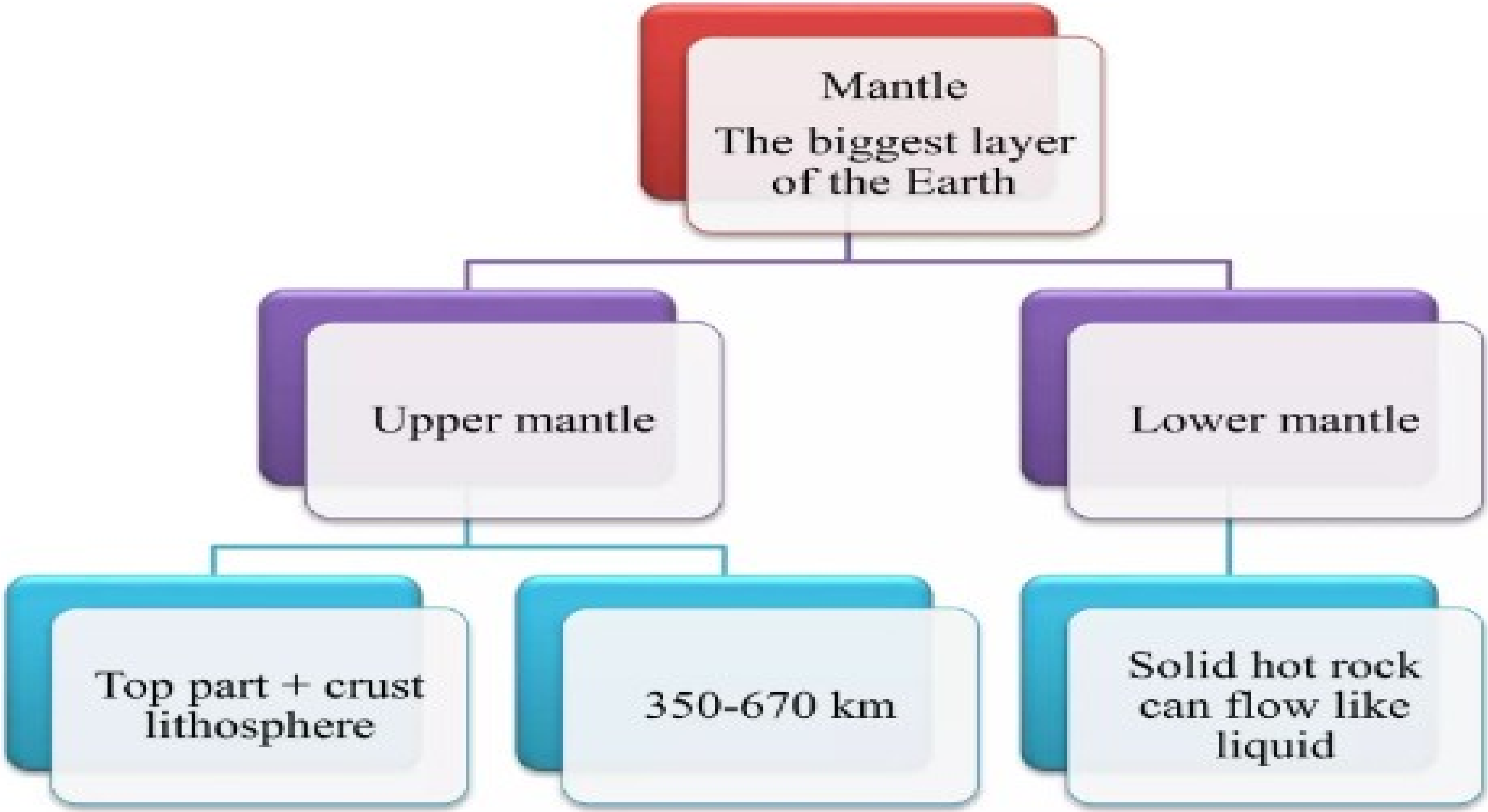
- The lithosphere is a layer that includes the crust & the upper part most portion of the mantle. It has a part of the tectonic plates that cover surface of Earth.

- Asthenosphere is the top layer of the upper mantle 100-200 km below surface. It is a low seismic velocity zone where rocks are at or near melting point. It also has a part of tectonic plates.

- The lower mantle is probably mostly silicon, magnesium and oxygen with some iron, calcium and aluminum.

- The upper mantle is made up of mostly olivine and pyroxene (iron/magnesium silicates), calcium and aluminum.

MANTLE



Mantle

The biggest layer of the Earth

Upper mantle

Top part + crust lithosphere

350-670 km

Lower mantle

Solid hot rock can flow like liquid

2.3.Core:

A-Outer core

- The outer core is a hot and liquid layer comprising mainly of nickel and (liquid) iron. Therefore it is referred as NiFe layer.

- The outer core may also contain lighter elements such as Si, S, C, or O.

- The outer core ranges from 2900km to 5150km and is 2300 km thick.

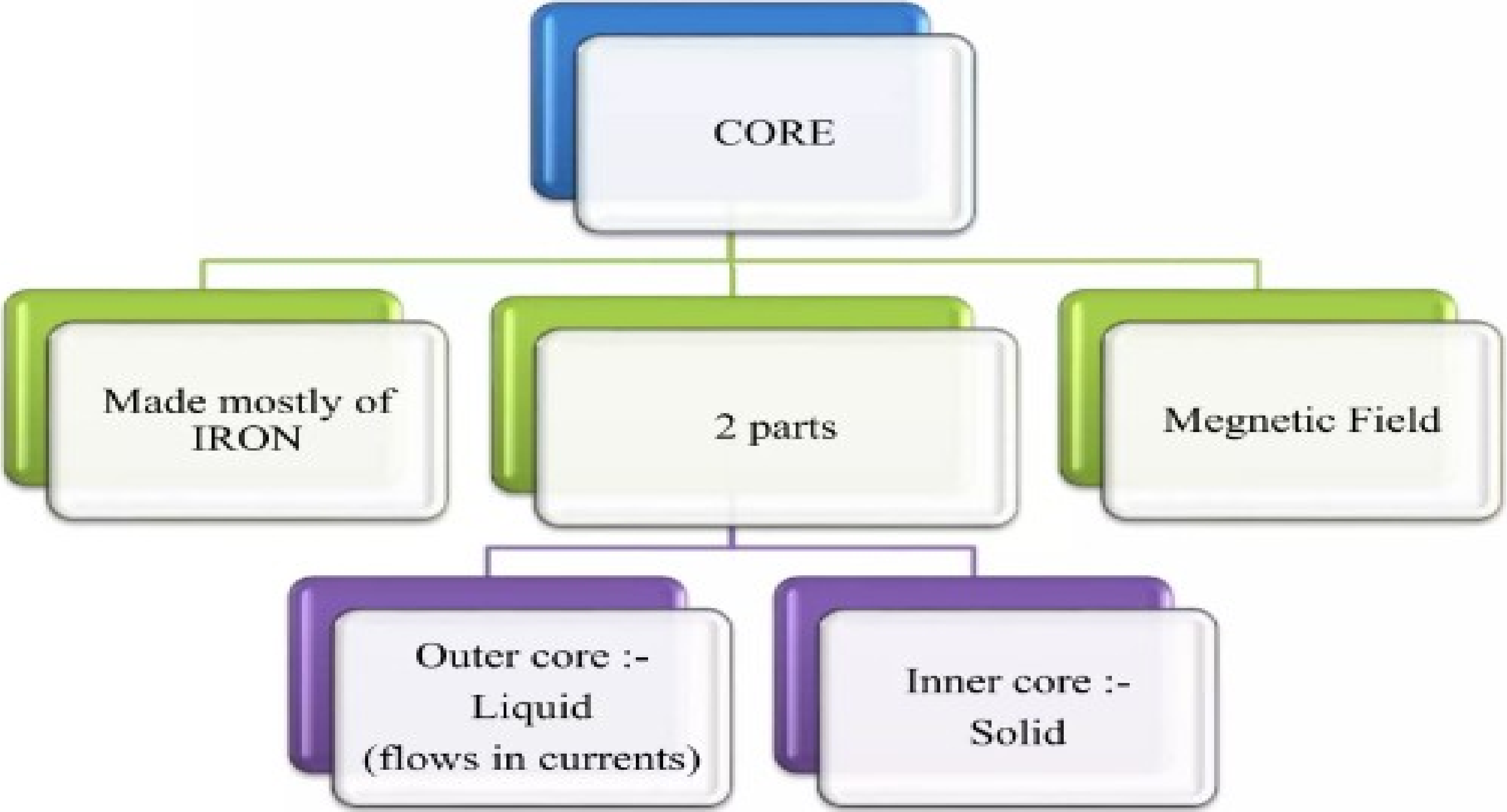
- The Earth's magnetic field is believed to be controlled by the liquid outer core. It is also believed to be the responsible force of earth's rotation and electric currents.

2.3.Core:

A-Inner core

- This layer stretches from 5150 km to 6370 km and is nearly 1200km thick.
- The inner core is mostly made of solid iron and has little amounts of nickel.
- It is unattached to the mantle and is suspended in the molten outer core.
- The inner core is believed to have the extreme temperature and pressure conditions.

CORE



CORE

Made mostly of IRON

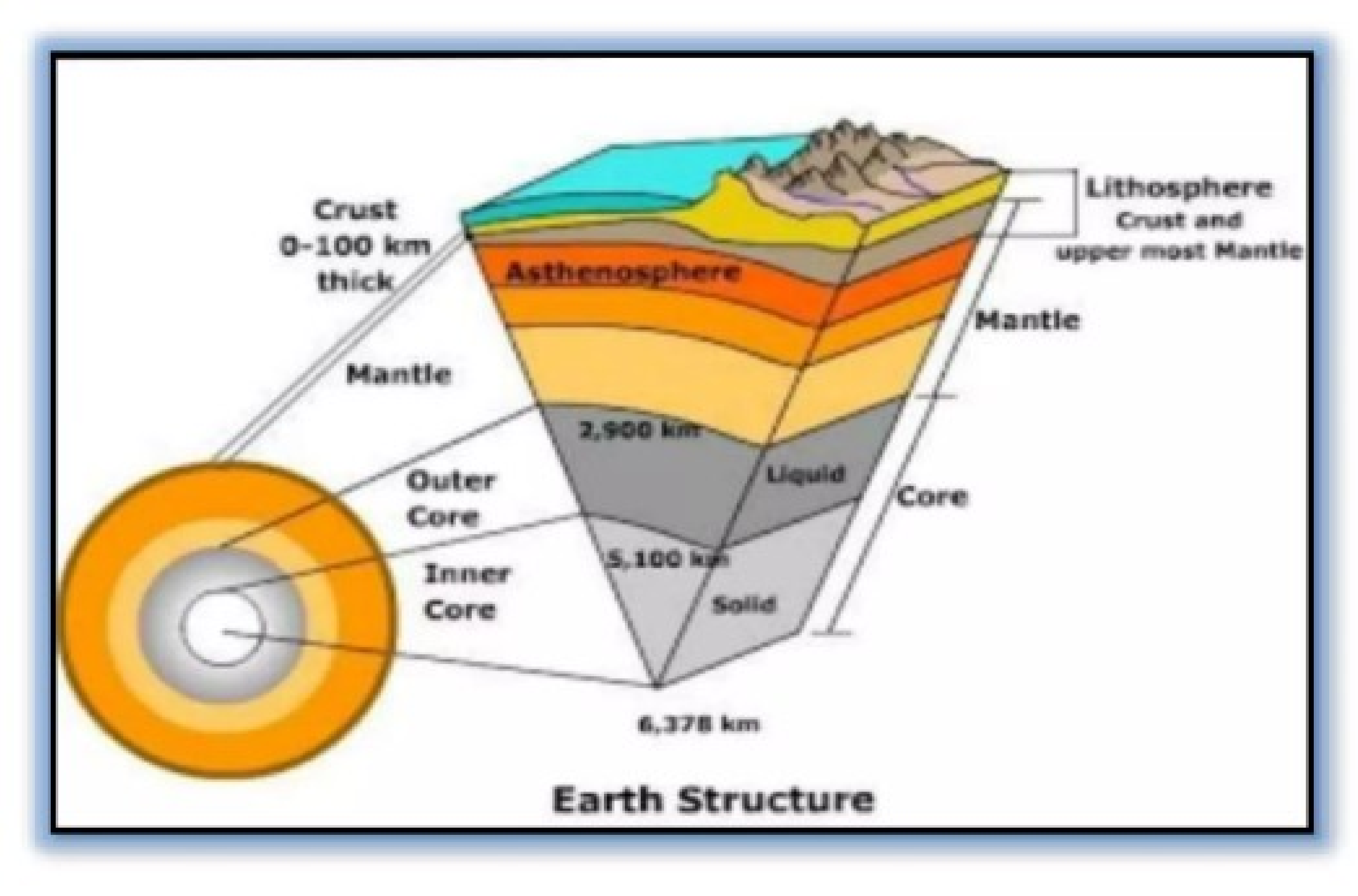
2 parts

Megnetic Field

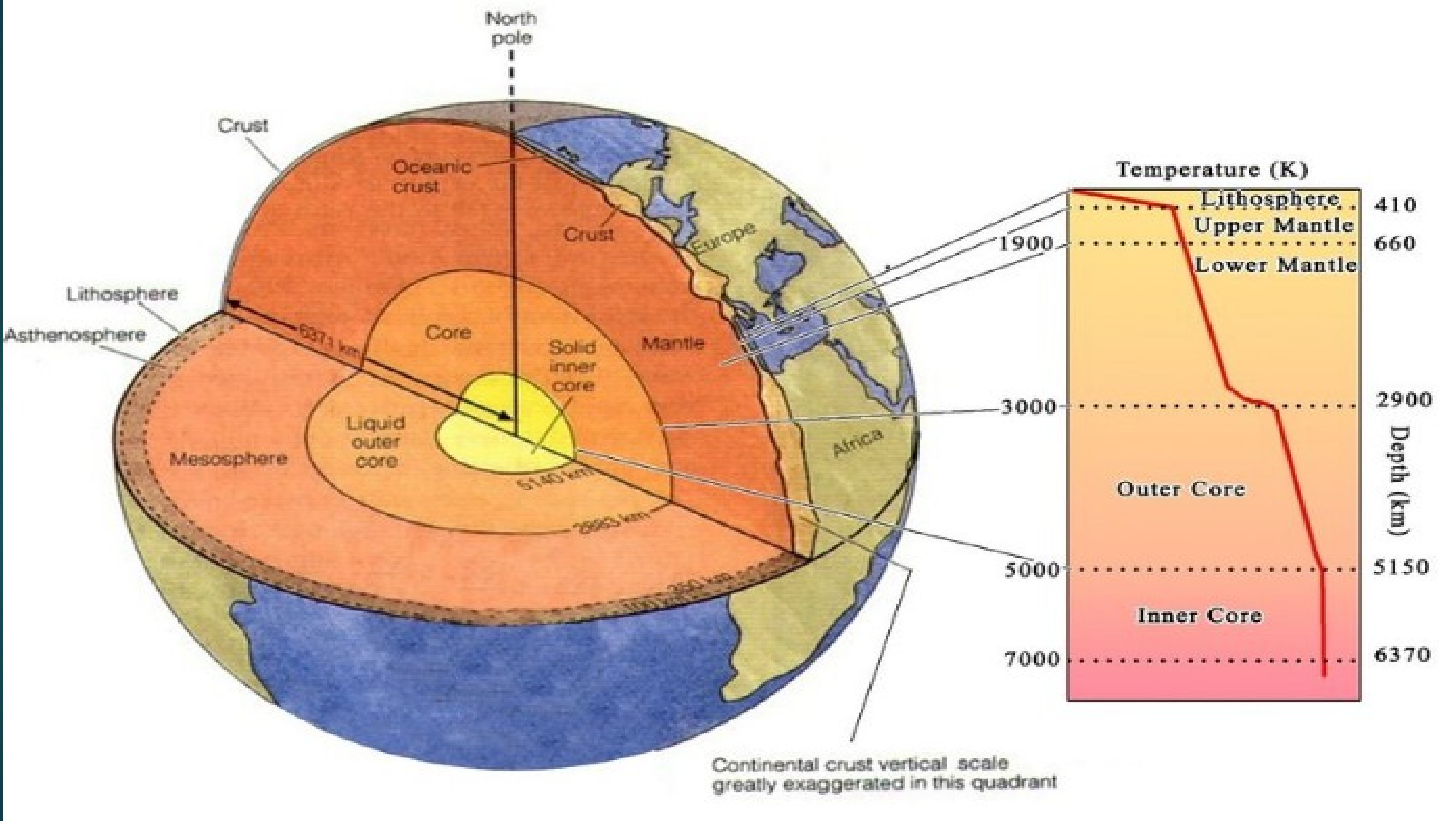
Outer core :- Liquid (flows in currents)

Inner core :- Solid

Structure of the earth



- Structure of the earth and temperature distribution



3. Heat Flow and Geothermal Gradient

3. 1.Heat Flow:

- Heat flow (often denoted as q or Q (W/m²).) is the amount of thermal energy transferred across a unit area per unit time. In simpler terms, it is the rate of heat energy transfer.

- The heat flow decreases with geological age due to the decay of the involved radioactive material.

- The flow is highest at the Earth's surface and decreases with depth because of the reduction in the amount of underlying radioactive material.
- The heat flow varies geographically but remains relatively uniform over large areas.

- For continents, the average geothermal heat flow ranges from 40 mW/m² in stable cratons to 70 mW/m² in tertiary tectonic provinces.

- The equation of heat flow is given by Fourier's law of heat conduction

$$q = -k\frac{dT}{dz}$$

- Where:
- q is the heat flux (in units of W/m², or milliwatts per square meter, mW/m², which is common in geophysics). It represents the amount of heat energy flowing per unit area per unit time.

- ***k*** is the thermal conductivity of the rock (in W/(m·K)). It measures the rock's ability to conduct heat.

- $\frac{dz}{dT}$ is the geothermal gradient (in K/m or °C/m). It's the rate at which temperature (T) increases with depth (z).

- The negative sign indicates that heat flows from areas of high temperature (the Earth's interior) to areas of low temperature (the surface).

3.2. Mechanisms of Heat Transfer:

- The Earth's heat transfer mechanisms describe how thermal energy moves within and around our planet. There are three primary mechanisms of heat transfer:

-Conduction -Convection -Radiation

3.2.1. Conduction

Definition: Transfer of heat through a solid material by direct contact of particles, without movement of the material itself.

In the earth:

- Occurs mainly in the lithosphere (crust and upper mantle).
- Heat moves from hotter regions (deeper interior) to cooler regions (surface) through solid rock.

Example: Heat conducted from Earth's hot mantle into the overlying crust.

3.2.2. Convection;

Definition: Transfer of heat by the movement of fluids (liquids or gases), where hot material rises and cooler material sinks, creating a continuous circulation.

In the Earth:

- **Hot mantle material rises, cools near the crust, and then sinks back down, driving plate tectonics.**
- **Also occurs in the outer core, where convection of molten iron generates Earth’s magnetic field.**

Example: Mantle convection currents moving tectonic plates.

3.2.3.Radiation

Definition: Transfer of heat energy through electromagnetic waves, without needing a medium.

In the Earth:

- ○ Occurs at the Earth’s surface and atmosphere.
- ○ The Sun’s energy reaches Earth through radiation.
- ○ The Earth re-emits infrared radiation back into space, balancing incoming solar energy.

Example: Solar radiation heating Earth’s surface.

4.Geothermal Gradient:

- The temperature of rocks increases with depth inside the earth. This phenomenon is called the geothermal gradient.

- The geothermal gradient is the rate at which temperature increases as we go deeper below the Earth's surface. It is a direct indicator of the heat flowing from the Earth's interior towards the surface.

- The geothermal gradient is not the same everywhere; it varies depending on the type of rocks, the structure of the Earth's crust, and local geological conditions.
- The geothermal gradient observed in the continental crust varies greatly from one place to another, although the normal value is around 3°C per 100 meters.

- However, some regions record more than 100°C per 100 meters, as is the case in Larder Ello (Italy), while other sites do not exceed 1°C per 100 meters, as in Padua (Italy).

<u>GEOTHERMAL GRADIENT:</u>

- The Geothermal Gradient (G) is calculated using the following relationship:

$$G = \frac{\Delta T}{\Delta z}$$

where:

G: Geothermal gradient (°C/km).

ΔT: Temperature difference between two points (°C).

Δz: Depth difference between the two points (km).

- The geothermal gradient (G) is usually expressed in °C/km (degrees Celsius per kilometer) or K/km (kelvins per kilometer)

5.The Importance of water in geothermal energy:

Water plays a critical role in geothermal energy systems, serving multiple essential functions that make it possible to extract and use heat from the Earth efficiently.

5.1. Heat Transfer Medium

Water absorbs heat from hot rocks deep underground and transports it to the surface, where it can be used to drive turbines and generate electricity.

5.2. Reinjection and Sustainability

Cooled water is reinjected underground to maintain reservoir pressure, sustain the geothermal resource, and reduce environmental impacts such as land subsidence

5.3.Working Fluid in Binary Systems

In binary plants, geothermal water transfers heat to a secondary fluid within a closed loop, enabling efficient electricity generation from moderate-temperature resources

5.4. Environmental and Economic Benefits

Using water in closed-loop geothermal systems ensures:

- ✓ Minimal greenhouse gas emissions
- ✓ Sustainable use of geothermal resources
- ✓ Reduced dependence on fossil fuels

6. Geothermal Resources:

☐ Geothermal resources are the natural heat stored inside the earth. This heat comes from the planet’s core, the decay of radioactive elements, and the residual heat from the Earth’s formation.

It is found beneath the Earth’s surface in the form of hot rocks, steam, and hot water.

Depending on the temperature and depth, geothermal resources are divided into:

-High-energy resources

-Low-energy resources

6.1.High-energy resources

High-energy geothermal resources, specifically those above 150◦ are high-temperature, high-pressure steam or hot water found deep underground, typically near tectonic plate boundaries. These resources are ideal for generating electricity by using the steam to spin turbines connected to a generator, similar to conventional power plants. This process is the basis for different types of geothermal power plants, which can provide continuous, 24/7 power .We will discuss power plants in detail in this chapter.

6.2.Low-Energy Geothermal Resources:

- Low-energy geothermal resources involve harnessing heat from the shallow subsurface of the Earth, typically at depths ranging from a few meters to a few hundred meters. These resources are characterized by low to moderate temperatures, generally between 20°C and 150°C (68°F - 302°F).

- Unlike high-energy geothermal resources (used for electricity generation from volcanoes or hot springs), low-energy geothermal is primarily used for direct heating and cooling applications. The heat comes from the solar energy stored in the shallow ground and the natural heat flux from the Earth's core and the radioactive decay of minerals in the Earth's crust.

6.2.1. Key Characteristics

- ✓ Low Temperature: The defining feature is its low thermal range, making it unsuitable for economical electricity generation with standard turbines.
- ✓ Wide Availability: These resources are available almost everywhere on the planet, not just in tectonically active regions (like Iceland or the Ring of Fire). This makes them accessible to many countries.
- ✓ Shallow Depth: They can be accessed with relatively simple and less expensive drilling technology compared to deep, high-temperature wells.

6.2.2. Methods for Exploiting Low-Temperature Geothermal Energy

There are two primary methods for exploiting low-temperature geothermal energy:

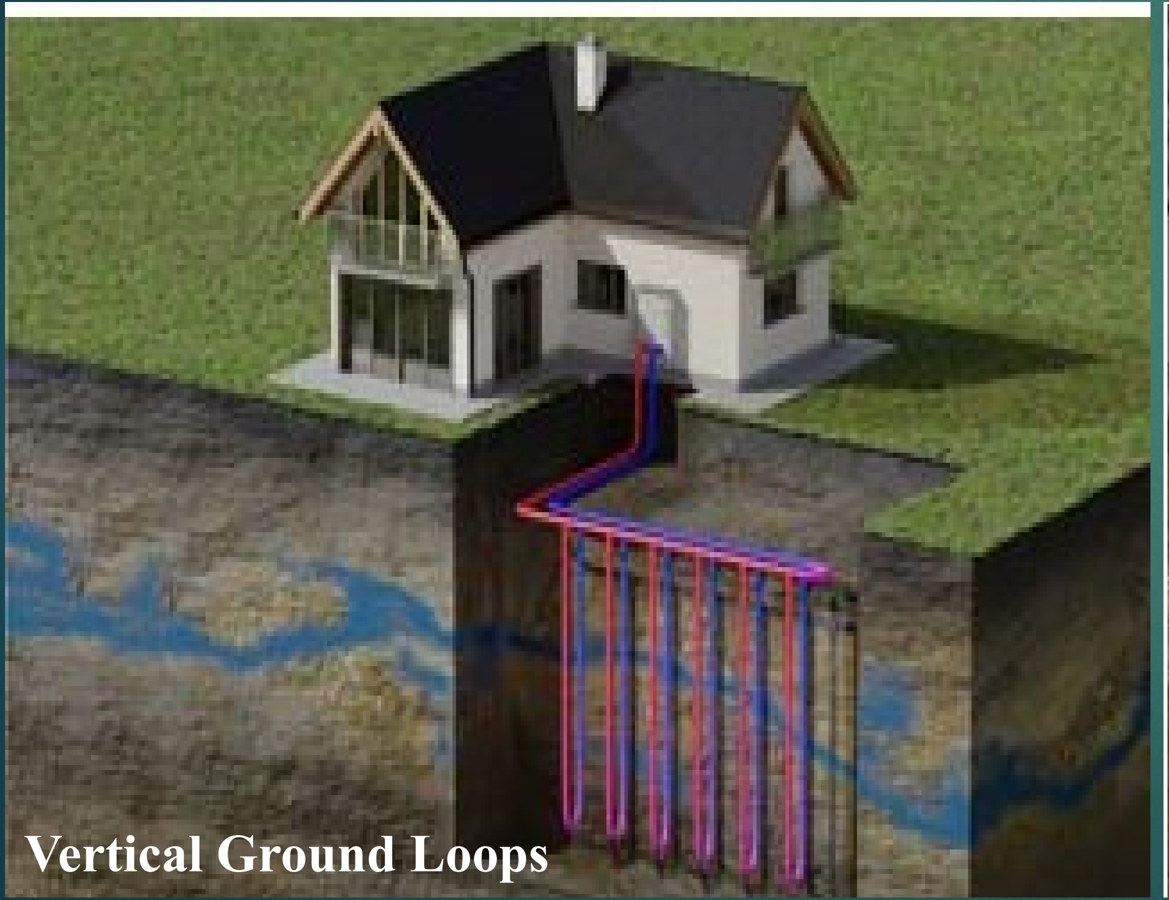
A. Geothermal Heat Pumps (GHPs) or Closed-Loop Systems

This is the most common and widely used technology for homes, offices, and other buildings.

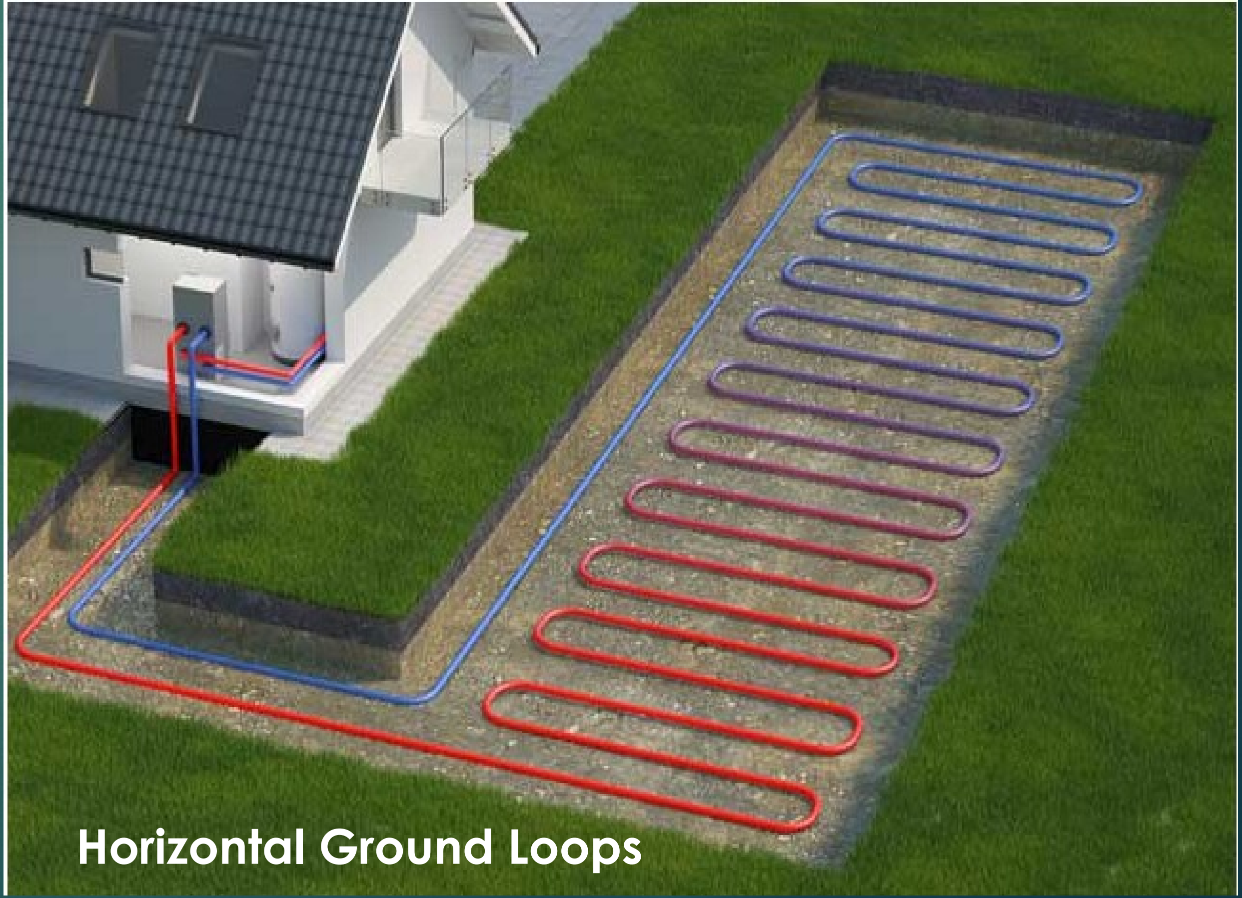
Principle: GHPs don't extract heat directly from deep within the Earth. Instead, they use the Earth as a giant thermal battery, leveraging the stable temperature of the shallow ground (typically 7°C to 21°C / 45°F to 70°F) below the frost line. This ground temperature is warmer than the air in winter and cooler than the air in summer.

How it Works:

- A loop of pipes (a "ground loop") is buried underground, either horizontally in trenches or vertically in deep boreholes. A fluid (water or antifreeze solution) circulates through these pipes.



Vertical Ground Loops



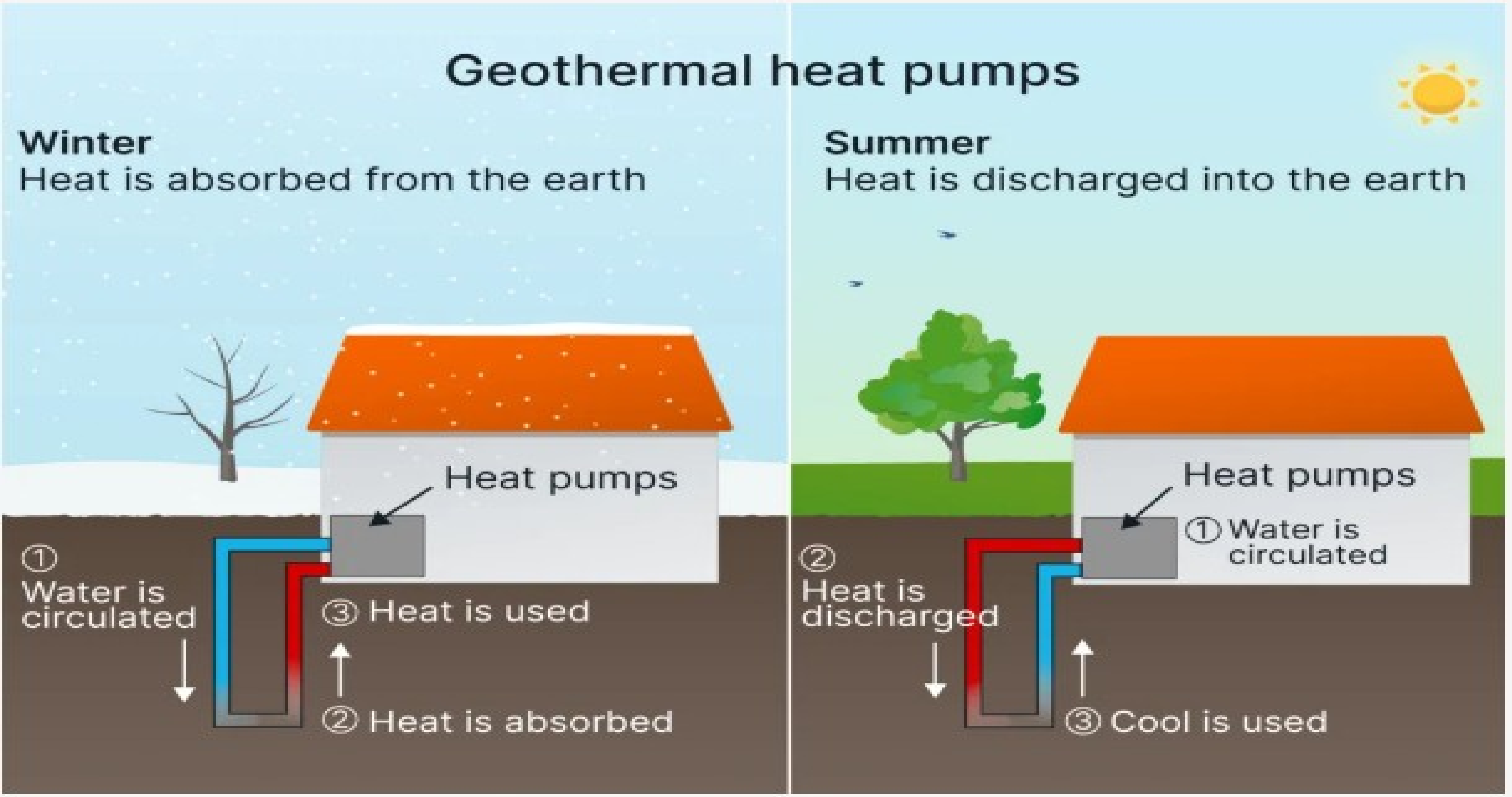
Horizontal Ground Loops

How it Works:

- **In Winter (Heating Mode): The fluid in the pipes absorbs heat from the relatively warm ground. This heat is carried to the heat pump inside the building, which compresses it to a higher temperature and releases it to heat the building.**

- **In Summer (Cooling Mode): The process is reversed. The heat pump extracts heat from the building and transfers it to the fluid, which then carries it into the ground where it is dissipated. This provides highly efficient air conditioning.**

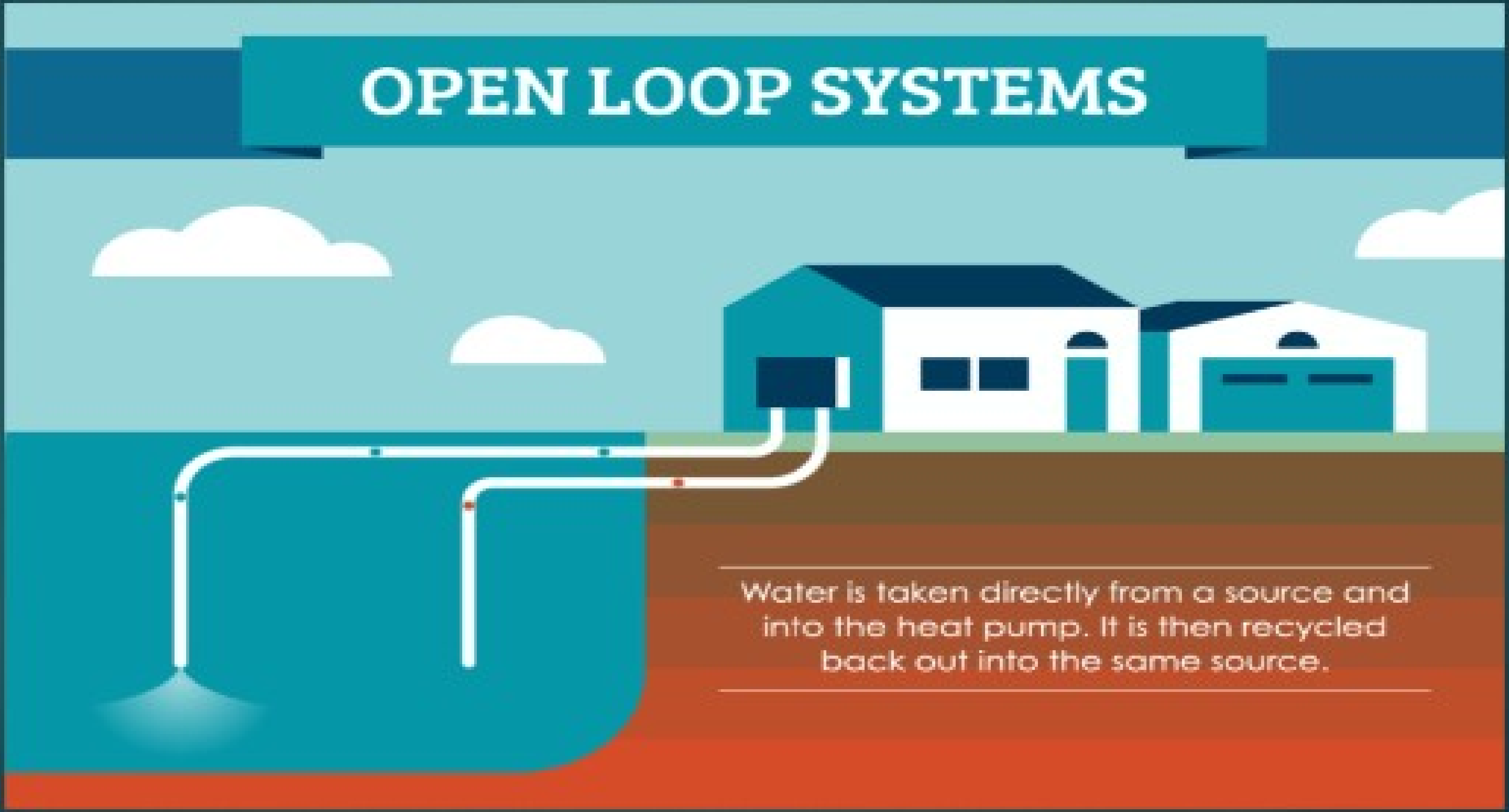
How They Are Harnessed:



B. Direct Use of Geothermal Resources (Open-Loop Systems)

This method directly uses warm groundwater from shallow aquifers.

Principle: A well is drilled into a geothermal aquifer to pump warm groundwater to the surface.



6.2.3. Applications:

- The water can be used directly in underfloor heating systems or passed through a heat exchanger to transfer its heat to a separate circuit that heats buildings or provides domestic hot water.
- After its heat is extracted, the cooled water is typically re-injected back into the aquifer through a second well (an injection well) to maintain the reservoir's pressure and sustainability.
- Aquifer Thermal Energy Storage (ATES): This advanced form uses dual wells to store summer heat for winter use, and winter "cold" for summer cooling.

7.Geothermal energy production technique:

Engineers have developed smart technologies to harness the Earth's geothermal heat and convert it into useful energy. The most prominent of these technologies are:

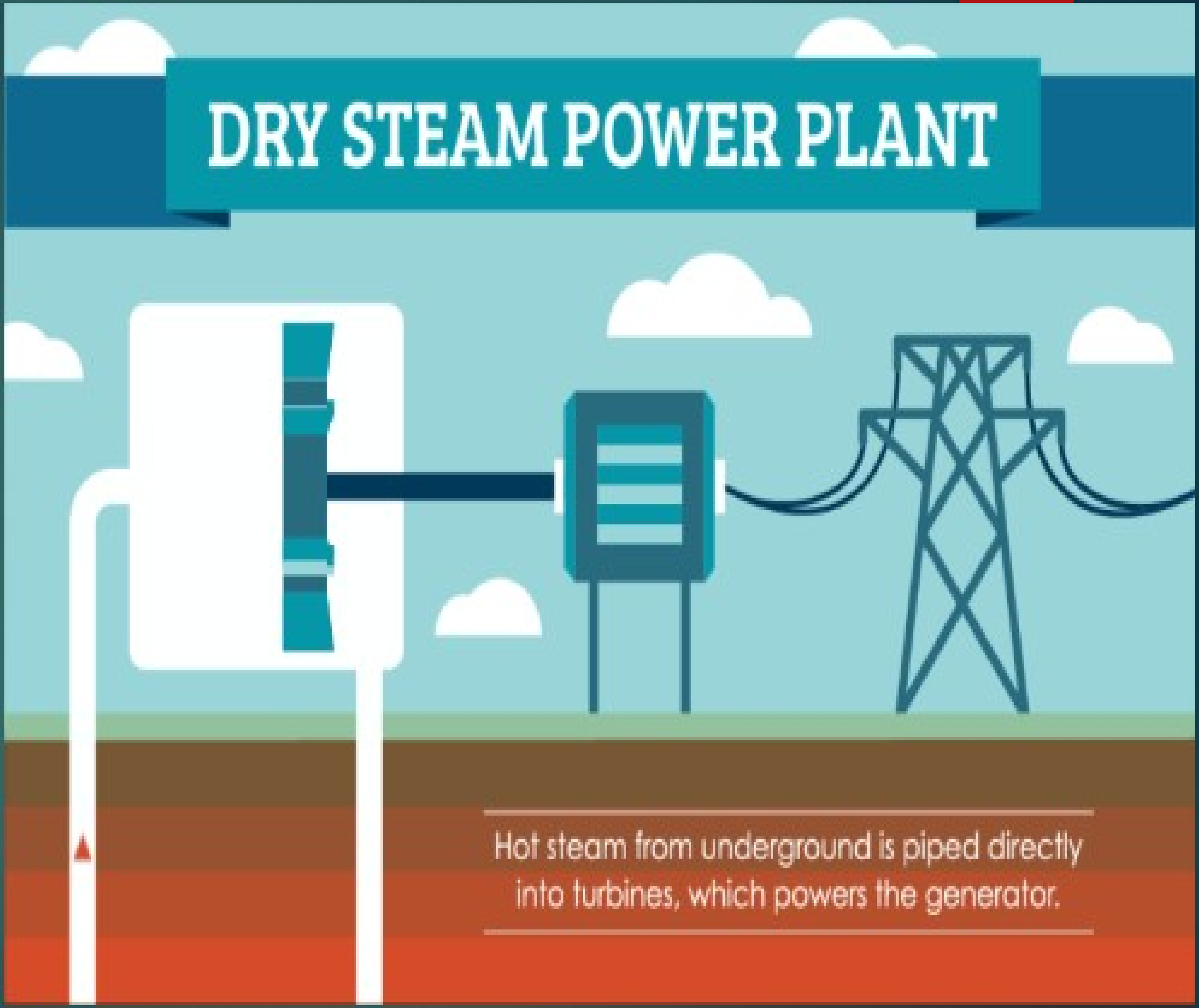
1-Dry Steam Plants
2-Flash Steam Plants
3-Binary Cycle Plants
4-Enhanced Geothermal Systems (EGS)
5-Geothermal Heat Pumps (GHP)

7.1.Dry Steam Plants :

Dry steam plants directly

tap into underground reservoirs of superheated steam and send it straight to turbines, spinning them into electrical magic.

It's the oldest and simplest technique, but requires rare natural steam fields.

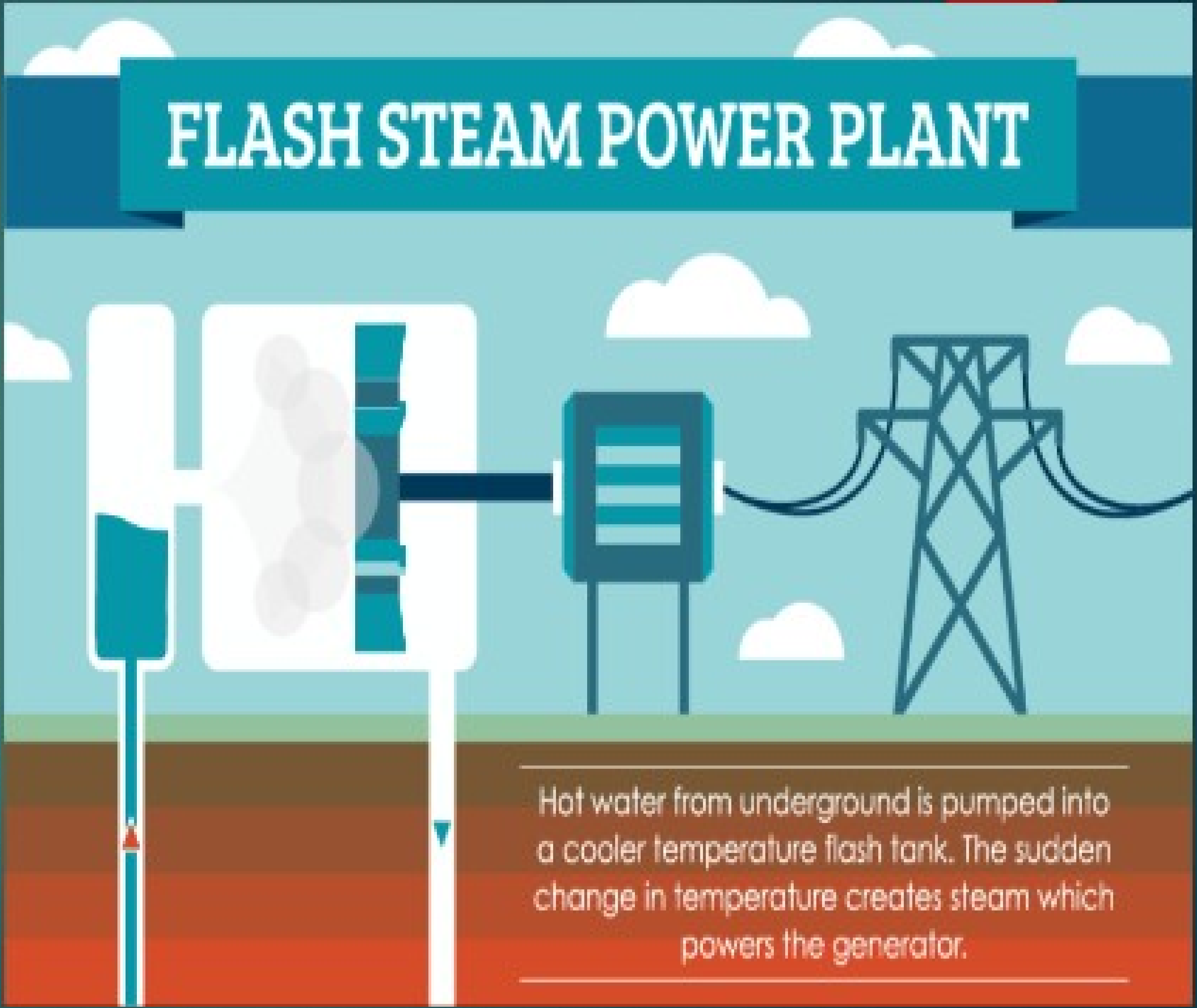


7.2. Flash Steam Power Plants :

Flash Steam Power Plants rely on pumping very hot water from deep underground to the surface, where the drop in pressure causes part of the water to instantly turn into steam.

The steam is then separated and used to drive turbines to generate electricity, while the remaining water is reinjected underground to sustain the resource.

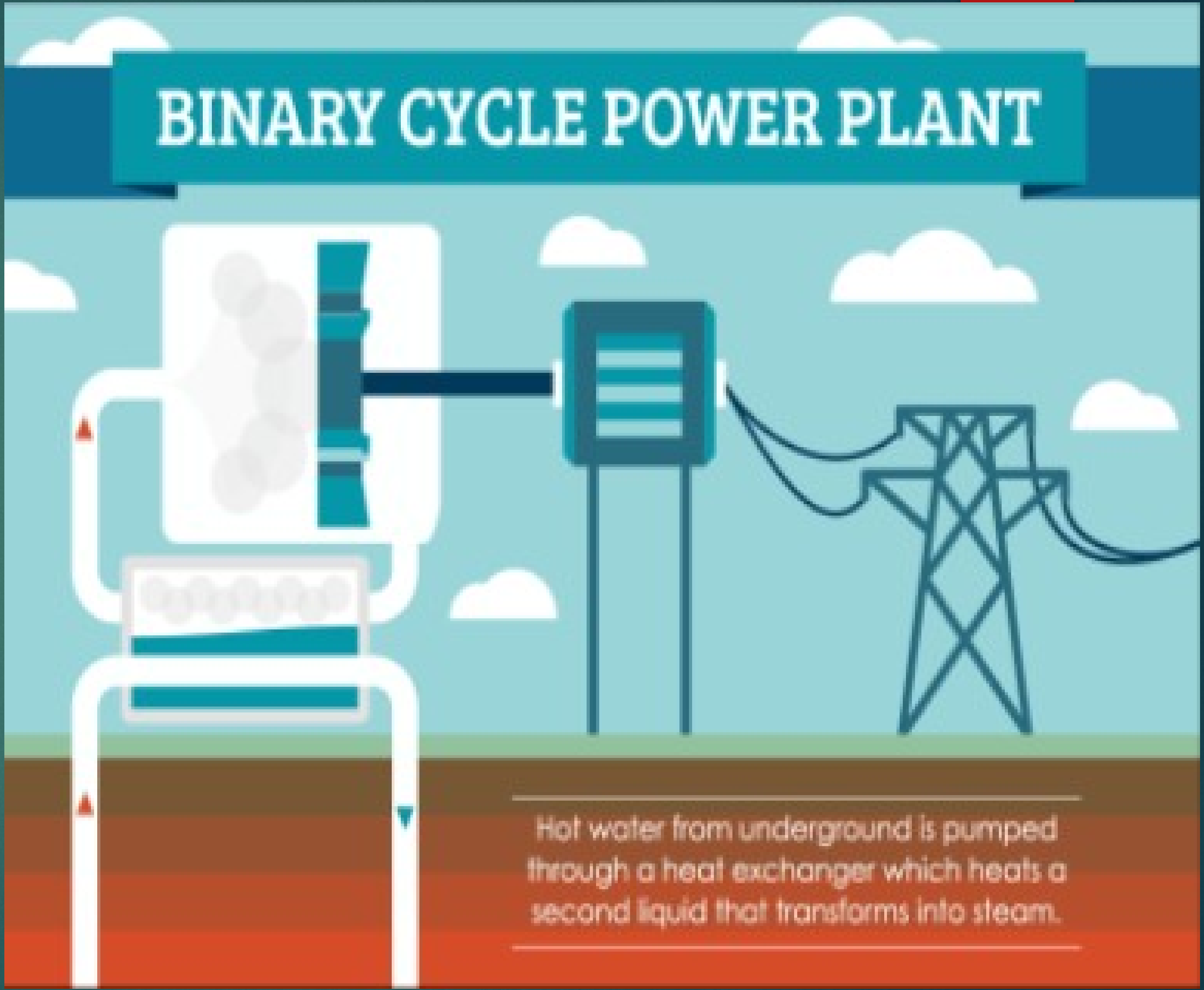
This technology is suitable for high-temperature, liquid-dominated reservoirs.



Hot water from underground is pumped into a cooler temperature flash tank. The sudden change in temperature creates steam which powers the generator.

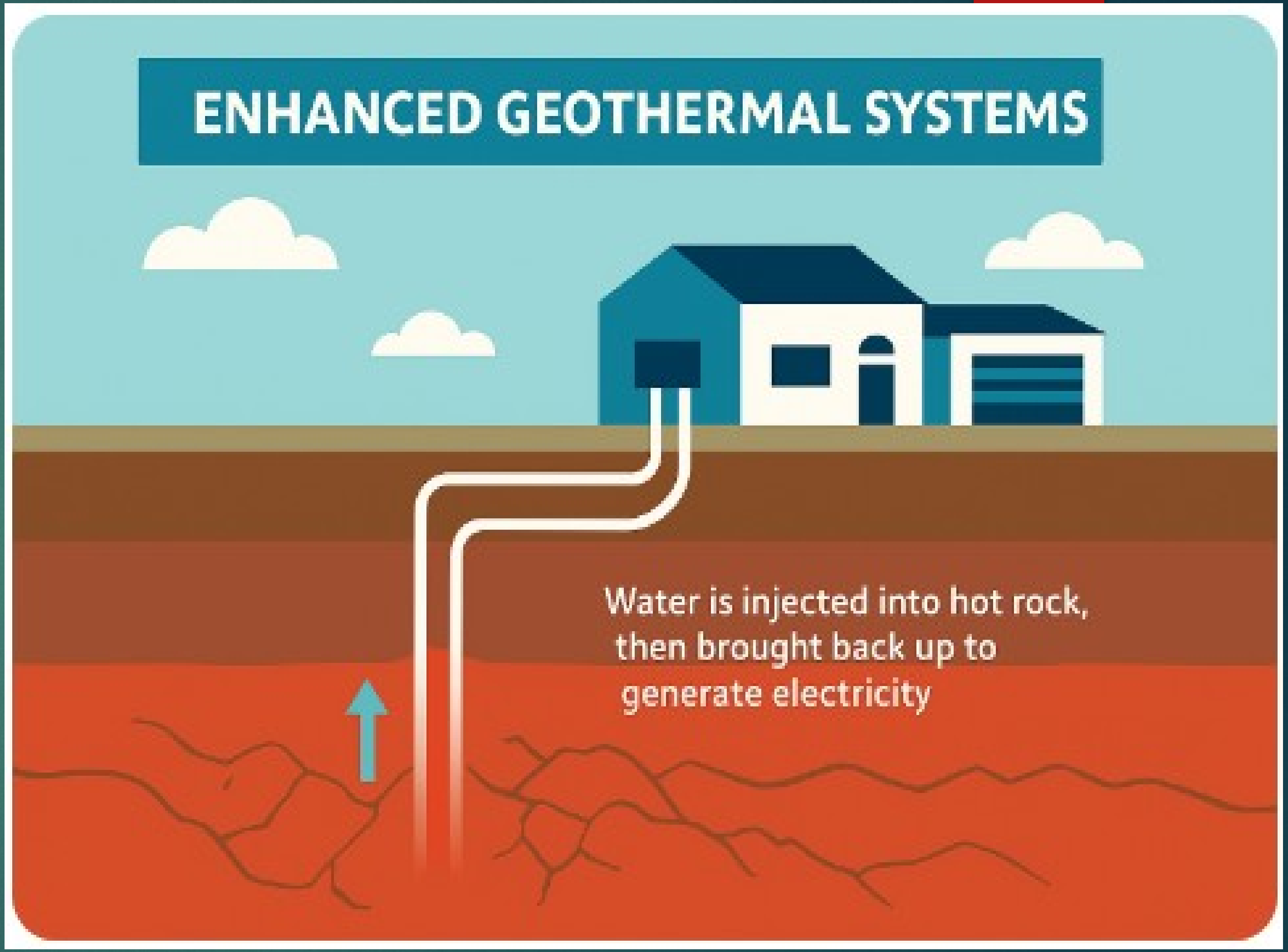
7.3-Binary Cycle Plants:

Binary cycle power plants use moderately hot geothermal water to heat a secondary fluid with a low boiling point. The secondary fluid vaporizes, drives a turbine to generate electricity, then condenses and recirculates in a closed loop. Because they don't require extremely high temperatures, these plants can operate in many more locations.



7.4. Enhanced Geothermal Systems (EGS):

When nature hasn't prepped the perfect hot water reservoir, humans improvise. Engineers inject water into hot, dry rock deep below the surface, cracking pathways and creating an artificial geothermal sponge. The heated water comes back up to generate electricity.



7.5. Geothermal Heat Pumps (GHP):

Not for electricity but cozy comfort. These systems use the Earth’s stable shallow-ground temperature to heat and cool buildings. A fluid circulates through ground loops, exchanging heat with the Earth in winter and sending excess heat back underground in summer.

8. Design and Operation of Geothermal Energy Installations:

Geothermal installations harness the Earth's internal heat to generate continuous, reliable baseload electricity. The specific design and operation depend primarily on the resource's temperature and fluid state, , leading to three main types: dry steam, flash steam, and binary cycle power plants.

8.1.Key Design Considerations

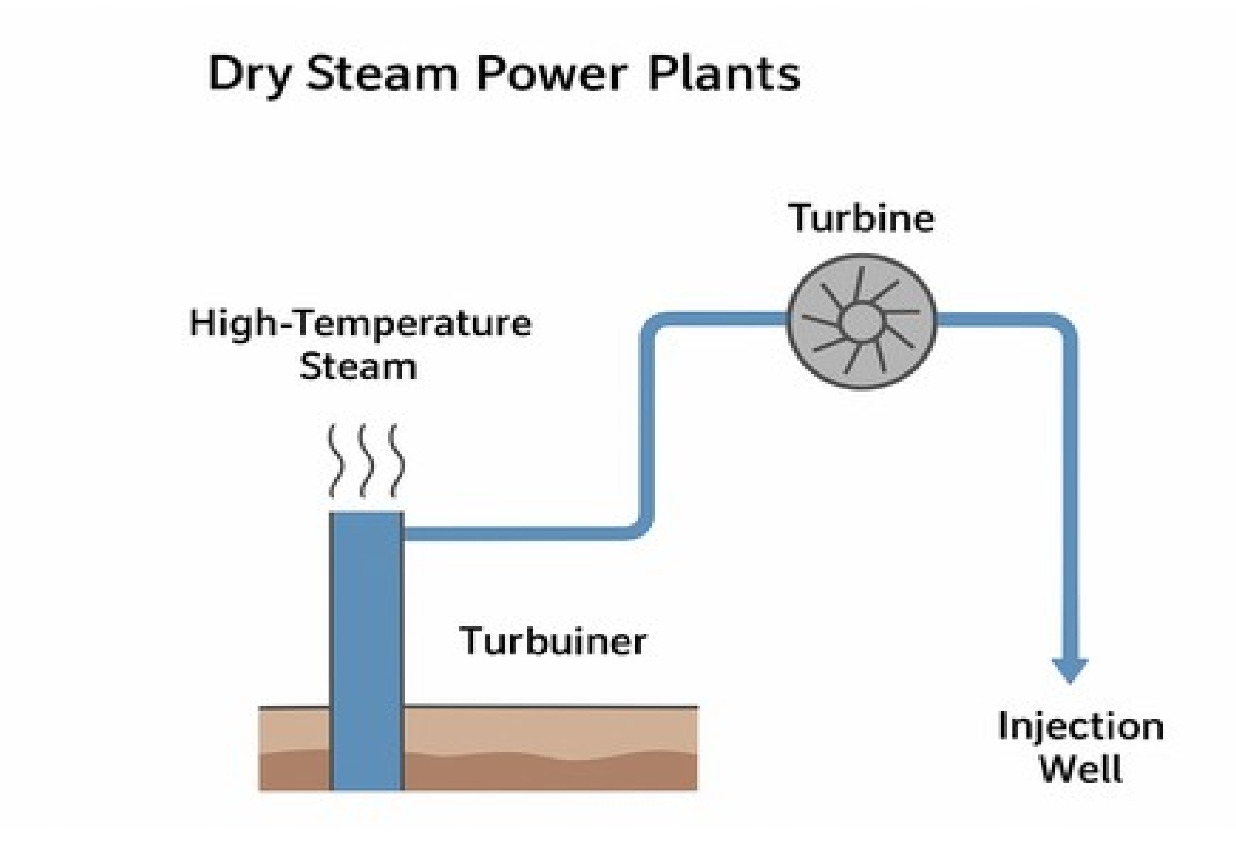
- ✓ Resource and Site: Plants must be located close to natural underground reservoirs with sufficient heat, fluid, and permeability, as it is difficult to transport hot water or steam over long distances.
- ✓ Environmental and Engineering: Design must account for managing potential emissions (e.g., hydrogen sulfide), using cooling systems, and integrating specialized materials and techniques to handle the corrosive nature of geothermal fluids and manage thermal stress.
- ✓ Core Components: Essential infrastructure includes production wells, turbines, generators, heat exchangers (for binary systems), cooling systems, and injection wells to return fluids to the reservoir.

8.2. Operational Mechanisms: Types of Plants

8.2.1 Dry Steam Power Plants:

Operation: High-temperature natural steam is piped directly from the ground to turn the turbine. The condensed water is then reinjected.

Application: The oldest and simplest technology, used only with naturally occurring pure steam reservoirs.

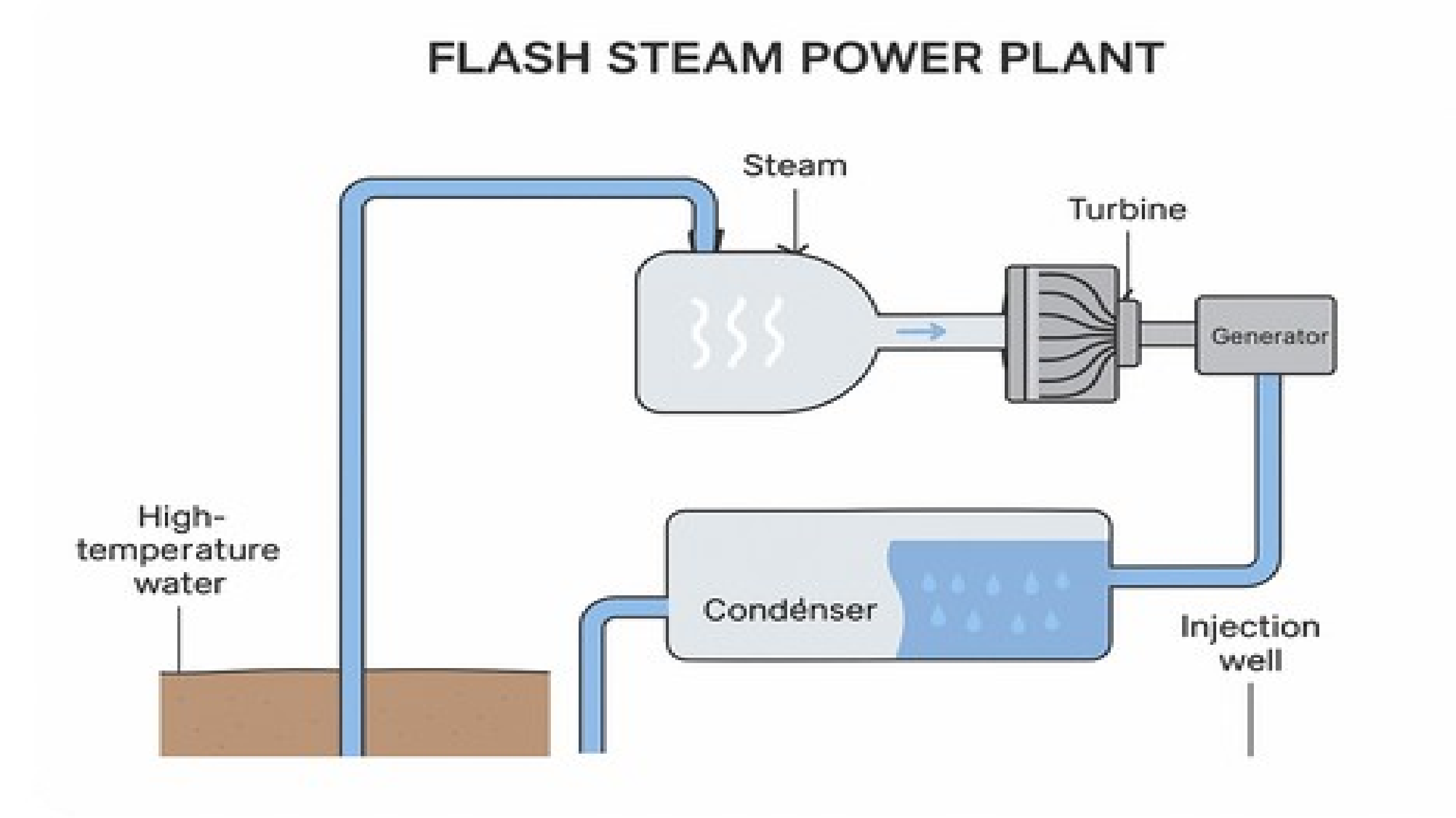


8.2. Operational Mechanisms: Types of Plants

8.2.2 Flash Steam Power Plants:

Operation: High-pressure hot water is pumped from the well into a low-pressure flash tank at the surface. The pressure drop causes some water to "flash" into steam, which powers the turbine. The remaining water is reinjected.

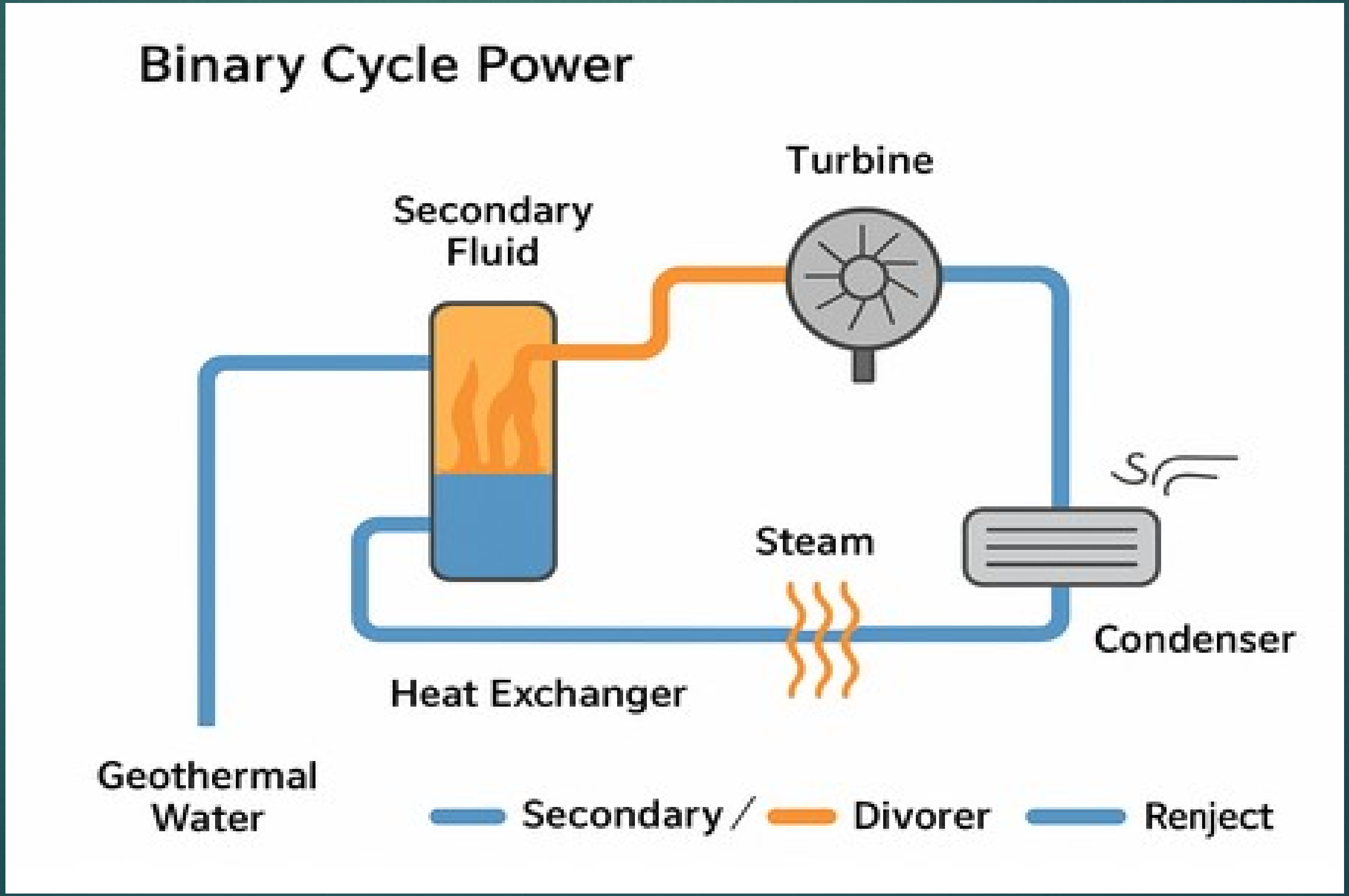
Application: The most common type, suitable for high-temperature water resources.



8.2. Operational Mechanisms: Types of Plants

8.2.3 Binary Cycle Power Plants:

Operation: Geothermal water passes through a heat exchanger, heating a secondary fluid (with a lower boiling point) into vapor, which drives the turbine in a closed loop. The geothermal water never directly touches the turbine or atmosphere.



8.3. Key Operational Considerations

- ✓ **Sustainability**: Re-injection of cooled water is critical to maintain reservoir pressure and ensure long-term sustainability.

- ✓ **Emissions**: Flash and Dry plants may release some gases; Binary plants are very clean.

- ✓ **Baseload Power**: Geothermal provides continuous, reliable energy, unlike intermittent solar or wind.

9.Application of Geothermal Energy to Heating

Geothermal heating is one of the most efficient and cost-effective uses of the Earth's thermal energy. It can be categorized into two main scales:

9.1. Large-Scale Direct Use Heating

This method uses hot water from geothermal reservoirs (typically between 40°C and 150°C / 104°F to 302°F) directly for heating.

How it Works: The Basic System

- ✓ **Production Well: A well is drilled into a geothermal aquifer to bring hot water to the surface.**

- ✓ **Heat Exchanger: The geothermal fluid transfers its heat to a closed, clean loop of water that circulates through the district heating network or building. The geothermal fluid itself usually does not enter the buildings.**

- ✓ **Distribution Network**: Insulated pipes carry the heated water to multiple buildings or facilities.

- ✓ **Injection Well**: The cooled geothermal water is pumped back into the same reservoir to be reheated, making the system sustainable.

9.1.1.Key Applications of Direct Use Heating:

A-District Heating:

It is a central geothermal plant heats water that is distributed via a network of underground pipes to heat multiple buildings, an entire neighborhood, or even a city.

B-Agricultural Applications:

- ✓ **Greenhouse Heating:** Provides a constant, controllable temperature for year-round crop cultivation, significantly boosting production in cold climates.
- ✓ **Aquaculture (Fish Farming):** Heats water to optimal temperatures for breeding fish, prawns, and alligators, speeding up growth rates.

C-Industrial Process Heating:

Using geothermal heat for industrial processes that require low to medium temperatures.

Examples:

- ✓ Food processing (drying onions, fruits, vegetables)
- ✓ Pasteurization of milk
- ✓ Timber and paper drying
- ✓ Wool washing

D-Balneology (Spas and Swimming Pools):

One of the oldest and most widespread uses. Geothermal water is used to fill public baths, spas, and therapeutic centers.

Examples: The Blue Lagoon (Iceland), Japanese Onsen, Hungarian thermal baths.

9.2. Small-Scale: Geothermal Heat Pumps (GHPs):

Also known as Ground-Source Heat Pumps, this technology uses the shallow ground (the top ~200 meters) as a heat source in winter and a heat sink in summer. The key difference is that it leverages the Earth's stable ambient temperature, not a hydrothermal resource.

How it Works:

- ✓ **Ground Loop**: A loop of pipes (horizontal trenches or vertical boreholes) is buried underground. A fluid (water or antifreeze) circulates through these pipes.
- ✓ **Heat Pump Unit**: Inside the building, a heat pump acts like a reversible refrigerator.
- ✓ **In Winter**: The fluid in the ground loop absorbs heat from the relatively warm earth. The heat pump extracts and concentrates this heat to warm the building.
- ✓ **In Summer**: The process reverses. The heat pump extracts heat from the building and transfers it to the cooler ground, providing air conditioning.

10. Advantages of Geothermal Heating:

- ✓ **High Efficiency:** Geothermal heat pumps are 300-600% efficient, meaning they move 3-6 units of heat for every 1 unit of electricity used to run them.
- ✓ **Cost-Effective:** After the initial investment, operating costs are very low and stable, insulated from fossil fuel price spikes.
- ✓ **Reliable & Constant:** The Earth's temperature is constant 24/7, unlike intermittent solar or wind energy.
- ✓ **Environmentally Friendly:**

  Dramatically reduces greenhouse gas emissions compared to gas or oil furnaces.
  Direct use systems have a very small footprint.
- ✓ **Sustainable:** With re-injection, geothermal resources can provide heat for decades or even centuries.