Introduction to renewable Energy (0611341)
مقدمة في الطاقة المتجددة
Chapter 7- Geothermal Energy

Geothermal Energy (GE) is the heat from the Earth. It is one of the less well recognized forms of RE. It is the only form of RE that is independent of the Sun. The amount of heat flowing through the Earth's surface is 1×10^{21} J/y (Joule per year). One way to classify the GE resources is according to their Enthalpy content.

Enthalpy is defined as the heat content of a substance per unit mass, and is a function of pressure and volume as well as temperature. The term enthalpy is used because temperature alone is not sufficient to define the useful energy content of steam/water mixture. A mass of a steam at a given temperature and pressure can provide much more energy than the mass of water under the same conditions. However, for the purpose of this course, it is usually sufficient to think of temperature and enthalpy as going hand in hand.

Heat Source

Heat flows out of the Earth because of the massive temperature difference between the surface and the interior (7000 °C is the temperature of Earth's center). There are two reasons for Earth's center being hot:

1. When the Earth formed millions years ago, the interior was heated rapidly as kinetic and gravitational energy of accreting material was converted into heat.
2. Earth contains quantities of long-lived radioactive isotopes, which liberate heat as they decay.

- Second mechanism is of much great importance than the first one.

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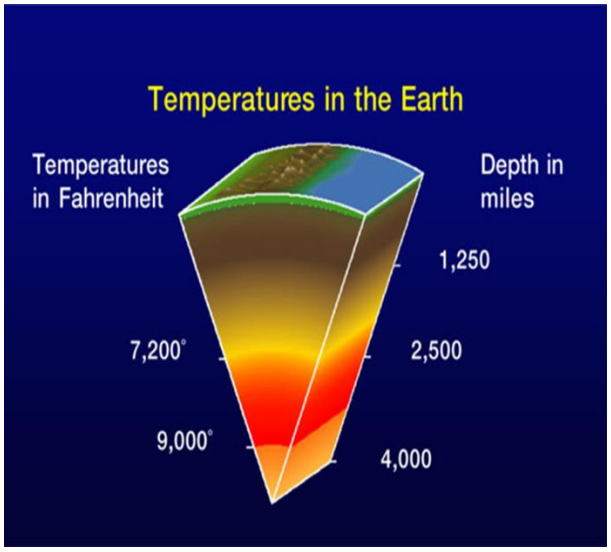
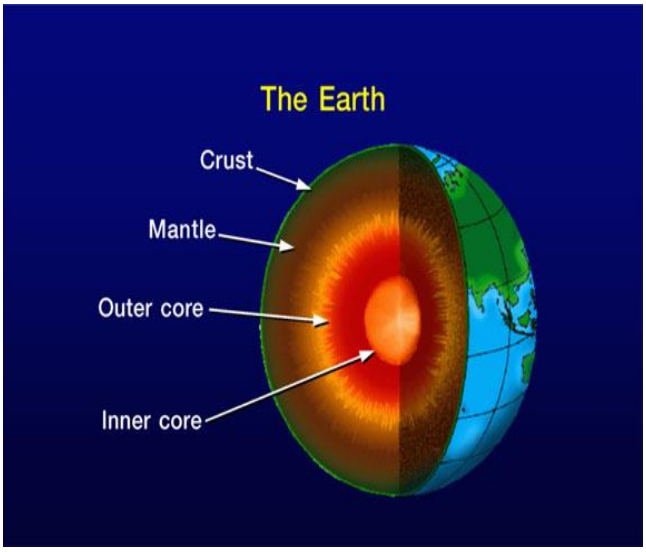
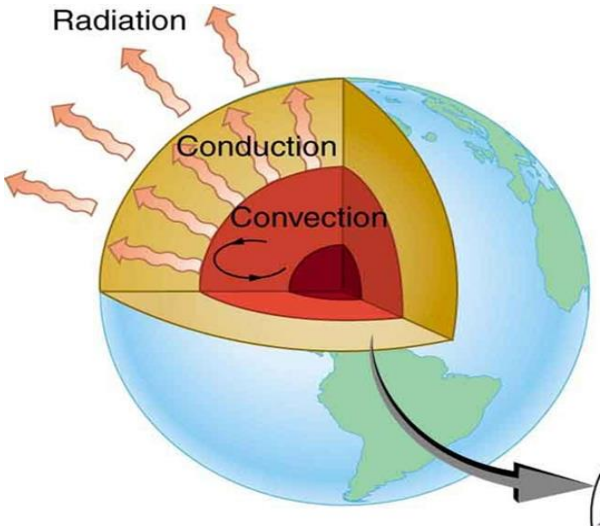
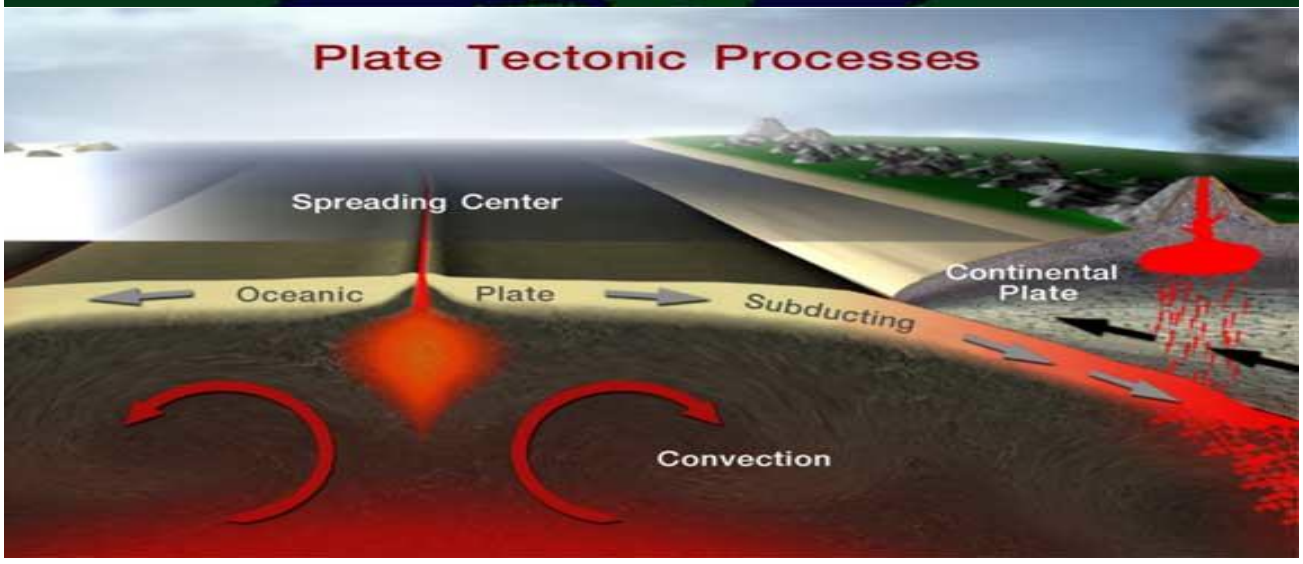




Heat is transferred through the main body of the Earth principally by convection. Closer to the Earth's surface (across the outer 100 km), the material is too rigid to convict because it is colder. So that,

heat is transported by conduction and there are much larger increases of temperature with depth. At boundaries between the plates, heat flow reaches a maximum. Here, the heat energy flowing through the surface averages around 300 mW/m^2 as compared with the global mean of 60 mW/m^2.



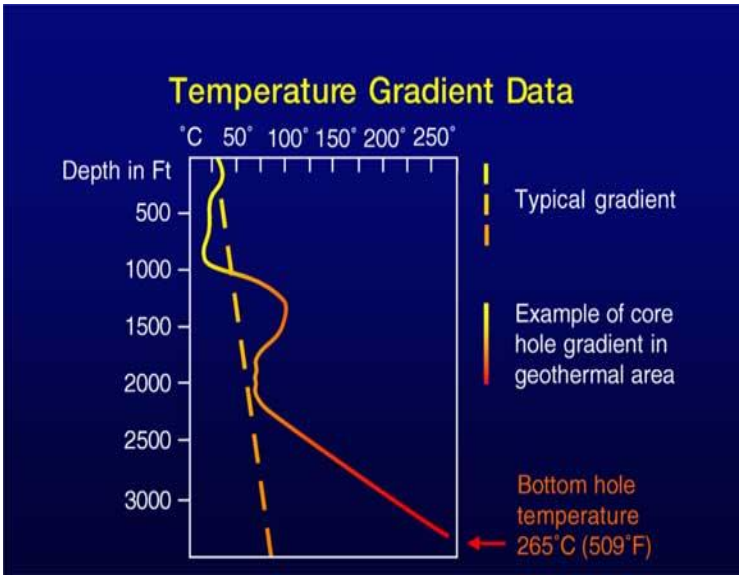


GE Resources

GE resources are classified into:

- **High Enthalpy resource:** Water and steam are above 180°C
- **Medium Enthalpy resource**: Water and steam are about 100 to 180 °C
- **Low Enthalpy resource**: Water and steam are below 100 °C

The techniques for exploiting the resources are similar to those of extracting oil and gas. One or more boreholes are drilled into the reservoir, the hot fluid flows or is pumped to the surface. Then, it is used in conventional turbines or heating equipment.

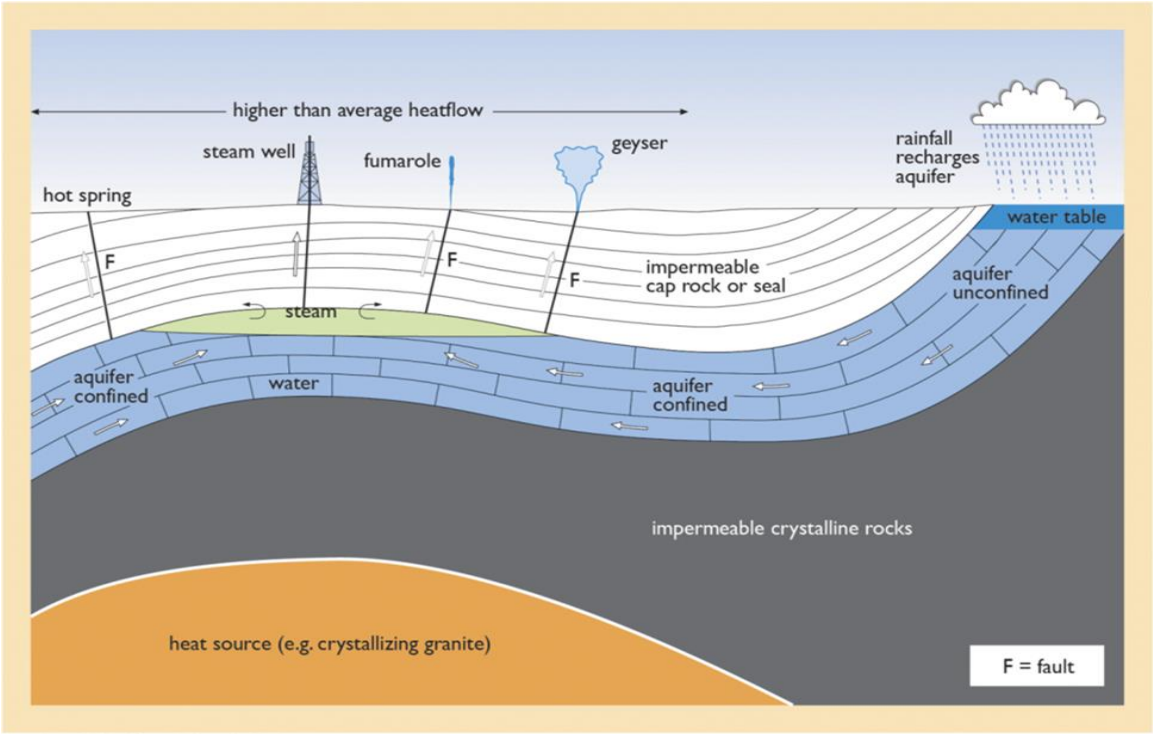


Physics of Geothermal Resources

Geothermal resources of most types must have three characteristics:

1. An aquifer containing water that can be accessed by drilling.
2. A cap rock to retain the geothermal fluid.
3. A heat source.

The aquifers are porous rocks that can store water and through which water will flow. The aquifer is unconfined where it is open to the surface in the recharge area. The rainfall infiltrates to keep the aquifer full as indicated by the water table just below the surface



Cap rock is a relatively impermeable rock, or seal, to prevent fluid escaping upwards. It is essential if a steam field is to develop. There are **two main types of GE resources**:

1. Those located in **deep sedimentary basins** where aquifers carry water to depths where is becomes warm enough to exploit.
2. Those located in **"hot dry rocks"** where natural heat production is high, but an artificial aquifer must be created by enhancing the rock fractures in order that the geothermal resource may be exploited.

Steam and water escape naturally through **faults** in the cap rock, forming:

- **fumaroles (steam only),**
- **geysers (hot water and steam),**
- **or hot springs (hot water only).**

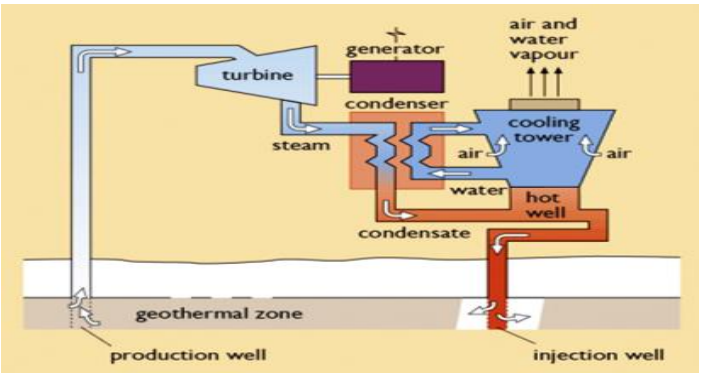
Electricity Generation Using GE Resources

The technologies for electrical power generation depend critically on the nature of the geothermal resources (such as their salinity and content of other gases, …), in addition to the fluid temperature and pressure. All these factors affect the plant efficiency and design. A typical geothermal unit is usually 30 – 50 MW_e. This is because the amount of steam delivered by one well is usually sufficient to generate only a few MW_e, and wells are linked across the field back to the station pipeline. Above a certain capacity, the cost of pipelines is such that it is cheaper to develop a separate station in another part of the field.

The **four main types** of geothermal electrical energy production are:

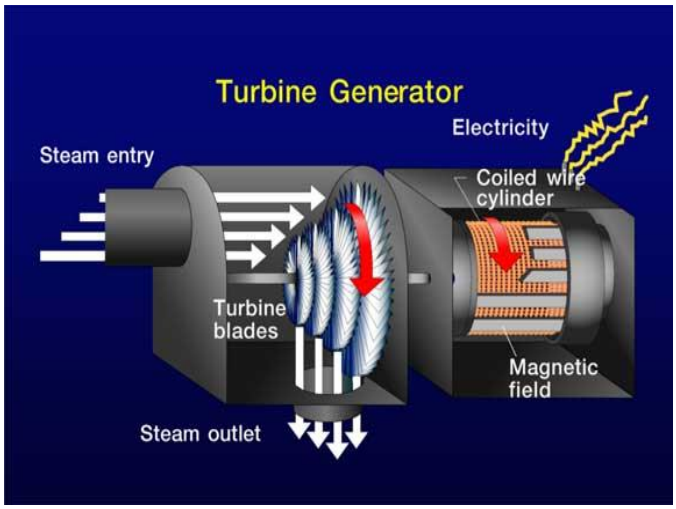
1. **Dry steam power plant.**
2. **Single flash steam power plant.**
3. **Double flash power plant.**
4. **Binary cycle power plant.**

Dry steam power plant will be discussed in this section only. As the name implies, it is ideal for vapour dominant resources whose steam production is not contaminated with liquid. In general, it is the simplest and most commercially attractive. The reservoir produces superheated steam reaching the surface at several hundred kilometers per hour.



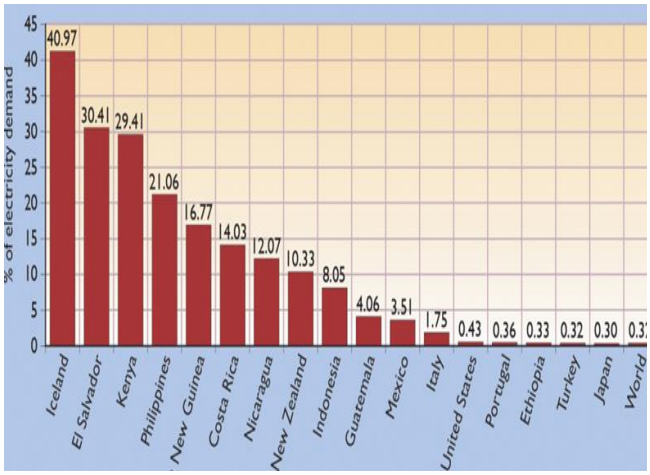
Typically the superheated steam is at 180-225 °C and 4-8 MPa. However, temperatures up to 300-350 °C and great pressures are increasingly being exploited, leading to greater efficiency. Passing through the turbine, the steam expands, causing the blades and shaft to rotate and hence generating power. The condensing unit condenses the exhaust steam to liquid, thus dramatically increasing the pressure drop across turbine because liquid water occupies a volume roughly 1000 times less than the same mass of steam. The cooling tower generates waste heat (similar to coal- and oil-power stations).

At typical temperatures for geothermal fluids, efficiencies are low, and rarely exceed 20%. In modern dry steam power plants, a 55 MWe requires 100 kg/s of steam or 6.5 kg steam per kWh. It is a common practice to reinjection the spent fluid, in order not to over-exploit fields, a cooperative reinjection policy to make the resources more sustainable. Nowadays, about 70% of the mass or produced steam in usually reinjected. The remaining part is evaporated from the cooling towers.



GE Electricity and Heat Generation

By 2010, world electrical power generating capacity from GE resources had reached 10.7 GW_e, and supplied energy of a total of 67.2 TWh. By 2015, world electrical power generating capacity from GE resources is expected to reach 18.5 GW_e. USA, Philippines, and Indonesia are the leading countries in electrical power generating capacity from GE resources. By 2010, non-electrical, direct use capacity for applications such as, space heating, agriculture, aquaculture, industrial processes,… reached about 50.6 GW_t, and supplied energy by a total of 122 TWh. The total amount of geothermal electricity produced in 2010 accounted for only about 0.32%. However, large percentage of electricity demand was covered by GE resources in countries such as Iceland, Salvador, and Kenya.



Advantages of GE

- Use 25% - 50% less electricity than conventional heating/cooling systems
- Reduce emissions up to 40% compared to conventional heating/cooling systems
- Maintain 50% relative indoor humidity
- Can be new or retrofitted
- Piping lasts 25-50 years
- Heat pumps last 20+ years
- Underground pipes not easily accessible
- Need electricity to operate, not zero emissions- unless combined with solar PV
- Installation requires large trench
- Toxic refrigerants