

Co-funded by the
European Programme
of the European Union

Geothermal Energy

Co-funded by the
European Programme
of the European Union

Introduction to the lecture

- Lecture of Geothermal energy has 3 parts.
- Part 1 focuses on the fundamental concept of geothermal energy, history of geothermal energy, present global status of geothermal utilization, advantages, origin, nature of geothermal energy and global geothermal sites.
- Part 2 provides an overview of mechanism for geothermal power plant.
- Part 3 discusses on the utilization of geothermal resources and its environmental impacts.

2

Co-funded by the
European Programme
of the European Union

Aim and Learning outcomes

- The aim is to introduce students to the concept, utilization, mechanism and environmental impacts of geothermal energy.
- On completion of lecture “Geothermal energy” students will be able to:
 - Identify the fundamental concept, physical characteristics and processes in geothermal systems.
 - Differentiate between types of geothermal resources and their location.

3

Co-funded by the
European Programme
of the European Union

Aim and Learning outcomes

- On completion of lecture “Geothermal energy” students will be able to:
 - Know the mechanism of geothermal power plant and its types.
 - Distinguish between the different types of geothermal technologies and appropriate uses of them.
 - Identify environmental impacts and benefits of geothermal energy exploitation.

4

Co-funded by the
European Programme
of the European Union

Talk outline

- Part-I
- Introduction – Geothermal Energy
 - Geothermal History
 - Present status of geothermal utilization
 - Origin and nature of Geothermal Energy

5

Co-funded by the
European Programme
of the European Union

Talk outline

- Part-II
- How does a Geothermal power plant work?
 - Geothermal power plant

6

Talk outline

Part-III

- Utilization of geothermal resources
- Environmental impacts



What is Geothermal Energy

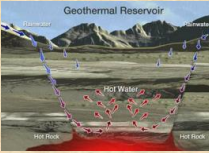


Heat is a form of energy and geothermal energy is literally the heat contained within the Earth

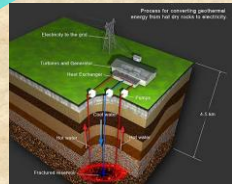
Geothermal energy in modern technologies is derived from natural heat

In effect, the earth serves as a boiler in which geothermal fluids can achieve the high temperatures and pressures

Typically, these fluids occur in reservoirs at depths of up to 3000 meters and can be recovered by drilling wells



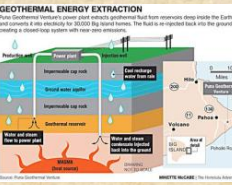
Cont'd.....



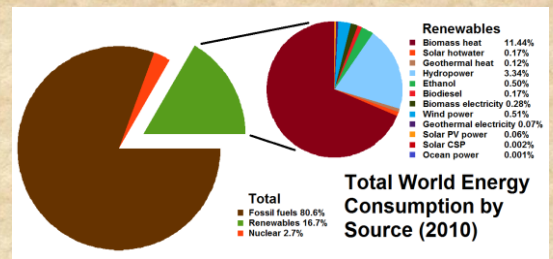
The amount of thermal energy is very large but useful energy is very limited to certain sites

These resources are not infinite and can be depleted at a particular site under intensive exploration

However, geothermal energy can be developed in a favorable locations



Global Overview of Geothermal Energy



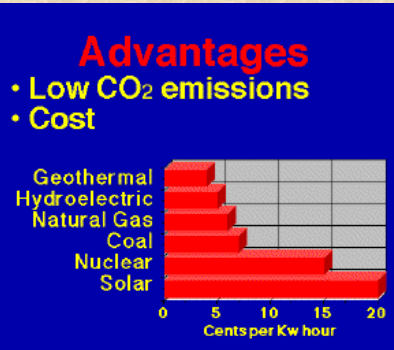
Geothermal in Context - USA

Energy Source	2000	2001	2002	2003	2004 ^e
Total	98.961	96.464	97.952	98.714	100.278
Fossil Fuels	84.965	83.176	84.070	84.889	86.186
Coal	22.580	21.952	21.980	22.713	22.918
Coal Coke Net Imports	0.065	0.029	0.061	0.051	0.138
Natural Gas ^a	23.916	22.861	23.628	23.069	23.000
Petroleum ^b	38.404	38.333	38.401	39.047	40.130
Electricity Net Imports	0.115	0.075	0.078	0.022	0.039
Nuclear Electric Power	7.862	8.033	8.143	7.959	8.232
Renewable Energy	6.158	5.328	5.835	6.082	6.117
Conventional Hydroelectric	2.811	2.242	2.689	2.825	2.725
Geothermal Energy	0.317	0.311	0.328	0.339	0.340
Biomass ^d	2.907	2.640	2.648	2.740	2.845
Solar Energy	0.066	0.065	0.064	0.064	0.063
Wind Energy	0.057	0.070	0.105	0.115	0.143

U.S. Energy Consumption by Energy Source, 2000-2004 (Quadrillion Btu)

<http://www.eia.doe.gov/cneaf/solar/renewables/page/geothermal/geothermal.htm>

Advantages of Geothermal



<http://www.earthsci.org/minerals/energy/geother/geother.htm>

History of Geothermal Energy



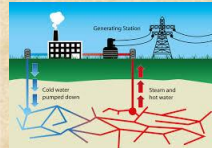
- In the **early part of the nineteenth century** the geothermal fluids were already being **exploited** for their energy content
- A **chemical industry was set up** in Italy, in the zone now known as Larderello, to extract **boric acid** from the hot
- The boric acid was **obtained** by **evaporating the hot fluids** in iron boilers, using the **wood** from nearby forests as fuel
- In 1827 Francesco Larderel, founder of this industry, **developed a system** for **utilizing the heat** of the boric fluids in the evaporation process,



History of Geothermal Energy



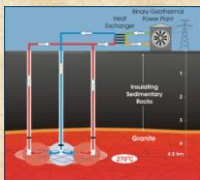
- **Exploitation** of the natural steam for its **mechanical energy** began at the same time
- Between **1910 and 1940** the low pressure steam was brought into use to **heat the industrial and residential buildings**
- The **first attempt at generating electricity** from geothermal steam was made at Larderello in **1904**
- The **success** of this experiment indicated the industrial value of geothermal energy



Present status of Geothermal Energy



- After the **Second World War** many countries were **attracted** by geothermal energy
- Considering it to be **economically competitive** with other forms of energy
- In some cases, it was the only energy source available locally
- The countries that utilize geothermal energy to generate electric power worldwide in 1995 (a world total of 6833 MWe) and in the year 2000 (7974 MWe)



Cont'd.....



Country	1995 (MW _e)	2000 (MW _e)	1995-2000 increase in MW _e	% increase
Argentina	0.67	0	-0.67	n/a
Australia	0.17	0.17	0	0
China	28.78	29.17	0.39	1.35
Costa Rica	55	142.5	87.5	159
El Salvador	105	161	56	53.3
Ethiopia	0	852	852	infinite
France	4.2	4.2	0	0
Guatemala	0	33.4	33.4	infinite
Iceland	50	170	120	240
Indonesia	309.75	589.5	279.75	90.3
Italy	6317	785	-1532	-24.2
Japan	413,705	546.9	133,195	32.2
Kenya	45	45	0	0
Mexico	753	755	2	0.3
New Zealand	286	437	151	52.8
Nicaragua	70	70	0	0
Philippines	1,227	1,909	682	55.8
Portugal	5	16	11	220
Russia	11	23	12	109
Thailand	0.3	0.3	0	0
Turkey	20.4	20.4	0	0
USA	2,816.7	2,228	-588	n/a
Total	6,833	7,974	1,141	17



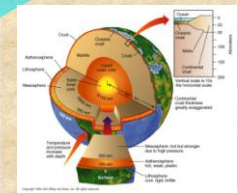
Cont'd.....



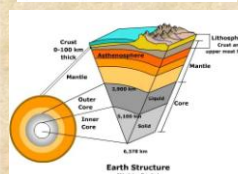
- There are now **58 countries** reporting direct uses, compared to 28 in 1995 and 24 in 1985
- The most common **non-electric use** worldwide
- Heat pumps (34.80%), followed by bathing (26.20%), space heating (21.62%), greenhouses (8.22%), aquaculture (3.93%), and industrial processes (3.13%).

Country	Power (MW _e)	Energy (TJ/yr)
Algeria	100	1586
Argentina	25.7	449
Armenia	1	15
Australia	34.4	351
Austria	254.3	1669
Bulgaria	3.9	107
Bulgaria	107.2	1637
Canada	377.6	1023
Caribbean Islands	0.1	1
Chile	0.4	7
China	2282	37908
Colombia	13.3	266
Costa Rica	113.9	555
Czech Republic	12.5	128
Denmark	74	75
Egypt	1	15
Finland	80.5	464
France	326	4895
Georgia	250	6307
Germany	397	1568
Greece	57.1	285
Guatemala	4.2	117
Honduras	0.7	17
Hungary	472.7	4087
Iceland	1469	20170
India	80	2517
Indonesia	2.3	43
Israel	63.3	1713
Italy	325.8	3774
Japan	1167	26693
Jordan	153.3	1540
Korea	1.3	10
Korea	35.8	753
Lithuania	21	599
Macedonia	81.2	510
Mexico	164.2	3919
Nepal	1.1	22
Netherlands	10.8	37
New Zealand	307.9	7081
Norway	6	32
Peru	2.4	49
Philippines	1	25
Poland	68.5	275

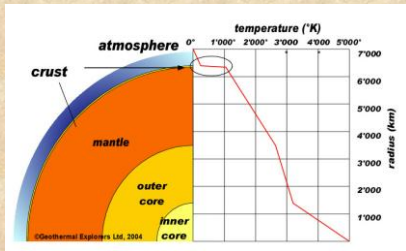
Origin and nature of Geothermal Energy



- Geothermal energy has its **origin** in the **molten core** of the earth
- Temperature is about **4000 C**
- The thermal energy is produced by the **decay of radioactive materials** within the interior
- Interior of the earth **consists** of central molten core **surround** by **semi-fluid materials** called molten mantle
- **Covered** by crust --- 30-90 km

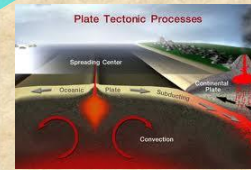


Origin and nature of Geothermal Energy



- The temperature of the earth increases
- Proportionally with depth
- 30 degree cen. per km
- Base of the crust is 1000 degree cen. Increases to the center

Origin and nature of Geothermal Energy

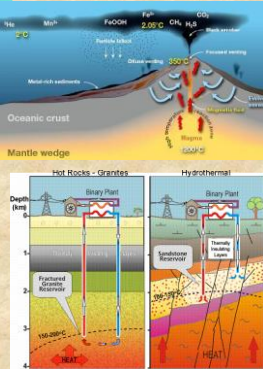


- In some regions hot molten materials comes through faults and cracks
- These regions are mainly at the junctions of tectonic plates



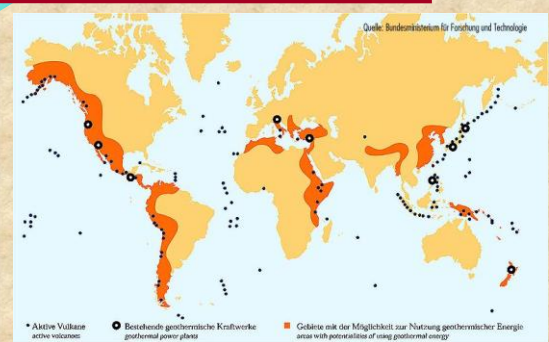
- That make up the earth's crust
- Most of the world's geothermal sites today located near the edge of the Pacific plate

Origin and nature of Geothermal Energy



- Commonly known as hydrothermal systems
- i.e. thermal energy of the magma is stored in water or steam that fills the pores and fractures in the rock
- Can be classified as wet steam and dry steam

Global Geothermal Sites



<http://www.deutsches-museum.de/ausstell/daue/umwelt/rlng/geothe.jpg>

Geothermal Site Schematic

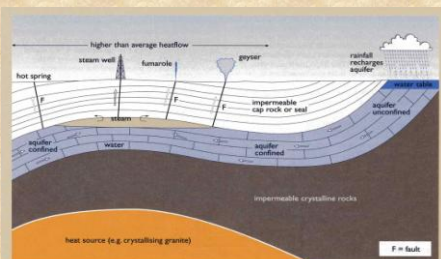


Figure 9.5 Simplified schematic cross-section to show the three essential characteristics of a geothermal site: an aquifer (e.g. fractured limestone with solution cavities), an impermeable cap rock to seal the aquifer (e.g. clays or shales), and a heat source (e.g. crystallizing granite). Steam and hot water escape naturally through faults (F) in the cap rock, forming fumaroles (steam only), geysers (hot water and steam), or hot springs (hot water only). The aquifer is unconfined where it is open to the surface in the recharge area, where rainfall infiltrates to keep the aquifer full, as indicated by the water table just below the surface. The aquifer is confined where it is beneath the cap rock; impermeable crystalline rocks prevent downward loss of water from the aquifer.

Boyle, Renewable Energy, 2nd edition, 2004

Geysers



Clepsydra Geyser in Yellowstone

<http://en.wikipedia.org/wiki/Geyser>

Hot Springs



Hot spring in Steamboat Springs area

<http://www.eia.doe.gov/cneaf/solar/renewables/page/geothermal/geothermal.html>

Fumaroles

Clay Diablo Fumarole (CA)



White Island Fumarole
New Zealand



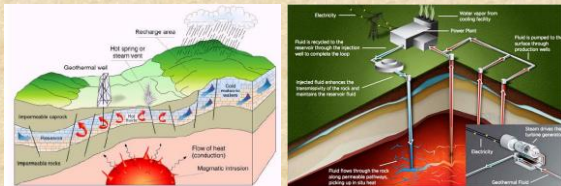
http://vo.w.r.usgs.gov/cf_mah.htm

http://volcano.und.edu/vv/docs/images/img_w_his_island_fumarole.html

Geothermal System



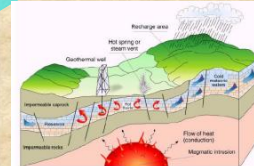
Co-funded by the
European Programme
of the European Union



Geothermal System



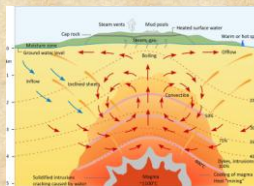
Co-funded by the
European Programme
of the European Union



➤ It can be described schematically as **'convecting water in the upper crust of the Earth'**

➤ A geothermal system is made up of **three main elements**: a **heat source**, a **reservoir** and a **fluid**

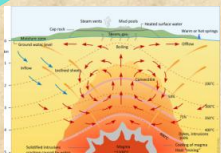
➤ Which is the **carrier** that transfers the heat



Geothermal System



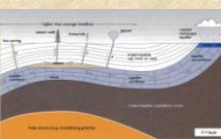
Co-funded by the
European Programme
of the European Union



➤ The reservoir is a volume of hot permeable rocks from which the **circulating fluids extract heat**

➤ The reservoir is generally overlain by a cover of **impermeable rocks** and connected to a surficial **recharge area**

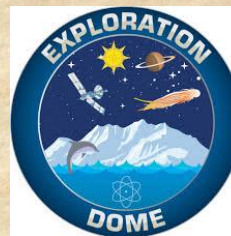
➤ Through which the **meteoric waters can replace or partly replace** the fluids that escape from the reservoir through springs or are extracted by boreholes.



Exploration of Geothermal Energy-Methods



Co-funded by the
European Programme
of the European Union



➤ Geological and Hydrological studies

➤ Geochemical surveys

➤ Geophysical surveys

➤ Drilling of exploratory wells

Utilization of Geothermal Resources



- Geothermal energy can be used for
- Electricity production
- commercial
- industrial, and
- residential direct heating purposes



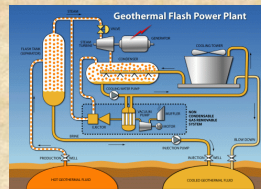
How does a power plant work



There are four commercial types of geothermal power plants: a. flash power plants, b. dry steam power plants, c. binary power plants, and d. flash/binary combined power plants.

➤ a. Flash Power Plant:

Geothermally heated water under pressure is separated in a surface vessel (called a steam separator) into steam and hot water (called "brine" in the accompanying image).

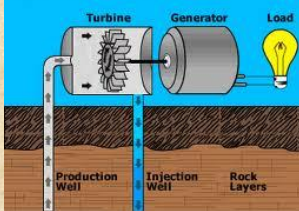


➤ The steam is delivered to the turbine, and the turbine powers a generator. The liquid is injected back into the reservoir.

How does a power plant work



Dry Steam Power Plant



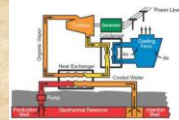
b. Dry Steam Power Plant:

- Steam is produced directly from the geothermal reservoir to run the turbines that power the generator, and
- No separation is necessary because wells only produce steam

How does a power plant work



Binary Cycle Power Plant Example



c. Binary Power Plant:

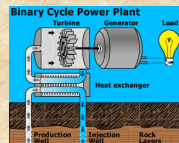
➤ Economic production of electricity from geothermal resources lower than 150°C (302°F)

➤ Typically use an Organic Rankine Cycle system.

➤ The geothermal water heats isobutane, pentafluoropropane, which boils at a lower temperature than water.

➤ The two liquids are kept completely separate through the use of a heat exchanger, which transfers the heat energy from the geothermal water to the working fluid

➤ The secondary fluid expands into gaseous vapor.

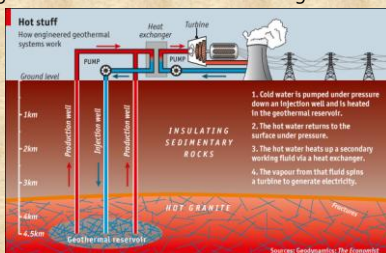


How does a power plant work



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.



Environmental Impacts



The first perceptible effect on the environment is that of **drilling**

The next stage, **installation** of the pipelines that will transport the geothermal fluids, and construction of the *utilization plants*, will also affect animal and plant life and the surface morphology

Environmental problems also arise **during plant operation**. Geothermal fluids (steam or hot water) usually contain *gases* such as carbon dioxide (CO₂), hydrogen sulphide (H₂S), ammonia (NH₃), methane (CH₄), and trace amounts of other gases, as well as *dissolved chemicals* whose concentrations usually increase with temperature. For example, sodium chloride (NaCl), boron (B), arsenic (As) and mercury (Hg) are a source of pollution if discharged into the environment.

Environmental Impacts



Air pollution may become a problem when **generating electricity in conventional power-plants**. Hydrogen sulphide is one of the main pollutants. Carbon dioxide is also present in the fluids used in the geothermal power plants,

Discharge of waste waters is also a potential source of chemical pollution. Spent geothermal fluids with high concentrations of chemicals such as boron, fluoride or arsenic should be treated, re-injected into the reservoir, or both

Extraction of large quantities of fluids from geothermal reservoirs may give rise to *subsidence* phenomena, i.e. a gradual sinking of the land surface. This is an irreversible phenomenon, but by no means catastrophic, as it is a slow process distributed over vast areas.

The withdrawal and/or re-injection of geothermal fluids may trigger or increase the frequency of *seismic events* in certain areas.