Renewable and Alternative Energies

Topic 5. Geothermal energy

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5.1. Geothermal resources

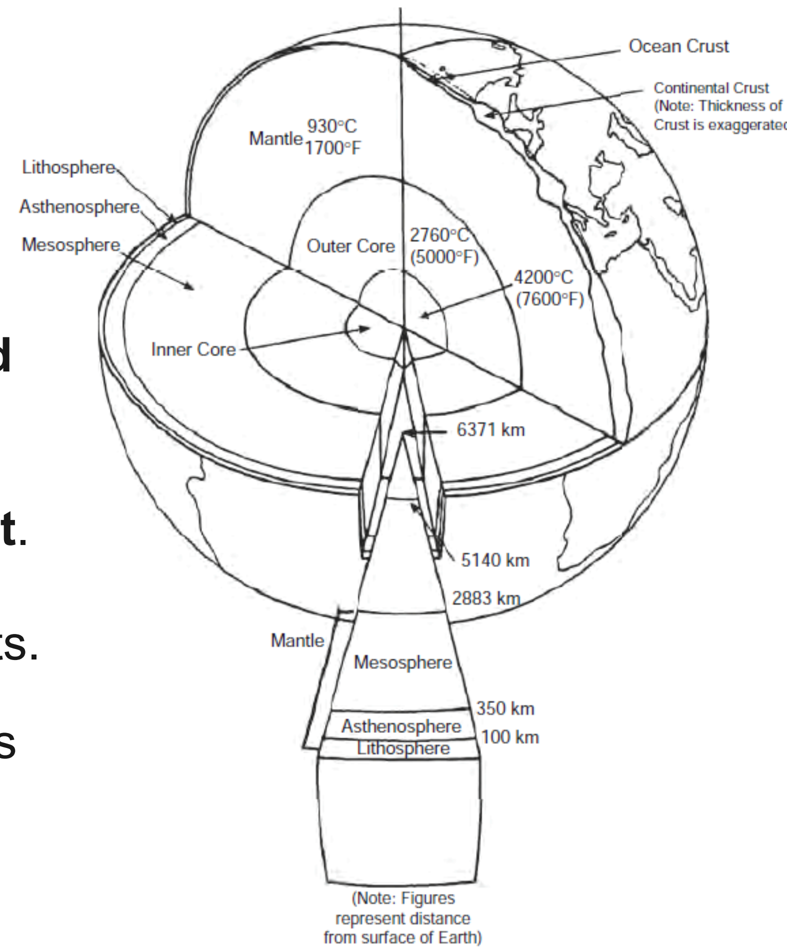
- The **interior of the earth** or the earth's core **is extremely hot** with a temperature of about **4200°C**.
- Although some of the heat is a relic of the formation of the earth some 4.5 billion years ago, **the decay of radioactive materials** in the core **is the source of the heat**.
- It is not possible to capture this vast amount of heat, which is estimated to be $42 \cdot 10^{12}$ W, but several **natural geologic processes allow** for some of **this heat to be concentrated** at temperatures and depths favorable **for commercial exploitation**.
- Large **bodies of water are trapped in** the fissures and pores of the **underground rocks and are heated** by the earth's heat. The temperature of the rocks and water get hotter, progressing towards the inner core.
- **Geothermal energy is considered a renewable energy source, because water is replenished** by rainfall **and the heat is continuously produced** inside the earth.

5.1. Geothermal resources

- The **interior consists of two layers**. The inner layer is **a solid iron core** that is surrounded by the **molten rock, called Magma**. The heat from this hot inner core flows to the cooler outer crust of the earth.

- The outer core or the **Magma is surrounded by a mantle**, approximately **2,897 km thick**. It is made of Magma and rocks. The **outermost layer** of the earth **is called Crust**. It is 4.82 to 8.05 km thick under the oceans and 24.14 to 56.32 km thick on the continents.

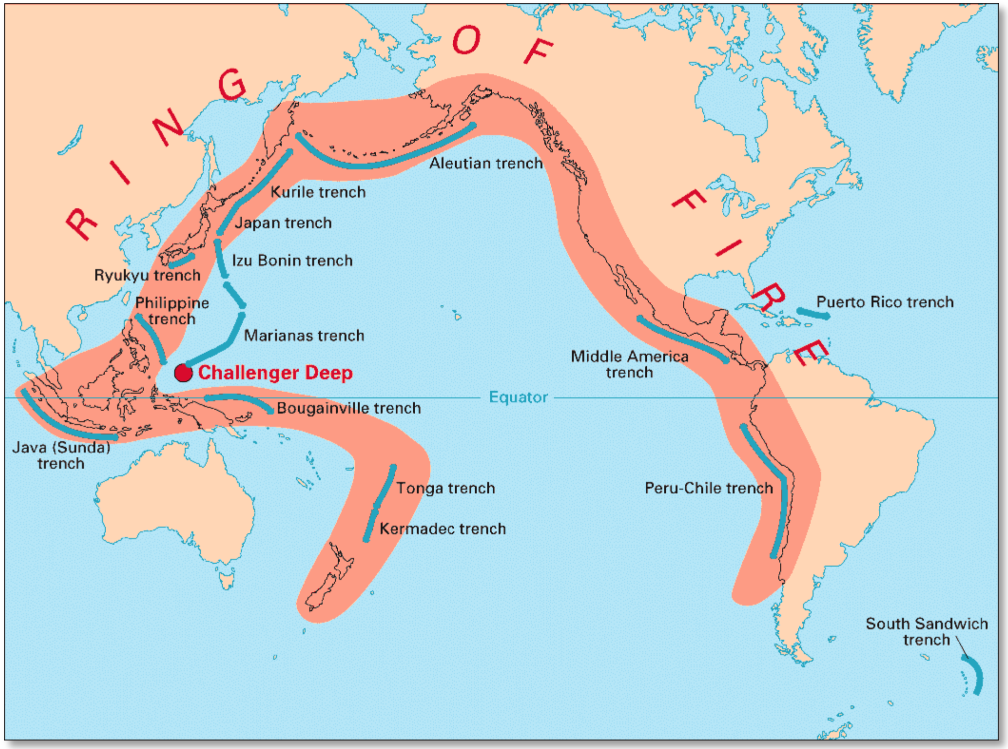
- The earth's **crust is made of pieces** of lands and oceans, **called Plates**. **Magma is extended to the earth's surface, near the edges of these Plates**, where volcanic activities occur.



5.1. Geothermal resources

- **Most of the geothermal activities** in the world **occur in the Pacific Ocean rim**, known as the **Ring-of-Fire**. A number of active volcanoes exist around the ring. It also contains many high-temperature hydrothermal-convection systems.

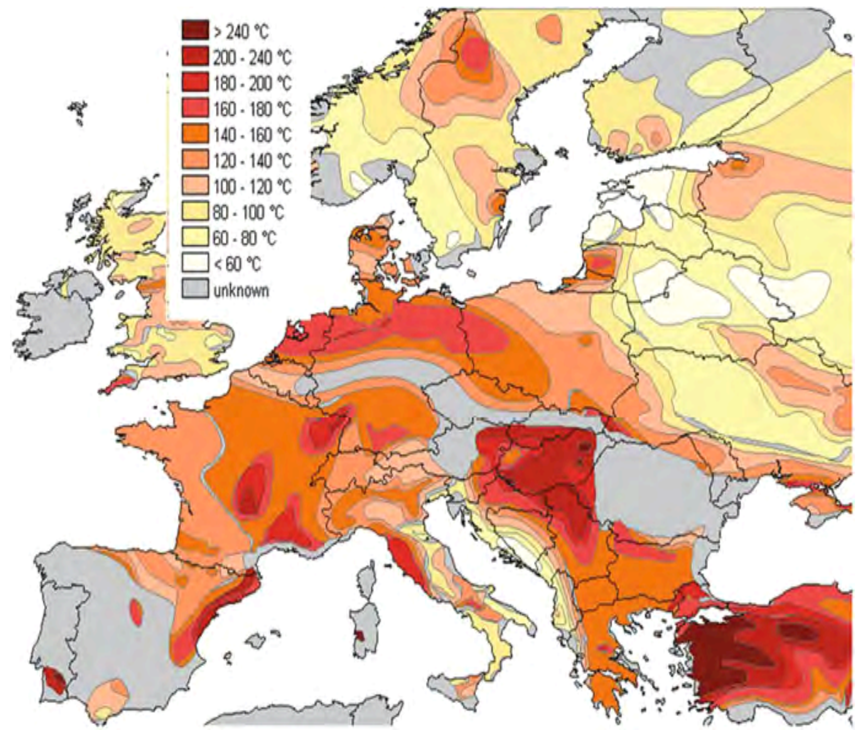
- **Several countries** around this Ring-of-Fire **are utilizing the geothermal energy** and it is already **contributing to their economic development**.



5.1. Geothermal resources

- Since the 1980s, **Europe has been very active in identifying** and quantifying its **geothermal resources**. Various regional mapping projects were published based on the data obtained from drilling boreholes.

- Areas of **high enthalpy are located in Iceland, Italy, Greece, parts of France, Germany and Austria**. Countries such as Ireland, Norway, Sweden, the UK, and Poland contain low enthalpy regions, so geothermal development may not be economically viable.



Temperature distribution at a depth of 5,000 m in Europe.
Source: Shell International.

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5.2. Geothermal exploration methods

- A **geothermal system consists of three** major **elements: a heat source, a reservoir and a fluid**.

- The **heat source can come from the Magma** having a temperature greater than 600°C at depths of 5-10 km. Additionally, a heat source can **also** be low-temperature systems **using the earth's normal temperature, which increases with depth**.

- **The reservoir** that is naturally formed by hot permeable rocks **can heat a circulating fluid, which is generally water**.

- The **heat is transferred to the fluid mainly by convection**. The hot water rises upward due to its lower density and is replaced by cold dense water.

- **If the geothermal fluid is used for steam generation or direct heating, it must be replenished** continuously to maintain the hydrostatic pressure and the fluid mass.

5.2. Geothermal exploration methods

- The **identification** and quantification **of geothermal resources require geological, hydrological, geophysical, and geochemical techniques** that enable gathering information regarding the potential use of specific sites.
- The information **is necessary to determine if the site is suitable** for development as a geothermal energy source.
- The **preliminary indication** of the presence of geothermal resources **is given by volcanoes, hot springs, fumaroles and geysers**.
- Any **geothermal exploration** should **address the following items:**
  1) Identification of geothermal phenomena.
  2) Determining if a useful geothermal production field exists.
  3) Estimating the shape, size, and depth of the resource.
  4) Determination of any characteristics that might cause problems during field development.
  5) Assessing the geothermal system (i.e. water or vapor-dominated).
  6) Determining the homogeneity of the water supply.
  7) Determining the source of recharge water.

5.2. Geothermal exploration methods

- **For** the **practical use** of geothermal energy, **large geothermal reservoirs must be found. Drilling a well** and testing the temperature deep underground **is the only way to ensure** that a geothermal reservoir exists.
- However, a number of **other studies prior** to drilling **should be performed** and these include:
  - Satellite imagery and aerial photography.
  - Volcanological studies.
  - Geologic and structural mapping.
  - Geochemical surveys.
  - Geophysical surveys.
  - Temperature gradient hole drilling.
- **Satellite images** and aerial survey **provide the initial indications** of existence of geothermal activities. **Geologic** landform and rock **analysis** can **provide further information** on the presence of geothermal energy.
- **Once** the existence of a geothermal source **is identified, drilling and various temperature measurements are carried out** to determine the size of the source and economic feasibility.

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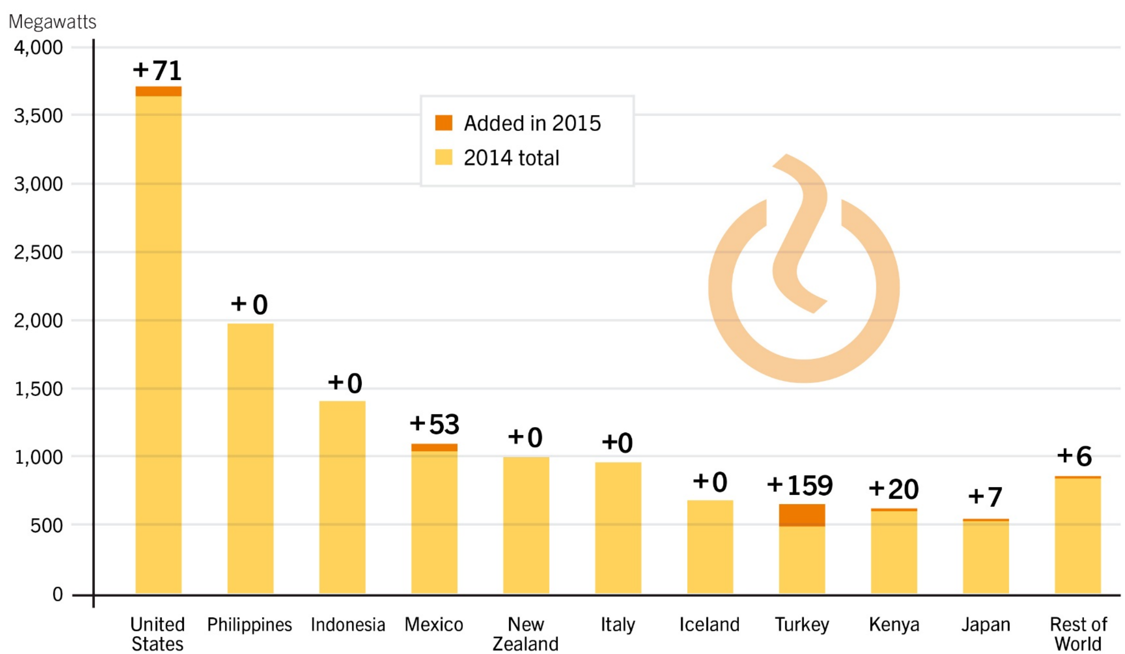
5.3. Geothermal energy application

Worldwide application

Global output:
Power 75 TWh
Heat 75 TWh

Geothermal Power Capacity and Additions, Top 10 Countries and Rest of World, 2015



5.3. Geothermal energy application

Worldwide application

- The **use** of the geothermal energy **depends on the temperature** of the resources.
- **For electricity** generation, the temperature of the resources must be **above 150°C**. If the temperature of geothermal resources is below 150°C, it can be still used for a number of other applications.
- The main applications of geothermal energy can be divided into the following categories:
  - Electricity generation.
  - Direct district heating.
  - Heat pump.
  - Industrial applications.

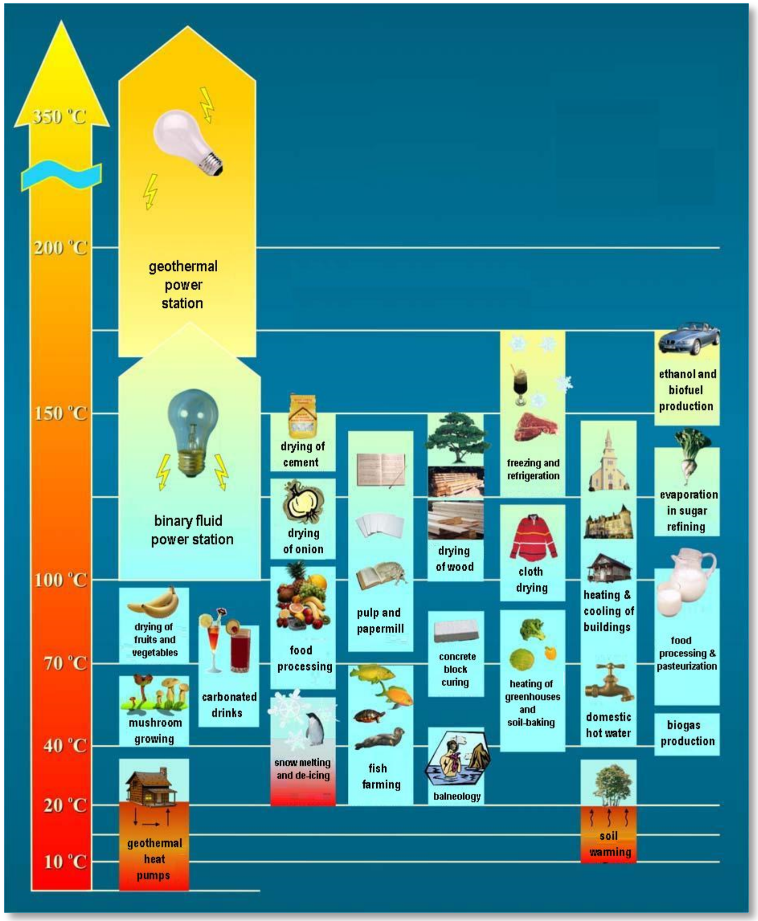
5.3. Geothermal energy application

Lindal Diagram

- **Various uses of the geothermal energy corresponding to** a particular **temperature are illustrated** in a diagram, which is currently known as t**he Lindal diagram**.

- From this figure, the **minimum useful temperature** for any application should be **above 20°C**.

- The **Lindal diagram is** now **widely used** in the geothermal community.



5.3. Geothermal energy application

Electricity generation

- **Worldwide about 75 million kWh** of electricity were produced in 2015 **from 12.8 GW of installed** geothermal power plants.

- At present **24 countries are utilizing the geothermal energy.**

- In Europe, **Italy** is expected to nearly **double** its installed capacity **by 2020**. Germany is planning 150 new plants with most of the activities centered in Bavaria.

- In Asia, the **Philippines is also planning to increase** its installed geothermal capacity from about 2,000 MW to 3,130 MW.

- The geothermal development potential of the Great Rift Valley in Africa is enormous. **Kenya** has announced a **plan to install about 1,700 MW** of new geothermal capacity within 10 years.

5.3. Geothermal energy application

Electricity generation

- ***Geothermal resources that can be used to generate electricity may be divided into the following four categories:***
  1) Hydrothermal fluids.
  2) Geopressurized brines.
  3) Enhanced (Engineered) geothermal systems or Hot dry rock systems.
  4) Magma.
- Of these four resources, **only hydrothermal fluids have been developed commercially for power generation**.
- The extraction of **geopressurized brine is technologically challenging and its potential is enormous**, but so far an economically feasible technology is not available for extracting this energy in a commercially useable way.
- Although the temperature of molten **Magma** is above 2000°C, **there is no technology to take advantage** of this energy.
- The **ambient ground heat is** generally **too low** for most of the applications.

5.3. Geothermal energy application

Electricity generation

1) Hydrothermal fluids:

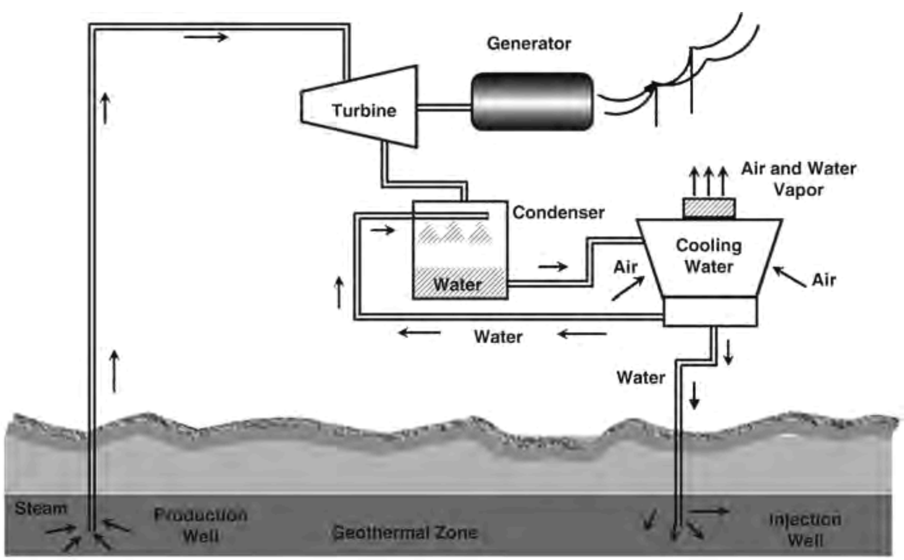
- **Three methods can be used** for the generation of electricity **from hot hydro-thermal fluids**.
- **Methods** suitable for electricity generation **depend on the state of the fluid** (whether it is steam or hot water) as determined by its temperature.
- These methods are called:
  - **1.1.** Dry steam.
  - **1.2.** Flash steam.
  - **1.3.** Binary cycle.

5.3. Geothermal energy application

Hydrothermal fluids

1.1. Dry steam method:

- If the geothermal energy is available in the form of **steam**, it **can be used directly to run a conventional steam turbine**.
- The dry steam geothermal system **is the oldest type** of geothermal power plant.
- These plants **emit excess steam and very small amounts of other gases** to the atmosphere.

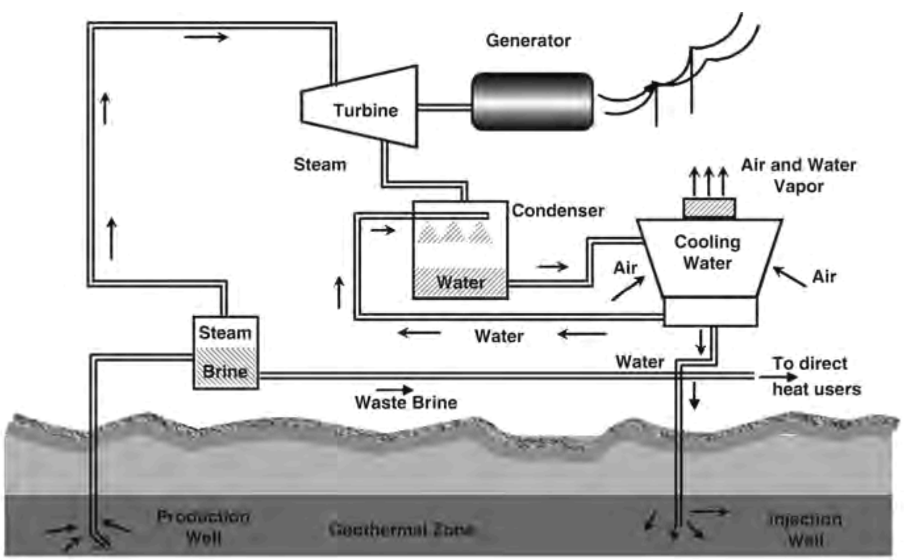


5.3. Geothermal energy application

Hydrothermal fluids

1.2. Flash steam method:

- Flash steam power plants use the hydrothermal fluid, which is primarily **water, for electricity generation**. Water is available **at temperatures above 200°C and at a high pressure**.
- **Water is sprayed into a flash-tank** that operates at a lower pressure than the inlet water, **causing** some of **the fluid to** rapidly **vaporize**, or flash, to steam.
- The **steam is used** to drive a turbine and a generator.



5.3. Geothermal energy application

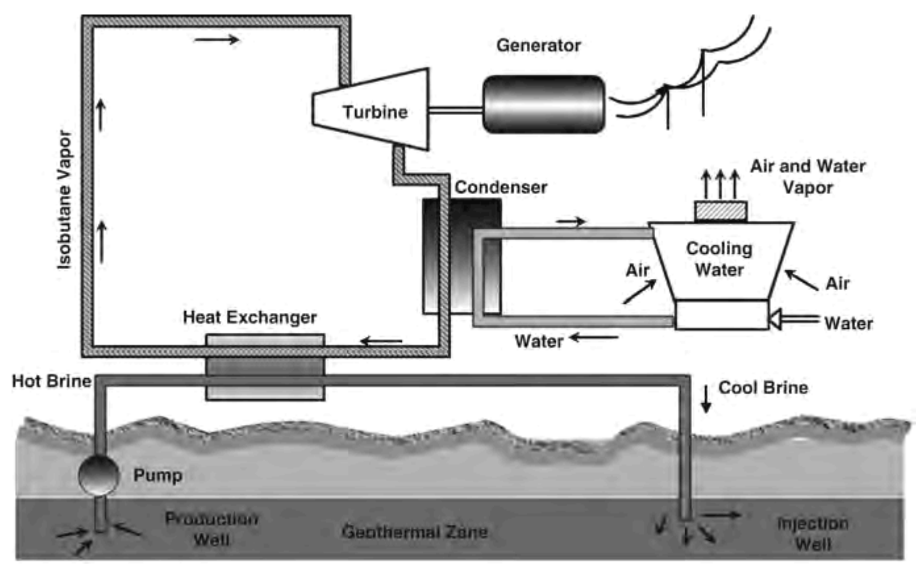
Hydrothermal fluids

1.3. Binary cycle method:

- If the **water temperature is less than 200°C**, a **binary cycle method** may **be most suitable** and cost effective for the generation of electricity.

- In this method the **geothermal energy is used to vaporize another working fluid**, **which** then **drives a turbine and a generator**. Generally, hydrocarbons are preferred as the working fluid.

- In a **closed loop cycle**, the vapor produced from the binary liquid drives the turbine-generator unit, and then it is condensed back to liquid before being reused in the heat exchanger.

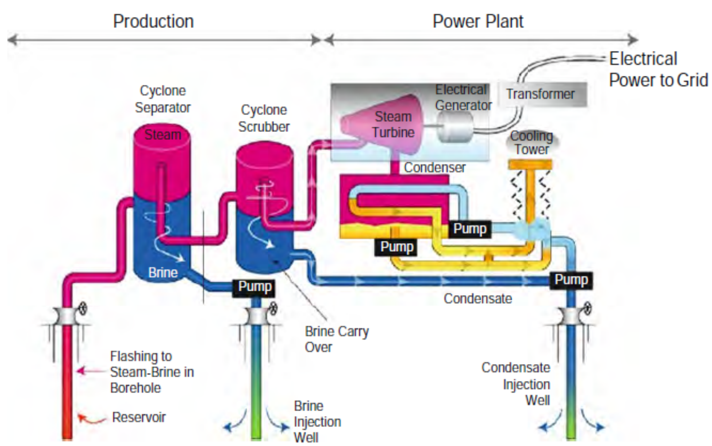


5.3. Geothermal energy application

Electricity generation

2) Geopressurized brines:

- Geopressurized reservoirs **exist at depths of 3,000-6,000 m** below the earth's surface that **contain brine and dissolved methane**.
- These types of reservoirs **are located all over the world**.
- These brines are hot with **temperatures** in the range **of 150-200°C**.
- The geopressurized brine **can provide:**
  - **Thermal energy** from the temperature of the fluid.
  - **Mechanical energy** from the fluid pressure.
  - **Chemical energy** from the methane that is dissolved within the fluid.
- The **brine** from these reservoirs **is extremely corrosive**. Therefore, the chemical behavior of brine needs to be properly understood and implemented before power plants can be economically viable.

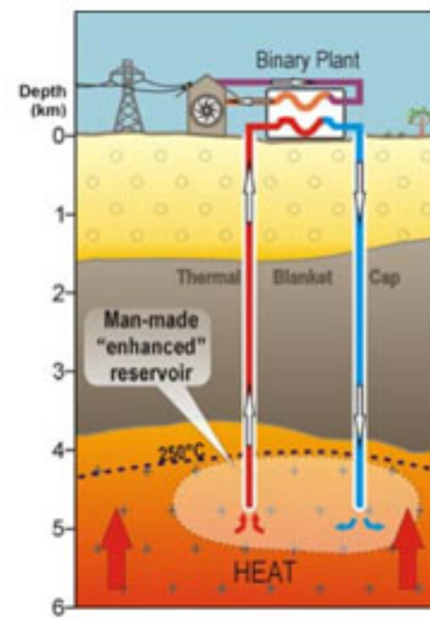


5.3. Geothermal energy application

Electricity generation

3) Enhanced (Engineered) geothermal systems or Hot dry rock systems:

- A **significant amount of heat is stored in hot rocks** underneath the earth's surface.
- This heat **can be harvested through Enhanced or Engineered Geothermal systems (EGS)**.
- **EGS** are engineered reservoirs below the earth's surface for **extracting energy from engineered geothermal resources** (mainly from hot rocks).
- **However, these resources are not economically viable** due to the lack of a body of water and/or permeability through the rock formation.
- The **estimations are** that the application of EGS technology is capable of providing at least **100,000 MW of electricity within the next 50 years**.

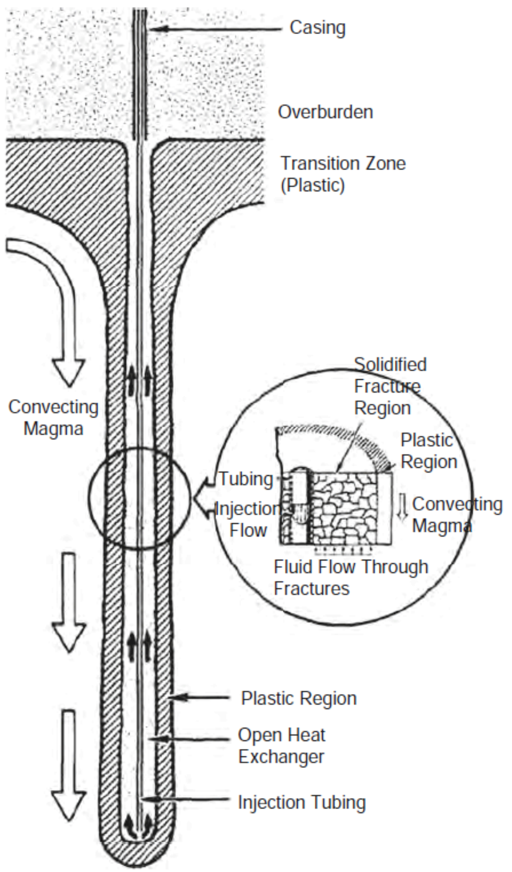


5.3. Geothermal energy application

Electricity generation

4) Magma:

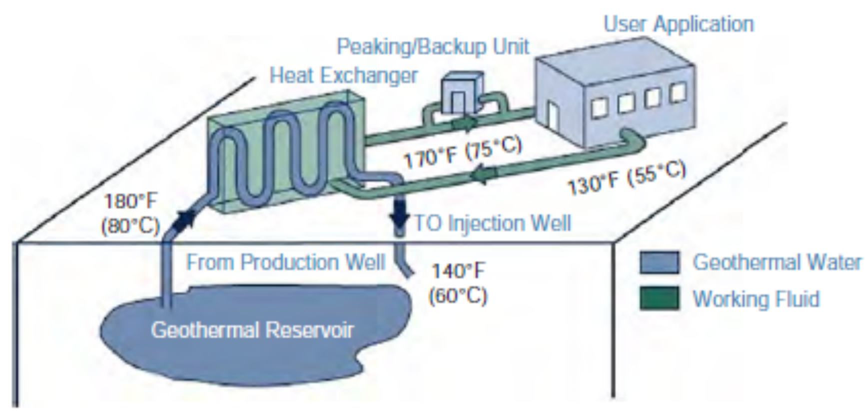
- **Magma is** potentially **a huge energy source**.
- **The greatest challenge** with the magma system **is the extraction of energy**.
- **An open heat exchanger can be formed** for the extraction of heat by solidifying magma around a cooled borehole and the resulting mass will be extensively fractured by thermally-induced stresses.
- However, **the construction materials must be chosen carefully**. Consideration of corrosion resistance, high-temperature strength, and cost suggest that Ni-base superalloys offer the most promise for use as construction material of a heat exchanger in magma.



5.3. Geothermal energy application

Direct district heating

- **Direct uses** of geothermal energy involve the **use of hot waters** from geothermal resources **directly for bathing and cooking, heating of homes and buildings (better known as district heating), heating of greenhouses for growing vegetables and flowers, fish farming (aquaculture), drying of foods and lumber, and the use of heat pumps**.
- In **Europe most** of the geothermal energy **is used for direct heating**.
- **Direct-use** systems typically **include three components:**
  - A **production facility** - usually a well to bring the hot water to the surface.
  - A **mechanical system** - piping, heat exchanger, and controls to deliver the heat to the space or processes.
  - A **disposal system** - injection well or storage pond to receive the cooled geothermal fluid.



5.3. Geothermal energy application

Direct district heating

- Geothermal **district heating represents about 35% of** the European **installed geothermal systems** that are dedicated to direct uses, totaling about 5,000 MWt.
- In Europe, **Iceland is the leader** in the utilization of geothermal energy. **The Paris area** in France **has the largest geothermal district heating systems**.

Major geothermal district heating sites in Europe (over 35 exceeding 5 MWt capacity).

5.3. Geothermal energy application

Geothermal Heat Pumps (GHP)

- **Carnot efficiency:** the limit factors are the temperature at which the heat enters the engine, TH, and the temperature of the environment into which the engine exhausts its waste heat, TC, measured in an absolute scale, such as the Kelvin or Rankine scale. From Carnot's theorem, for any engine working between these temperatures:

$$\eta_{carnot} \leq 1 - \frac{T_c}{T_H}$$

- **The Coefficient Of Performance (COP)** of a heat pump is a ratio of heating provided to electrical energy consumed.

$$COP = \frac{Q_{Heating}}{W}$$

- **The Energy Efficiency Ratio (EER)** of a particular cooling device is the ratio of output cooling energy to input electrical energy at given operating point.

$$EER = \frac{Q_{Cooling}}{W}$$

5.3. Geothermal energy application

Geothermal Heat Pumps (GHP)

- **Geothermal Heat Pumps (GHP) are extremely efficient** for home heating and air conditioning.
- Heat pumps are **electrical devices that transfer heat from a cool space into a warm space**, making the cool space cooler and the warm space warmer.
- During the **heating season** (i.e., during winter), heat pumps **move heat from the cool outdoors into the house making it warm**. The process is reversed during the **cooling season** (i.e., during summer). During the summer months, heat pumps **move heat from the house into the warm outdoors**.
- **GHPs reduce electricity use by 30-60%** compared with traditional electrical heating and cooling systems.
- **Geothermal heat pumps are making a big impact on energy efficiency** in the U.S. and Europe.

5.3. Geothermal energy application

Geothermal Heat Pumps (GHP)

- The **GHP unit** is generally **installed inside the building**. A **loop of plastic or metal pipe is placed** in a vertical hole bored **several hundred meters deep**, and the hole is then backfilled.
- An **antifreeze solution is circulated through the loop** and through the heat pump for removing heat from or transferring heat to the ground.
- The **heat transfer process takes place through the pipe wall** and between pipe and the earth or ground water.
- Therefore, **no physical contact takes place between the antifreeze and the ground**. The type of antifreeze that can be used in the loop depends on the ground temperature.
- The **loops** of plastic pipe **can be placed** in the ground **in various orientations**. They can be also placed in a nearby pond provided the pond does not freeze during winter months.

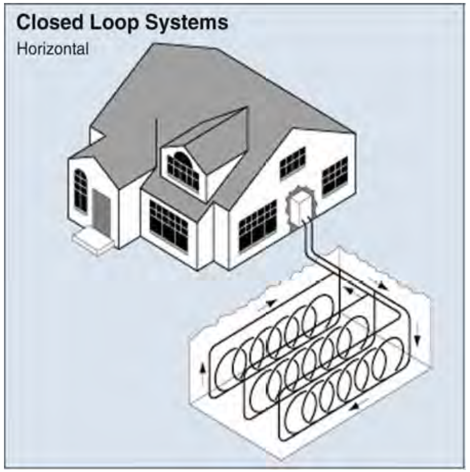
5.3. Geothermal energy application

Geothermal Heat Pumps (GHP)

- There are **four** basic **types of ground loop** systems. These are **horizontal, vertical, and pond/lake**, which are **closed-loop** systems, and an **open-loop** type system.
- The **choice** of the loop-system **depends on the climate, soil conditions, available land, and local installation costs at the site**.
- **All** of these approaches **can be used for both residential and commercial buildings**.

Closed-loop:

- *Horizontal:*
  - Closed loop systems are generally used for residential installations. They can be most cost effective, particularly for new construction if sufficient land is available.

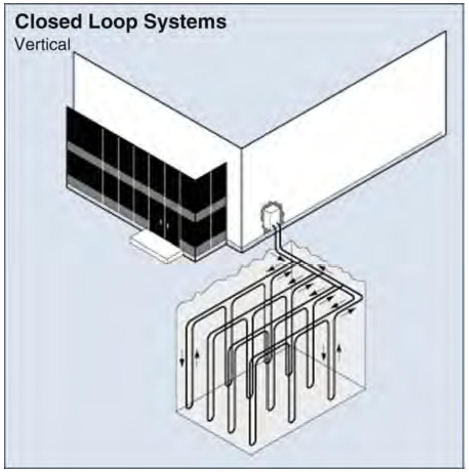


5.3. Geothermal energy application

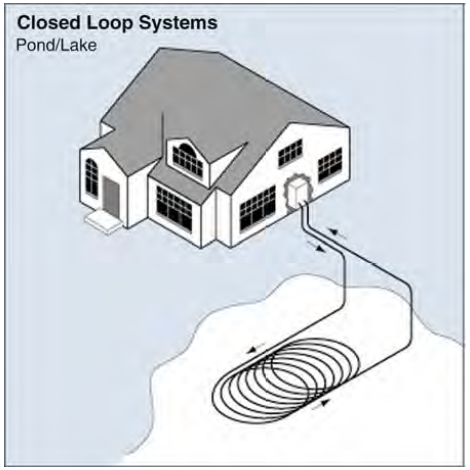
Geothermal Heat Pumps (GHP)

Open-loop:

- *Vertical:*
  - Vertical systems are **more convenient for large commercial buildings** and schools which often have limited availability of land.



- *Pond/lake:*
  - If the house has a large pond nearby, this type of loop can be used for the heat pump. This type of installation is **affordable for the residential customers costing the least of all the loop systems**. The underground pipe lines connect a heat pump inside the building to the loop in the pond.

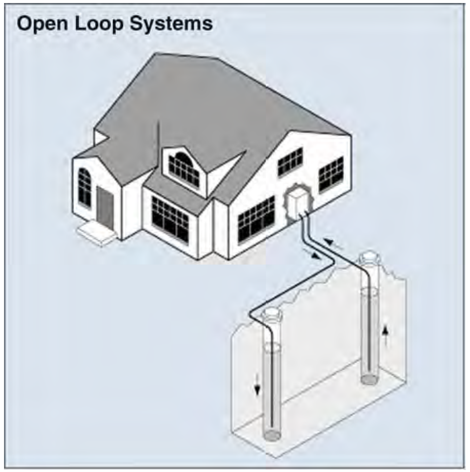


5.3. Geothermal energy application

Geothermal Heat Pumps (GHP)

Closed-loop:

- Open loop systems **take advantage of the groundwater** to operate the heat pump.
- This type of system **uses wells or other bodies of water as the heat exchange** fluid that is circulated directly through the GHP system.
- The water circulates in a closed loop and is returned to the ground either through a recharge well or by discharging to the surface.
- This option is practical **only where there is an adequate water supply** with relatively clean water for surface discharge.
- The **advantages** of open loop systems are **less heat loss and lower costs**.
- **Video:** Geothermal energy.



Sources

- Twidell, John & Weir, Tony (2006): *«Renewable energy resources»*. Taylor & Francis.

- Tushar K. Ghosh & Mark A. Prelas (2011): *«Energy resources and systems. Volume 2: Renewable resources»*. Springer.

- Paul Breeze & Aldo Vieira (et all.) (2009): *«Renewable energy focus handbook»*. Elsevier.