Energy Resources and Utilization

Image Source: www.leftfootforward.org

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- Physics of Geothermal Energy
- Techniques to utilize Geothermal Energy
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- Economics

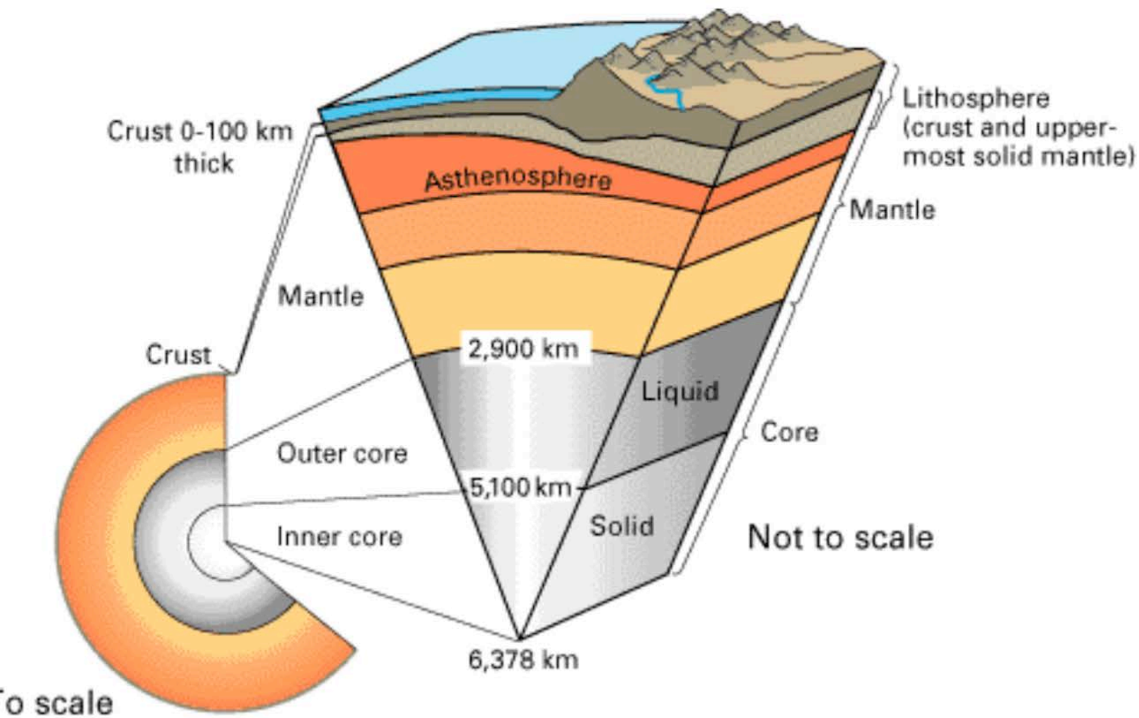
Introduction

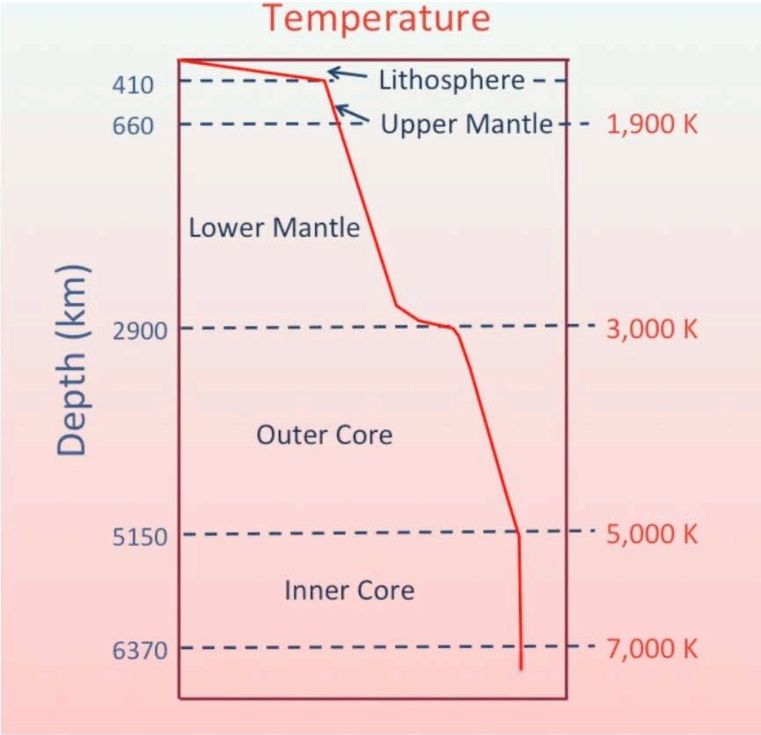
What is Geothermal Energy?

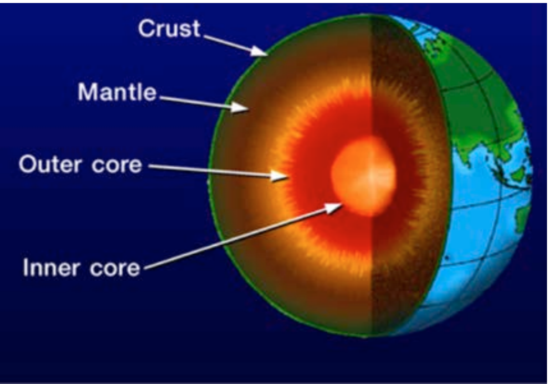
Geothermal energy is the thermal energy stored in the earth’s crust. It refers to the Earth's heat that can, or could, be recovered and exploited by man.

Is geothermal energy renewable?

Structure of Earth







Introduction

Heat passes by

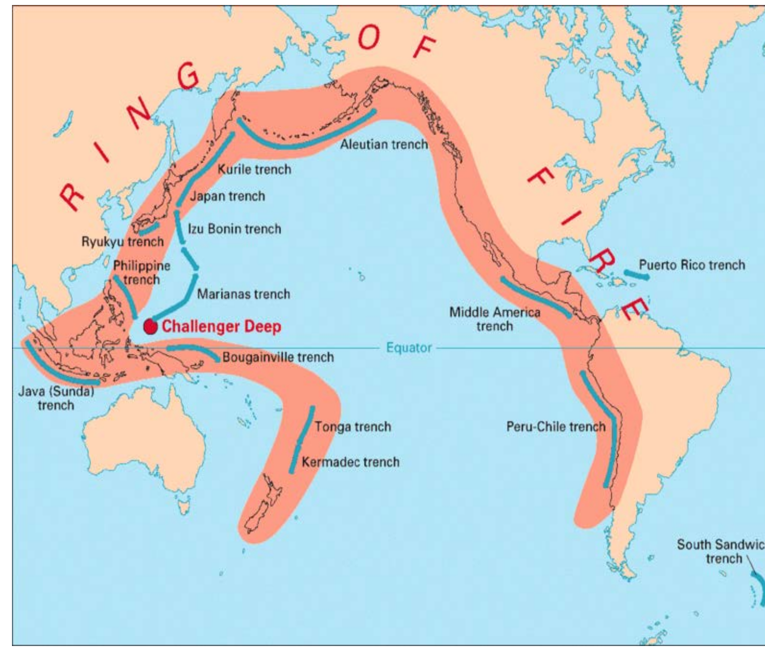
1. Natural cooling and friction from the core

1. Radioactive decay of elements such as uranium (U235 and U238), thorium (Th232) and potassium (K40). This represents the major source of heat

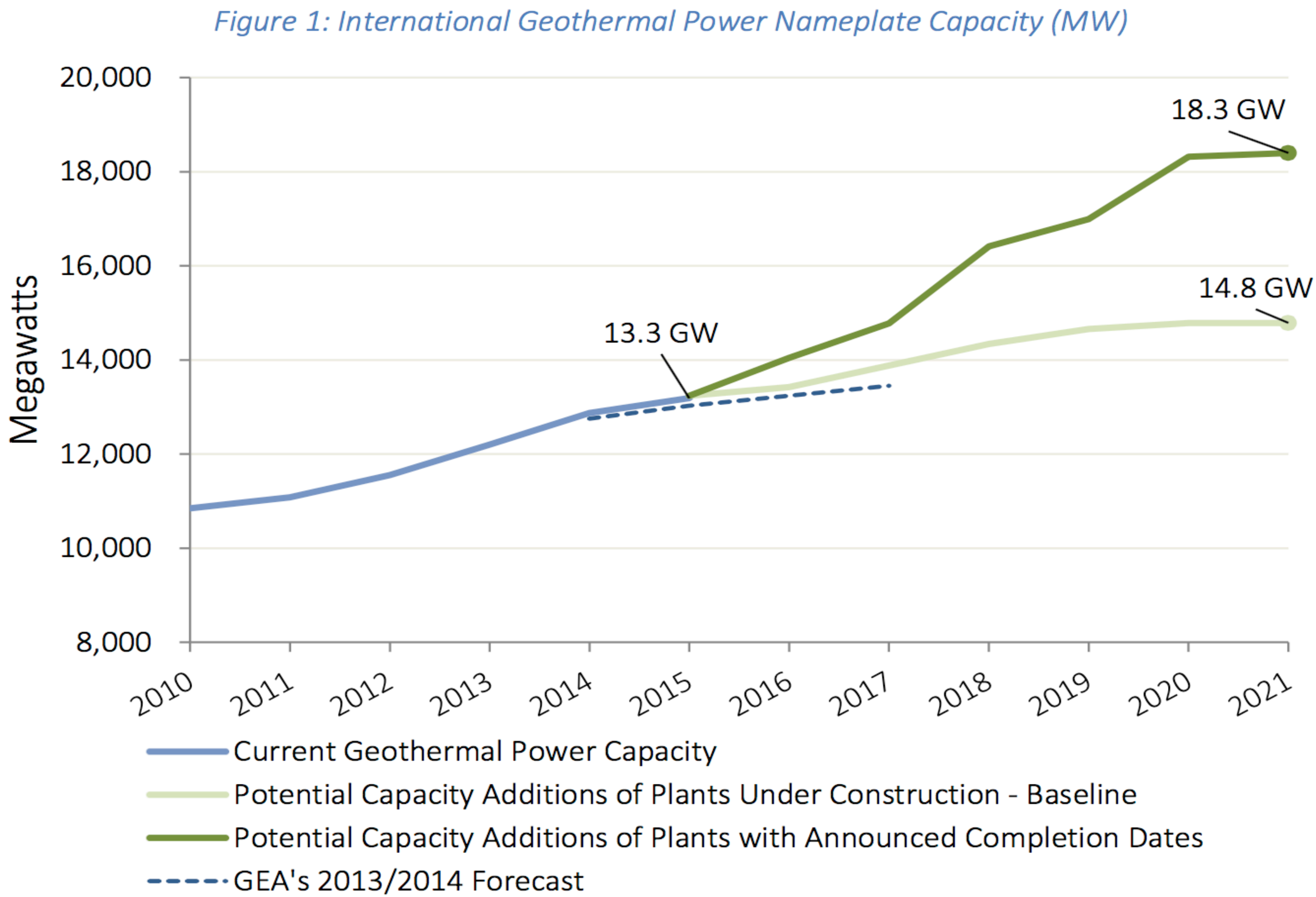
2. Chemical reactions

Location

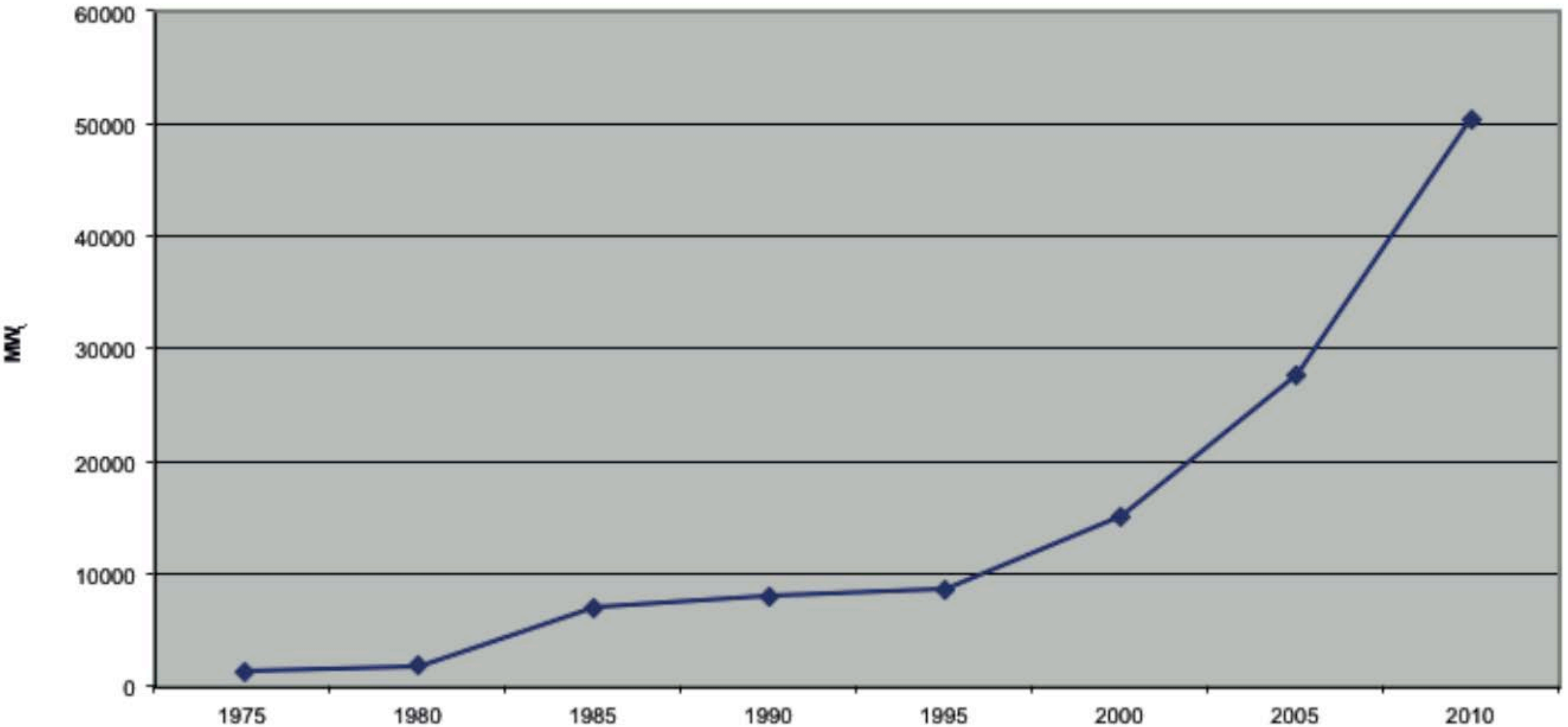
- Ring of Fire
- Over 20 countries: Iceland, U.S., Italy, France, China, Japan, ect.
- The United States is the country with the greatest geothermal energy production



Worldwide Geothermal Electricity Generation Capacity

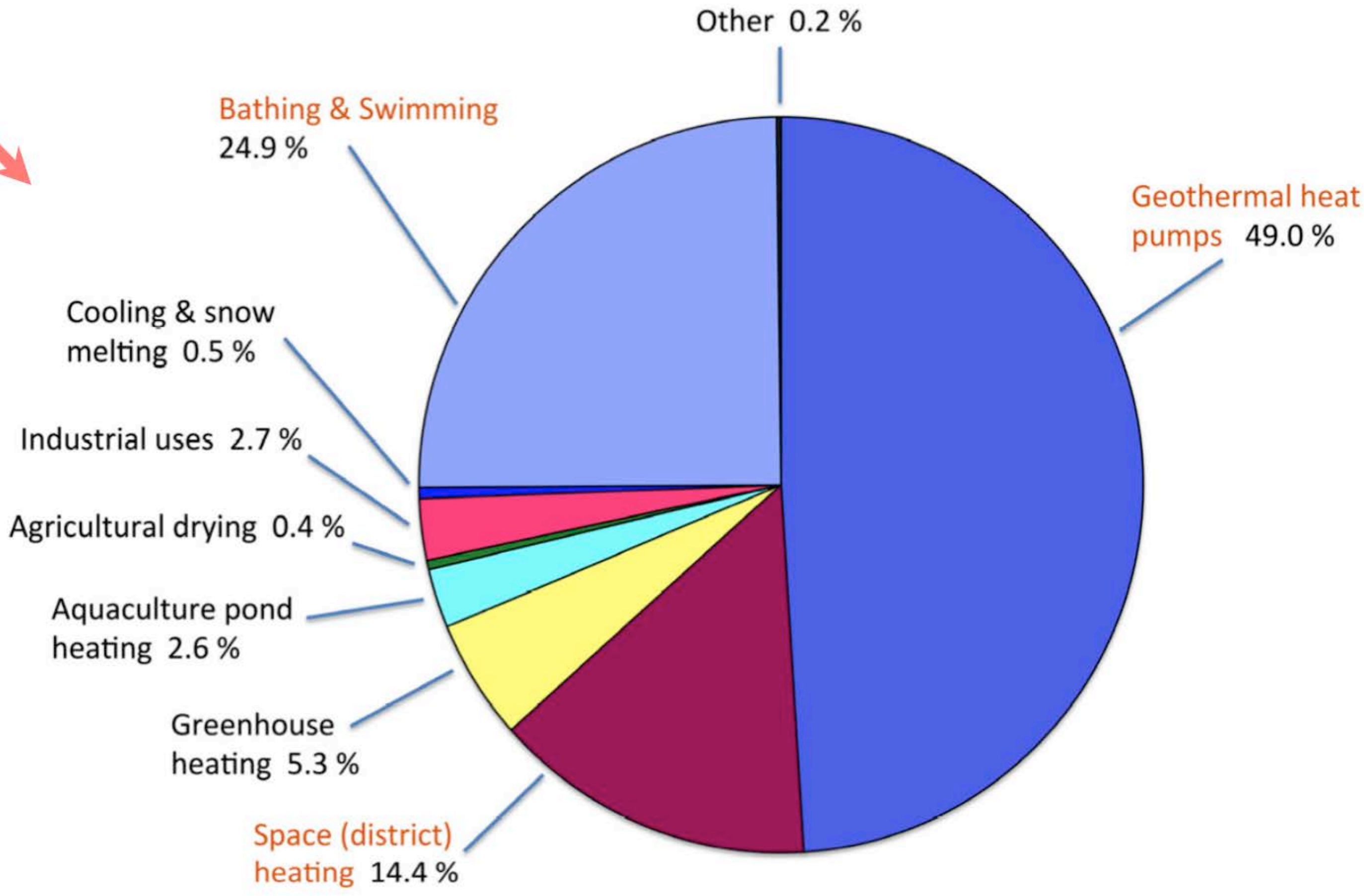


Worldwide Geothermal Direct Use



Source: International Geothermal Association

Worldwide Geothermal Direct Use



Geothermal Energy

Temperatures within the Earth's interior increase with depth.

The normal temperature gradient within the Earth's interior is about $2.5\sim3^{\circ}$ C/100 meters

Geothermal gradient: rate of temperature increase with depth [K/m] due to conductive heat transfer in the crust.

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

Classes of Geothermal Region

Hyperthermal Temperature gradient $\geq 80^{\circ}$ □C 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.

Semithermal Temperature gradient ~40–80° □C 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.

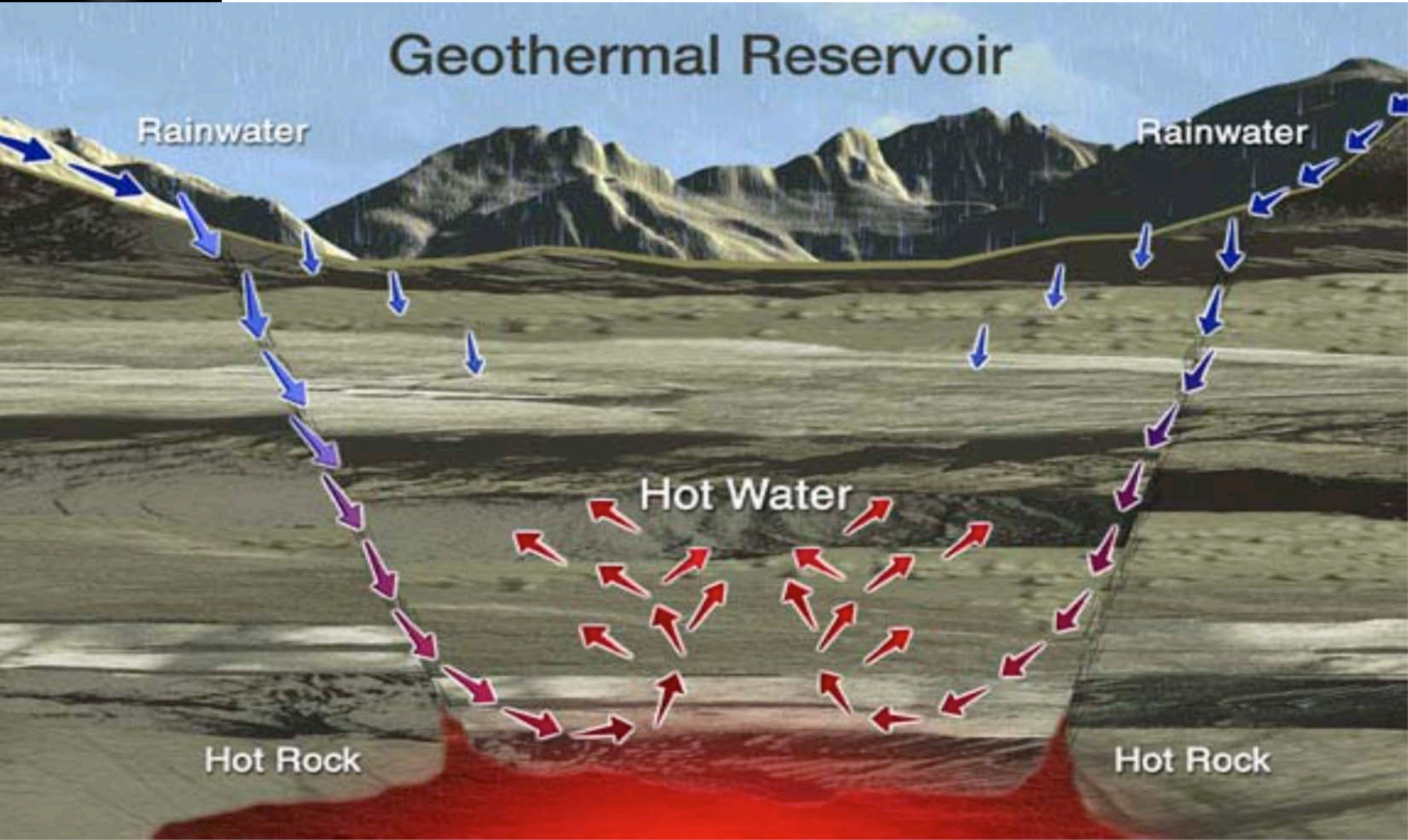
Normal Temperature gradient < 40 $^{\circ}$ □C km^{-1}. These remaining regions are associated with average geothermal conductive heat flow at ~0□.06Wm^{-2}. It is unlikely that these areas can ever supply geothermal heat at prices competitive to present (finite) or future (renewable) energy supplies.

Geothermal Reservoirs

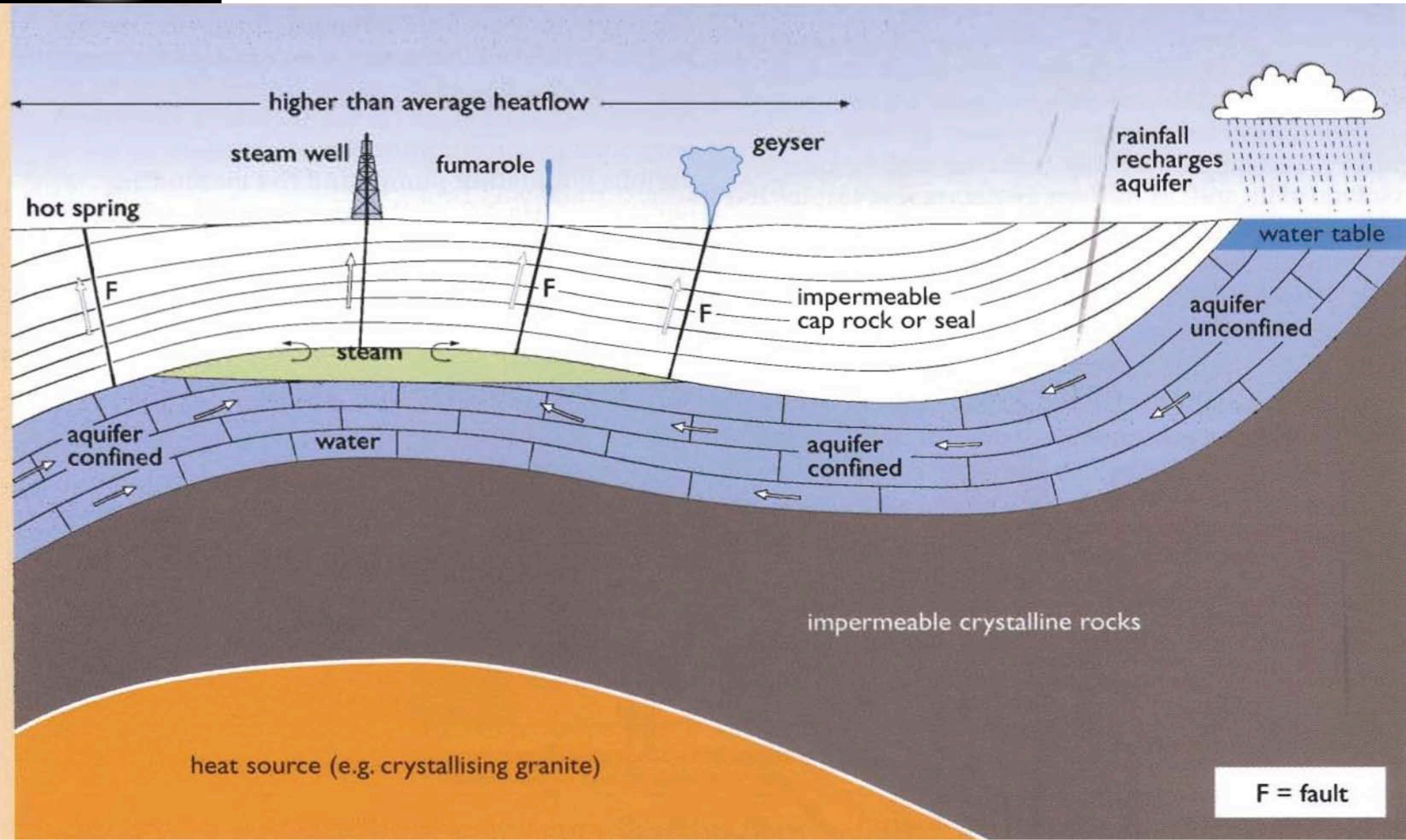
Geothermal resources have four important characteristics:

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



Primary Ingredients



Classification of Geothermal Resources

By Type:

- Low-enthalpy
- Intermediate-enthalpy
- High-enthalpy

By source

- Hot Dry Rock
- Liquid-Dominated (Hydro thermal)
- Vapor-Dominated
- Geopressurized fluids

Classification 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 low typically 0.5-1 MPa and the temperature is around 180 ° C

Classification by Source

Vapour-dominated systems

- 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 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 by Source

Hot Dry Rock (HDR)

- 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.

Classification 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

Advantages

1. Reserves are enormous- virtually infinite on historical scale.
2. Less polluting than combustible fuels or nuclear energy.
3. 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.
4. Highly versatile
5. Not subject to the variations of the weather.
6. Not labour intensive.

Disadvantages

1. Not many places on the earth that are highly suitable for exploit.
2. Expensive exploration
3. Brines are corrosive and poisonous
4. Complicated reservoir management
5. Sensitive to underground disturbances

Exploration

The main objectives of geothermal exploration are:

1. To identify geothermal phenomena.
2. To ascertain that a useful geothermal production field exists.
3. To estimate the size of the resource.
4. To determine the type of geothermal field.
5. To locate productive zones.
6. To determine the heat content of the fluids that will be discharged by the wells in the geothermal field.
7. To compile a body of basic data against which the results of future monitoring can be viewed.
8. To determine the pre-exploitation values of environmentally sensitive parameters.
9. To acquire knowledge of any characteristics that might cause problems during field development.

Strategies for Assessment of Geothermal Resources

- **Surveys** On national, local and site-scale
- ***Key parameters***: temperature, permeability, volume, existing infrastructure
- **Inventory** hot springs, temperature in drill holes
- **Satellite imagery and aerial photography**
- **Geological and hydrological** Stratigraphy, Lithology
- porosity permeability Structure modelling
- **Geochemical Chemistry of natural Water**
- **Geophysical** subsurface structure Gravity (porosity) ,Seismics (structure) ,Magnetic (structure, temperature) ,Electric (porosity) Electromagnetic (porosity) modeling

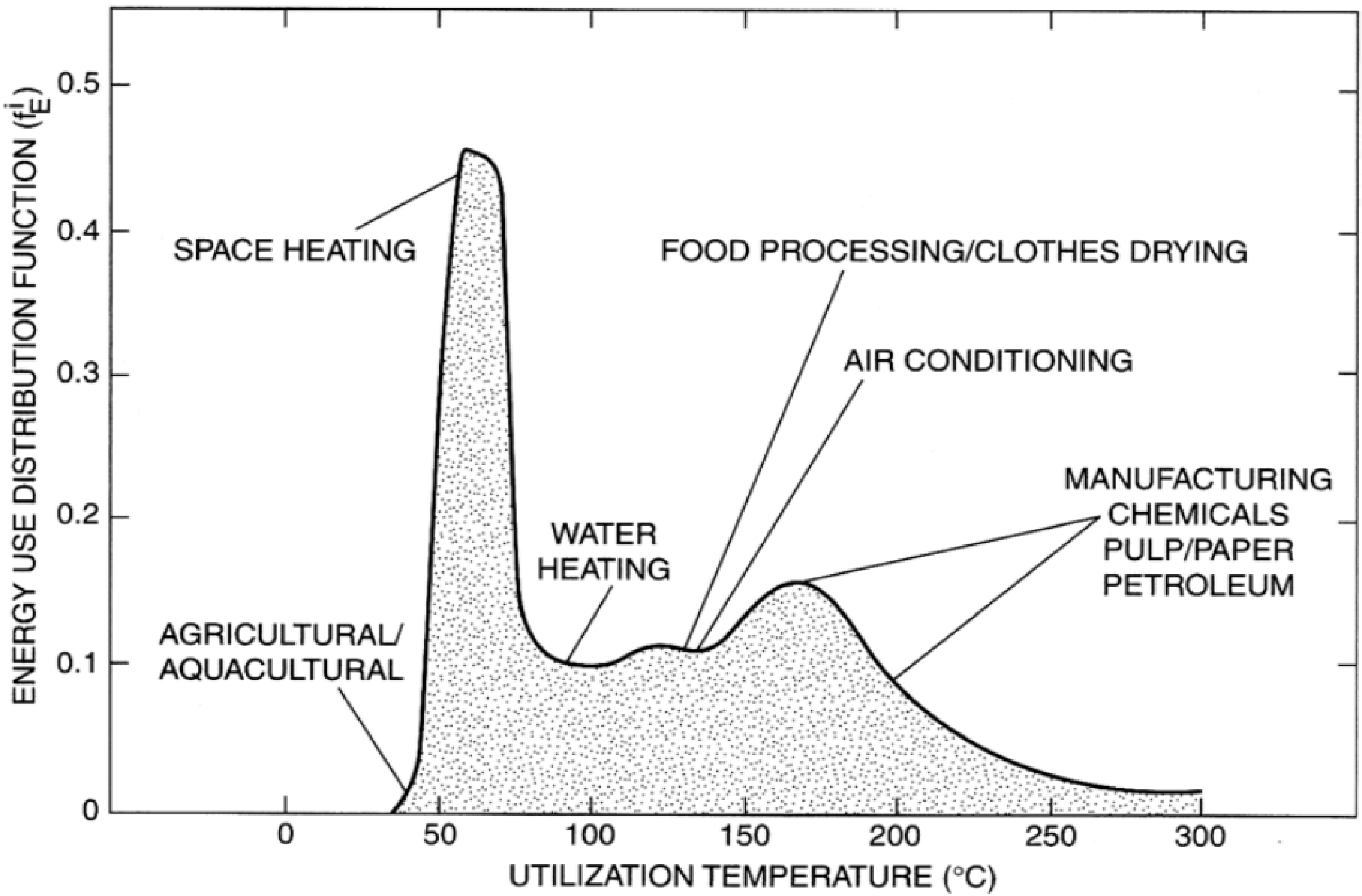
Utilization of Geothermal Energy

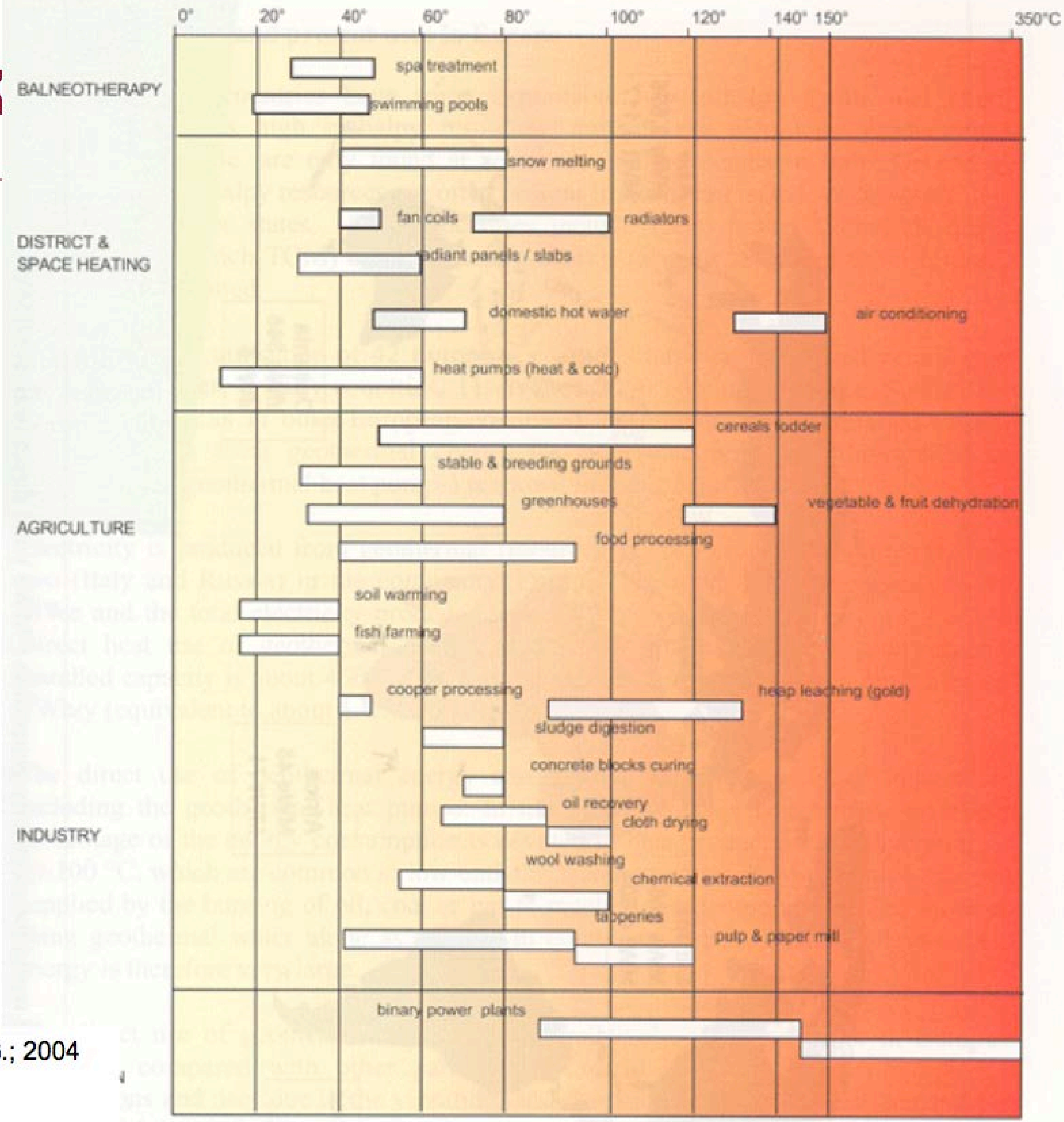
- DIRECT USE
  - **Cooling** — 0 – 20 °C
  - **Heating**
    - Low temperature 25-35 °C
    - High temperature 70 –110 °C
  - **Hot water** production

- 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





0°
20°
40°
60°
80°
100°
120°
140°
150°
350°C
BALNEOTHERAPY
spa treatment
swimming pools
DISTRICT & SPACE HEATING
snow melting
fan coils
radiators
radiant panels / slabs
domestic hot water
air conditioning
heat pumps (heat & cold)
AGRICULTURE
cereals fodder
stable & breeding grounds
greenhouses
vegetable & fruit dehydration
food processing
soil warming
fish farming
INDUSTRY
cooper processing
heap leaching (gold)
sludge digestion
concrete blocks curing
oil recovery
cloth drying
wool washing
chemical extraction
tanneries
pulp & paper mill
binary power plants

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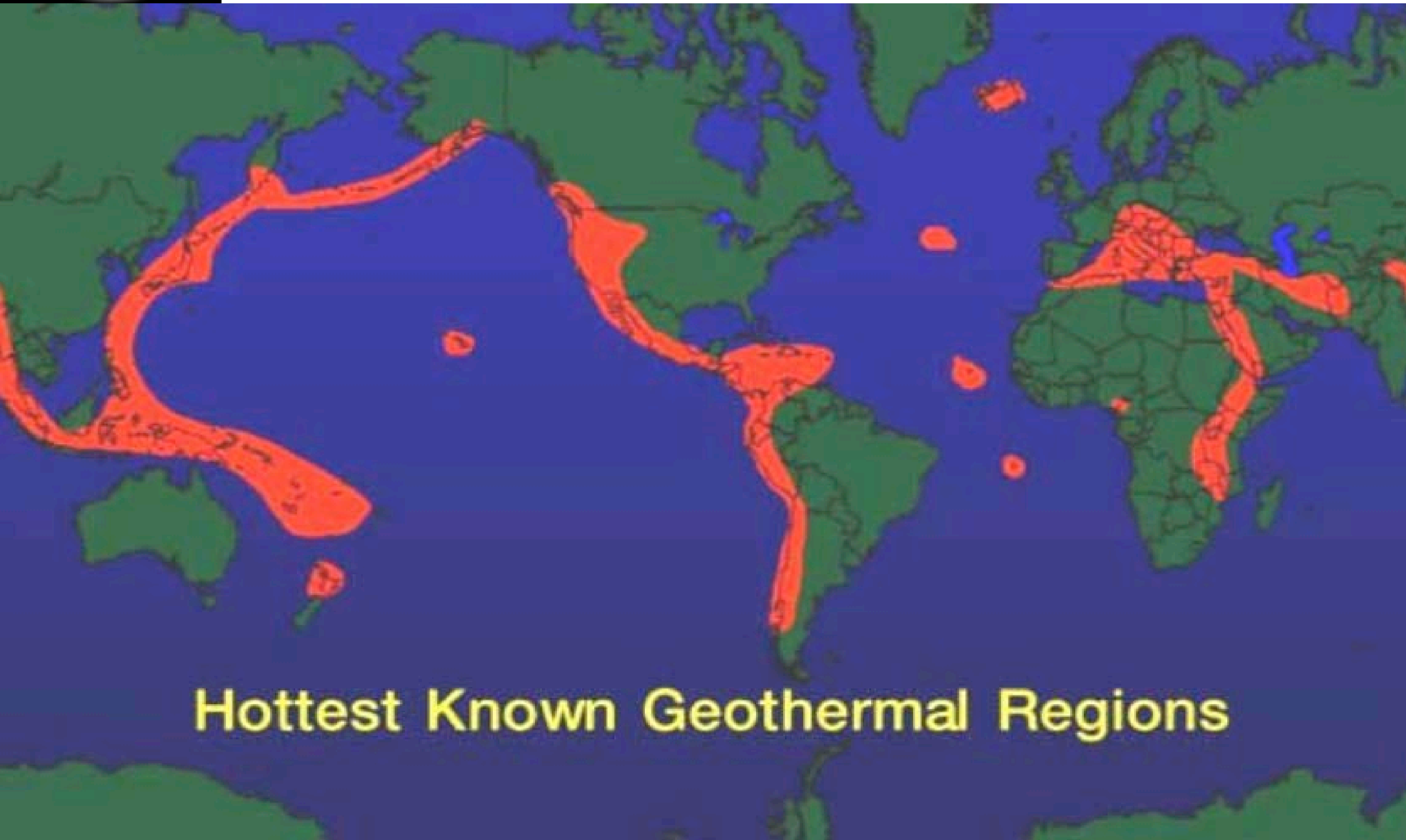
Environmental Impacts

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- Low level earthquakes from withdrawal and re-injection of fluids
- Effluent Disposal and Water Pollution

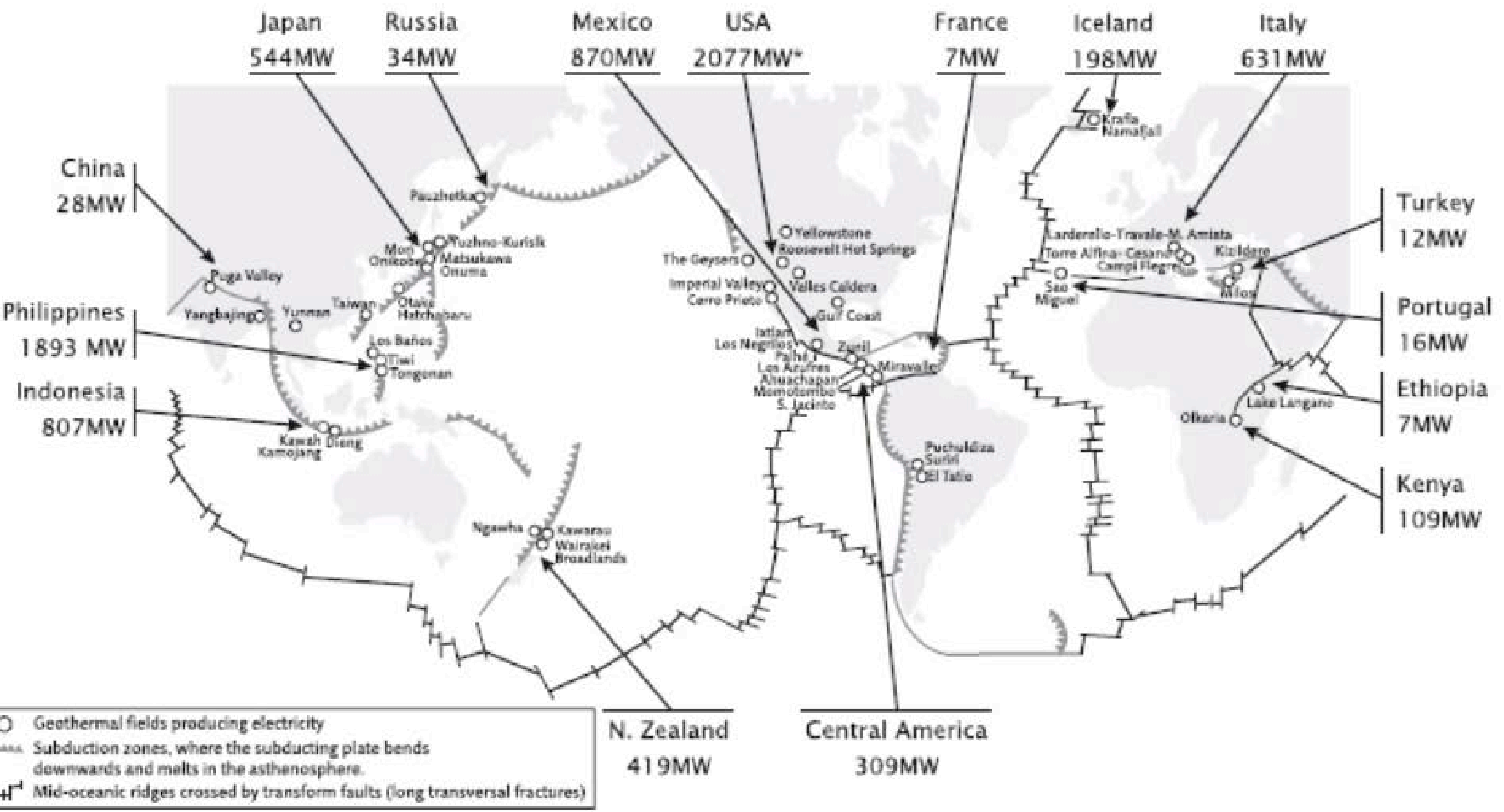
Environmental Impacts



Geothermal Power Generation

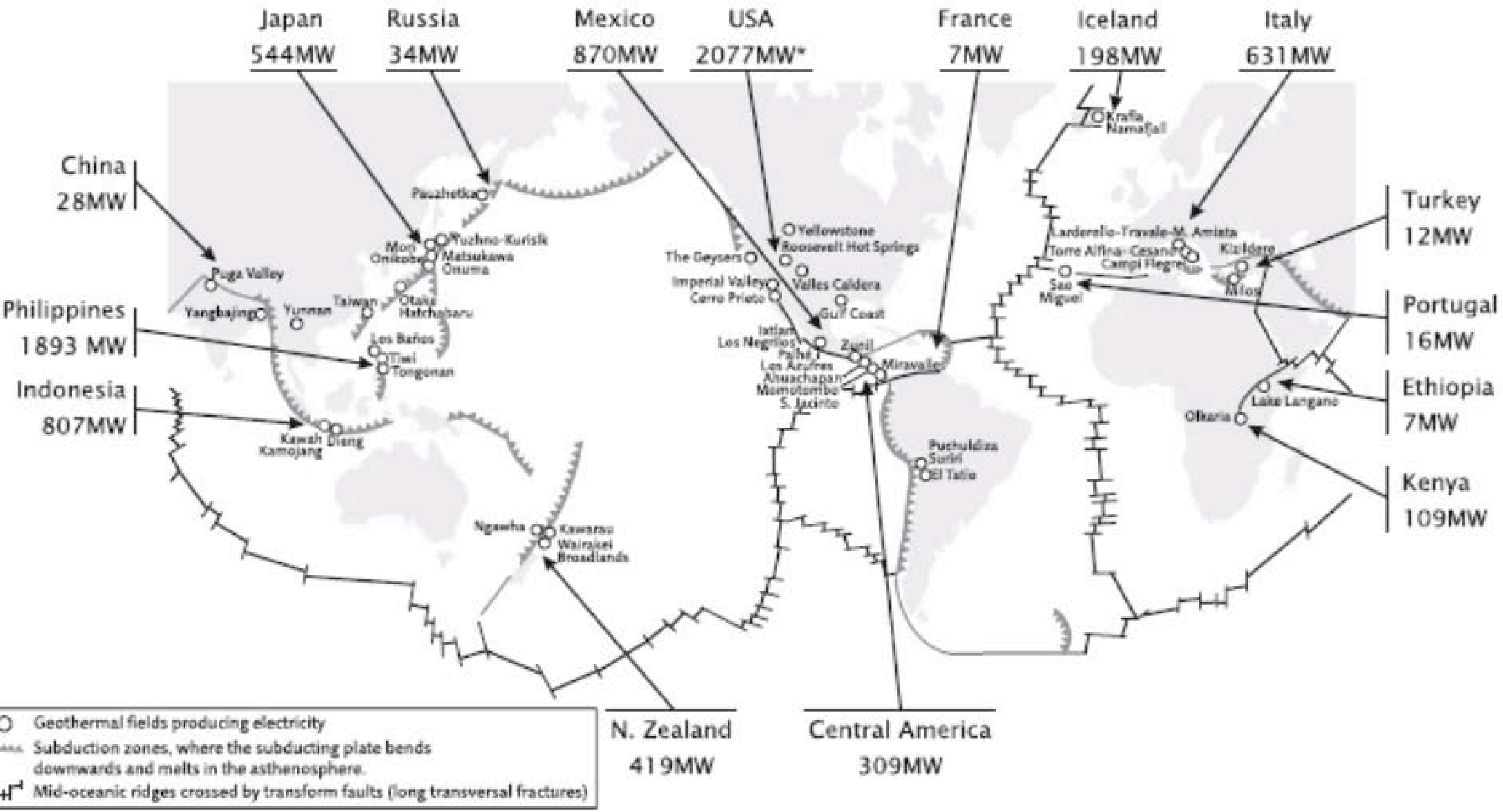
- Electricity from geothermal energy had a modest start in 1904 at Larderello, in the Tuscany region of north-western Italy, with an experimental 10 kW generator.
- This electricity production is serving an equivalent of 60 million people throughout the world, which is about 1% of our planet’s population.

Geothermal Power Generation



Source: Data from Huttrer.

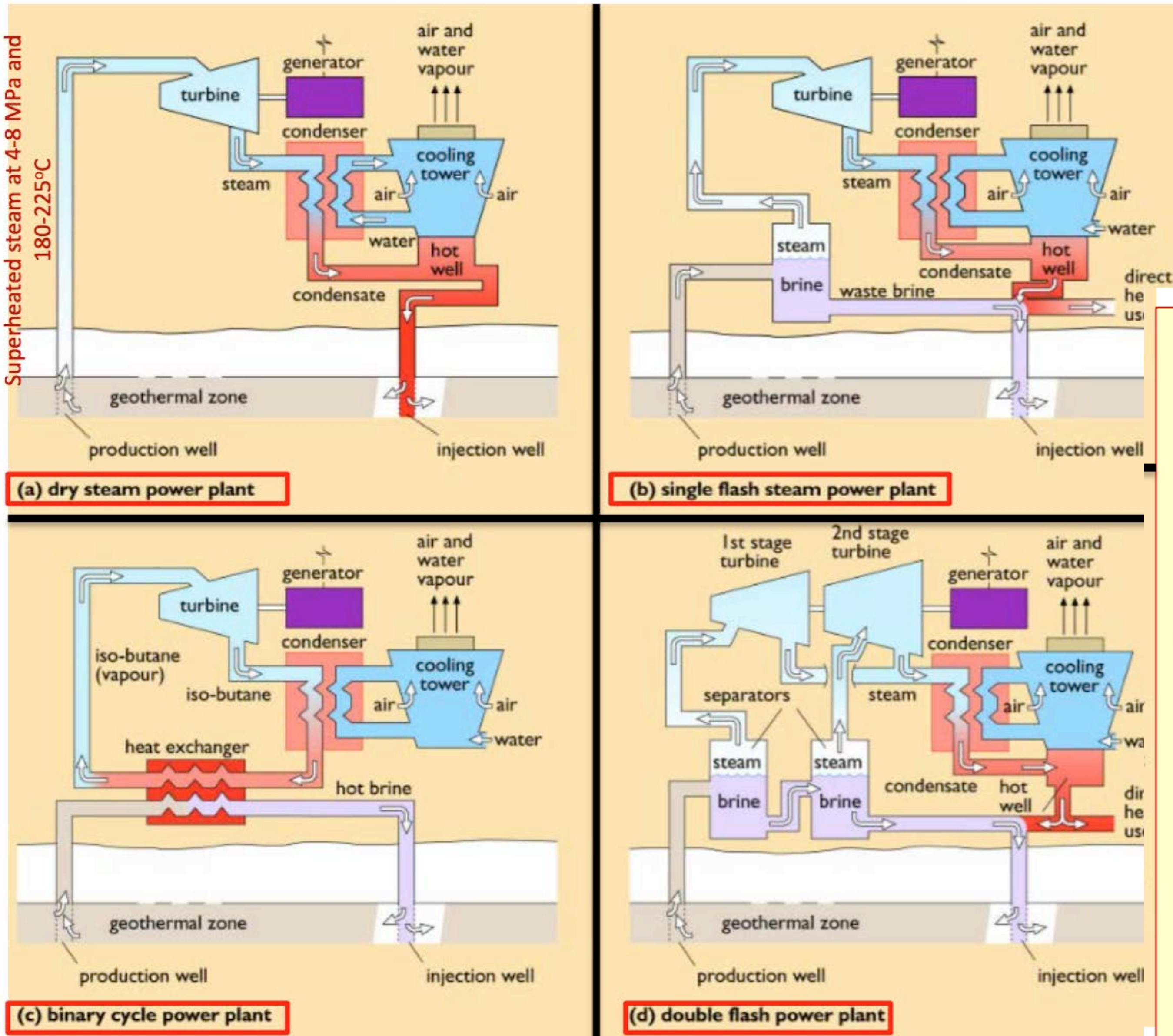
Geothermal Power Generation



Source: Data from Huttrer.

Geothermal Electrical Energy Production

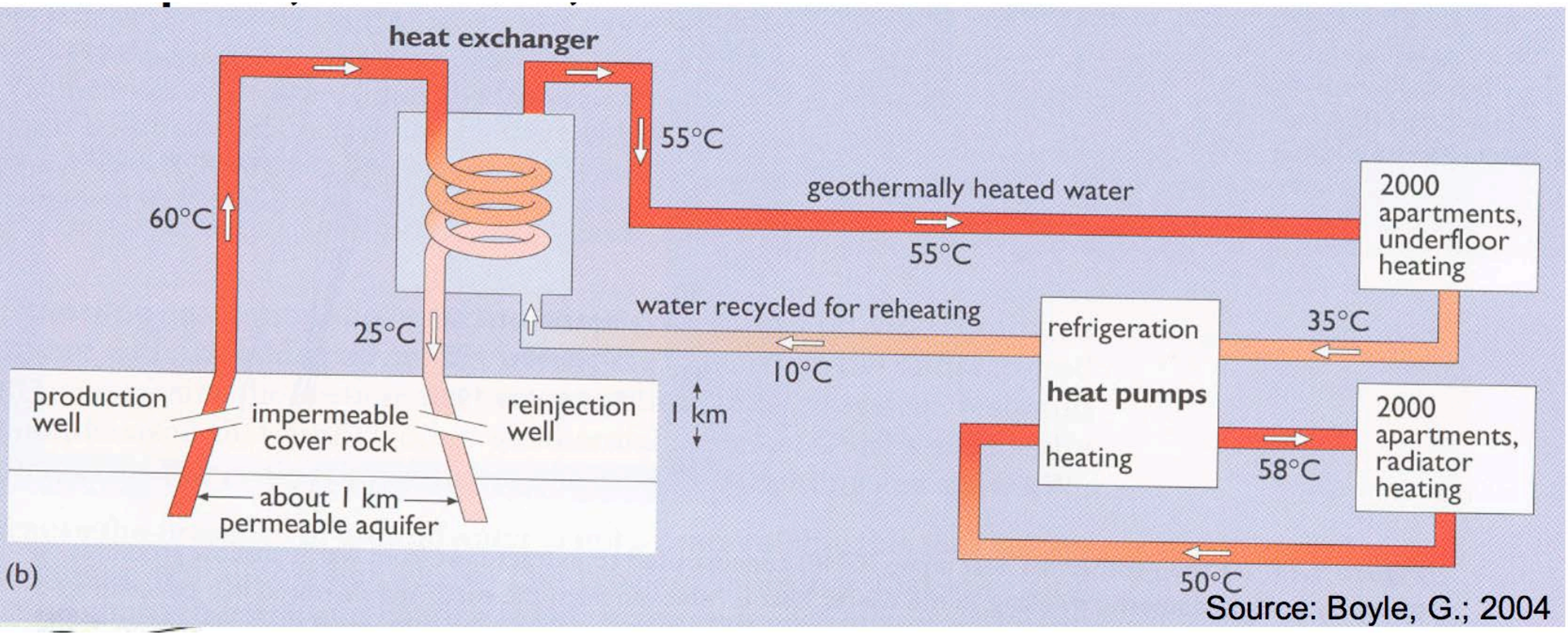
Thermal efficiency around 20%



A secondary working fluid with a lower BP than water (e.g., pentane or butane) which is vaporized and used to drive the turbine. It is commonly known as an **Organic Rankine Cycle (ORC) plant**

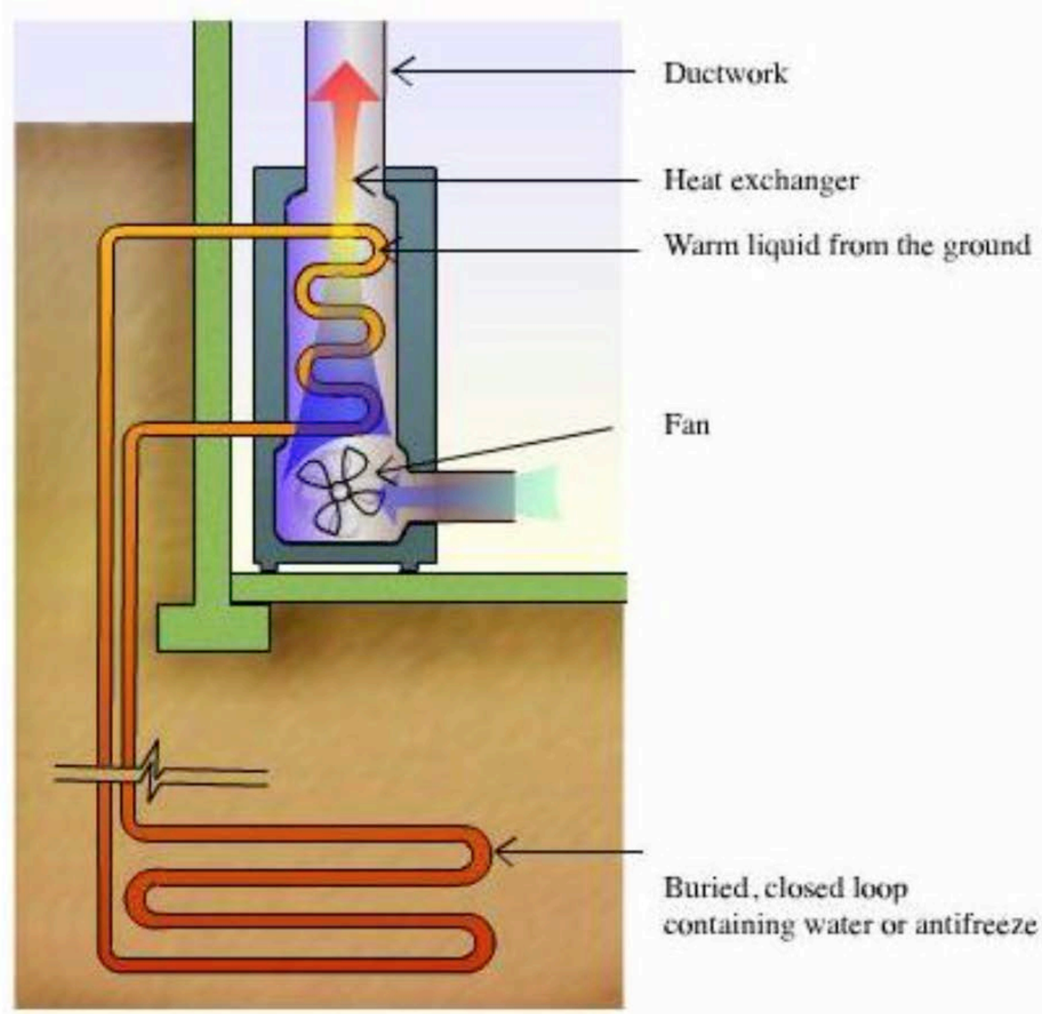
Unflashed liquid remaining after the initial high-pressure flashing flows to a low-pressure tank where another pressure drop provides additional steam. This steam is mixed with the exhaust from the high-pressure turbine to drive a second turbine. This process rises **the efficiency to ~ 25% for only 5% increase in plant cost.**

Space Heating



Geothermal Heat Pumps

Ground source heat pumps (GSHPs) are electrically powered systems that tap the stored energy in the earth. These systems use the earth's relatively constant temperature to provide heating, cooling, and hot water for homes and commercial buildings.



https://energy.gov/energysaver/geothermal-heat-pumps