Energy Resources

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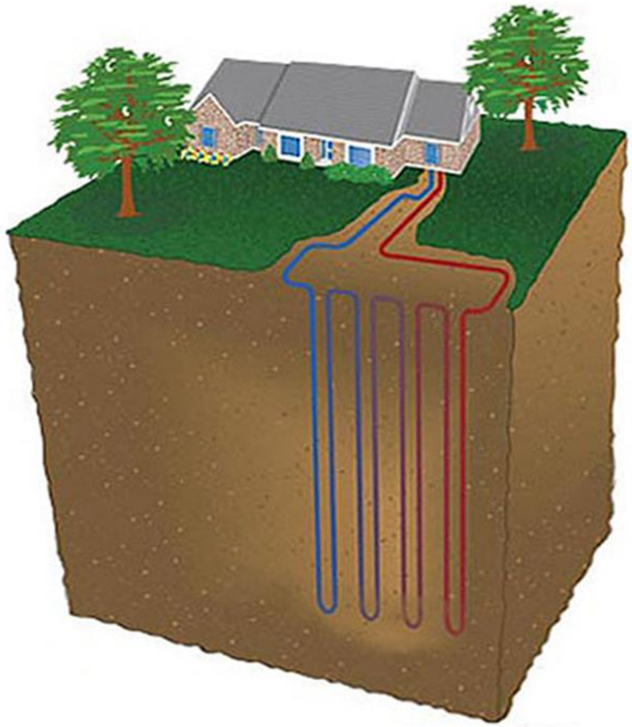
Geothermal Energy

Definition: *geothermal energy is the thermal energy stored in the earth's crust. 'Geothermal energy' is often used nowadays, however, to indicate that part of the Earth's heat that can, or could, be recovered and exploited by man.*

Energy Efficient and Cost Effective

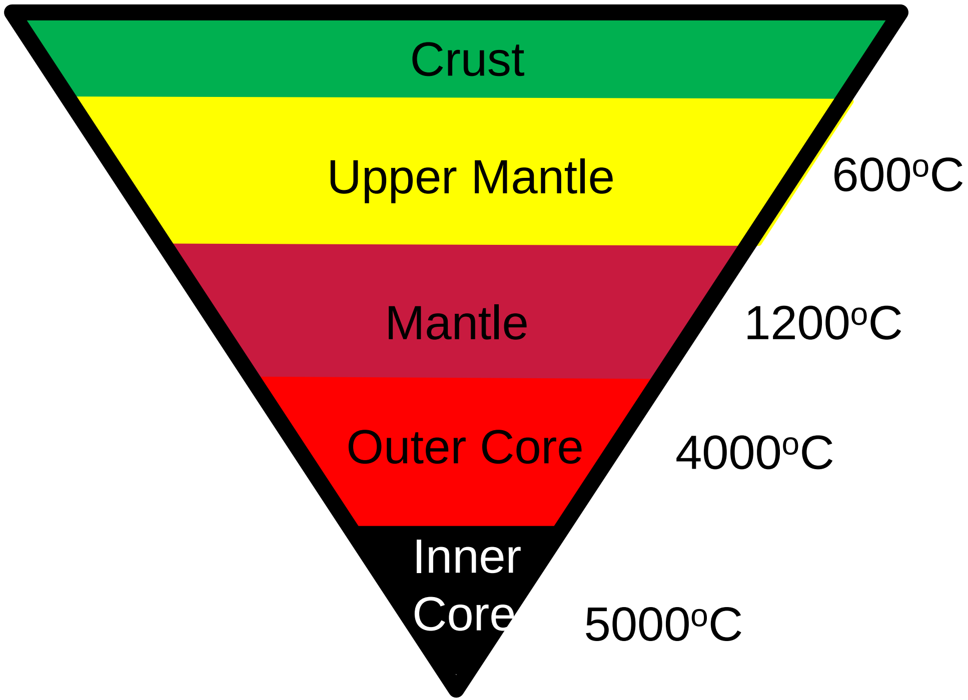
According to the EPA, geothermal are the most energy efficient, cost effective, and environmentally clean systems for temperature control.



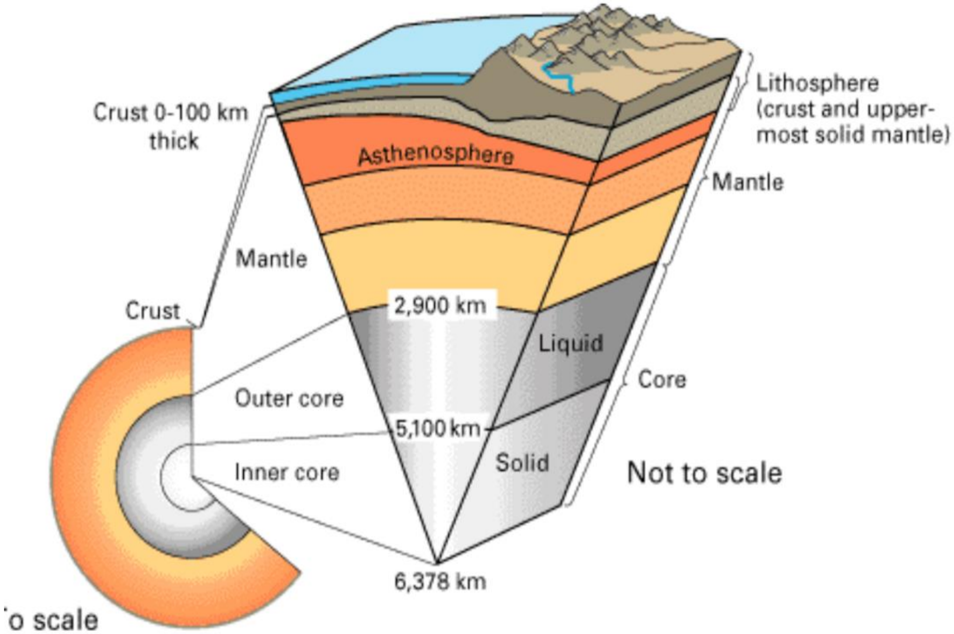
Origin of Geothermal Power

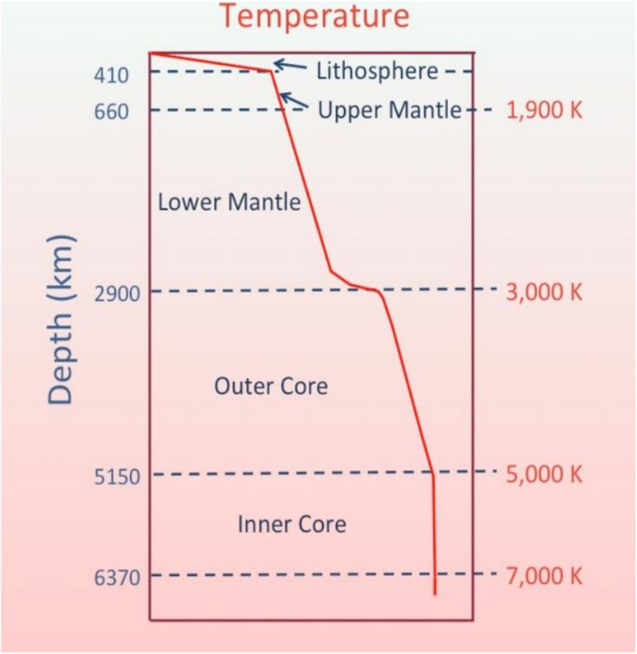
- Geothermal energy originates from the Earth's core, which is estimated to have a temperature of about 5,000 °C. This nearly constant temperature is possible because of continuous radioactive decay, compression, and because the core is very well insulated.

Structure of Earth



Structure of Earth

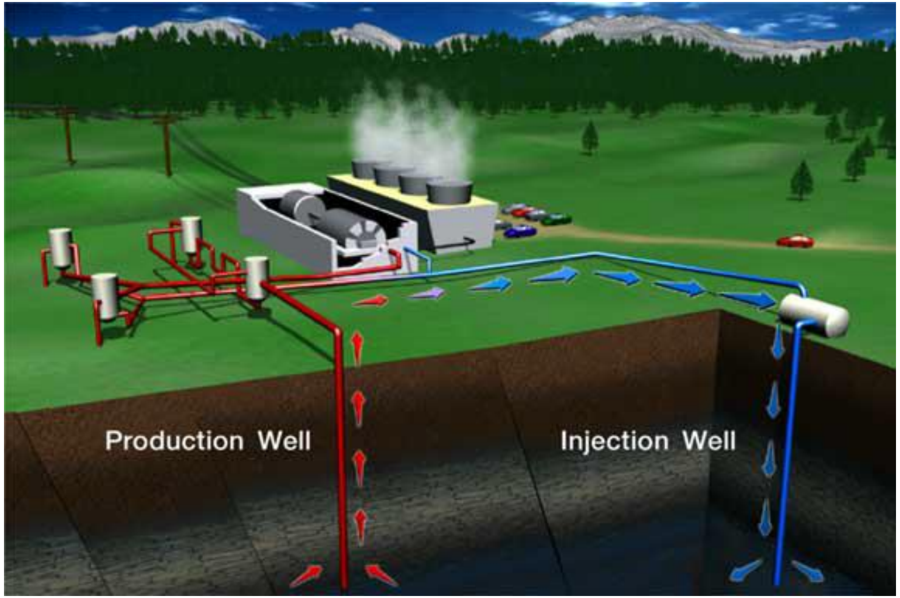




Geothermal Energy

Heat passes by

1. Natural cooling and friction from the core
2. Radioactive decay of elements such as uranium (U^{235} and U^{238}), thorium (Th^{232}) and potassium (K^{40}). This represents the major source of heat
3. Chemical reactions



Geothermal gradient

Temperatures within the Earth's interior increase with depth

The normal temperature gradient within the Earth's interior is about 2.5~3°C/100 meters

Examples of geothermal gradient in different areas

10 – 20 Kkm-1 in ***shield crust***

30 - 60 Kkm-1 in ***platform areas***

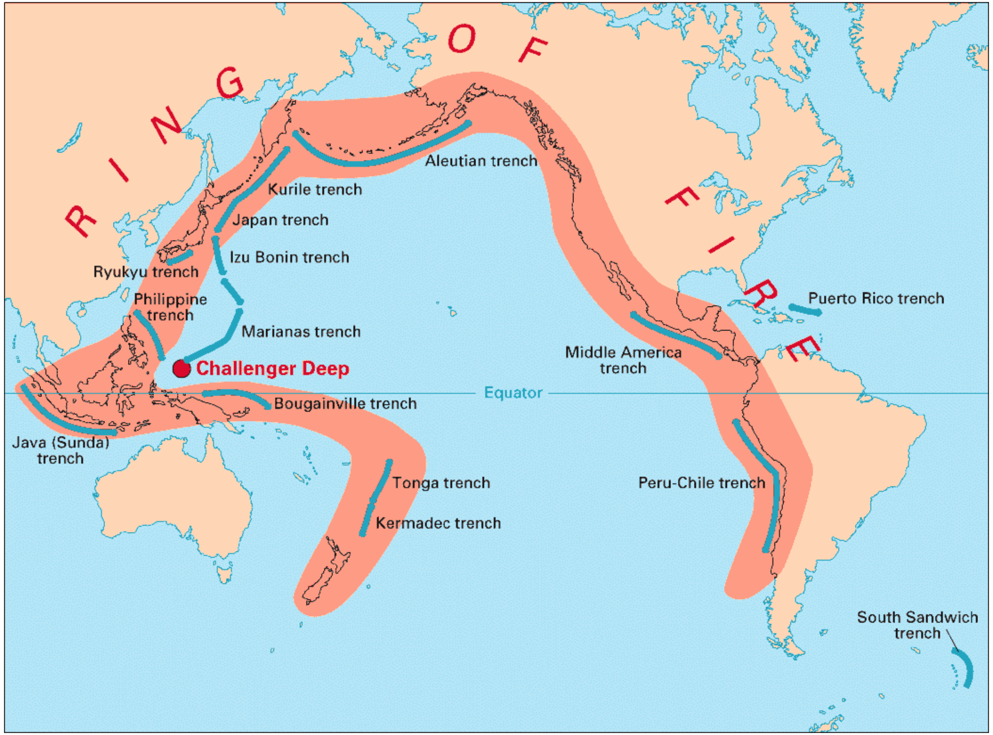
>100 Kkm-1 in ***volcanic areas***

Where is Geothermal Energy Found?

Found along major plate boundaries where earthquakes and volcanoes are concentrated

- Geysers
- Hot springs
- Fumaroles
- Geothermal reservoirs

Geothermal Areas-The Ring of Fire

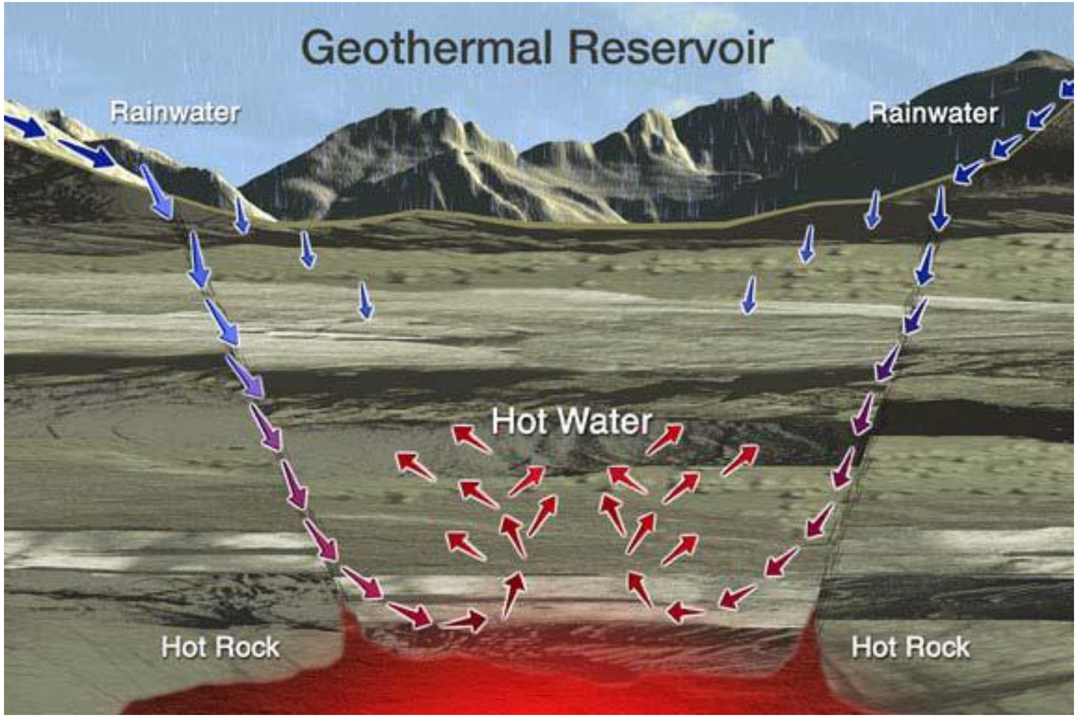


Geothermal Reservoirs

Geothermal resources have four important characteristics:

1. A permeable aquifer that contains fluids that is accessible by drilling.
2. An impermeable (nonporous) cap of rock that prevents geothermal fluids from escaping. Impermeable basement rock that prevents downward loss of the fluid.
3. A heat source need for exploitable geothermal resources.
4. Permeability and porosity of the reservoir rocks.

Geothermal Reservoir



Classification of geothermal resources

By type

Low-enthalpy

Intermediate-enthalpy

High-enthalpy

By source

Hot Dry Rock

Liquid-Dominated Hydrothermal

Vapor-Dominated

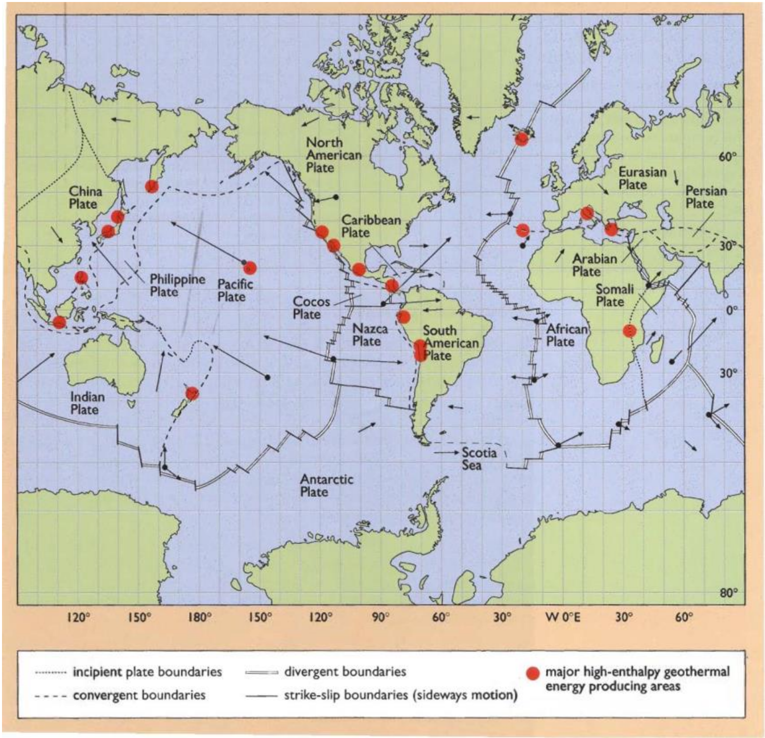
Geo-pressurized fluids

Magma

Classification of geothermal resources (By type)

	Muffler and Cataldi	Hoechstein (1990)	Benderitter and Cormy (1990)	Nicholson (1993)
High Enthalpy	> 150	> 225	> 200	> 150
Medium Enthalpy	90 – 150	125 – 225	100 – 200	-
Low Enthalpy	< 90	< 125	< 100	< 100

Classification of geothermal resources (By type)



Classification of geothermal resources (By source)

Liquid-dominated resources

These are the most commons of the hydrothermal resources. In a liquid dominated resource the water is the continuous phase. It can be present as vapour but also as bubbles. Depending on the temperature and pressure there is more

or less vapour.

The pressure in these resources is fairly slow typically 0.5-1 MPa and the temperature is around 180 °C.

Classification of geothermal resources (By source)

<u>Vapour-dominated systems</u>

liquid water and vapour normally co-exist in the reservoir, with vapour as the continuous, pressure controlling phase.

Geothermal systems of this type, the best known of which are Larderello in Italy and The Geysers in California, are somewhat rare, and are high-temperature systems.

They normally produce dry-to-superheated steam.

Classification of geothermal resources (By source)

Geopressurized fluids

Geopressurised geothermal systems are hot water reservoir (aquifer) mixed with dissolved gases like methane that can reach 200°C and are under huge pressures (50-100 MPa). The depth ranges from 3-6 km, and are normally located in sedimentary formations.

The resource can be exploited for their thermal energy, calorific energy of gases and hydraulic energy due to high pressure. The price of electricity generated by geopressurised fluids is not competitive when compared with conventional resources.

Classification of geothermal resources (By source)

<u>Hot Dry Rock (HDR)</u>

Projects were experimented for the first time at Los Alamos, New Mexico, USA, in 1970, both the fluid and the reservoir are artificial.

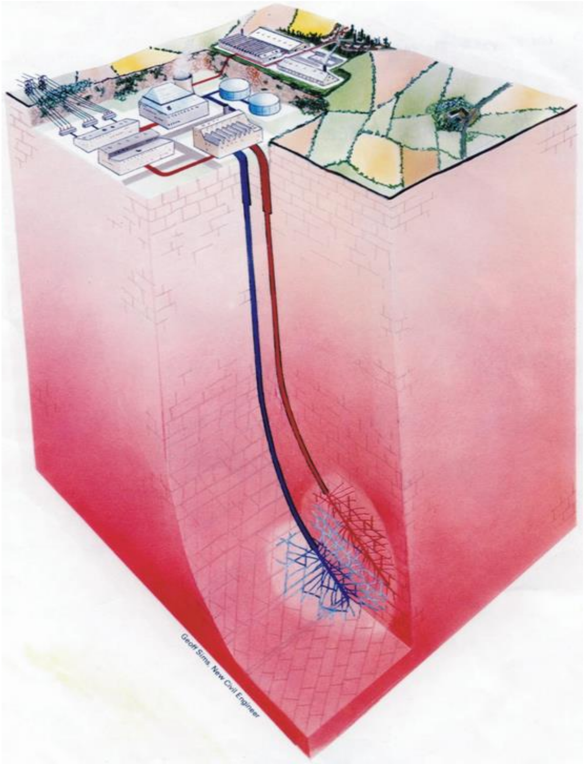
High-pressure water is pumped through a specially drilled well into a deep body of hot, compact rock, causing its *hydraulic fracturing. The water* permeates these artificial fractures, extracting heat from the surrounding rock, which acts as a natural reservoir. This 'reservoir' is later penetrated by a second well, which is used to extract the heated

water.

The system therefore consists of (i) the borehole used for hydraulic fracturing, through which cold water is injected into (ii) the artificial reservoir, and (iii) the borehole used to extract the hot water.

Schematic of a commercial-scale Hot Dry Rock

Developments in France, Australia, Japan, the U.S. and Switzerland. The biggest HDR project is currently installed in Australia.



Classification of geothermal resources (By source)

Magma

These resources offer extremely high temperature geothermal opportunities, but existing technology does not allow recovery of heat.

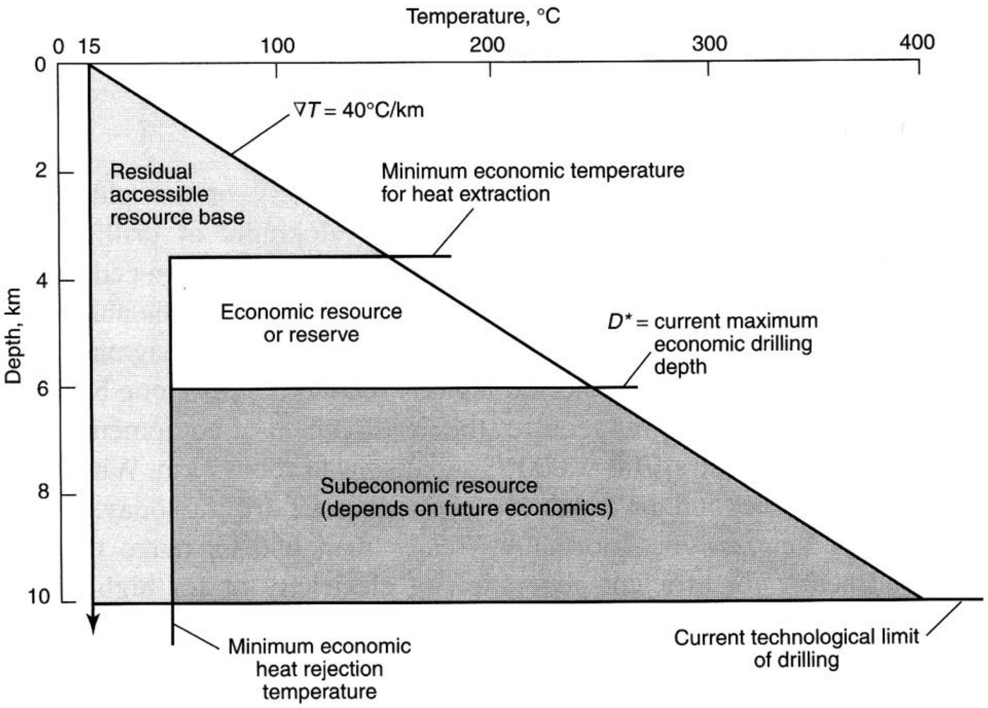
However, in the future there might be available them the technology required to exploit these resources, and thus might become an important resource of energy

Resource base estimates

Resource type	Total Q [10^{21} J]
Hydrothermal	130
Geopressurized	540
Magma	5’000
Hot Dry Rock	105’000
Moderate to high grade ($\nabla T >$ 40°C/km)	26’500
Low grade ($\nabla T >$ 40°C/km)	78’500

*For depths of 10 km

Depth vs Temperature



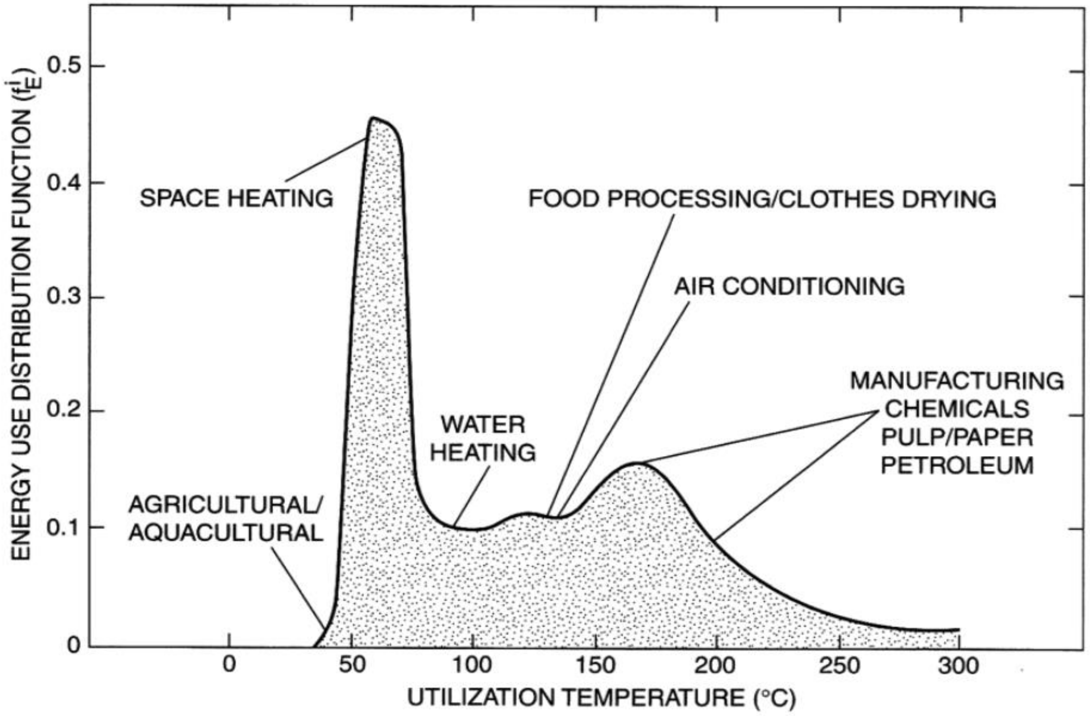
Utilization of geothermal energy

DIRECT USE
- **Cooling** 0 – 20 °C
- **Heating**
  - Low temperature 25-35 °C
  - High temperature 70 –110 °C
- **Hot water production**

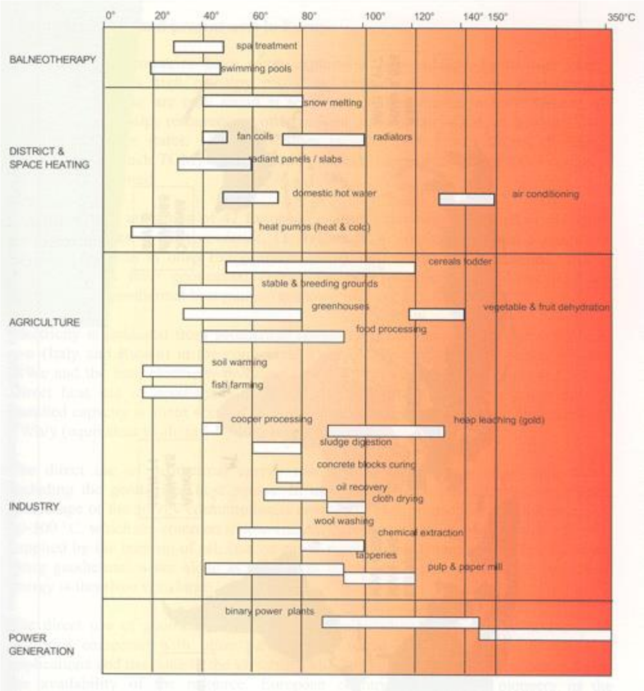
COMBINED USE
- Cooling – heating (seasonal storage systems)
- Heating – electricity

INDIRECT USE
- **Electricity**
  - low temperature 70-100 °C
  - High temperature 100 – 200 °C

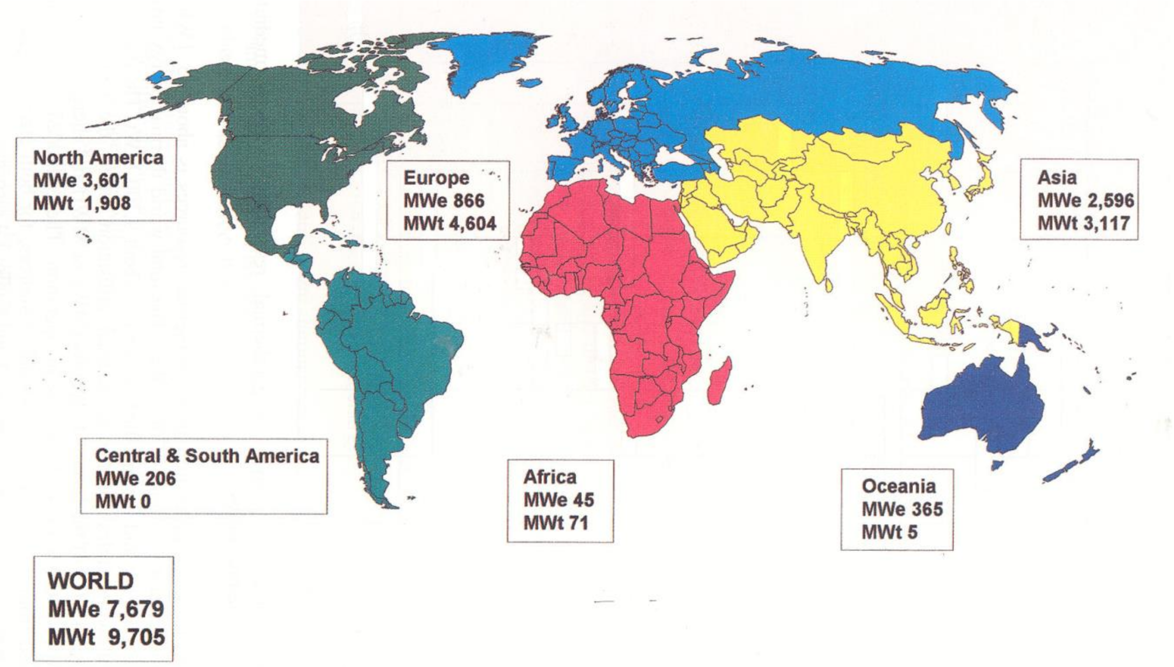
Utilization of geothermal energy



Utilization of geothermal energy



Geothermal utilization in the World



Advantages of geothermal energy

- Its reserves are enormous-virtually infinite on historical scale.
- It is less polluting than combustible fuels or nuclear energy.
- It is an indigenous resource that can be developed and make a country less reliant politically and economically and can alleviate the national balance of payments.
- As a rule of thumb; one kilowatt of geothermal base load can substitute about 2 tons of oil annually.
- Less polluting than combustible fuels or nuclear energy.
- Not subject to the variations of the weather.
- Not labour intensive.

Disadvantages

- Can’t provide our current energy needs
- Can only be used in certain geologically active areas
- Water contains minerals that can be corrosive and difficult to dispose of safely
- Harmful gases can escape from deep within the earth
- Piping system requires large areas of land
- Initial costs can be high
- Expensive exploration
- Brines are corrosive and poisonous
- Complicated reservoir management
- Sensitive to underground disturbances

Geothermal-sustainability

The earth ***radiogenic heat production*** and average ***heat flow*** are ***insufficient to sustain geothermal energy retrieval over very long time*** periods.

Geothermal energy uses the ***stored heat in the uppermost crustal regions (***5 km depth), accumulated over a very long period of heat diffusion and warming.

Geothermal energy retrieval results in long term slow cooling of the heat exchange region at reservoir depth.

Geothermal-sustainability

Depending on ***flow rate and re-injection temperature, a two hole exchange*** system with ca 1.5 km spacing is calculated to last ca 20 years.

After that period adjacent volumes can be explored. In the exhausted volume gradually ambient temperatures will be re-established.

Heat exchange volumes may gradually degrade by poor reservoir management, precipitation of minerals in the flow paths, compaction of exhausted volumes, …

Geothermal-Sustainability

There are some important ***exceptions to the stated situations:***

If heating requirements can be balanced with cooling requirements over the seasonal cycle

Increased sustainability can be achieved by low temperature drop, low temperature heating systems or energy cycles, and proper reservoir management.

Environmental sustainability requires closed systems for the heat exchange (re-injection of extracted ground water).

The best energy is the energy not used

Geothermal-Environmental Impacts

The most important issues regarding geothermal energy are:

- Land Used
- Disposal of Drilling Fluids
- Noise
- Ground subsidence
- Non-Condensable Gas Emissions and Air Pollution
- Induced Seismicity
- Effluent Disposal and Water Pollution

Geothermal-Environmental Impact

Key issues: Air pollution, water pollution, noise

Dissolved in natural water CO_2 , H_2S (oxidizes to SO_2 and finally H_2SO_4), N_2, R_n (from uranium containing rocks, radioactive decay products emit α-radiation), NH_3, B, Hg, HgS,3H (age indicator)

Contained in steam CO_2, H_2S, HCl, HF, NH_3, CH_4, H_2.

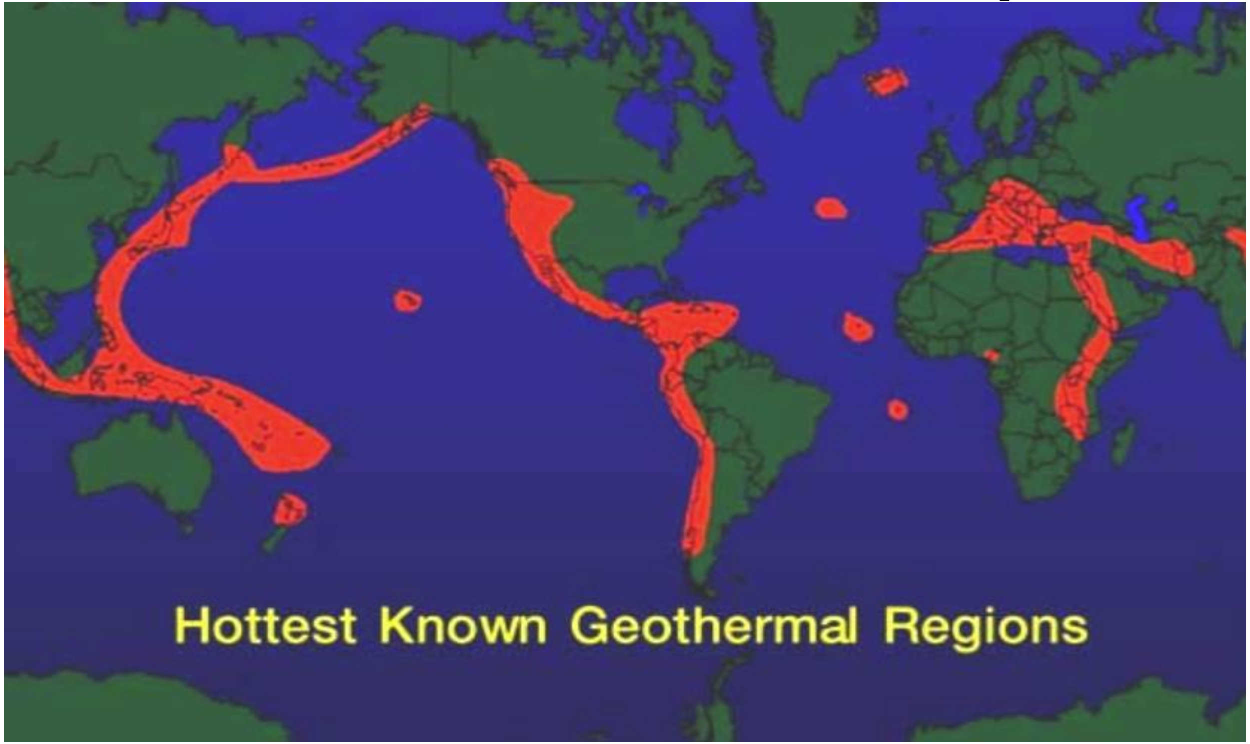
From added energy

When produced by combustion (of oil, gas, biomass…)

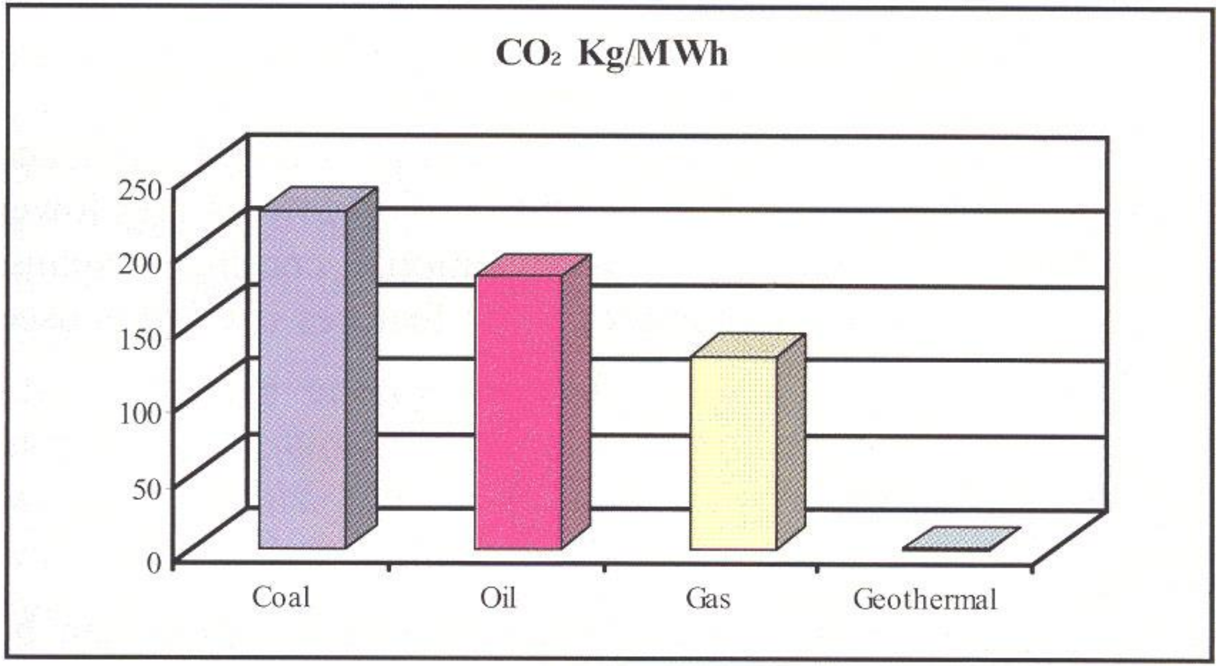
CH_4, H_2, CO_2

NO_x causes ozone formation in lower atmosphere

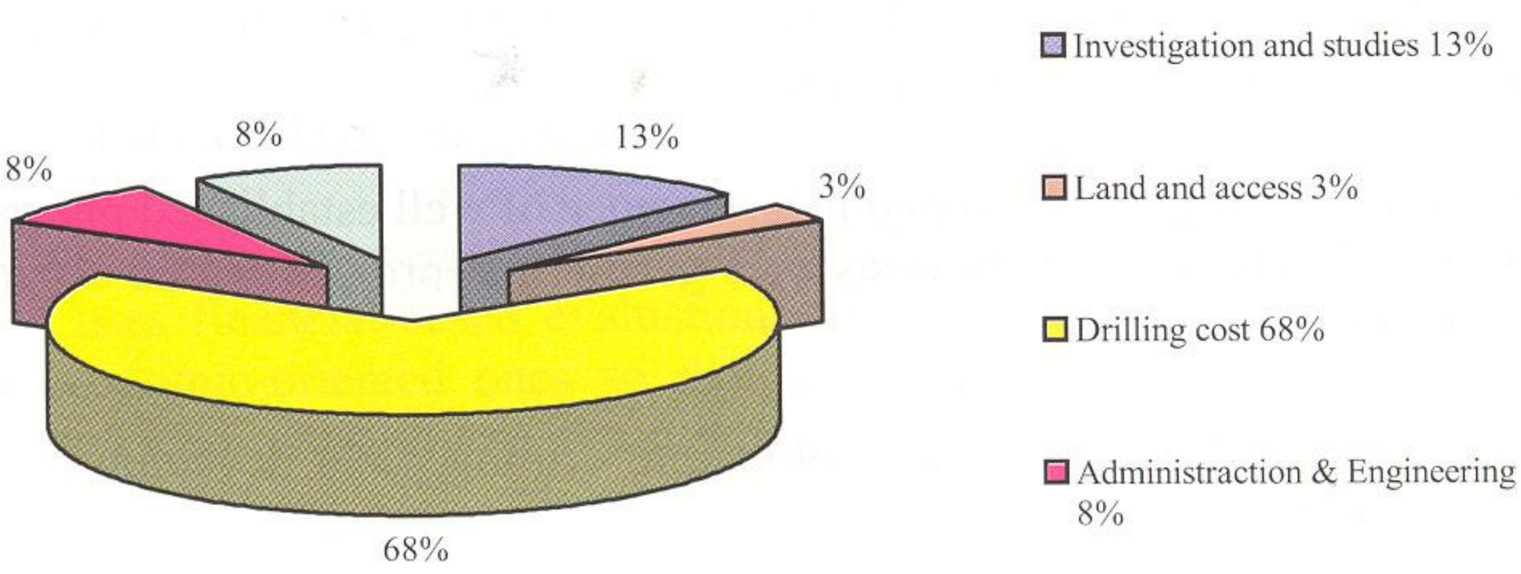
Geothermal-Environmental Impact



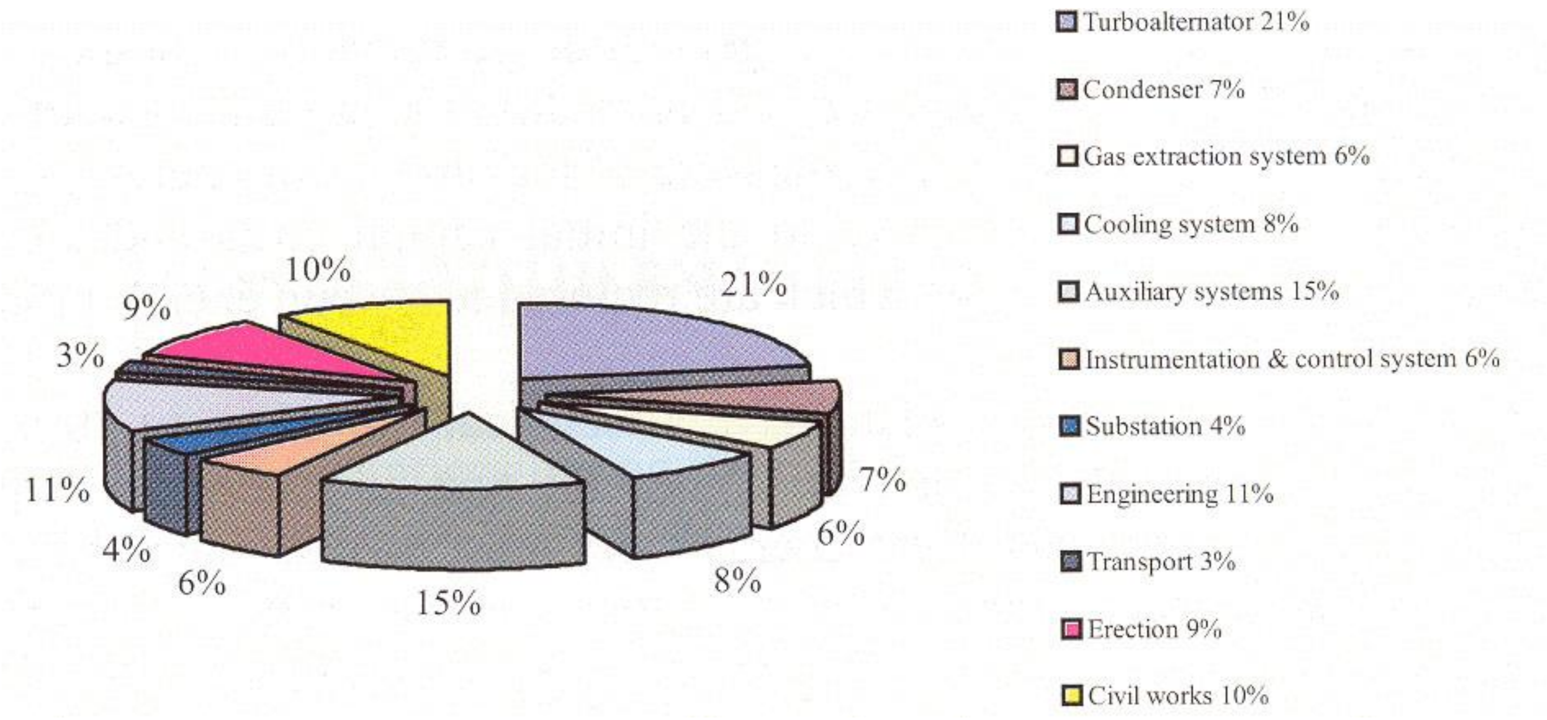
Geothermal-CO2 Production



Typical cost breakdown (Field cost)



Typical cost breakdown (Plant cost)



Geothermal-Applications

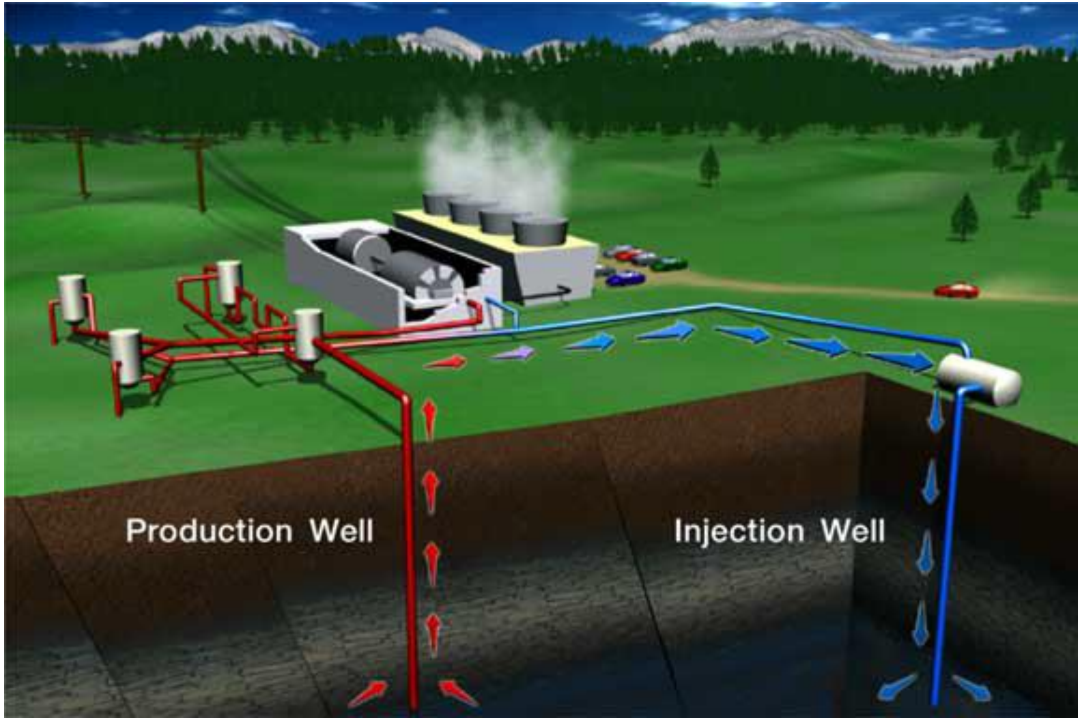
Electricity from geothermal energy had a modest start in 1904 at Larderello, in the Tuscany region of north-western Italy, with an experimental 10 kW generator.

Components of geothermal system

A geothermal system consists of three main elements:

- ➢a heat source,
- ➢a reservoir and a fluid - the carrier for transferring heat from the source to the power plant
- ➢power plant

Components of geothermal system



Geothermal Power Plants

Require high temperatures (300 F – 700 F) hydrothermal resources that may either come from dry steam wells or hot water wells

There are three types of geothermal power plants: dry steam plants, flash steam plants, and binary cycle power plants

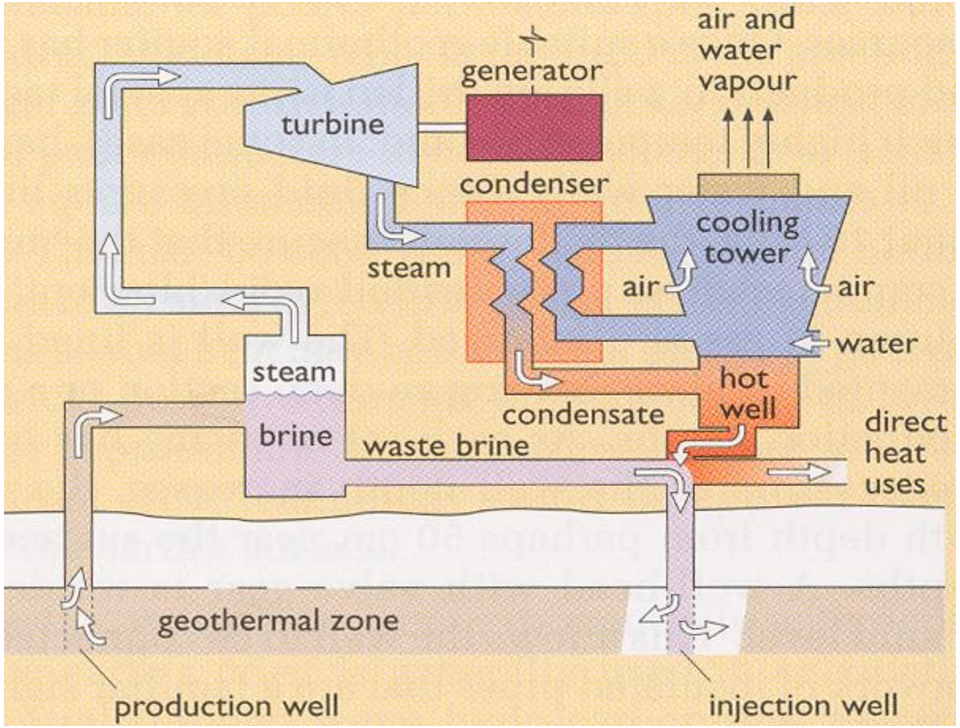
Single flash steam power plant

Mainstay of the geothermal power Industry. The geothermal fluid might be:

Steam (flashed within the well as pressure dropped during ascent) or

Hot water at high pressure

The unit power capacity ranges from 3 to 90 MW



Single flash steam power plant

Typical steam conditions: 155-165°C and 0.5-0.6 MPa

Design conditions: currently it is required about 8 kg steam per saleable kWh.

Waste brine (unflashed) can be up to 80% of the fluid produced

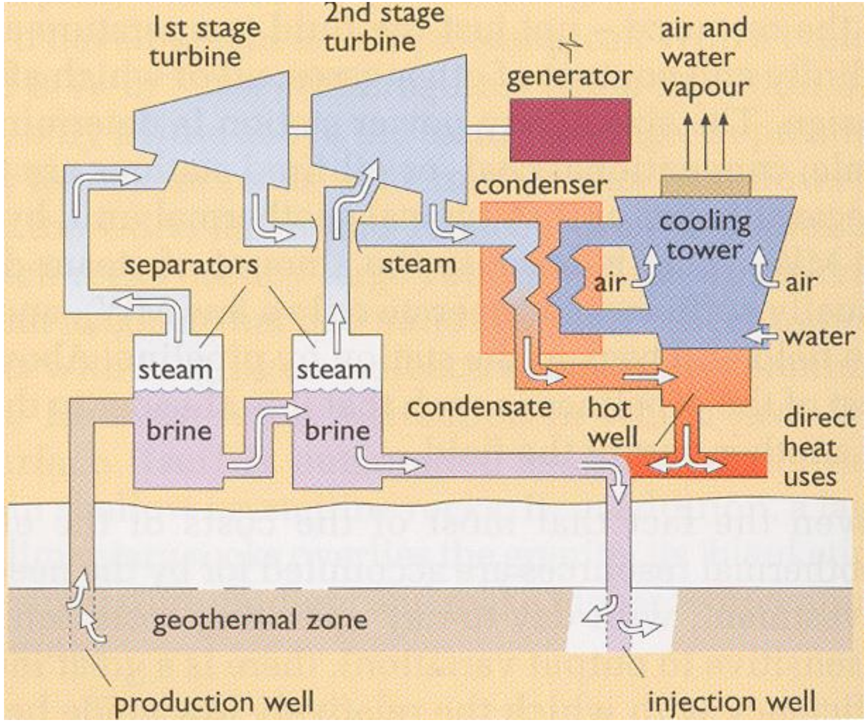
The waste brine is reinjected unless there is a direct heating application

Double flash steam power plant

Is an improvement of the single-flash design

it can produce 15-20% more power output for the same geothermal fluid conditions.

Ideal where geothermal fluids contain low levels of impurities



Double flash steam power plant

Scaling and non-condensable problems are minimum

Raises the efficiency up to 20-25% and the plant cost only by 5%

Extremely large volumes of geothermal fluid are required > sometimes can be as much as 5 times more fluid than for a dry steam plant with the same power output.

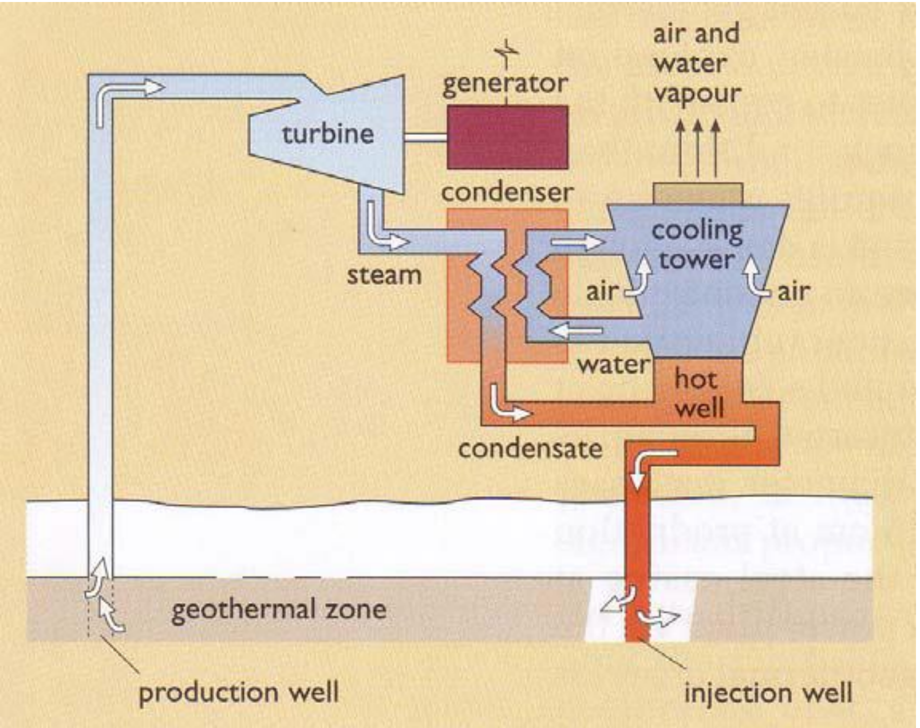
Dry steam power plant

Used in vapour dominated resources (steam production is not contaminated with liquid)

Typical steam conditions: 180-225°C and 4-8 MPa, η rarely exceed 20%

Design conditions:

currently it is required about 6.5 kg steam per saleable kWh.



Dry steam power plant

Efficiency is strongly affected by non condensable gases (CO_2, H_2S, etc)

The gases cause higher residual pressures at the back end of the turbine

They reduce the suction efficiency > direct economical impact

To avoid the presence of gases the plants are equipped with ejectors which have an impact on efficiency (steam supply or electrical power is required for their operation)

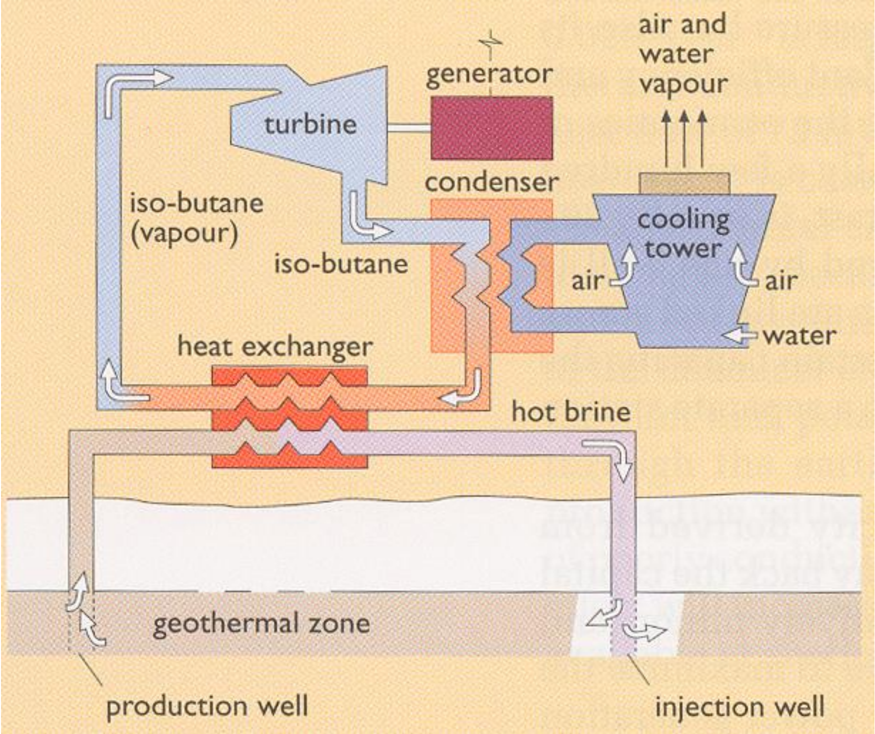
Non-condensable gases cannot longer be released to the atmosphere so they must be trapped chemically or reinjected with the waste water

Binary cycle power plant

Uses the Organic Rankine Cycle (ORC).

The working fluid is typically pentane or butane

Low temperature resources can be developed (not possible with single flash systems.



Binary cycle power plant

The geofluid is compressed and passed through the heat exchangers and finally disposed in the injection wells still in liquid phase

Binary plants constitute 33% of all geothermal units in operation but generate only 3% of the total power

Typical geofluid conditions: 150°C

η ranges between 10% and 13%

(η_{carnot} =26% for T = 150°C)

Binary cycle power plant

Most benign of all power plants

Only thermal pollution (i.e. geothermal plants of all types discharge more waste heat per unit of power output than other thermal power plants).

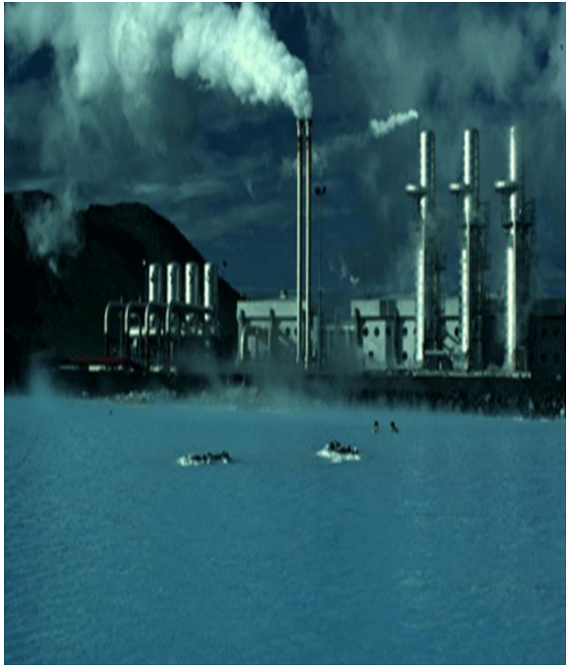
Geothermal Power Plants and the Environment

Geothermal power plants do not burn fuel to generate electricity so their emission levels are very low.

Release less that 1% of carbon dioxide emissions of a fossil fuel plant

Use scrubber systems to clean the air of hydrogen sulfide.

Emits 97% less acid rain-causing sulfur compounds than fossil fuel plants.



Thank You