ANKARA UNIVERSITY
Department of Energy Engineering

Geothermal Energy

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CONTENTS

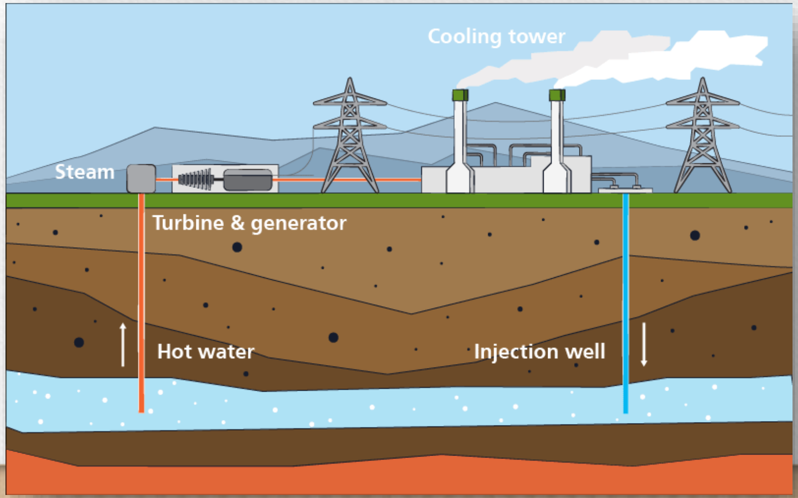
- a) Fundamentals of geothermal energy
- b) Sources, uses and advantages

Geothermal Energy

- Geothermal energy is produced from heat originating in the earth's interior. Volcanoes, geysers, hot springs, and boiling mud pots are visible evidence of the great reservoirs of heat that lie within and beneath the earth's crust.

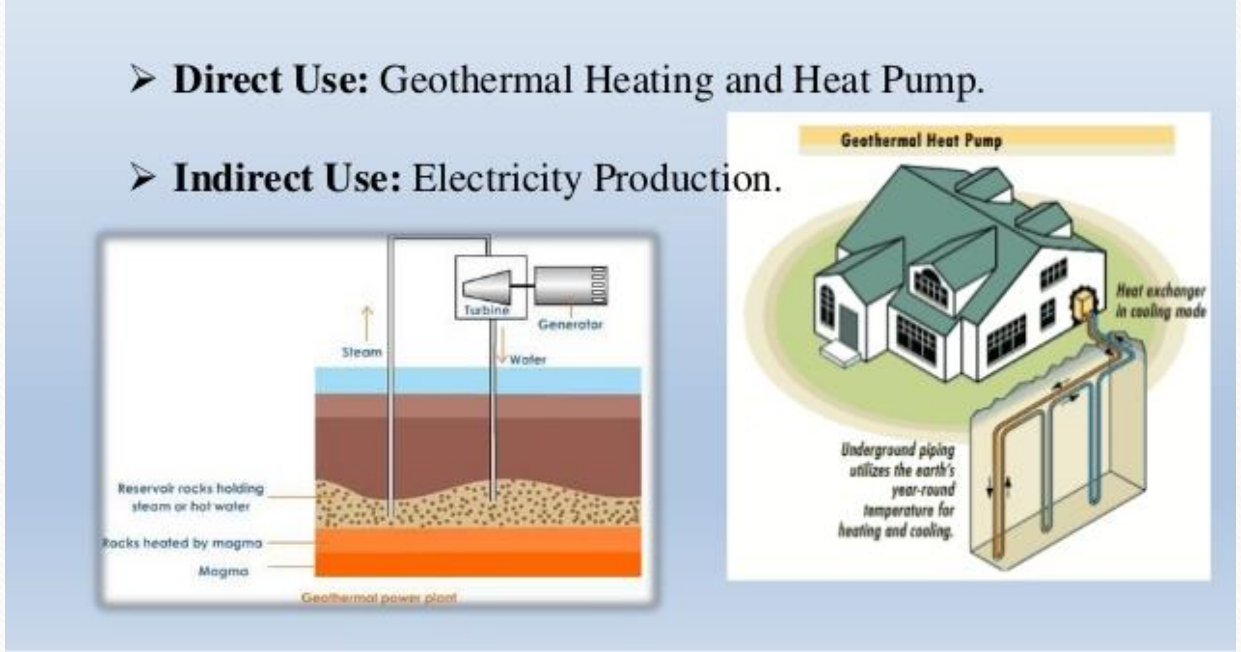
Geothermal Energy

- These underground reservoirs of steam and hot water can be tapped to generate electricity or to heat and cool buildings directly.
- To produce geothermal-generated electricity, wells, sometimes a mile (1.6 kilometers) deep or more, are drilled into underground reservoirs to tap steam and very hot water that drive turbines linked to electricity generators. The first geothermally generated electricity was produced in Larderello, Italy, in 1904.



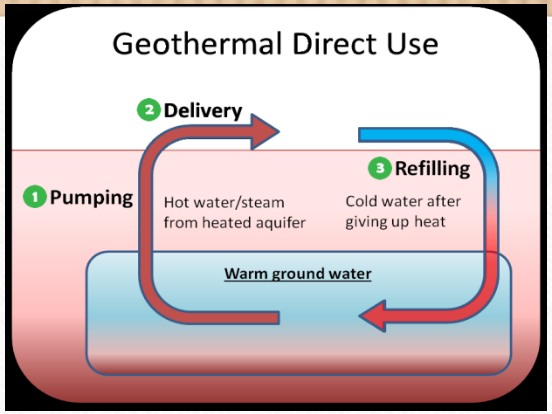
Uses of Geothermal Energy

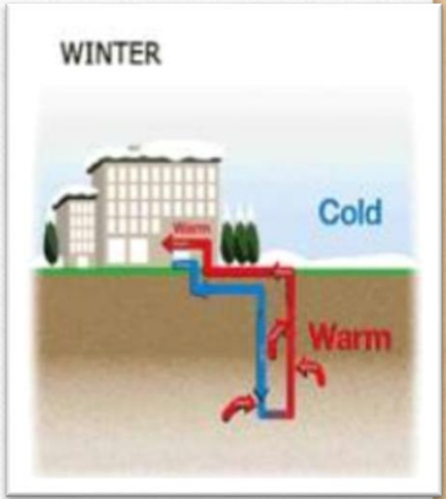
Geothermal water from deeper in the Earth can be used directly for heating homes and offices, or for growing plants in greenhouses. Some U.S. cities pipe geothermal hot water under roads and sidewalks to melt snow.



Direct Use of Geothermal Energy

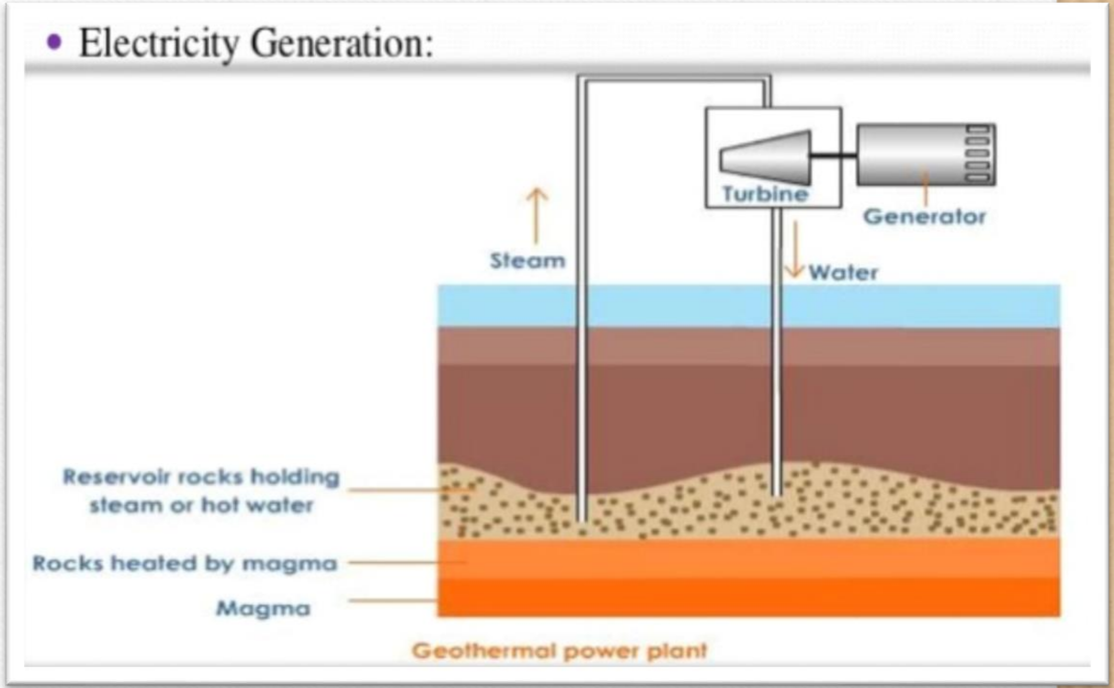
Direct use of geothermal resources is the use of underground hot water to heat buildings, grow plants in greenhouses, heat water for fish farming, and for many other applications. Some cities pipe the hot water under roads and sidewalks to melt snow. District heating applications use networks of piped hot water to heat buildings in whole communities.





Indirect Use of Geothermal Energy

- Source temperature is higher than 150°C
- Deep wells are drilled and steam from reservoirs is used to drive turbines and produce electricity
- Normally takes place by using heat present in the deeper subsurface at depths of 3 to 5 km. However, in specific areas, one does not need to drill that deep.



Geothermal Energy Advantages And Disadvantages

Advantages

- It can be extracted without burning a fossil fuel such as coal, gas, or oil.
- Geothermal fields produce only about one-sixth of the carbon dioxide that a relatively clean natural-gas-fueled power plant produces. Binary plants release essentially no emissions.
- It's also relatively inexpensive; savings from direct use can be as much as 80 percent over fossil fuels.

Disadvantages

- It may contain low levels of toxic materials. The release of hydrogen sulfide (H_2S).
- Not available everwhere.
- Although geothermal sites are capable of providing heat for many decades, eventually specific locations may cool down.

Geothermal Energy around the World

Geothermal energy is generated in over 20 countries. The United States is the world's largest producer, and the largest geothermal development in the world is The Geysers north of San Francisco in California. In Iceland, many of the buildings and even swimming pools are heated with geothermal hot water. Iceland has at least 25 active volcanoes and many hot springs and geysers.

FIGURE 4
Locations of geothermal operations around the world

Source: P.G. Pálsson, 2013. (Based on UN map No. 4170 Rev. 13, April 2012. Department of Field Support, Cartographic Section).

Table 15.1 Installed electricity generating capacity (MW_e) using only geothermal sources. The countries with major experience are listed (after Goodman and Love, 1980 and the International Geothermal Association, 2004)

Country	*Key regions*	*1980*	*1990*	*2000*
China			19	29
El Salvador		100	95	161
Iceland	Namafjall	40	45	170
Indonesia			145	590
Italy	Larderello	420	545	785
Japan	Matsukawa	250	215	546
Kenya	Rift Valley		45	45
Mexico	Cerro Prieto	150	700	755
New Zealand	Wairakei	250	283	437
Nicaragua			70	70
Philippines		250	891	1909
Russia			11	23
Turkey			20	20
USA	Geysers, California	700	2775	2228
Total (2 significant figures)		2200	5900	8000

Table 18.1 GEOTHERMAL POWER PLANTS

	Installed Capacity (MWe)	
Site	**1990**	**2010**
United States	2775	3086
Philippines	890	1904
Indonesia	145	1197
Mexico	700	958
Italy	545	843
New Zealand	283	628
Iceland	45	575
Japan	215	536
El Salvador	95	204
Kenya	45	167
Costa Rica	0	166

Source: International Geothermal Association

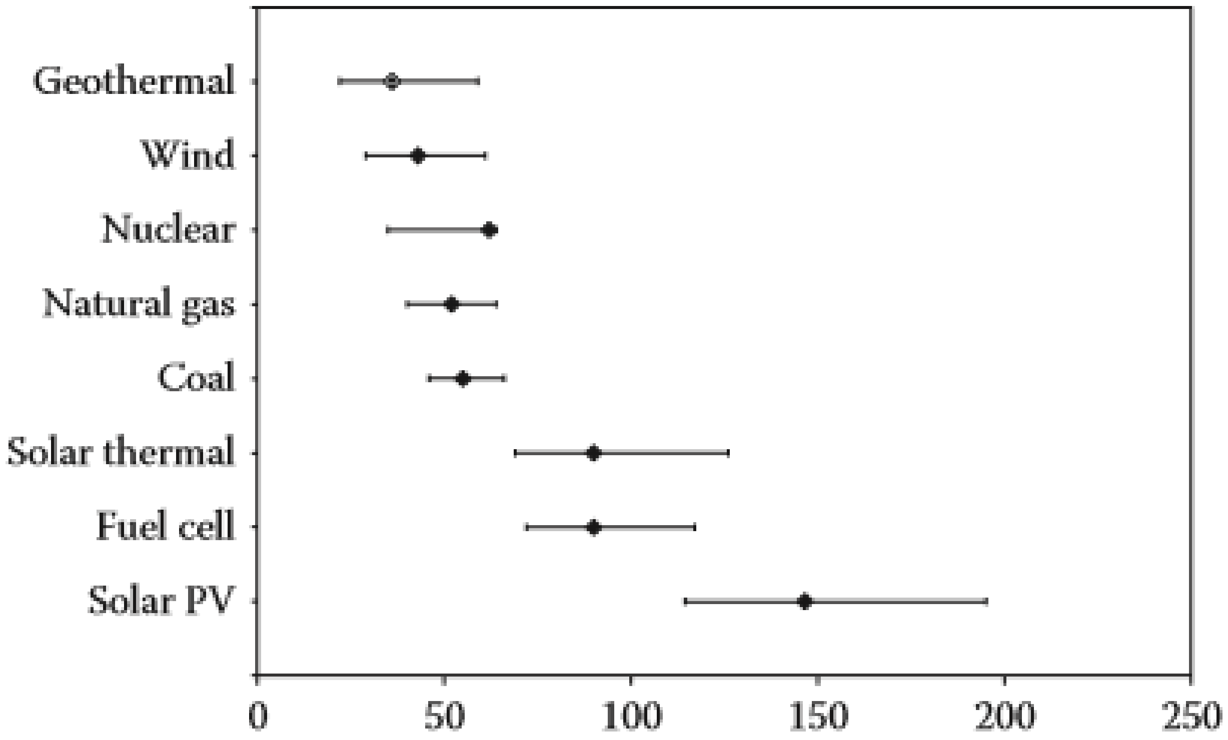


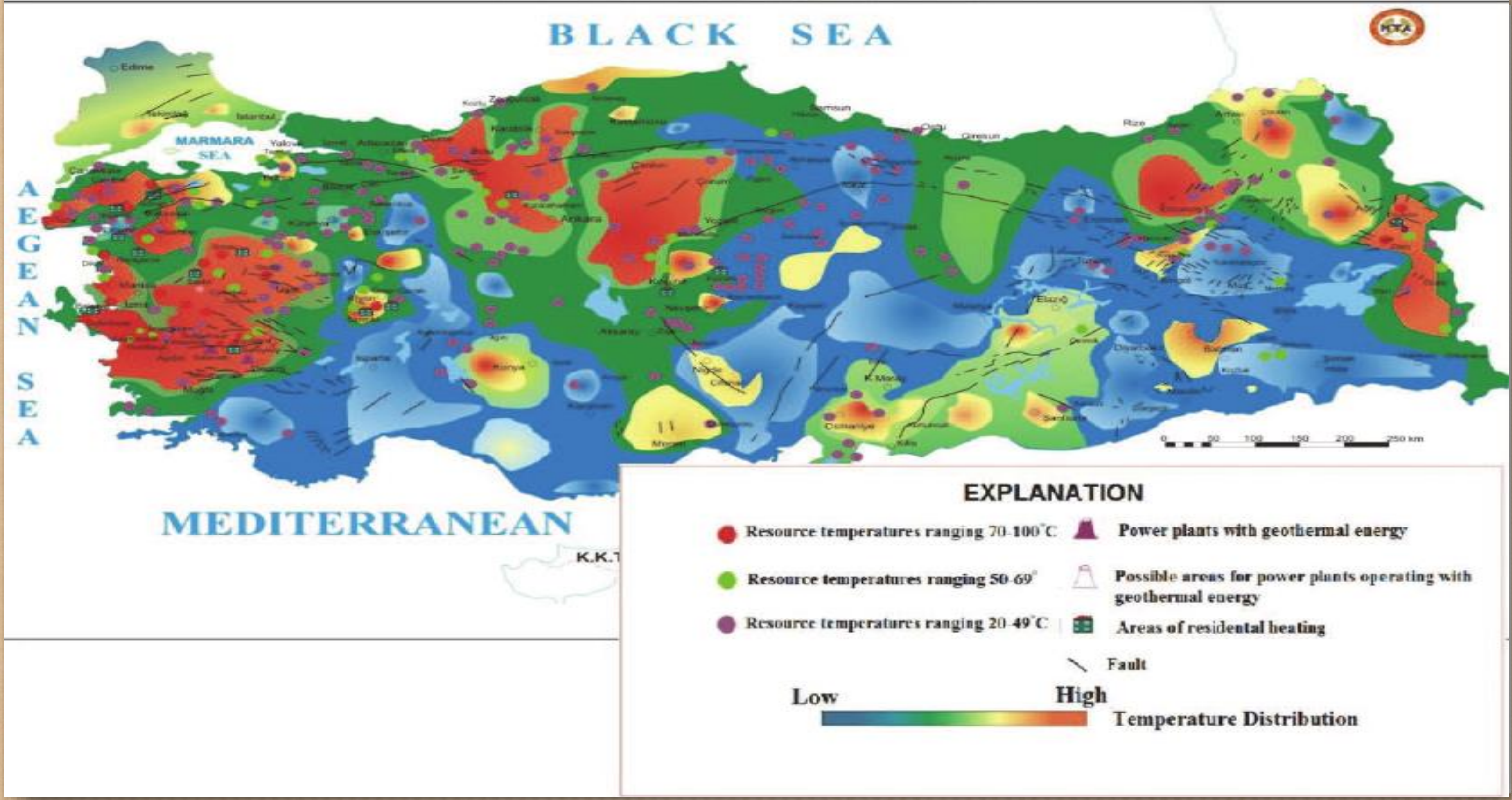
Figure 6.2 Comparison of electricity generation costs in dollars per megawatt-hour for eight fuel sources. The bars show high and low estimates for the ranges. The costs are for plants in the United States, and they include a $19/MWh tax incentive for renewable sources. Moreover, these are levelized costs, which assume that the same interest rates can be obtained for highly capital-intensive sources compared to others. These data are based on high and low estimates for a plant entering service in 2017, and they are based on US Energy Information estimates.

Geothermal Energy in the Turkey

Geothermal energy is clean, cheap and environmentally friendly, which is our domestic energy source. Turkey is located on an active tectonic zone as geological and geographical location and for this reason our country is rich in terms of geothermal energy resources. Our country have approximately 1.000 geothermal springs that located all over the country that have various of temperatures.

The geothermal capacity of our country is very high. **78%** of these geothermal fields are situated in **Western Anatolia**, **9%** in **Central Anatolia**, **7%** in the **Marmara Region**, **5%** in **Eastern Anatolia** and **1%** in the **other regions**. 90% of our geothermal resources are low and medium enthalpy geothermal areas which are suitable for direct applications (heating, thermal tourism, industrial usage, etc.), while 10% are suitable for indirect applications (generation of electricity).

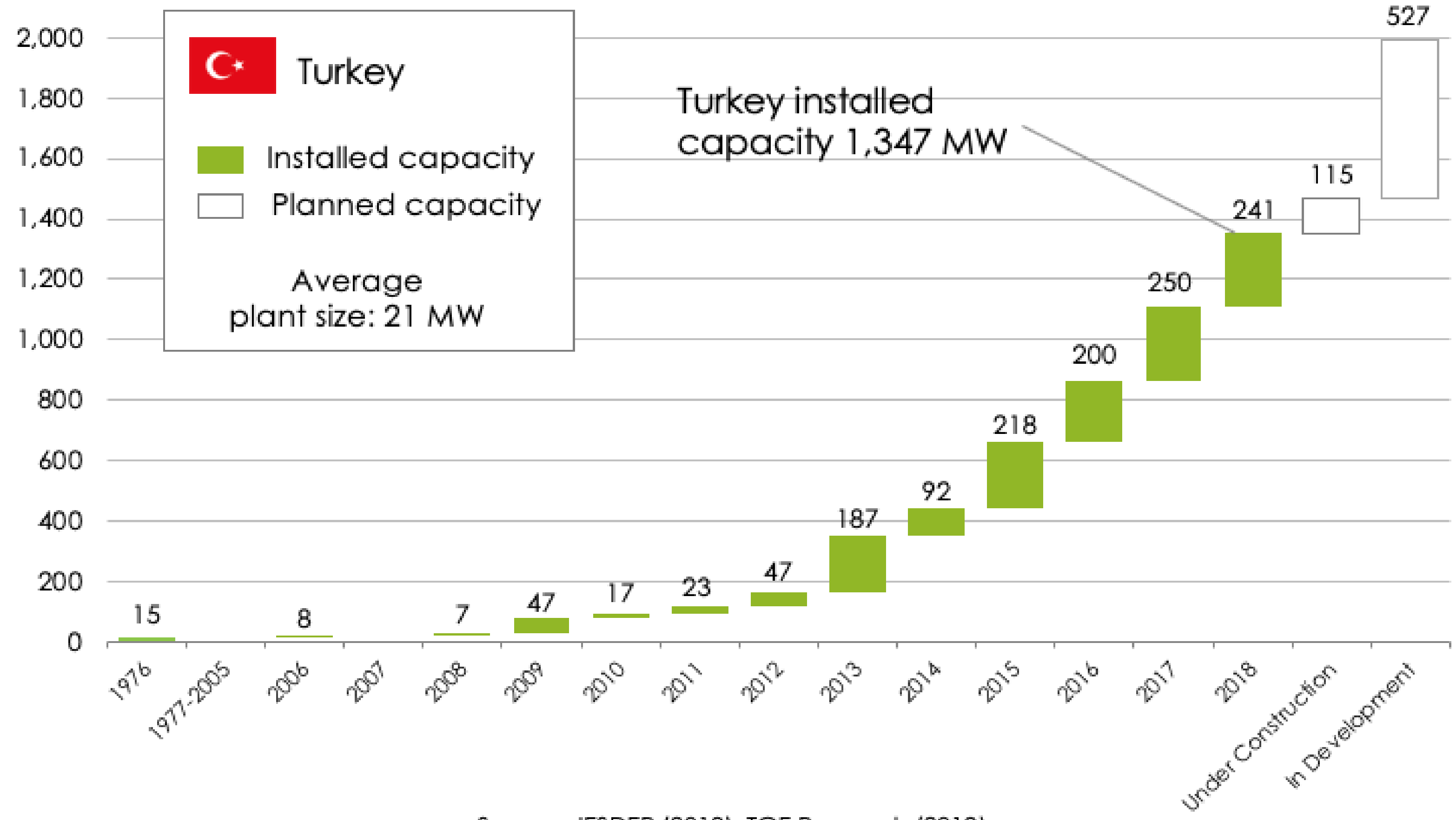
GEOTHERMAL SOURCES AND APPLICATION MAP



GEOTHERMAL DEVELOPMENT - TURKEY

POWER GENERATION CAPACITY ADDITIONS BY YEAR (MW) + PLANNED

STATUS – January 2019



Source: JESDER (2019), TGE Research (2019)

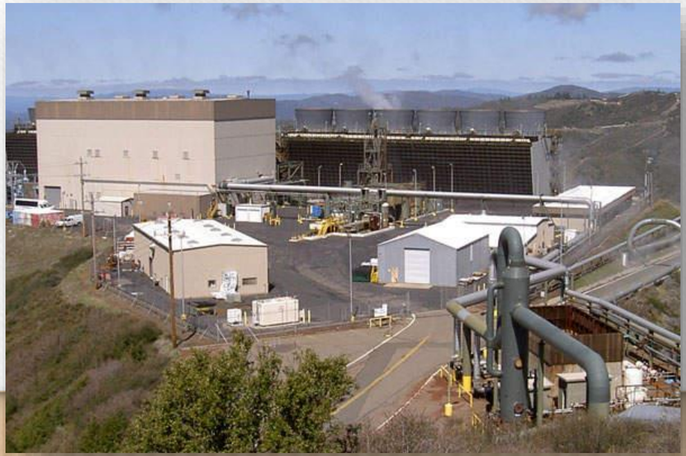
Largest Geothermal Power Plants In The World

1. The Geysers Complex, CA, USA (1,520 MW capacity)

The Geysers Complex, located in the Mayacamas Mountains, 72 miles north of San Francisco, California, USA, is the largest geothermal field in the world.

2. Lardarello Complex, Italy (770 MW capacity)

The Lardarello Geothermal Complex is found in central Italy, near Tuscany. Lardarello is comprised by 34 plants with a total capacity of 770 MW of electricity generation.



3. Cerro Prieto Station, Mexico (720 MW capacity)

The Cerro Prieto Geothermal Power Station is a large complex comprised by several geothermal power stations located near Mexicali, in the Baja California region of Mexico.

4. Makiling-Banahaw Complex, Phillipines (460 MW capacity)

The Makiling-Banahaw complex in the Philippines was set up by the Chevron Geothermal Philippine Holdings, Inc. Commercial production started at this plant in 1979, when the two 55 MW units started operating.

5. CalEnergy-Salton Sea, CA, USA (340 MW capacity)

The CalEnergy Salton Sea Geothermal, with a generating capacity of 340 MW electricity, is the fifth largest of its kind in the world. The facility covers a large area that includes 10 geothermal energy generating plants in Calipatria, near the Salton Sea in California, USA.

Nature of Geothermal Energy

Geothermal energy has its origin in the molten core of the earth, where temperatures are about 4000^0C (7200^0F) nature's own boiler. This thermal energy is produced primarily by the decay of radioactive materials within the interior, leading some people to refer to geothermal energy as a form of "fossil nuclear energy." The interior of the earth is thought to consist of a central molten core surrounded by a region of semifluid material called the mantle.

This is covered by the crust, which has a thickness between 30 and 90 km.

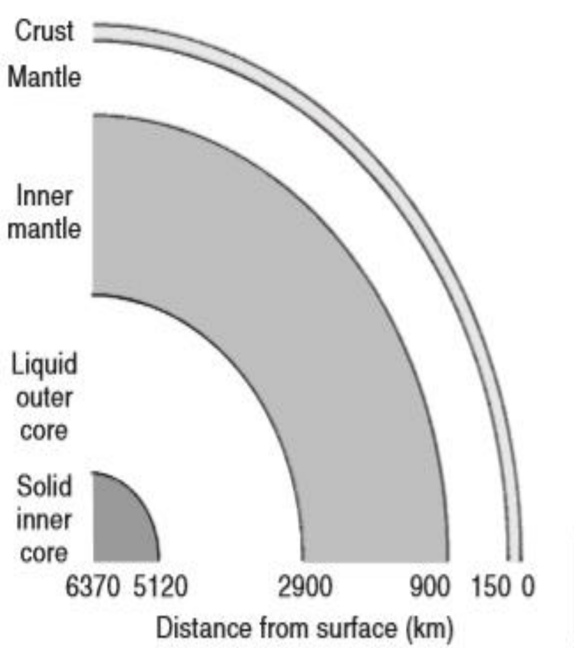


Figure 18.1 Cross section of the earth, showing the layered structure.

Heat passes from the crust by natural cooling and friction from the core, radioactive decay of elements such as uranium and thorium, and chemical reactions. The time constants of such processes over the whole Earth are so long that it is not possible to know whether the Earth's temperature is presently increasing or decreasing. The radioactive elements are concentrated in the crust by fractional recrystallisation from molten material, and are particularly pronounced in granite.

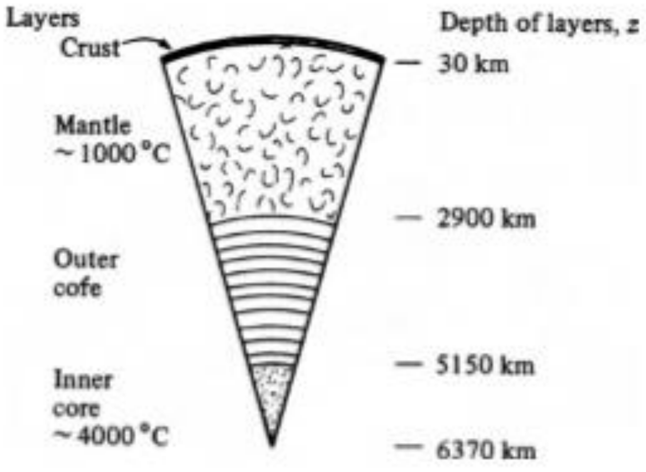
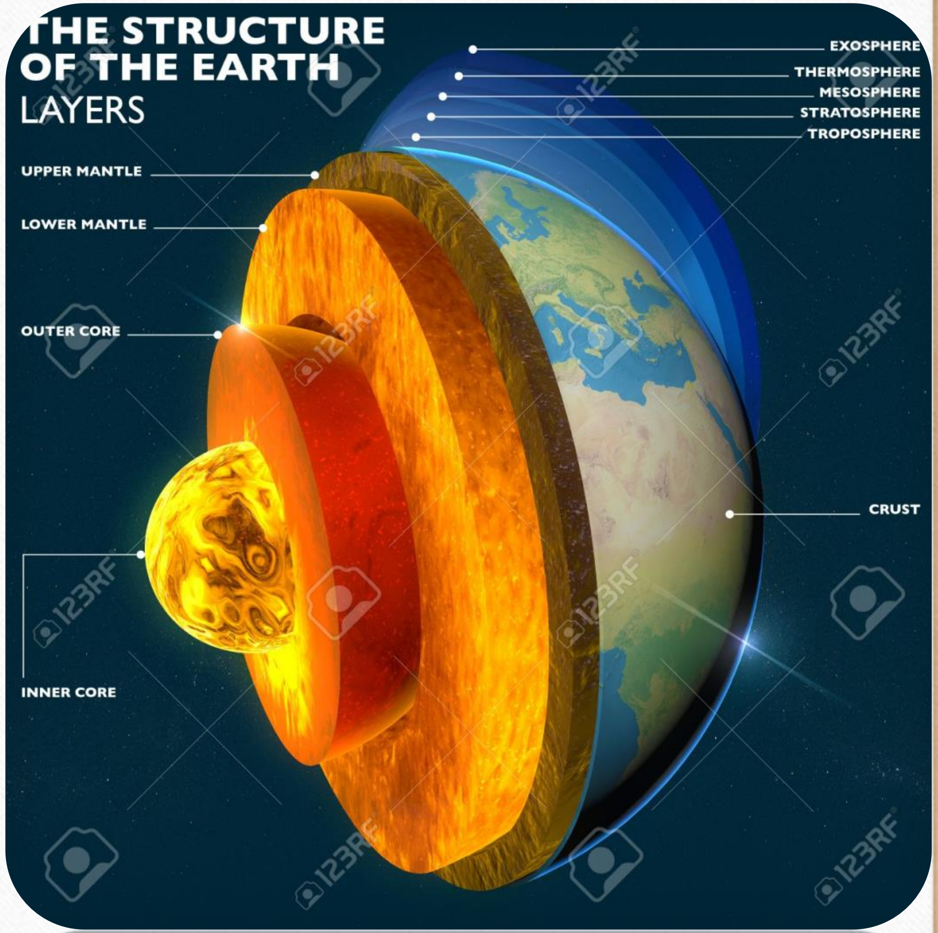


Figure 15.1 Section through the Earth, showing average lower depths of named layers. The crust has significant variation in composition and thickness over a local scale of several kilometres.

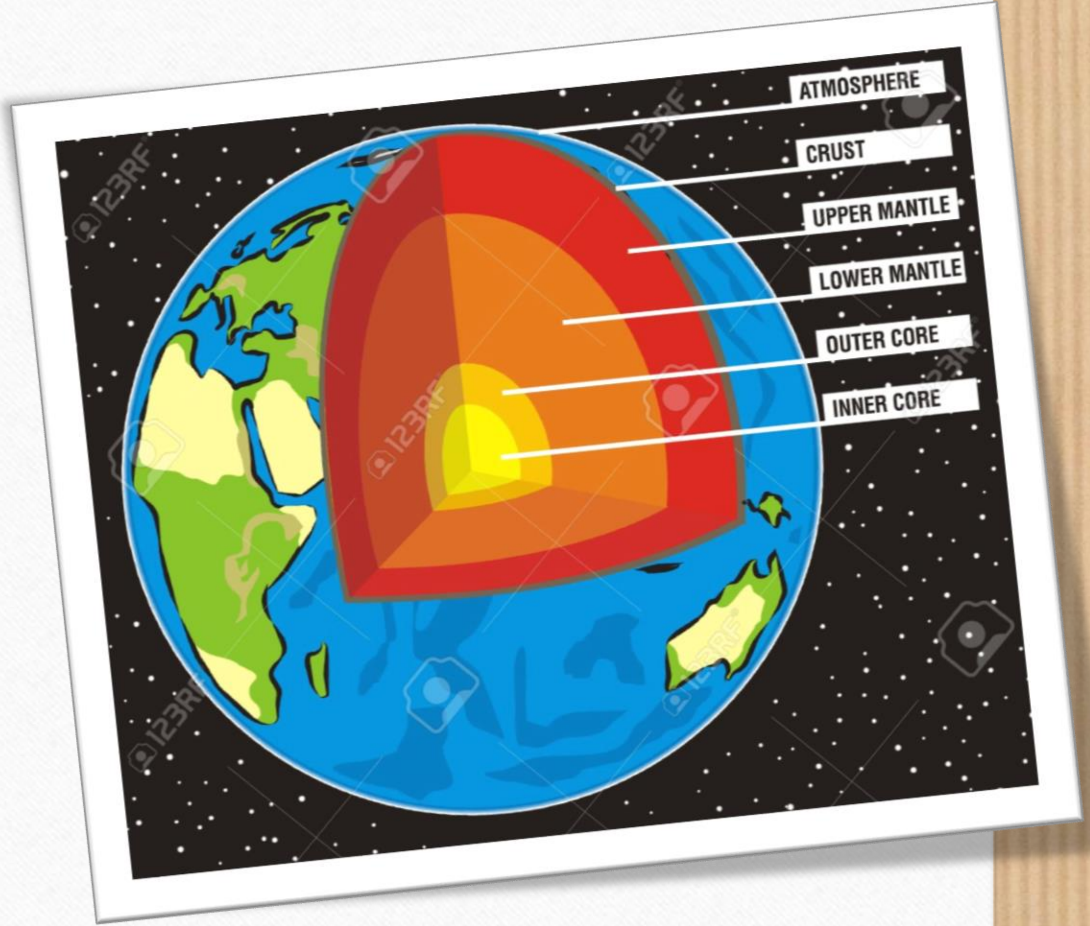
Geophysics Of The Earth's Interior

Core: *The core extends out to half the Earth's radius (6400 km) and is made mostly of iron (80%) and nickel (20%), whose inner half (by radius) is solid and whose outer half is liquid. This iron and nickel core is the source of the Earth's magnetic field, which is believed to be created by electric currents in the core.*



• ***Mantle****: The mantle makes up most of the rest (83%) of the Earth's volume and made mostly of rocky material, whose inner part is semirigid and whose outer and cooler part is plastic and, therefore, can flow (think lava).*

• ***Crust****: The crust is the outermost thin layer (1% of the Earth's volume), whose average thickness is 15 km. The crustal thickness ranges from a high of 90 km under continental mountains to as little as 5 km under some parts of the oceans. On a scale where the Earth is the size of a soccer ball, the crust would be a mere 0.25 mm thick.*

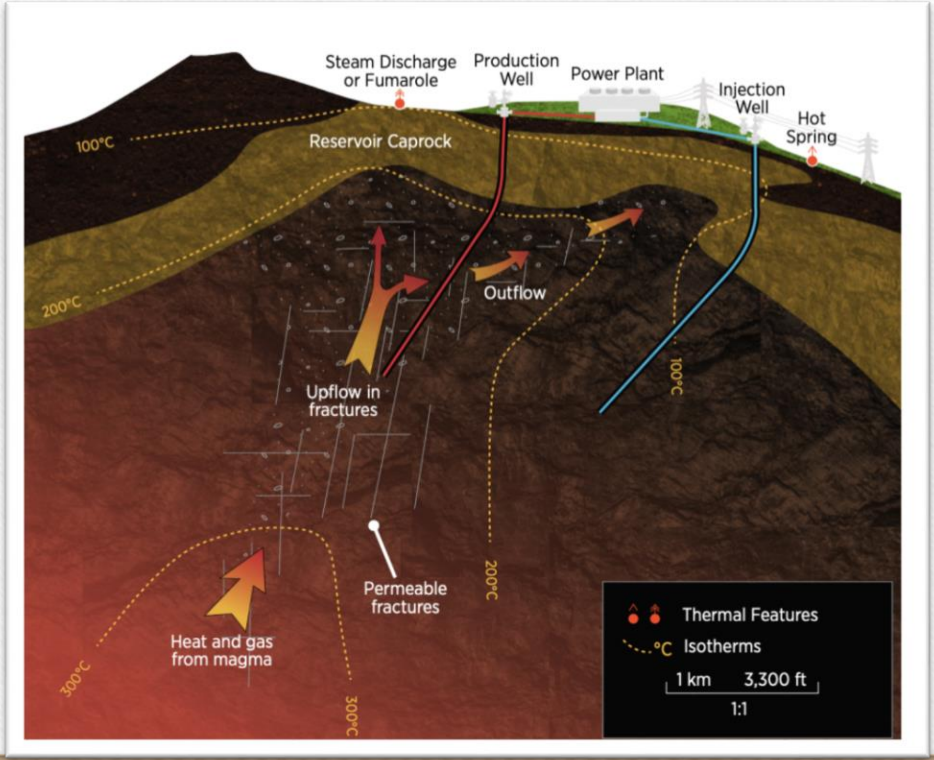


There are three classes of geothermal region:

1. **Hyperthermal**: Temperature gradient ≥80 $C^0\ km^{-1}$. These regions are usually on tectonic plate boundaries. The first such region to be tapped for electricity generation was at Larderello in Tuscany, Italy in 1904. Nearly all geothermal power stations are in such areas.

2. **Semithermal**: Temperature gradient ~40–80$C^0\ km^{-1}$. Such regions are associated generally with anomalies away from plate boundaries. Heat extraction is from harnessing natural aquifers or fracturing dry rock. A well-known example is the geothermal district heating system for houses in Paris.

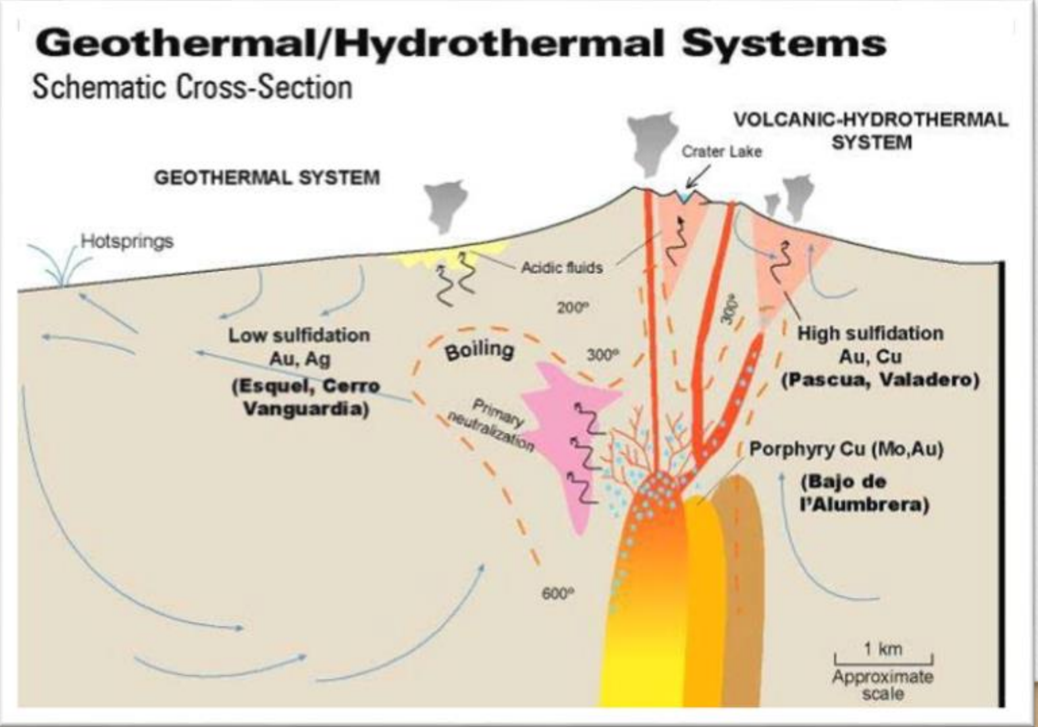
Normal: Temperature gradient <40C^0 km^{-1}. These remaining regions are associated with average geothermal conductive heat flow at ~0.06Wm^{-2}. It is unlikely that these areas can ever supply geothermal heat at prices competitive top resent (finite) or future (renewable) energy supplies.



Hydrothermal Systems

Hydrothermal systems, the thermal energy of the magma is stored in water or steam that fills the pores and fractures in the rock.

Although the wet steam systems are 10 to 20 times more abundant, the dry steam systems have been used more often in the generation of electricity because of their convenience.



Wet Steam Systems

When water is trapped in an underground reservoir and is heated by the surrounding rocks, it is under high pressures and can reach temperatures as high as 370^0 C(700^0F) without boiling. If this hot water is released to the surface, it will “flash” into steam as the external pressure falls below that necessary to keep it a liquid.

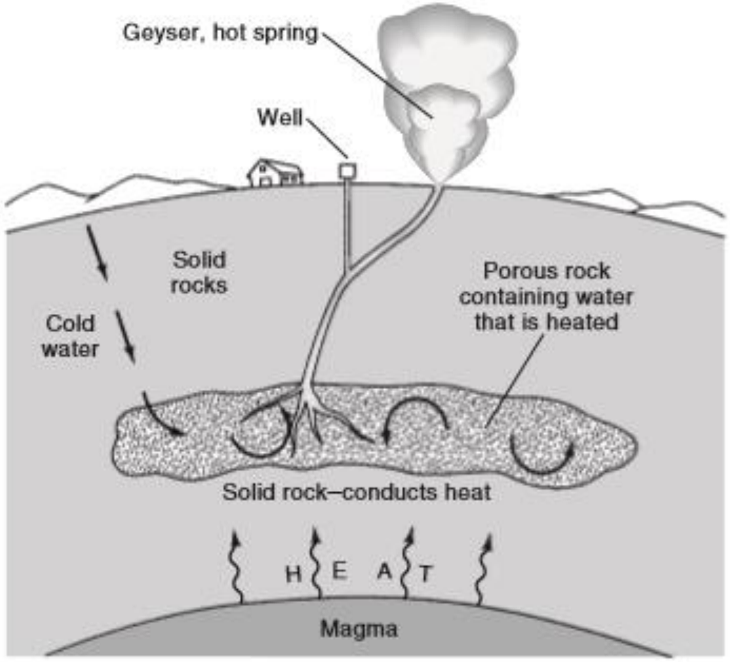
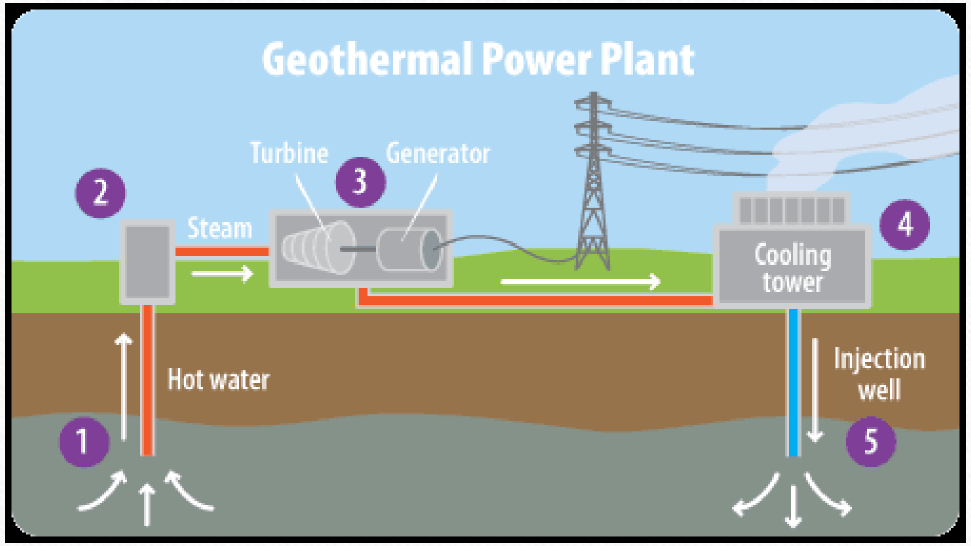


Figure 18.4 Model of a high-temperature hot water geothermal system. The water within the porous rock is heated by conduction from the magma. The hot water escapes through fissures to the surface, boiling near the top. A well to tap the steam within the fissure is also shown.

GEOTHERMAL ELECTRICITY POWER PLANTS

- Geothermal power plants use steam to produce electricity. The steam comes from reservoirs of hot water found a few miles or more below the earth's surface.

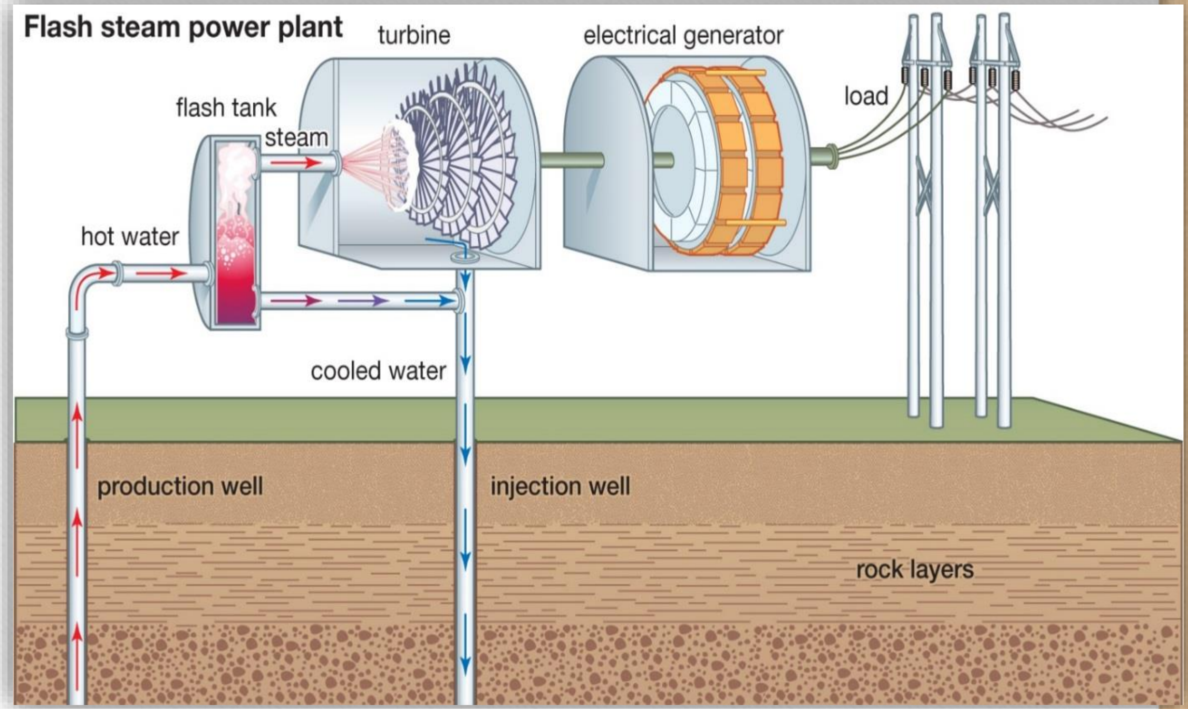
- There are three main types of geothermal power plants: **dry steam**, **flash**, and **binary cycle**, with the flash type being most common.



Flash Steam Plants:

In the flash type of power plant, high-pressure water comes up the production well and vaporizes (flashes) when its pressure is reduced to produce a flow of steam that drives a turbine, which then generates electricity.

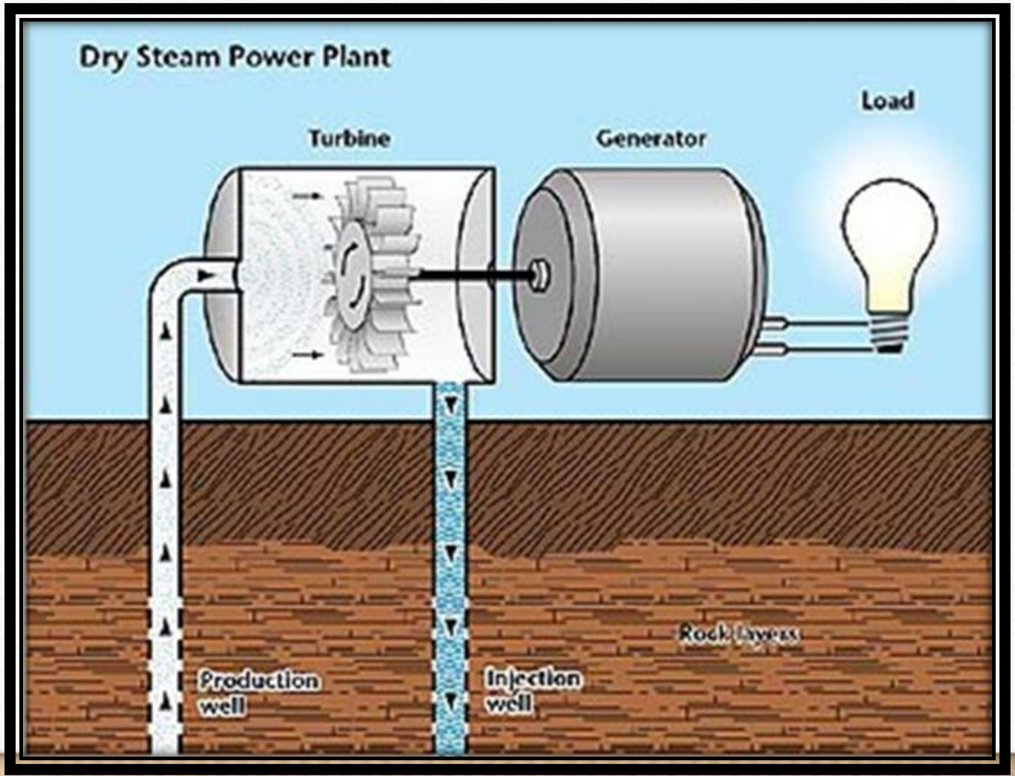
These types are the most common due to the lack of naturally occurring high-quality steam. In this method, water must be over 180°C, and under its own pressure it flows upwards through the well



Dry Steam Plants:

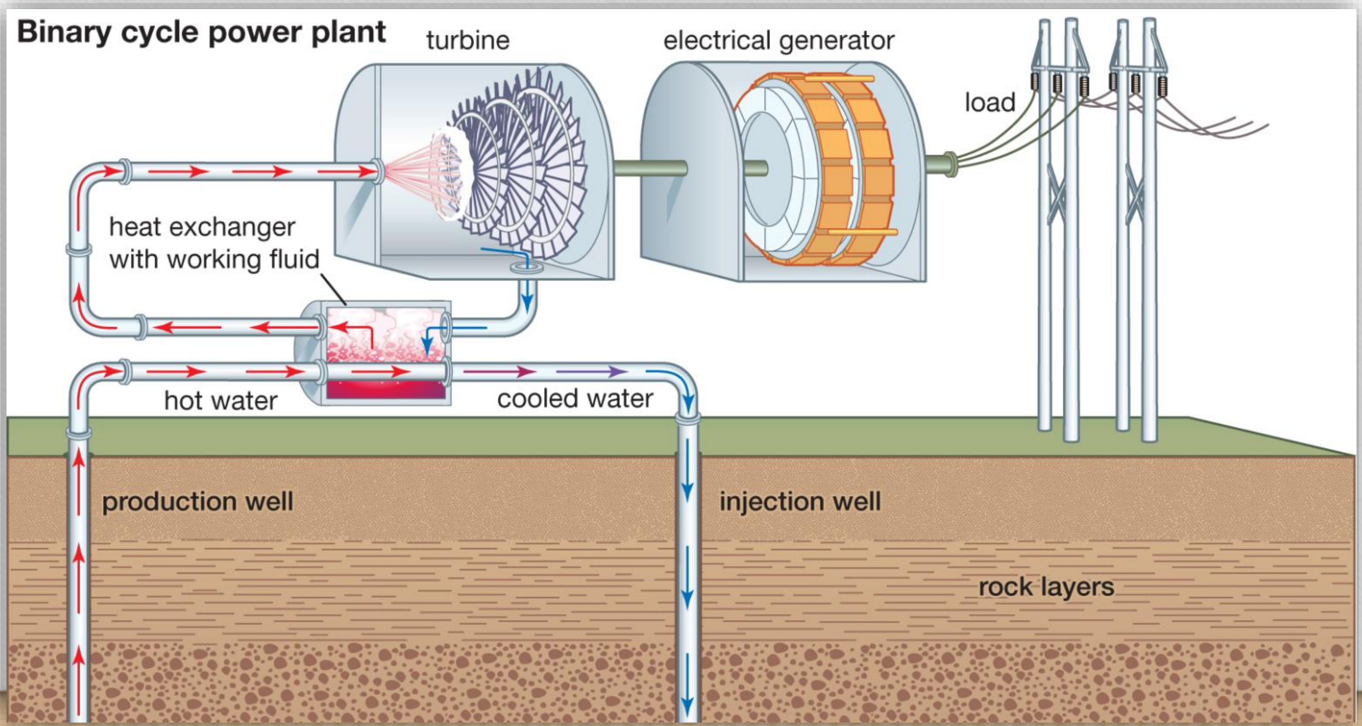
The dry steam type (not depicted) is similar to the flash type, but without the first step, since the dry steam directly coming up from the production well directly drives the turbine. This type of plant is rare because it is generally used in very high-gradient locations where steam spontaneously rises out of the production well.

Dry steam power plants at The Geysers in California.



Binary Cycle Plants:

Binary cycle power plants involve one additional step in the process. For these plants, high-temperature fluid coming up from a production well passes through a heat exchanger in which the secondary loop contains a low-boiling point liquid such as butane or pentane, which can vaporize at a lower temperature than water. This added step allows such plants to generate electricity at much lower temperatures than the other types.



The Carnot efficiency:

The maximum efficiency of a heat engine operating between a hot temperature T_H and a cold temperature T_C is given by the Carnot efficiency.

$$e_c = (1 - \frac{T_c}{T_H}) \text{ x } \% \, 100$$

The Highest Heat Temperature : T_H

The Lowest Temperature: T_c

Welcome to one of CalEnergy's geothermal power plants.

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