Renewable Energy 1: Solar and Geothermal (EG501J)

Geothermal Energy:

2. Sources, Technologies and Preliminary Environmental Analysis

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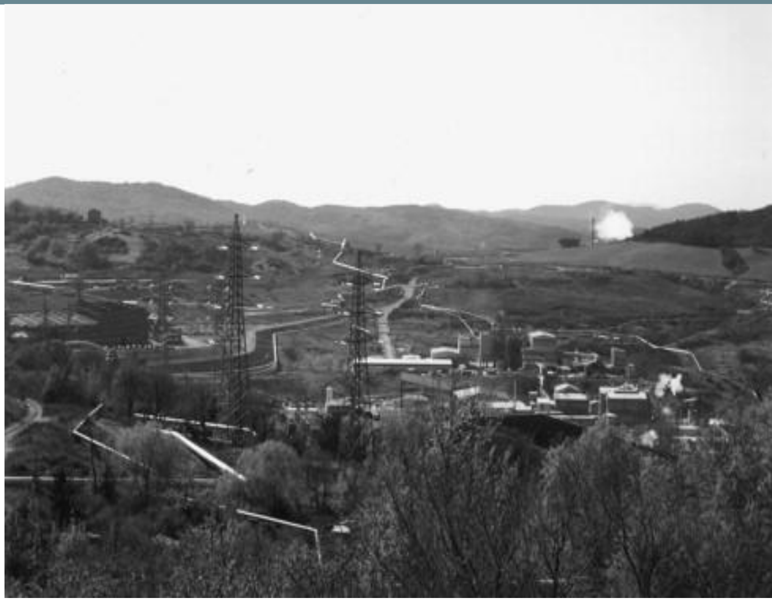
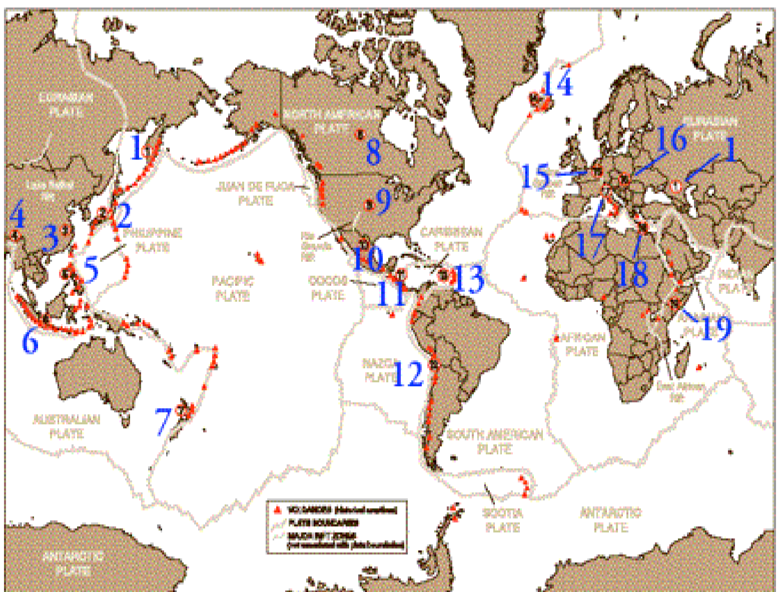
Outline

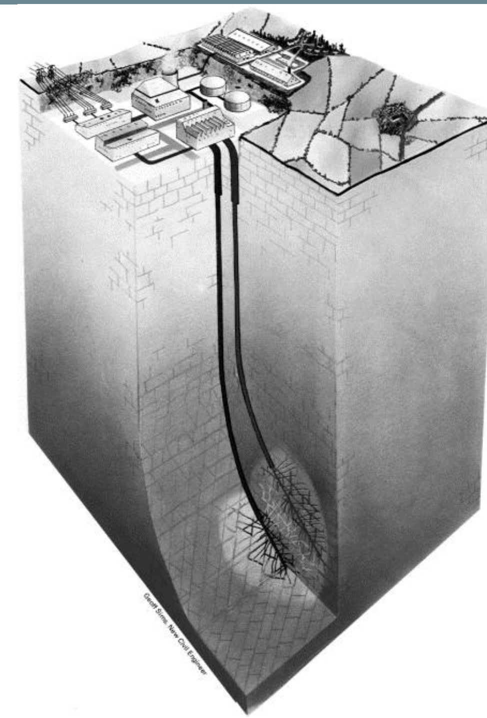
(Blue Lagoon, Iceland. Hot springs with geothermal plant in the background.)

- Economics of Geothermal Energy
- Geothermal Sources
- Basics of a Geothermal Power Plants
- Environmental Impact





Geothermal Energy: Initial Analysis



Geothermal Potential in the World Energy Mix

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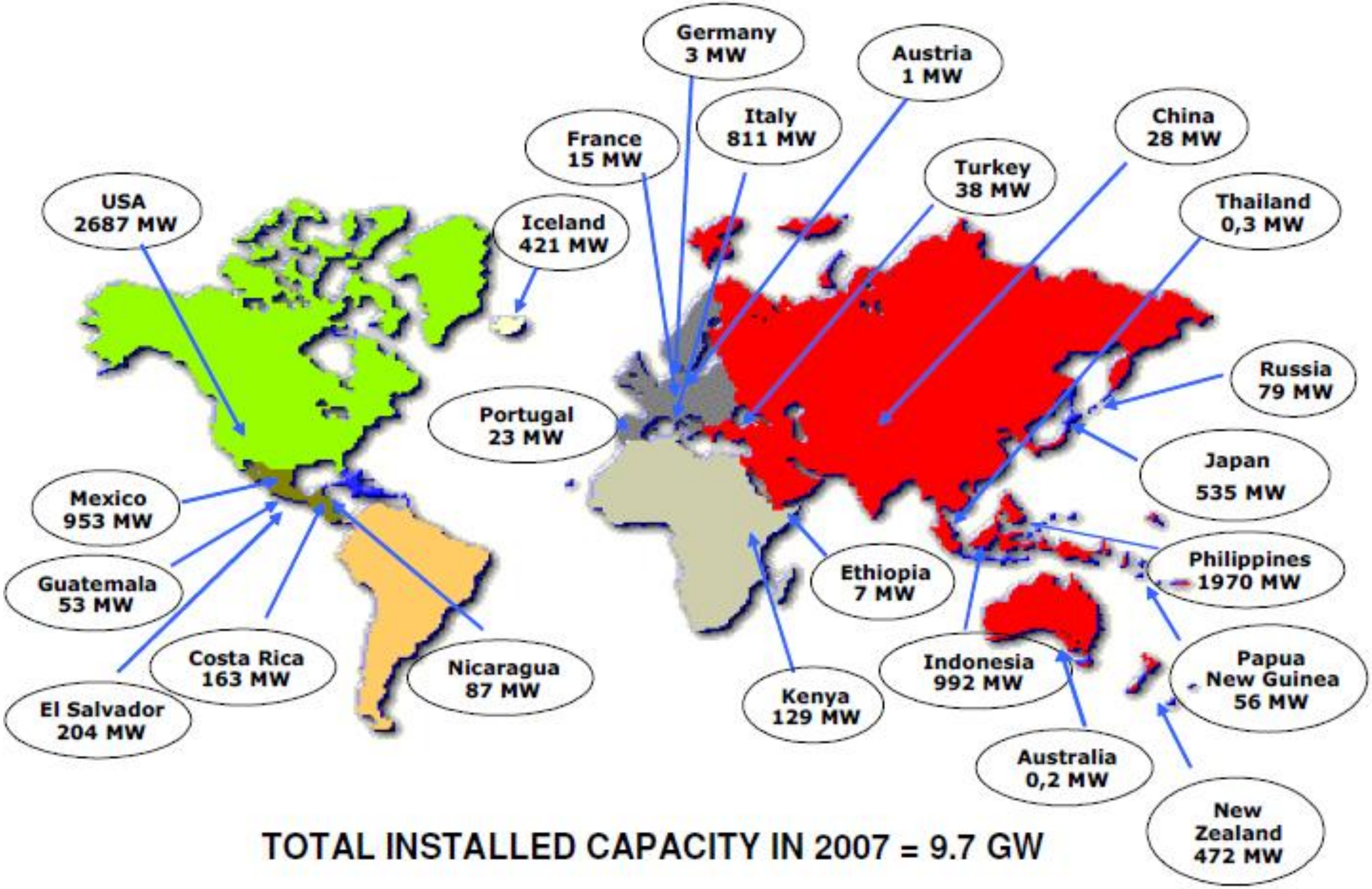


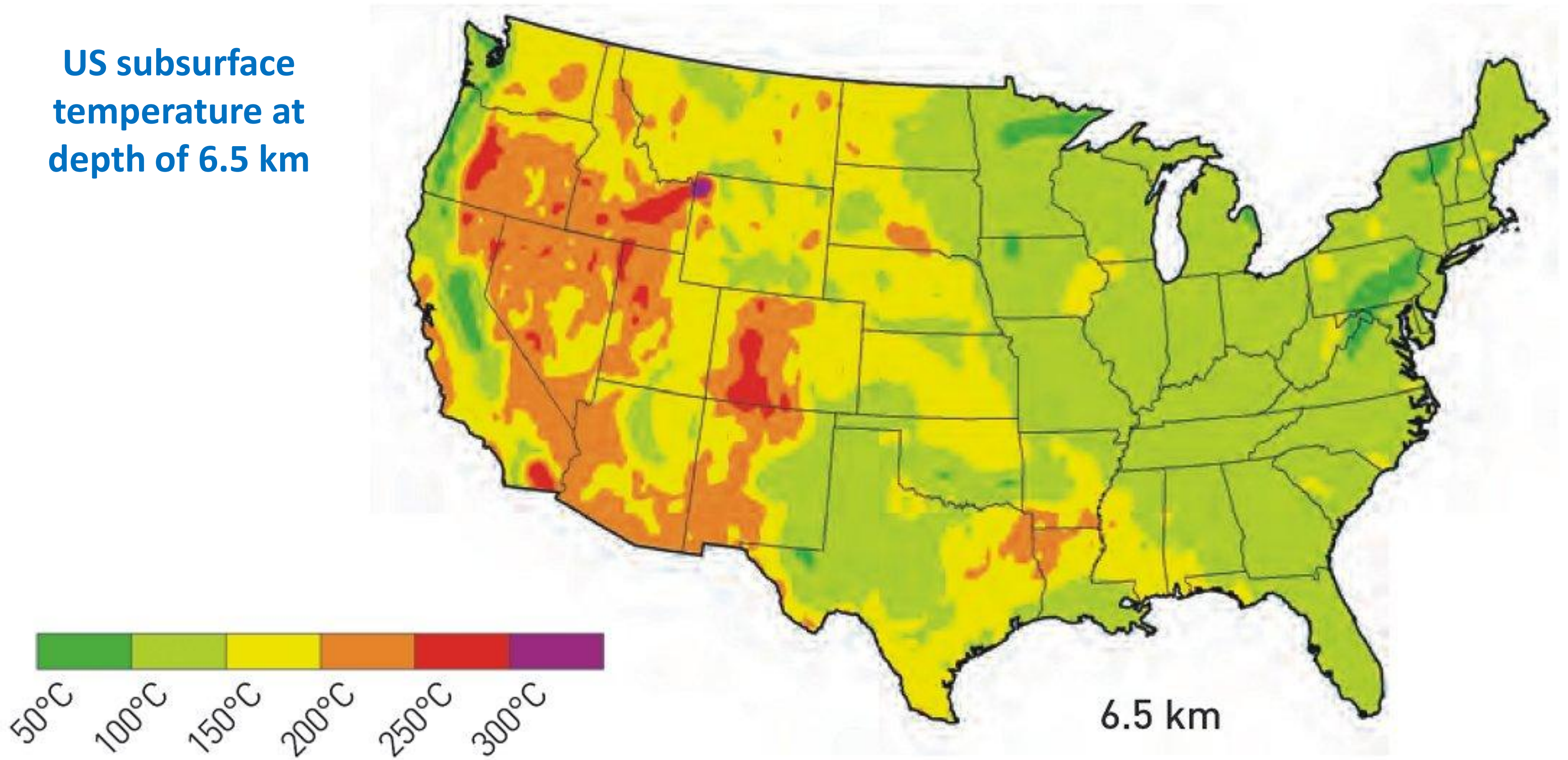
TOTAL INSTALLED CAPACITY IN 2007 = 9.7 GW

Source: IPCC, 2008

Geothermal Potential in the World Energy Mix

- Geothermal sources of T > 150ºC @ depths of 1500-3000 m: Electricity production;
- Thermal sources 90 ≤ T ≤ 150ºC @ depths below 1000m: Thermal generation.

US subsurface temperature at depth of 6.5 km



Source: MIT (006), The Future of Geothermal Energy

Geothermal Potential in the World Energy Mix

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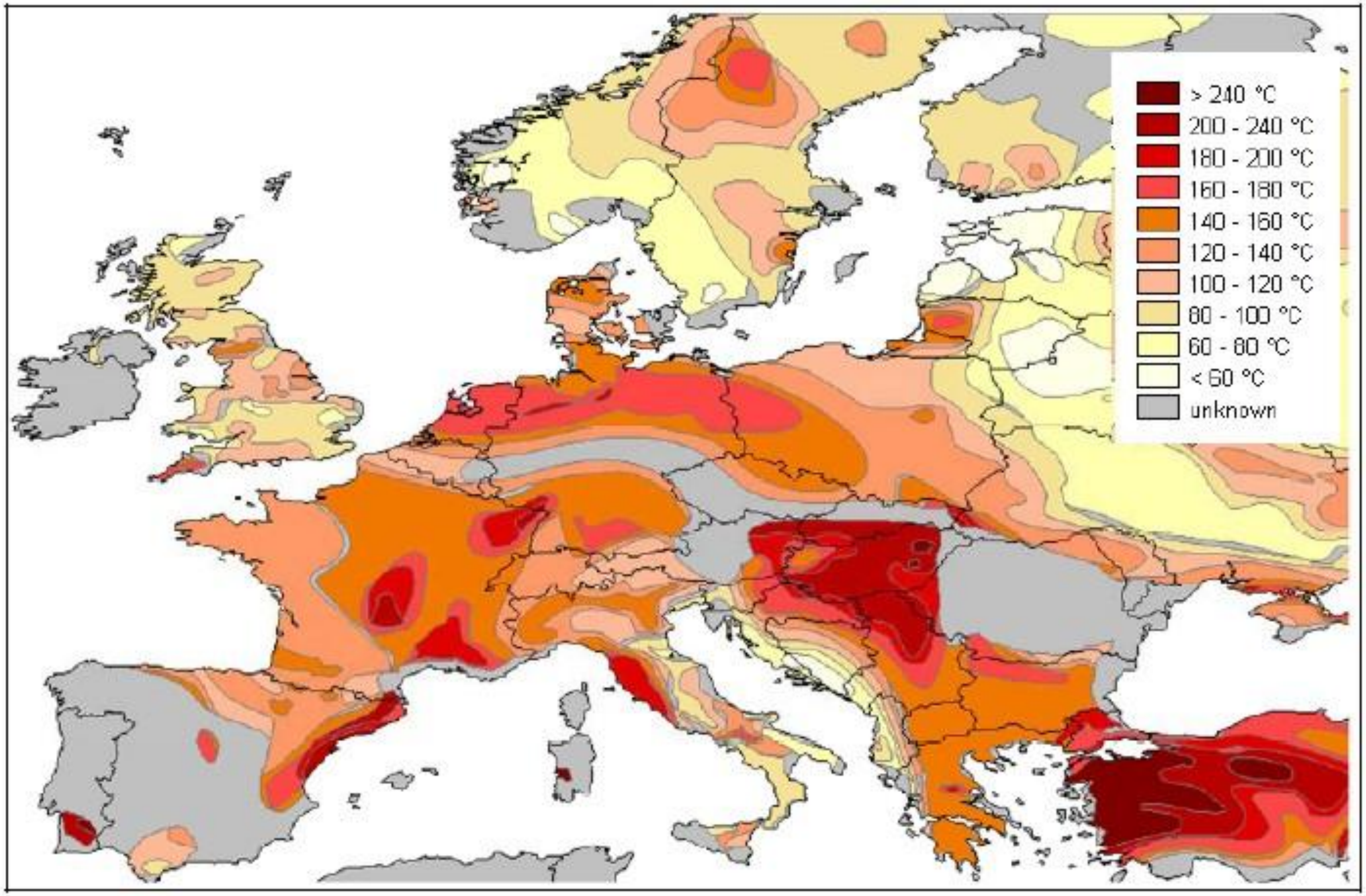
Europe subsurface temperature at depth of 5 km



Source: Trans-Mediterranean Interconnection for Concentrating Solar Power , Final Report (2006)

Geothermal Potential in the World Energy Mix

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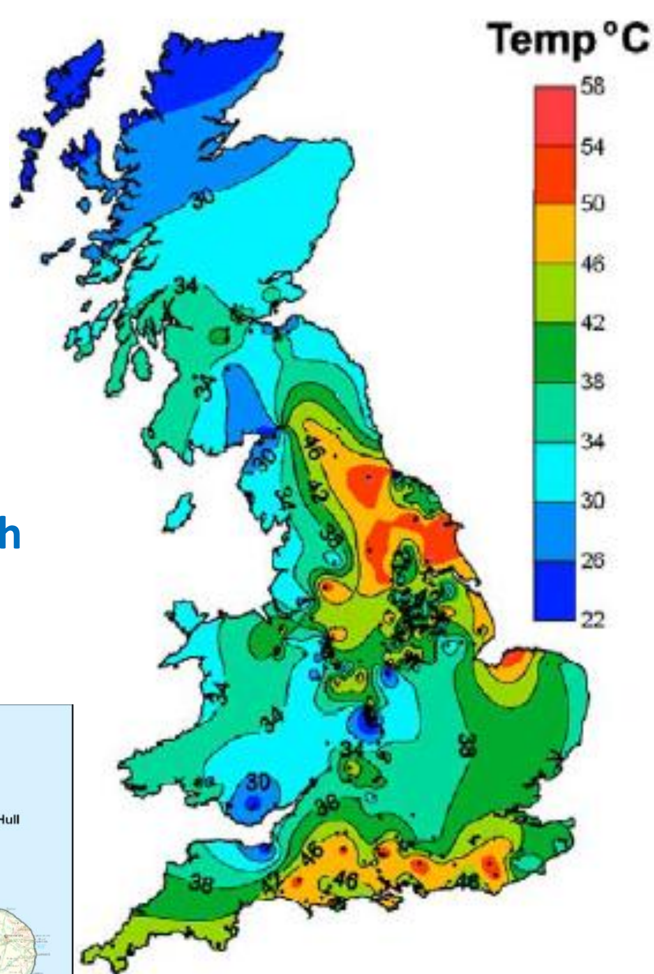
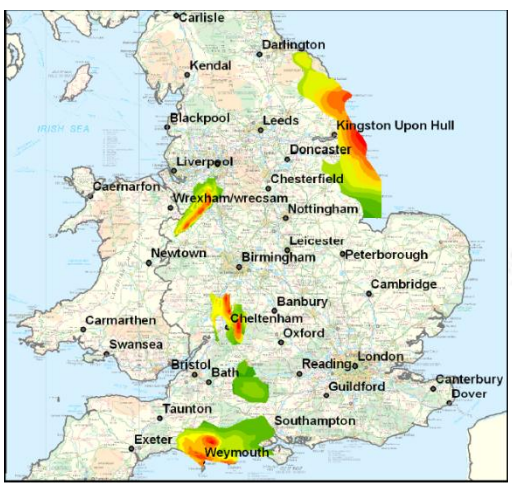
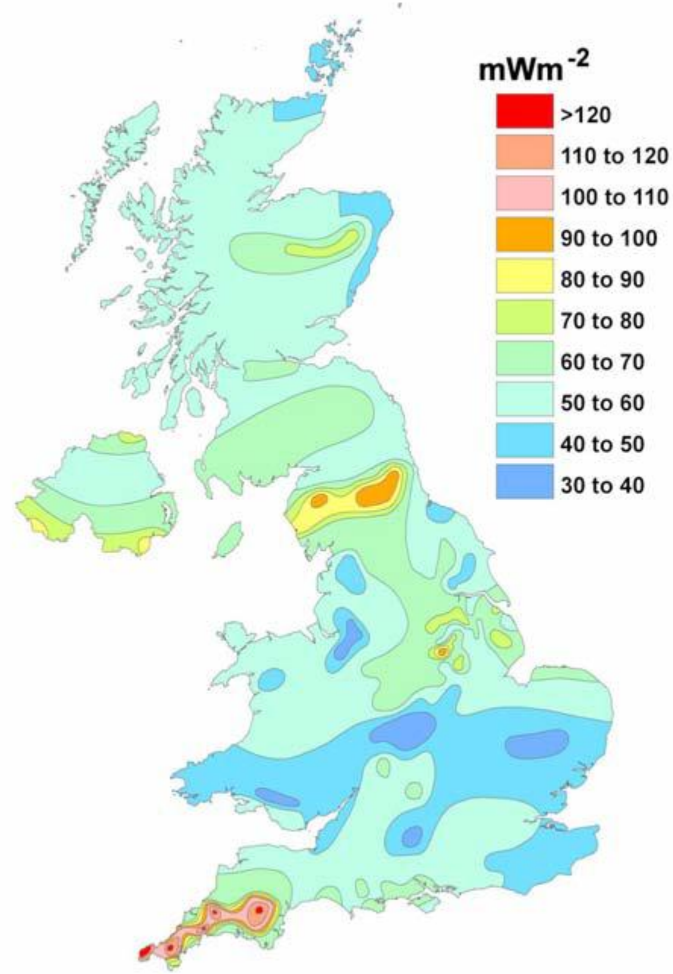
UK subsurface temperature at depth of 1 km



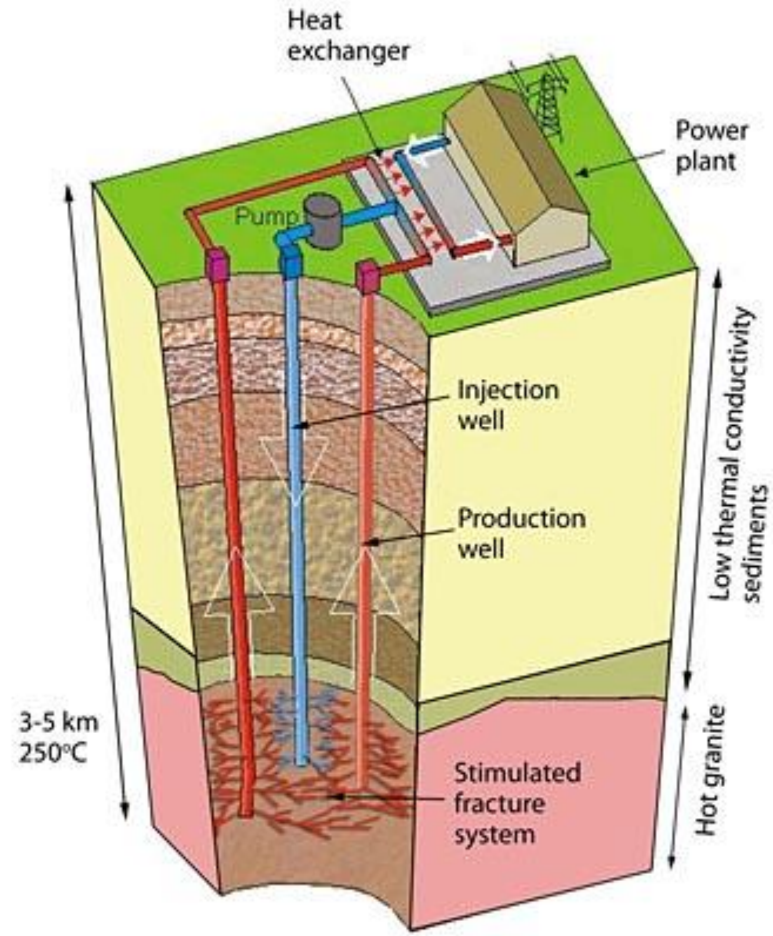




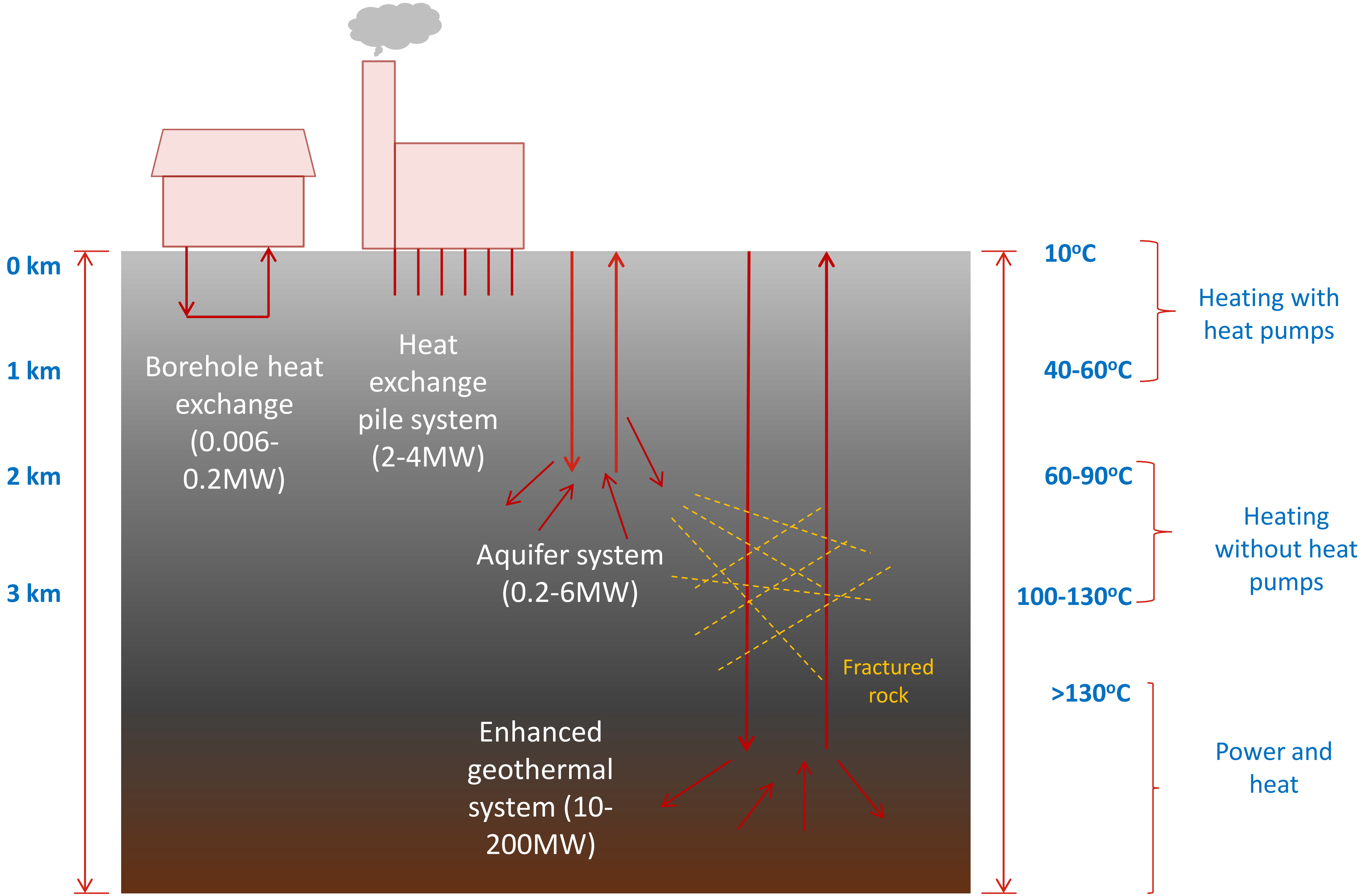
Heat flux based on UK geothermal map

Source: British Geological Survey

- **Classification:**
  - T > 150°C (high temperature): electricity production and direct heating;
  - 90 ≤ T ≤ 150°C (medium temperature): electricity production and direct heating;
  - 30 ≤ T < 90°C (low temperature): heat pump for heating and air conditioner;
  - T < 30°C (very low temperature): heat pump for heating and air conditioner.



Geothermal Sources



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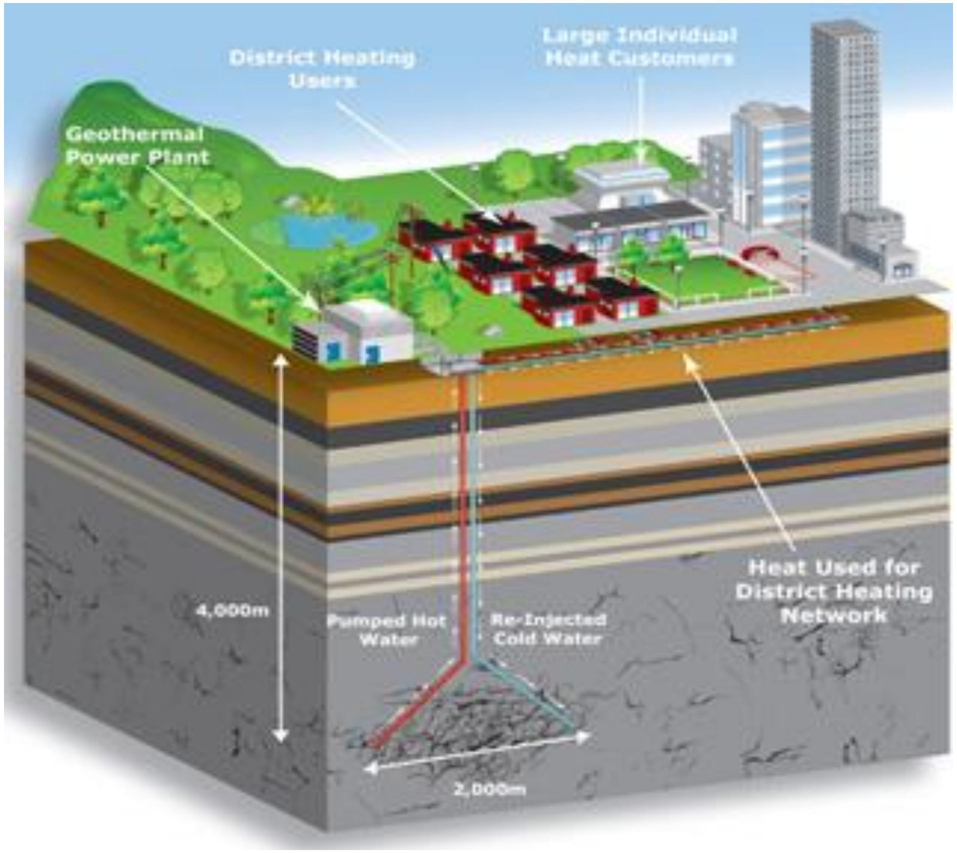
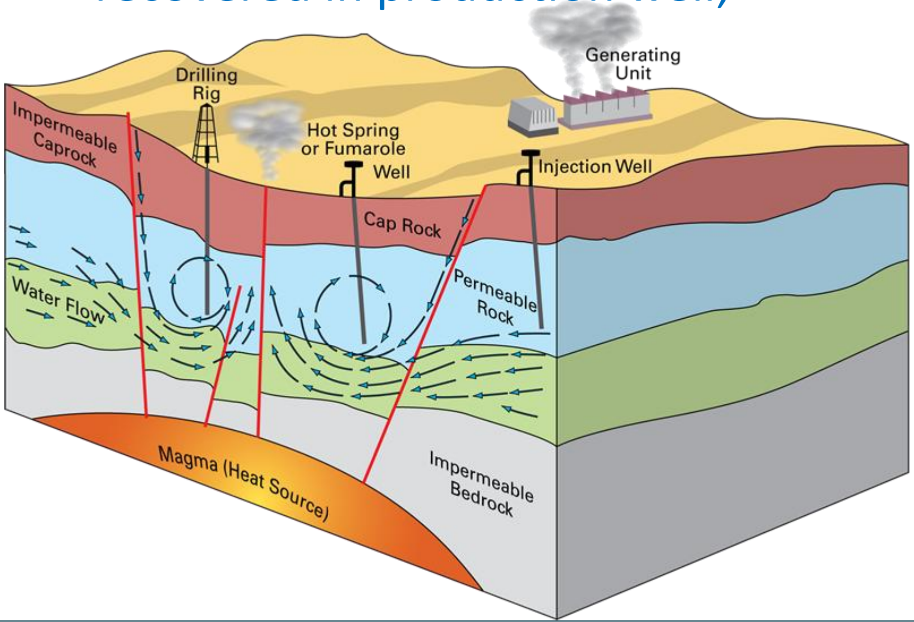
Geothermal Sources: Direct Use



- The **GS** can be exploited at high temperature with efficiency of 50-70%:
  - Cold water is injected into the permeable rock;
  - Leading to the fracturing of the hot rocks and heat transferring to water;
  - Heated water is diffused and recovered in production well;

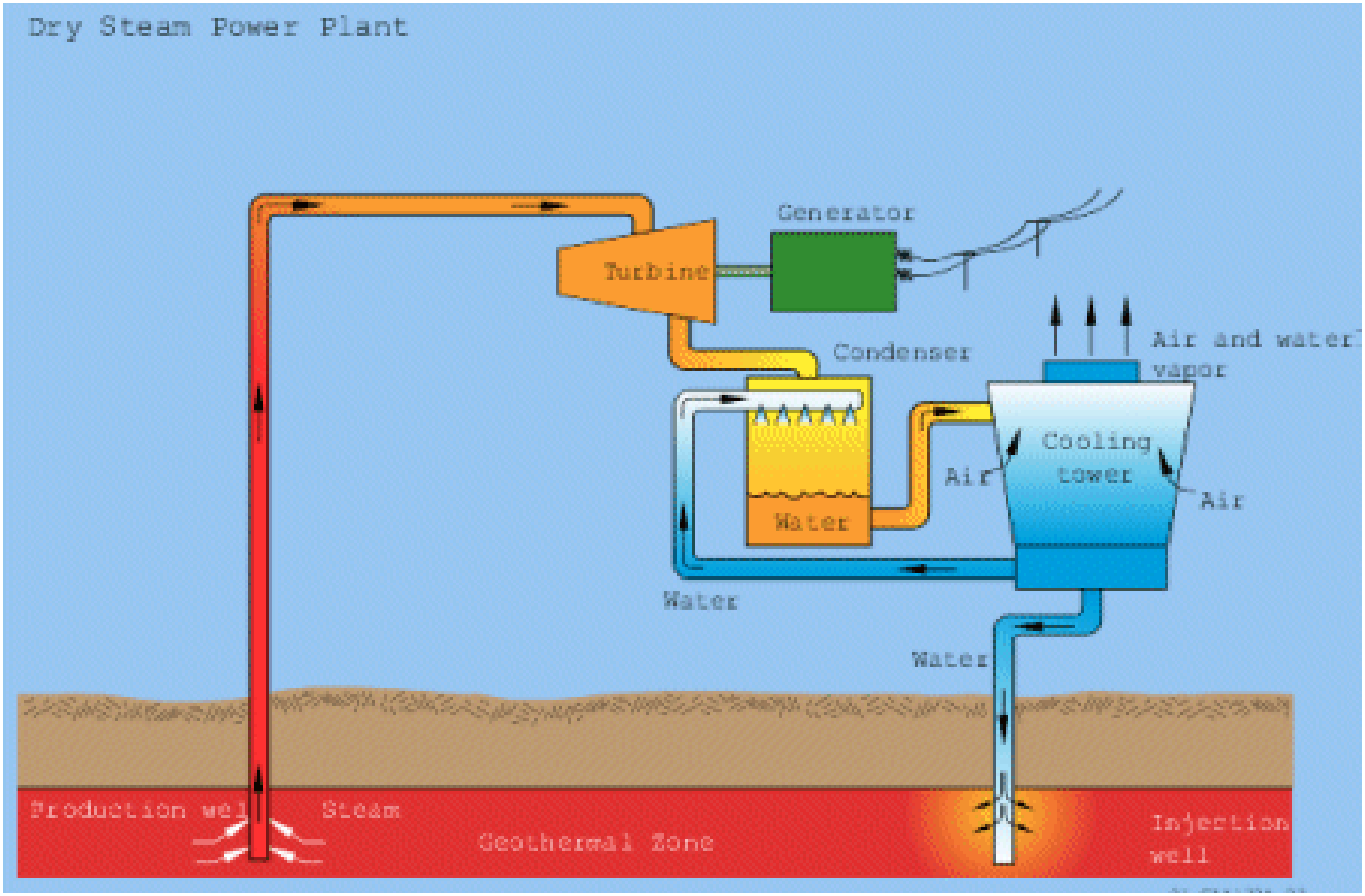


- Hot water can be used for: space heating (52%); bathing & balneology (hot spring, medical etc – 30%); agriculture (greenhouse, fish farming, etc – 12%); industry (4%).

Source: Lund *et al.* (2011) Geothermics 40:159-180.

- Convert energy stored in hydrothermal fluids to electricity;
- Three main conversion technologies:
  - Dry-steam power plant;
  - Geothermal flash power plant;
  - Binary-cycle power plant
- Choice of technology depends on:
  - Source temperature and reservoir pressure (i.e., depth of the hot fluid reservoir);
  - State of the driving thermal: dry or wet steam, water-steam solution, brine (hot water);
  - Thermo-physical properties of the driving fluid.

Dry Steam Geothermal Power Plant



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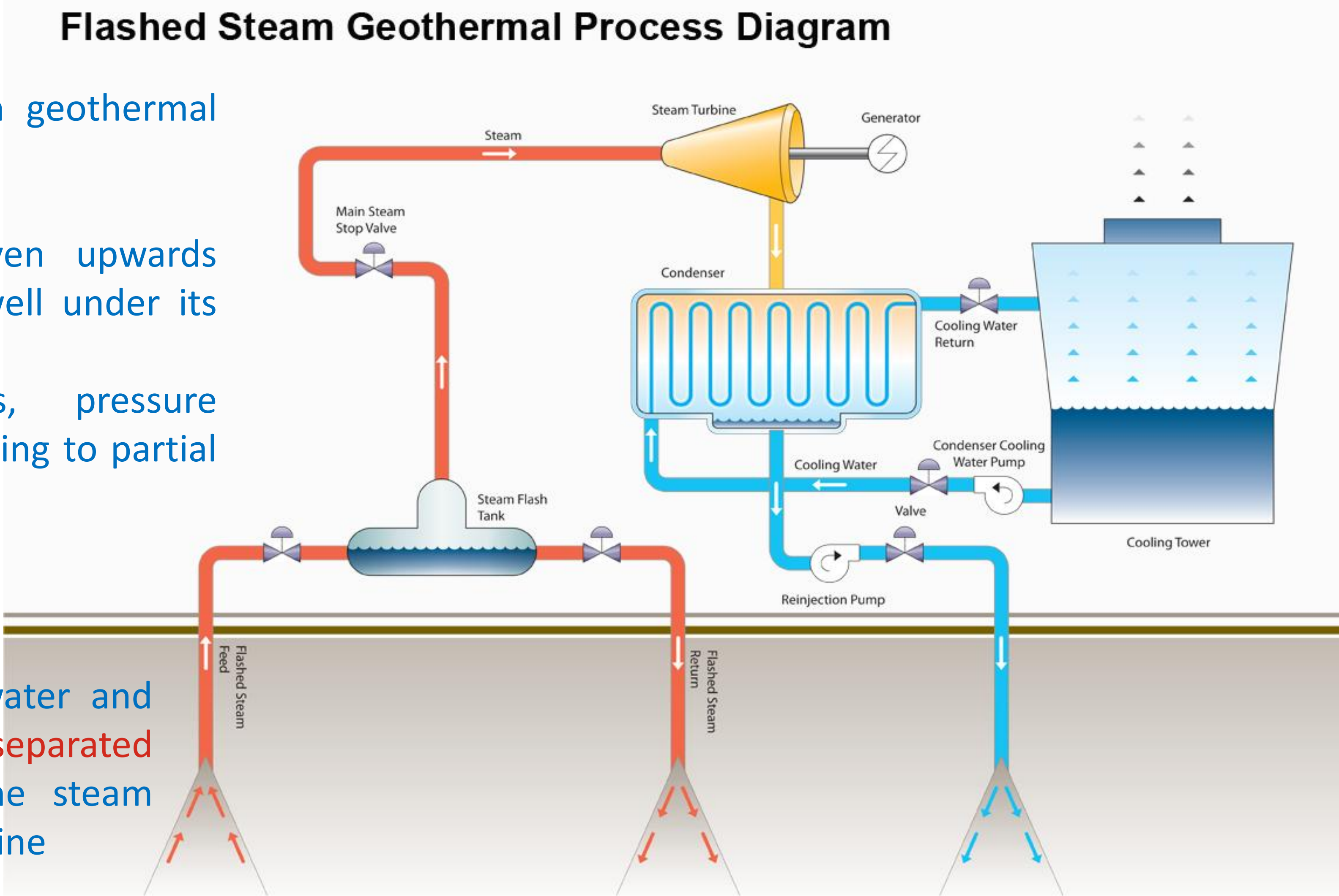
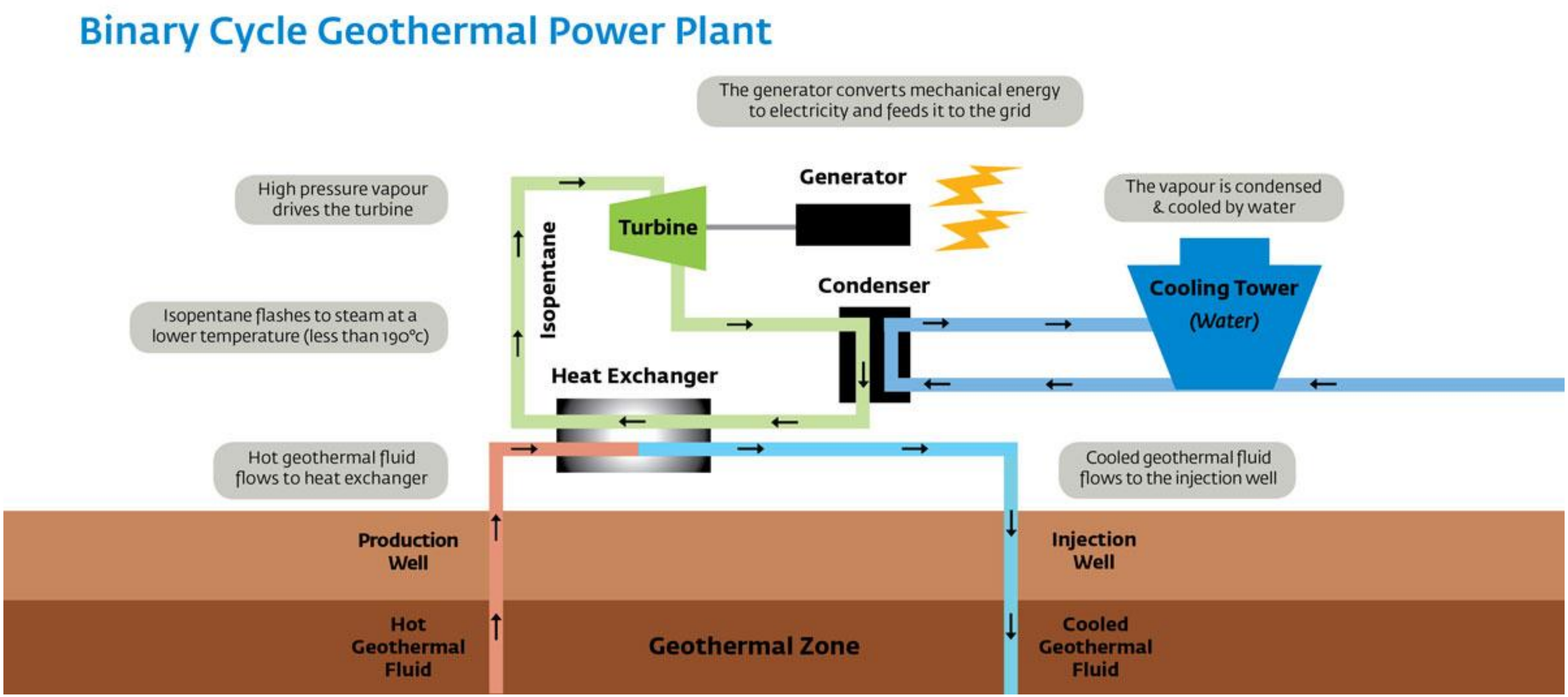
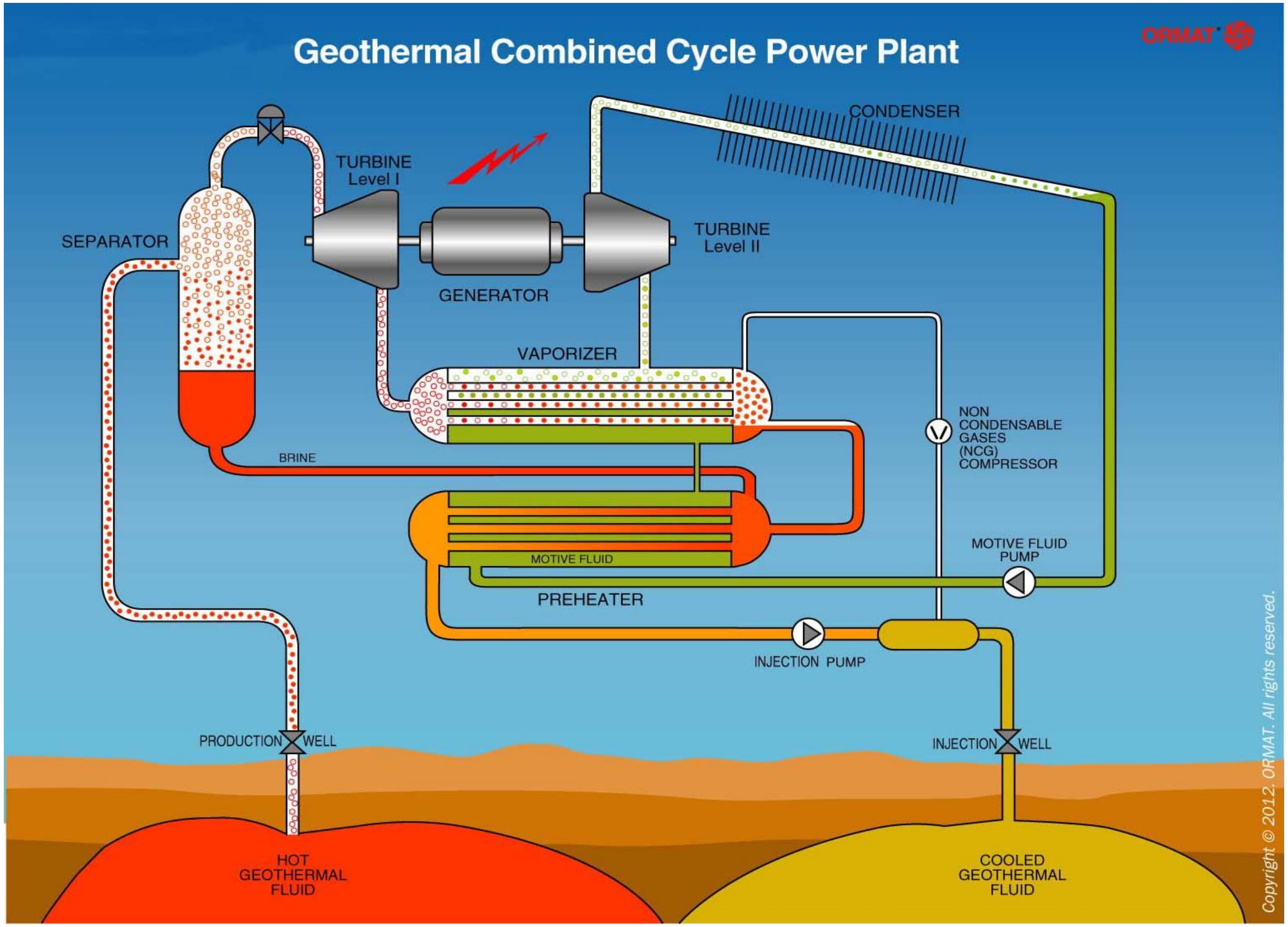


- Most common geothermal power plant;
- T > 182°C;
- Water is driven upwards through the well under its own pressure;
- As it rises, pressure decreases leading to partial boiling ;
- Liquid (hot) water and steam are separated (flash) and the steam drives the turbine



- 107≤T ≤ 182°C;
- Hot water is then used to boil the working fluid (often organic compound with low boiling point);
- The vaporized working fluid is used to drive the turbine;
- Thermal water and working fluid are operated in separated cycles with little emissions;

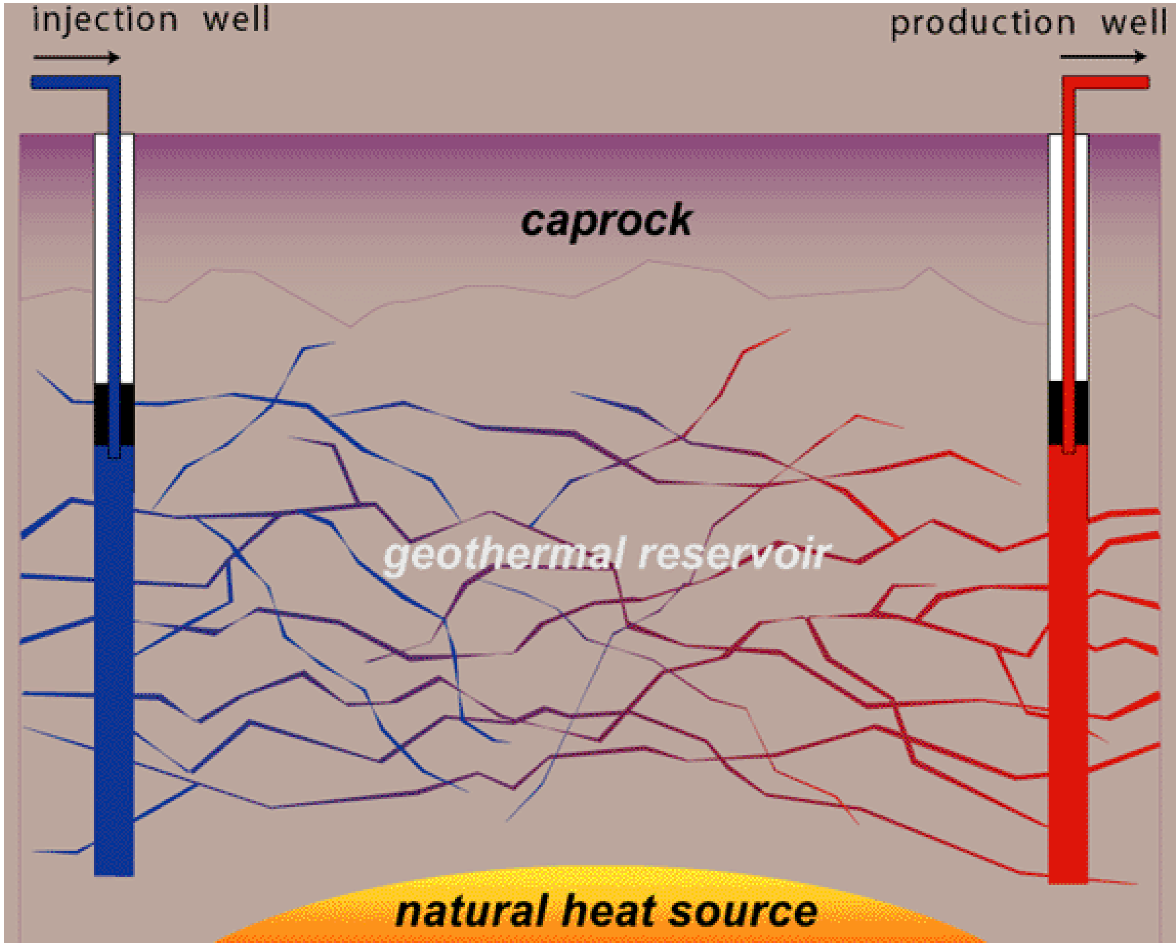
Geothermal Sources: Indirect Use (Power Generation)



- Designed to be used with high and medium temperature sources;
- Combining flash and binary power plant design.

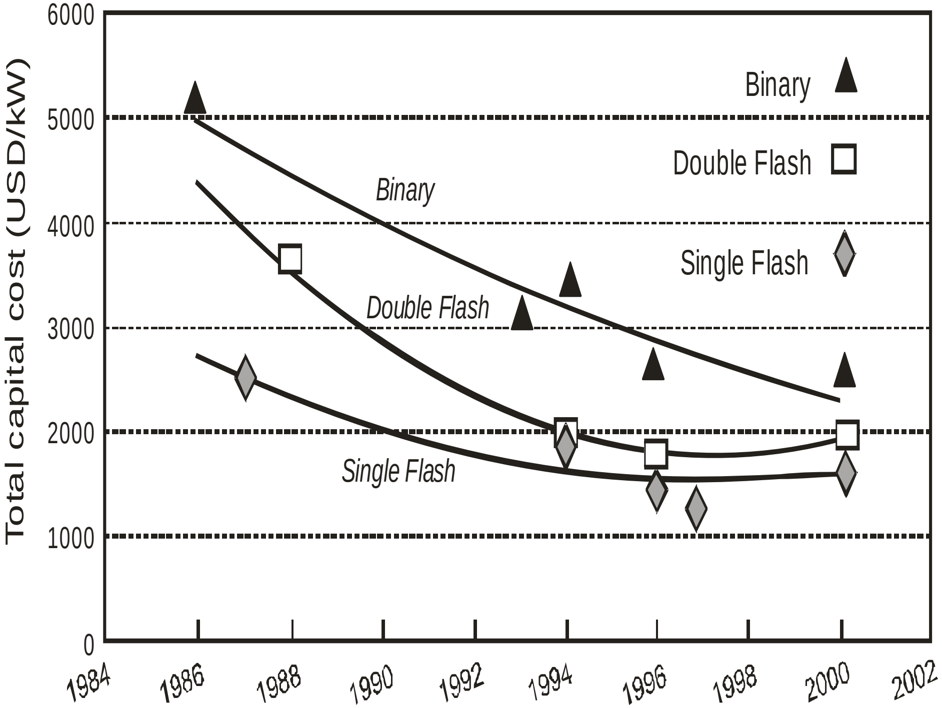
Enhanced Geothermal Systems (EGS)

- Used in deep subsurface with high temperature (150≤T ≤ 200°C);
- Fractures are induced by injection of cold water into deep wells (often with low permeability);
- Heat is transferred from the rocks to the water that is diffused through the fractures and;
- Collected in production wells;
- The hot fluid is then used as part of the previous power technologies.



Source: IPCC (2010) and http://energy.gov/eere/geothermal/how-enhanced-geothermal-system-works

Geothermal Sources: Indirect Use (Power Generation)

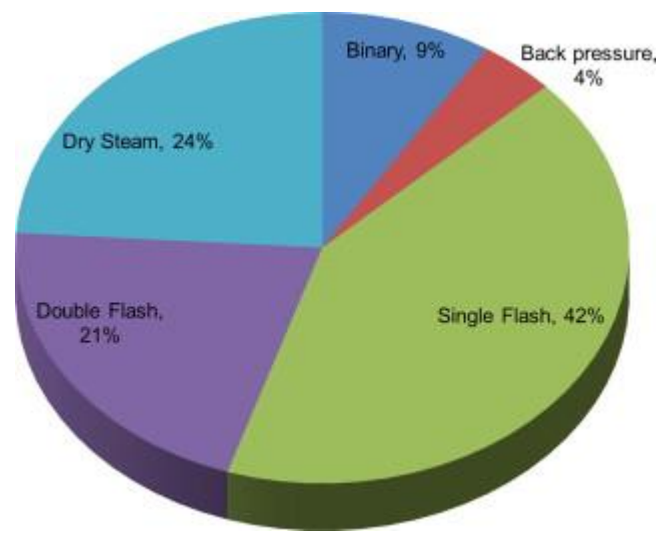


Capital Cost of Geothermal Power Plants in the US

Source: IEA(2006).

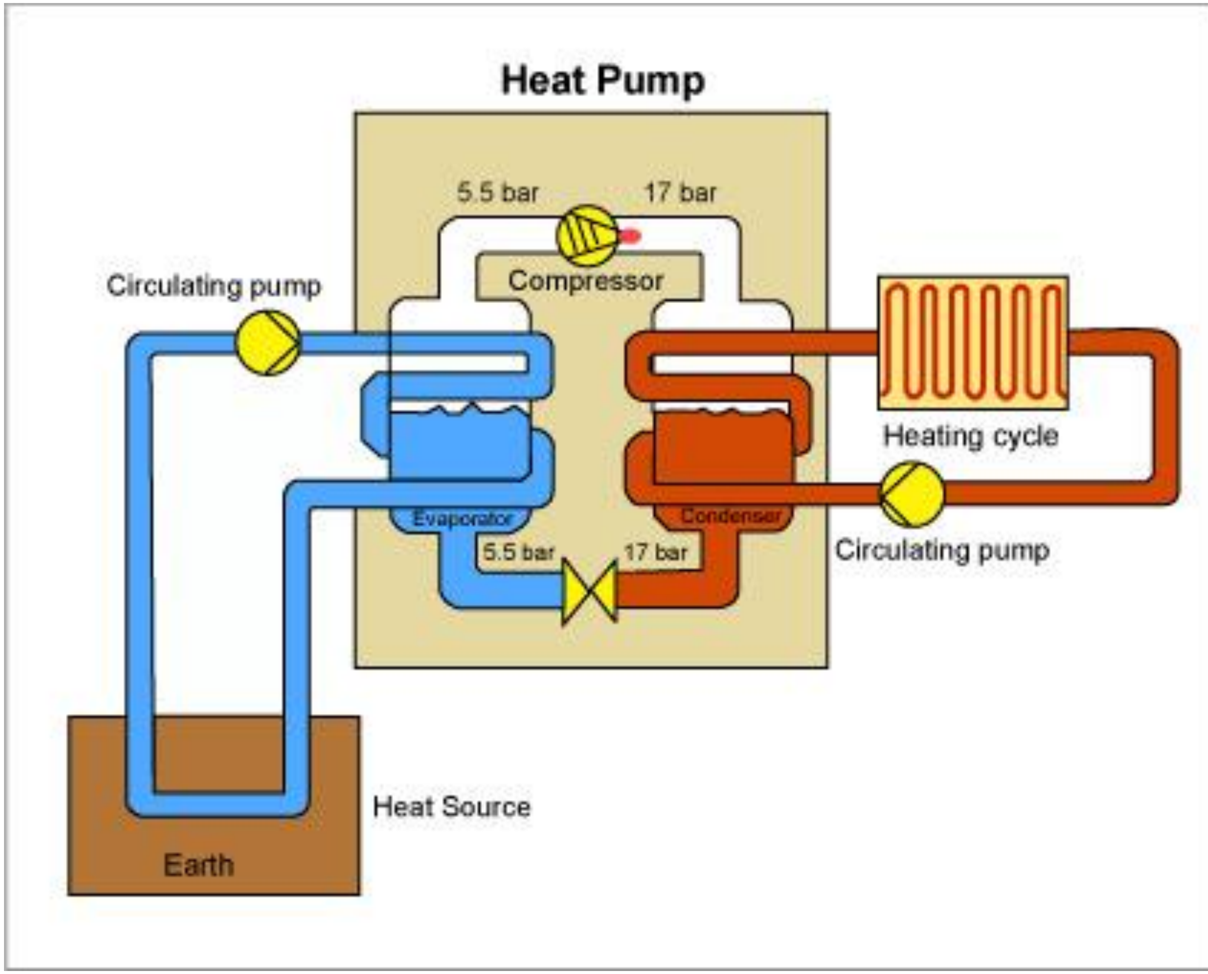
Share of different geothermal plant technologies in global electricity production.

Source: Renewable and Sustainable Energy Reviews 26(2013):446-463.

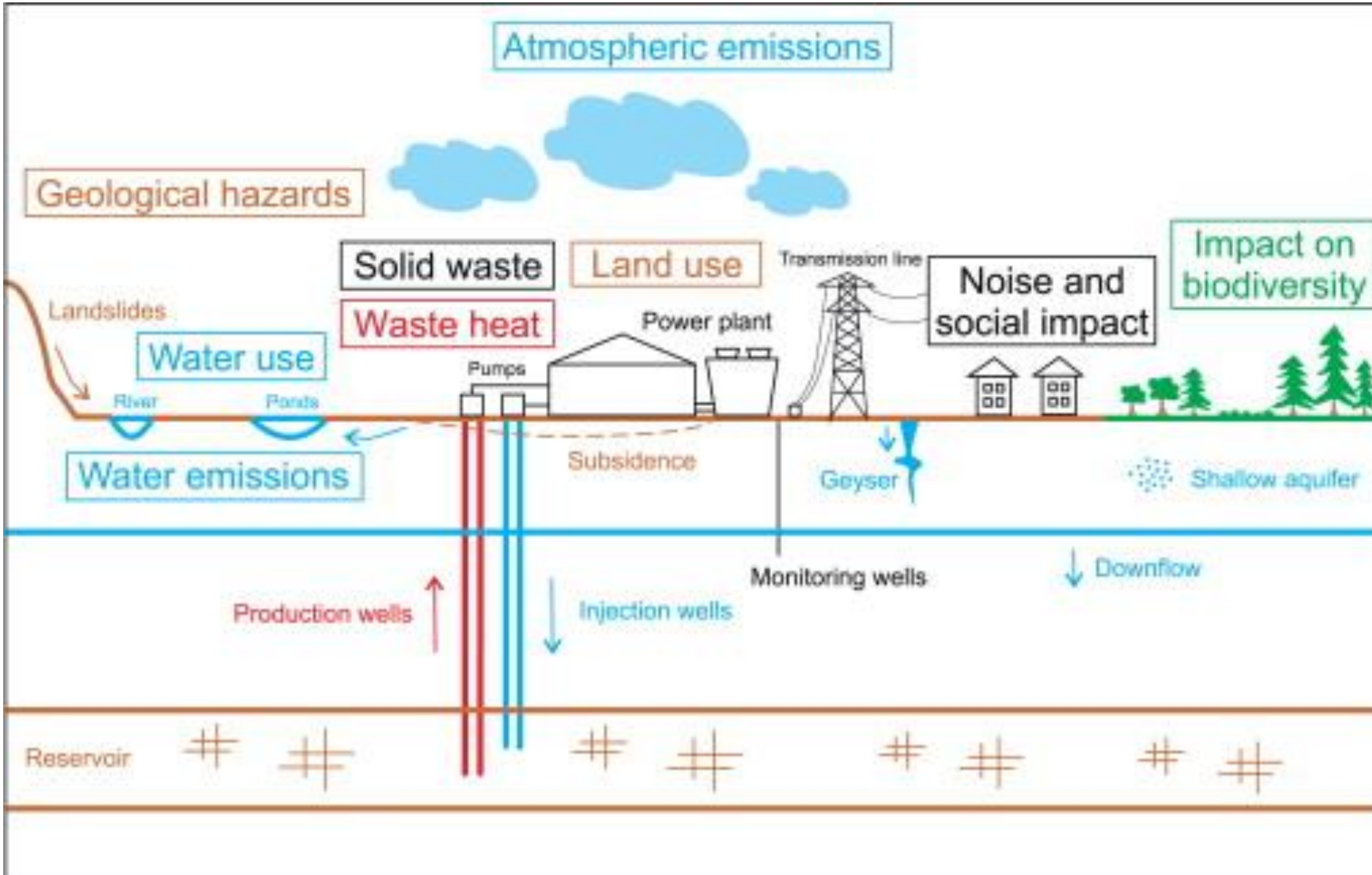


Geothermal Sources: Heat Pump

- The nearly constant temperature in the soil at low depths (< 4 m) is used by geothermal heat pumps for heating and cooling of houses and industrial facilities;
- Heat pumps are designed to use this low-grade heat source to keep temperatures of 10°–16°C;
- This temperature range is enough to keep the environment warmer in the winter and cooler during the summer;
- It operates two independent cycles.



Environmental Impact



Source: Renewable and Sustainable Energy Reviews 26(2013):446-463.

Environmental Impacts of Energy Matrix

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FUEL PHASE	Coal	Petroleum	Natural Gas	Nuclear	Hydro	Solar Photovoltaic	Solar Power Tower	Wind	Fusion	Geothermal
Extraction	Mining accident; Lung damage	Drilling-spills (off-shore)	Drilling	Mining accidents; Lung damage	Construction	Mining accidents	--	--	He, Li, H_2 production	--
Refining	Refuse piles	Water pollution	--	Milling tails	--	--	--	--	--	--
Transportation	Collisions	Spills	Pipeline explosions	--	--	--	--	--	--	--
On-Site										
Thermal	High efficiency	High efficiency	High efficiency	Low efficiency	--	High efficiency; Ecosystem change	Ecosystem change	--	--	Low efficiency
Air	Particulates, SO_2, NOx	SO_2, NOx	NOx	Radiation releases	--	--	--	--	--	H_2S
Water	Water treatment chemicals	Water treatment chemicals	Water treatment chemicals	Water treatment chemicals	Destroy prior ecosystems	Water treatment chemicals	Water treatment chemicals	--	Tritium in cooling water	Brine in streams
Aesthetic	Large plant transmission lines	Large plant transmission lines	Large plant transmission lines	Large plant transmission lines	Large plant transmission lines	Poor large areas	Poor large areas	Large areas; Large towers; Noise	Small area	Poor large area
Wastes	Ash; Slag	Ash	--	Spent fuel; Reprocessing waste storage	--	Spent cells	--	Irradiated structural material	--	--
Special Problems	--	--	--	--	--	Construction accidents	--	Bird; Human injuries	Occupational radiation doses	--
Major Accidents	Mining	Oil spills	Pipeline explosions	Reactor cooling and meltdown	Dam failure	Fire	--	--	Tritium release	--

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Source: MITOpenCourseWare

Environmental Impact

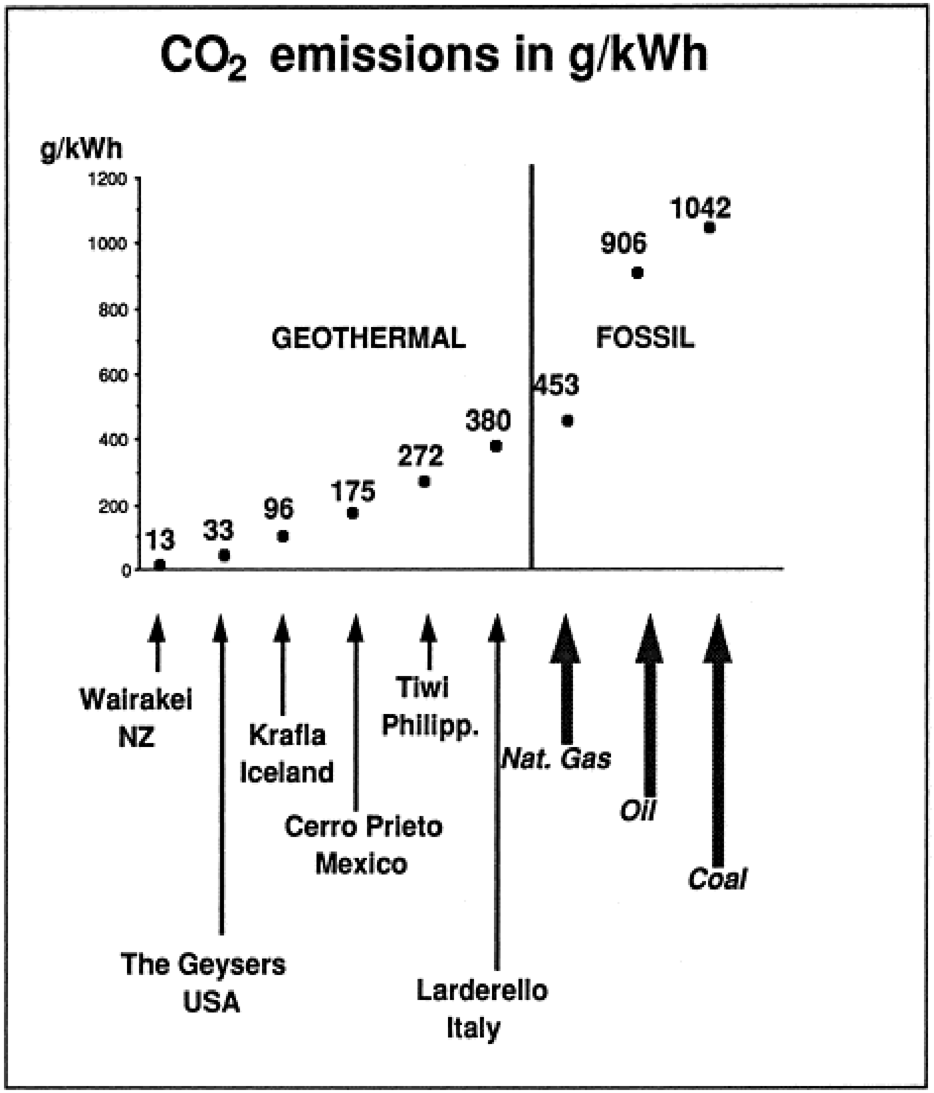
- **Atmospheric Emissions:**
  - NOx: small amounts mainly due to the combustion of H_2S;
  - H_2S (hydrogen sulfide): from volcano gases, petroleum deposits, natural gas and geothermal fluids and need to be captured;
  - SO_2: this compound is not directly released by geothermal power plants, but H_2S can react in the atmosphere and form SO_2;
  - Particulate matter (PM): this involves liquid droplets and particles from smoke, dust and ashes. Water-cooled geothermal power plants do emit small quantities of PM from cooling towers as steam condensates;
  - CO_2 : Geothermal power plants emit small quantities. Some geothermal reservoir fluids contain varying amounts of non-condensable gases, including CO_2.

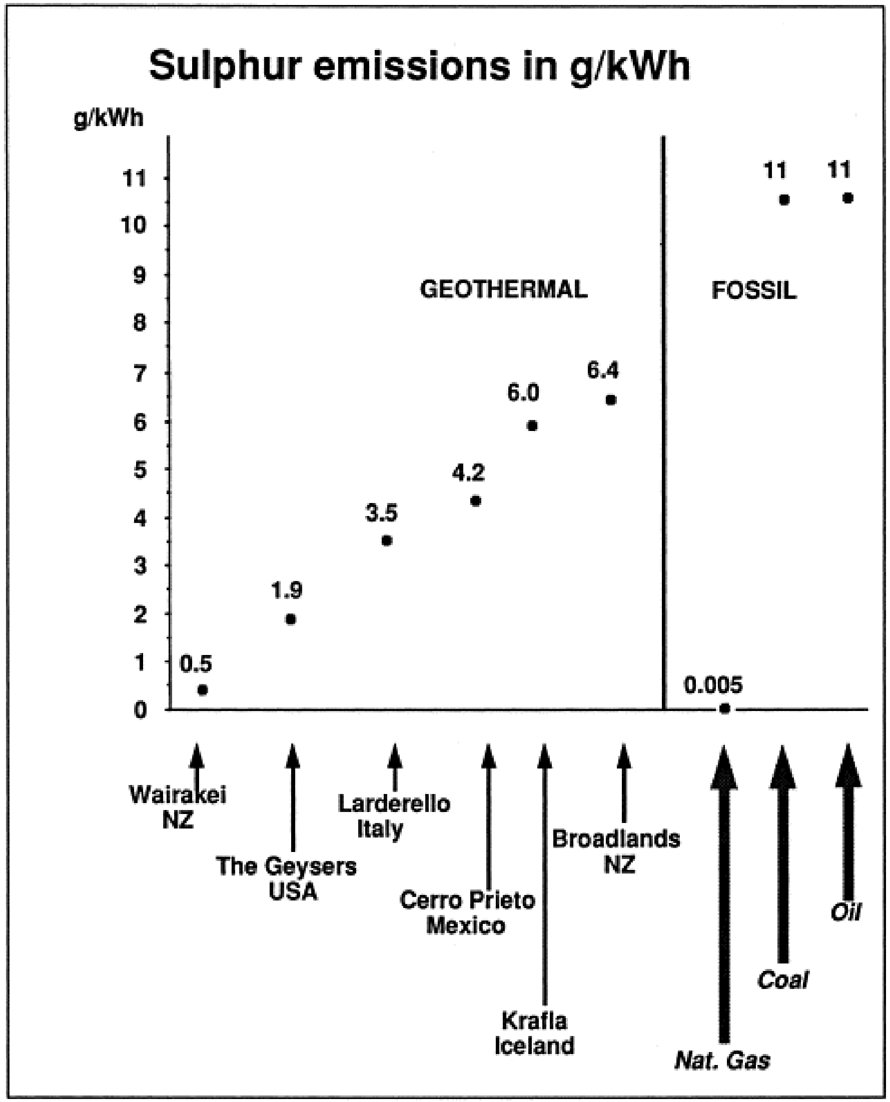
Environmental Impact

Plant Type	NO_x (kg/MWh)	SO_2 (kg/MWh)	CO_2 (kg/MWh)	PM
Coal-fired	1.95	4.71	993.82	1.01
Oil-fired	1.81	5.44	758.41	NA
Natural Gas-fired	1.34	0.10	549.75	0.06
Geothermal (flash)	0	0.16	27.21	0
Geothermal (binary & flash/binary)	0	0	0	Traces
Geothermal (geysers dry steam)	Traces	Traces	40.28	Traces

Source: Kagel *et al*. (2007) A Guide to Geothermal Energy and the Environment, http://www.geo-energy.org

Environmental Impact





Source: Renewable and Sustainable Energy Reviews 6(2002):3-65.

Environmental Impact

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- **Solid and Liquid Waste:** (Tutorial)
  - Arsenic is produced from the subsurface geothermal fluids as part of sludge and scales from the H_2S processing;
  - Waste is produced from drilling activities, as drilling cuttings (mainly bentonites). Mud and cuttings are stored as 'sumps' for disposal.
- **Land Use:** (Tutorial)
  - Properties of small sizes;
  - Subsidence;
  - Induced seismicity;
  - Land slides.
- **Water Quality** (Tutorial)
  - Chemical for water & wastewater treatment;
  - Cool brine.

Summary

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- Current geothermal technologies;
- Environmental impacts;
- Drive for the future.

Additional Reading

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- Annual Energy review 2011 (DoE/EIA-0384): http://www.eia.gov/totalenergy/data/annual/pdf/aer.pdf
- Energy for a Sustainable Future: Reports and Recommendations (2010), The Secretary-General's Advisory Group on Energy and Climate Change (AGECC): http://www.un.org/wcm/webdav/site/climatechange/shared/Documents/AGECC%20summary%20report%5B1%5D.pdf
- The Future of Geothermal Energy: https://www1.eere.energy.gov/geothermal/pdfs/future_geo_energy.pdf
- R. DiPippo (2012) 'Geothermal Power Plants'; Butterworth Heinemann.
- H.K. Gupta (1980) 'Developments in Economic Geology – 12. Geothermal Resources: An Energy Alternative'; Elsevier.
- H.C.H. Armstead (1983) 'Geothermal Energy: Its Past, Present and Future Contribution to the Energy Needs of Man'; E&FN Spon.
- E. Barbier (2002) 'Geothermal Energy Technology and Current Status: An Overview', *Renewable & Sustainable Energy Reviews* 6:3-65.
- S.J. Zarrouk & H. Moon (2014) 'Efficiency of Geothermal Power Plants: A Worldwide Review', *Geothermics* 51:142-153.
- L. Rybach (2003) 'Geothermal Energy: Sustainability and the Environment', *Geothermics* 32:463-470.
- H.N. Pollack, S.J. Hurter, J.R. Johnson (1993) 'Heat Flow from the Earth's Interior: Analysis of the Global Data Set', *Reviews of Geophysics* 31:267-280.