Energi Terbarukan

Pertemuan 12:
Geothermal Energy

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Geothermal Energy

Modified from:
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GEOTHERMAL OVERVIEW

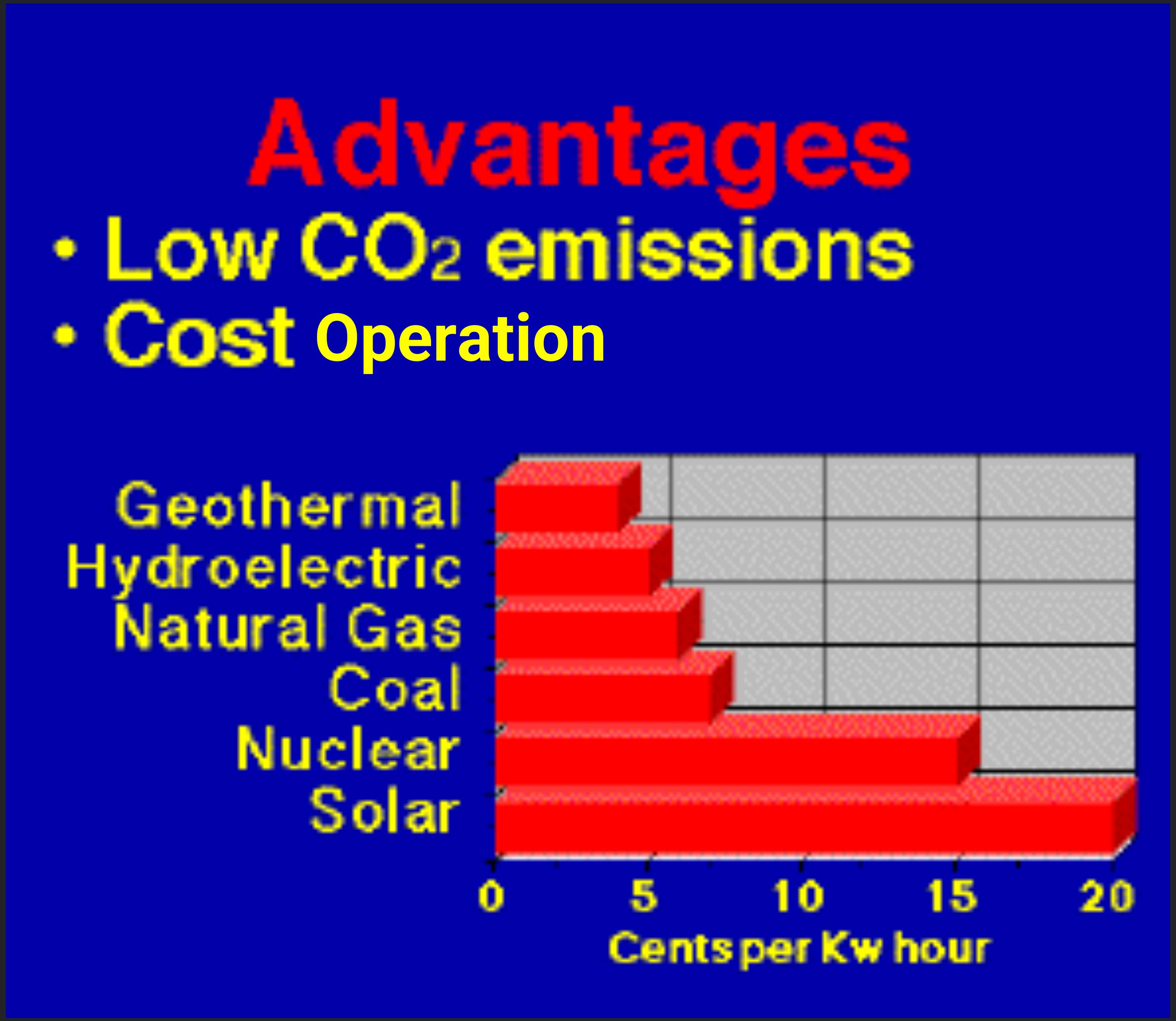
Geothermal in Context

Energy Source	2000	2001	2002	2003	2004[p]
Total [a]	**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[b]	23.916	22.861	23.628	23.069	23.000
Petroleum[c]	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.html

Advantages of Geothermal



http://www.earthsci.org/mineral/energy/geother/geother.htm

Heat from the Earth’s Center

Earth's core maintains temperatures in excess of 5000°C

Heat energy continuously flows from hot core

- Conductive heat flow
- Convective flows of molten mantle beneath the crust.

Mean heat flux at earth's surface

- 16 kilowatts of heat energy per square kilometer
- Dissipates to the atmosphere and space.
- Tends to be strongest along tectonic plate boundaries

Volcanic activity transports hot material to near the surface

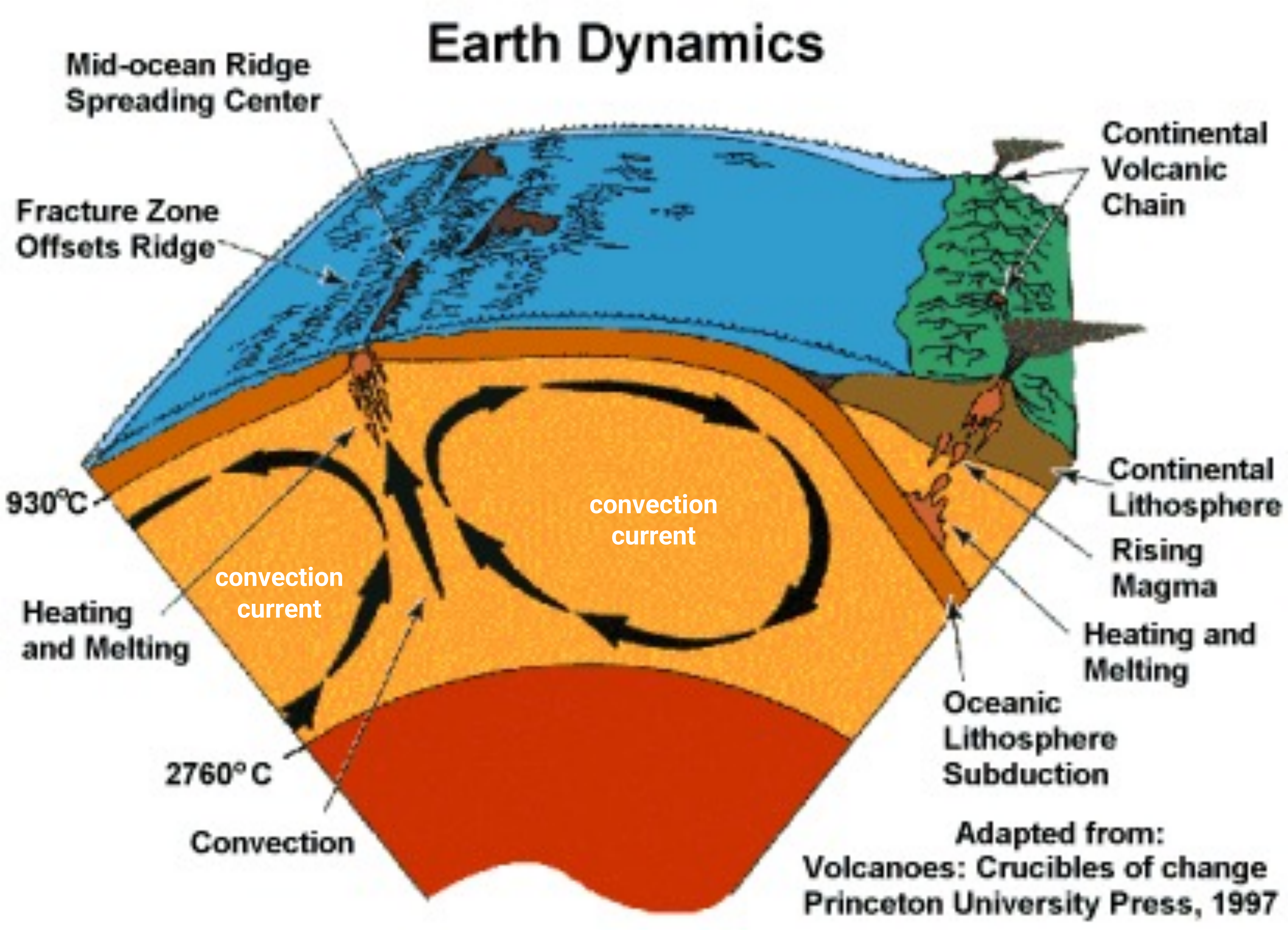
- Only a small fraction of molten rock actually reaches surface.
- Most is left at depths of 5-20 km beneath the surface,

Hydrological convection forms high temperature geothermal systems at shallow depths of 500-3000m.

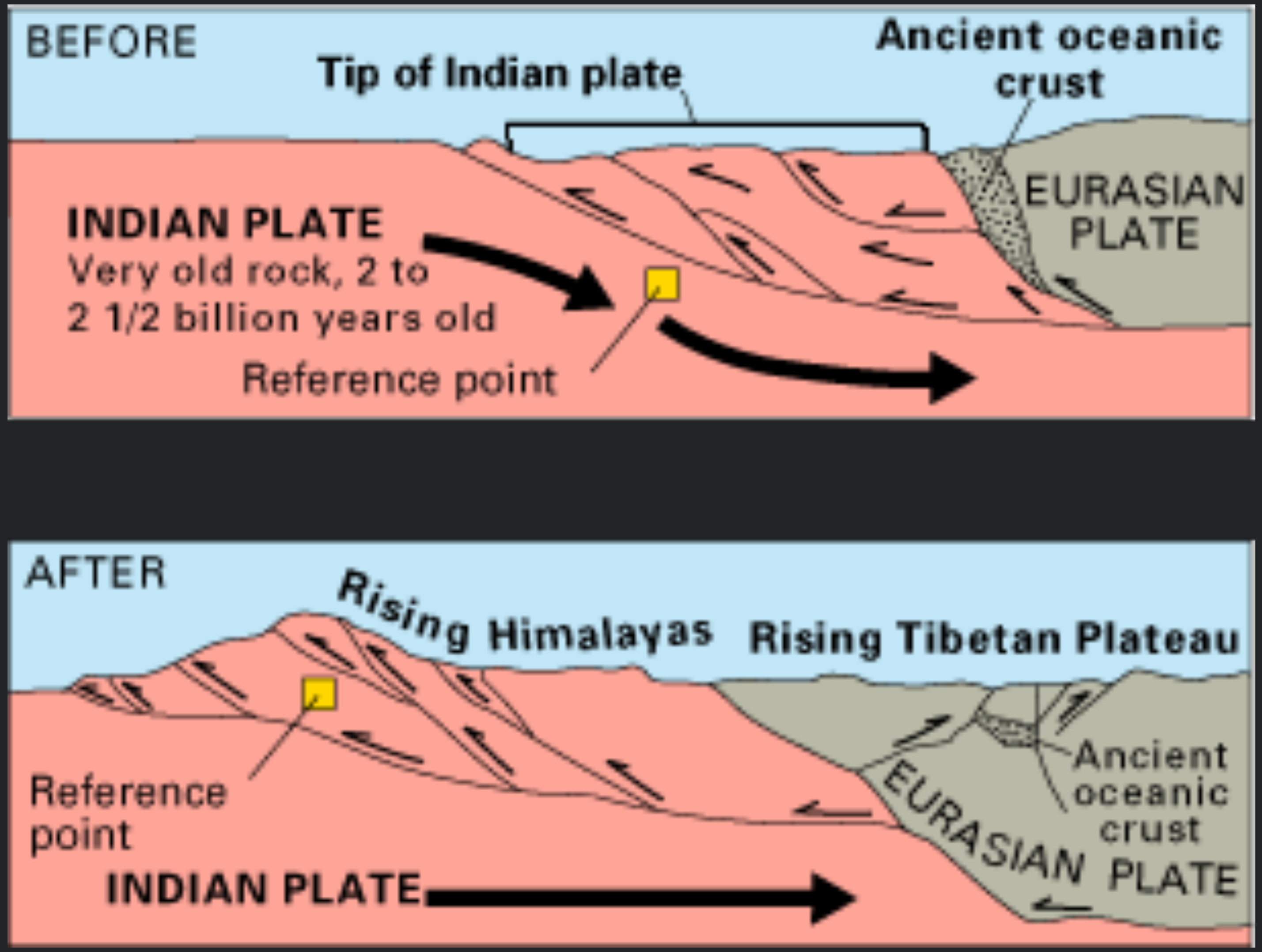
http://www.worldbank.org/html/fpd/energy/geothermal/technology.htm

Earth Dynamics

Convection is the transfer of heat through a fluid (liquid or gas) by the physical movement of the fluid itself

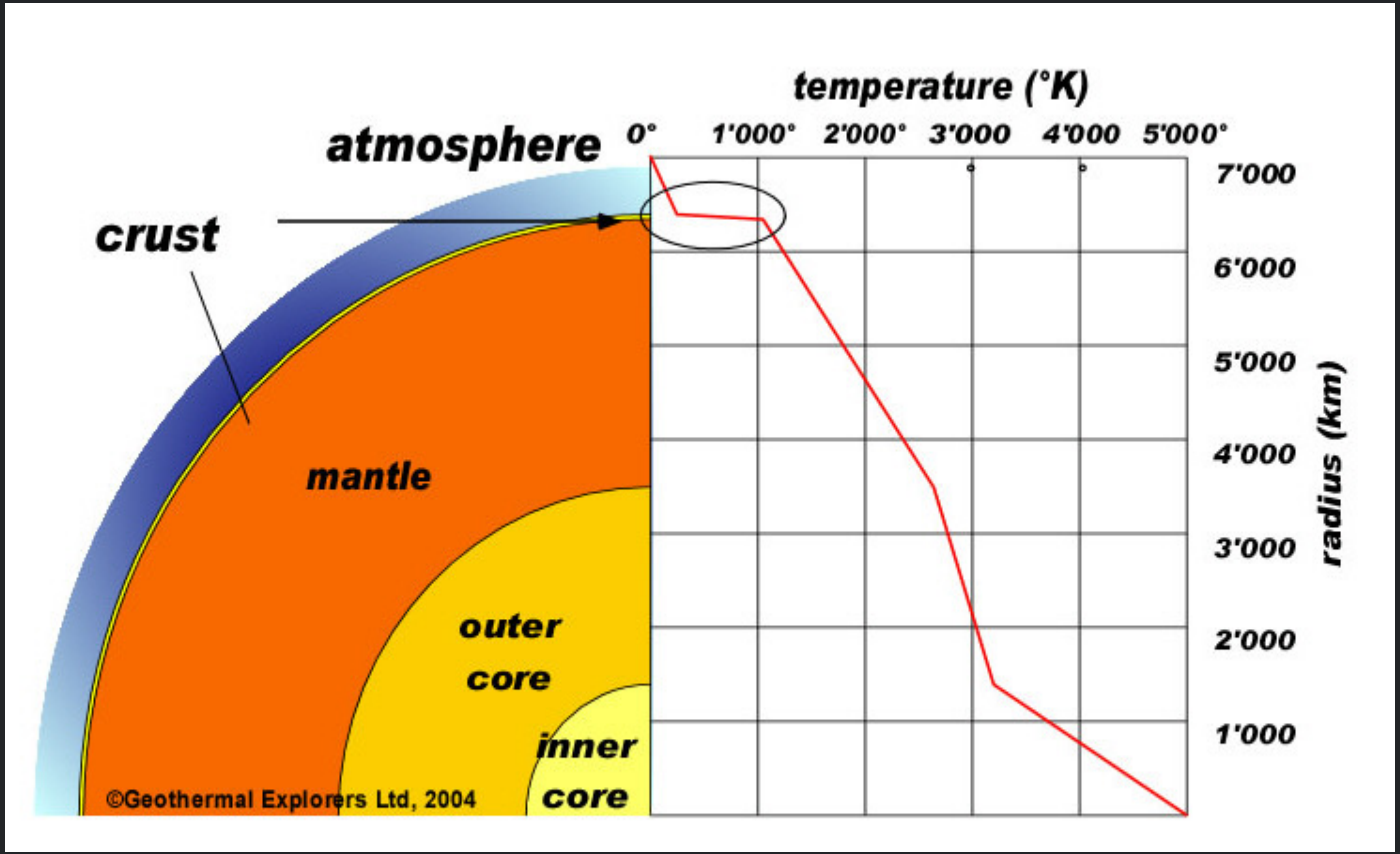


http://www.worldbank.org/html/fpd/energy/geothermal/technology.htm



G-MAP: https://www.google.com/maps/place/Reykjanes/@63.8150202,-22.6865514,3779m/data=!3m1!1e3!4m6!3m5!1s0x4929e432592fd8e7:0x35e22e0c33129eb6!8m2!3d63.8086111!4d-22.6944444!16s%2Fm%2F0y624ws!5m2!1e2!1e4?entry=ttu&g_ep=EgoyMDI1MDYwMS4wIKXMDSoASAFQAw%3D%3D

Earth Temperature Gradient



http://www.geothermal.ch/eng/vision.html

Geothermal Site Schematic

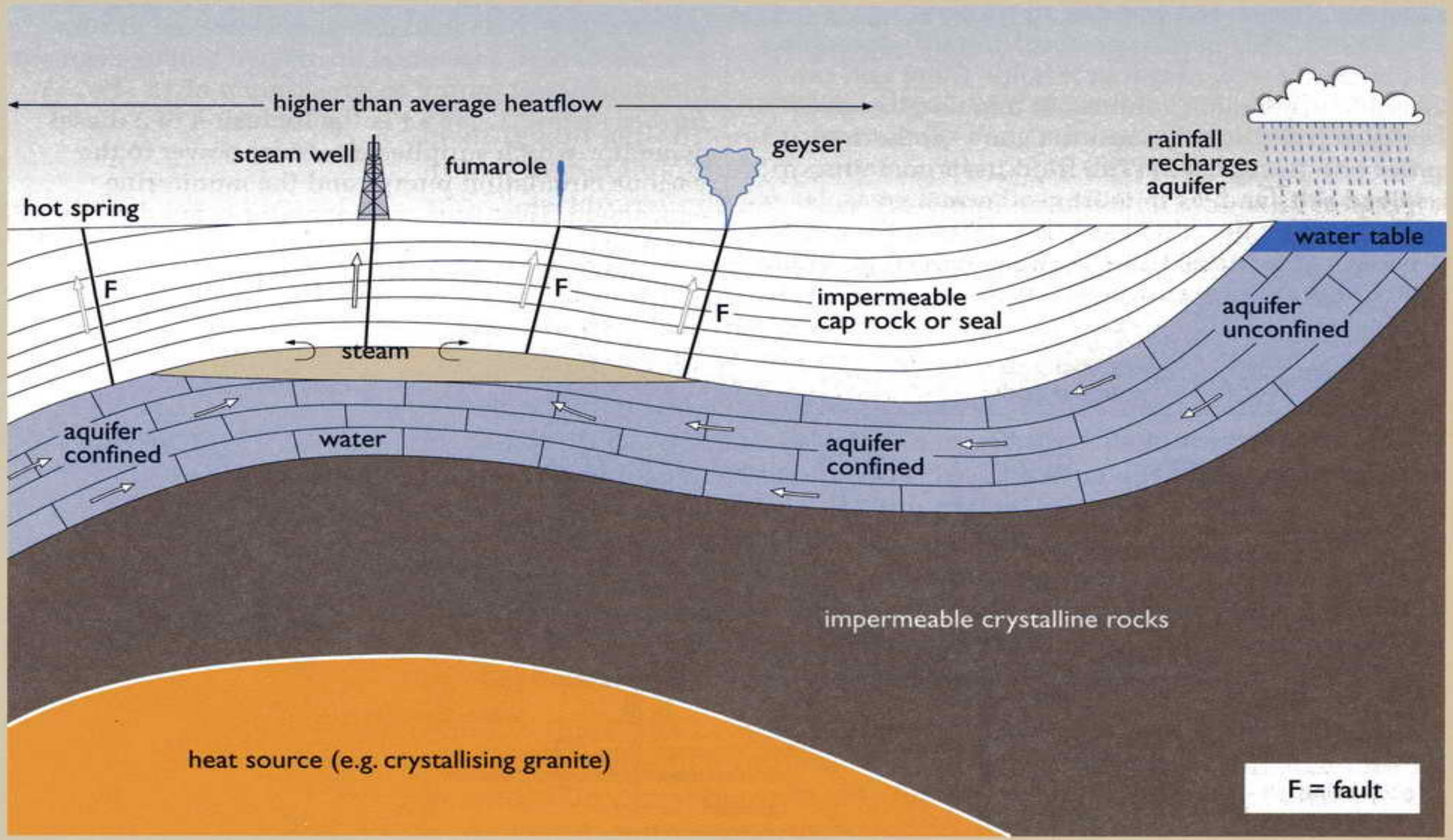


Figure 9.5 Simplified schematic cross-section to show the three essential characteristics of a geothermal site: an aquifer (e.g. fractured limestone with solution cavities); an impermeable cap rock to seal the aquifer (e.g. clays or shales); and a heat source (e.g. crystallising granite). Steam and hot 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 springs in Steamboat Springs area.

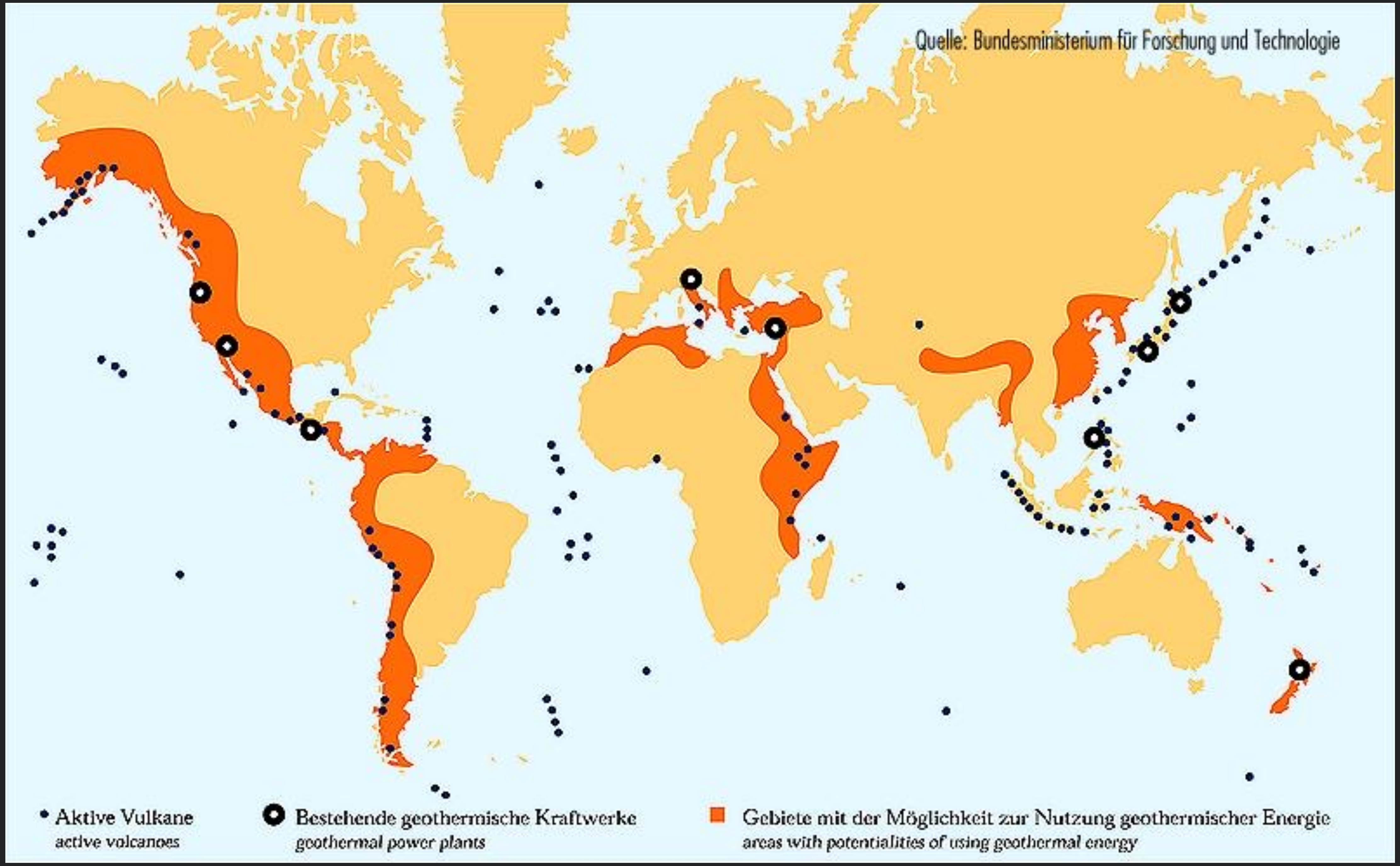
http://www.eia.doe.gov/cneaf/solar.renewables/page/geothermal/geothermal.html

Fumaroles

http://lvo.wr.usgs.gov/cdf_main.htm

http://volcano.und.edu/vwdocs/volc_images/img_white_island_fumerole.html

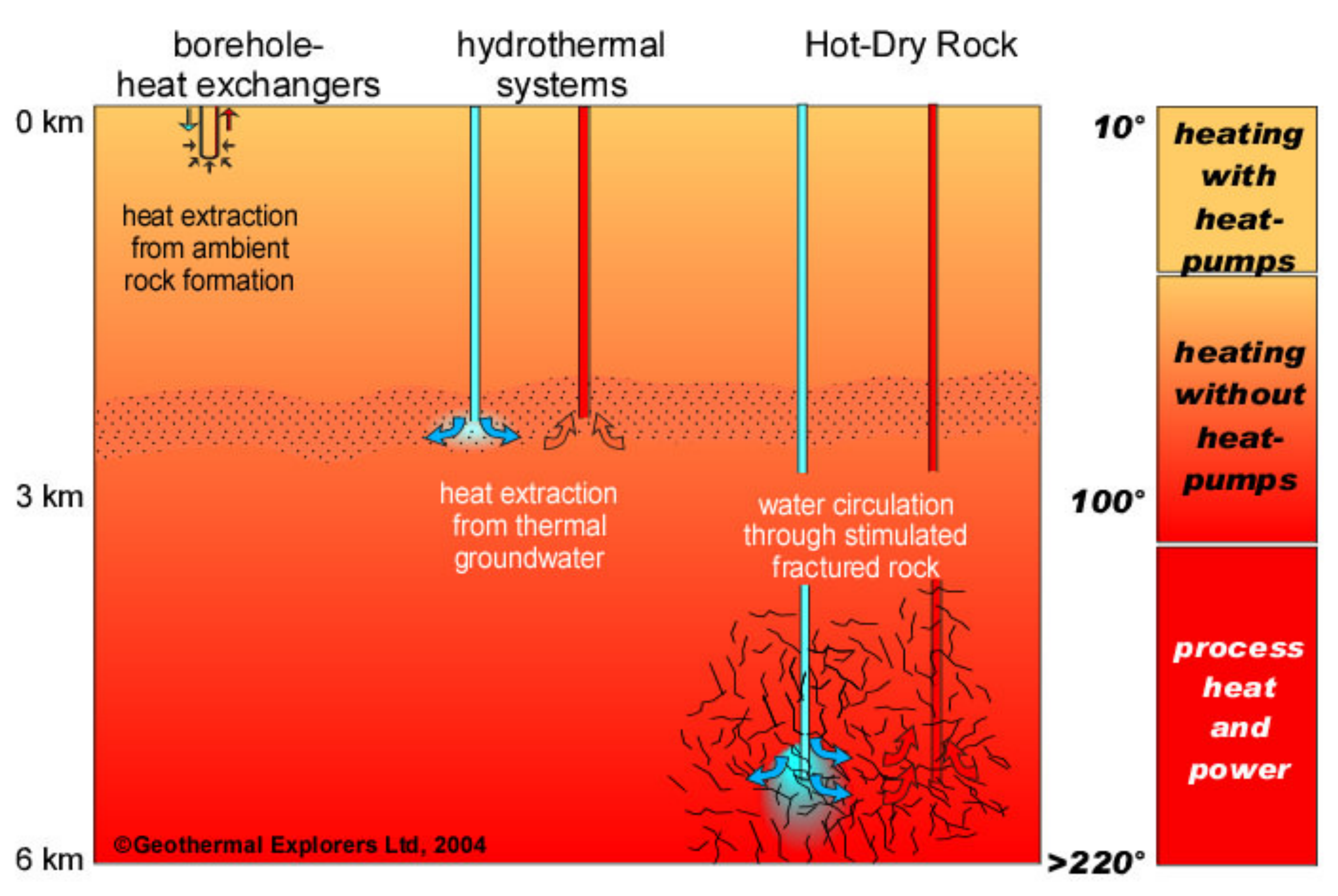
Global Geothermal Sites



http://www.deutsches-museum.de/ausstell/dauer/umwelt/img/geothe.jpg

Extracting Geothermal Energy

Methods of Heat Extraction



http://www.geothermal.ch/eng/vision.html

Units of Measure

Pressure

1 Pascal (Pa) = 1 Newton / square meter

100 kPa = ~ 1 atmosphere = ~14.5 psi

1 MPa = ~10 atmospheres = ~145 psi

Temperature

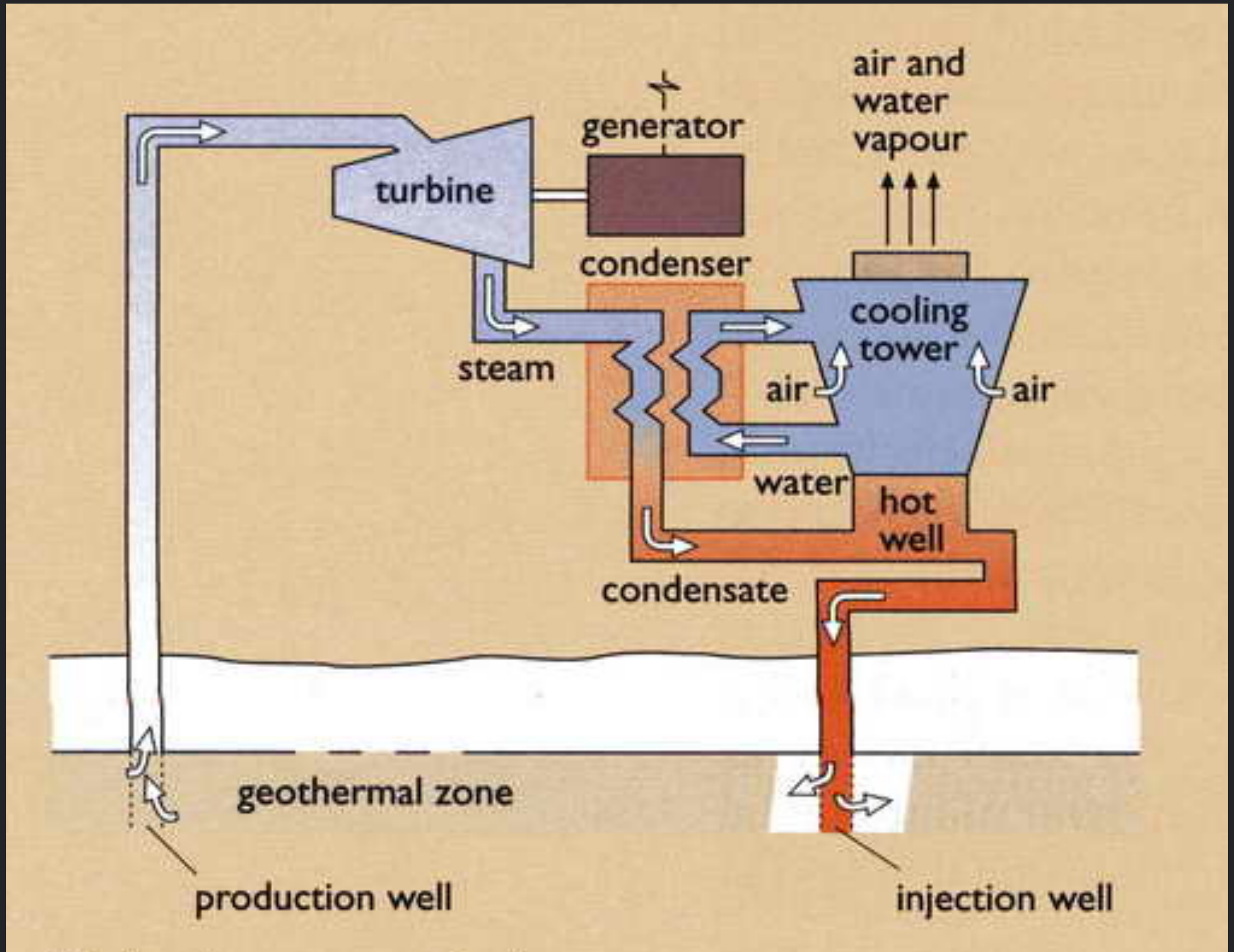
Celsius (ºC); Fahrenheit (ºF); Kelvin (K)

0 ºC = 32 ºF = 273 K

100 ºC = 212 ºF = 373 K

Dry Steam Schematic

- "Dry" steam extracted from natural reservoir
  - 180-225 ºC (356-437 ºF)
  - 4-8 MPa (580-1160 psi)
  - 200+ km/hr (100+ mph)
- Steam is used to drive a turbo-generator
- Steam is condensed and pumped back into the ground
- Can achieve 1 kWh per 6.5 kg of steam
  - A 55 MW plant requires 100 kg/s of steam



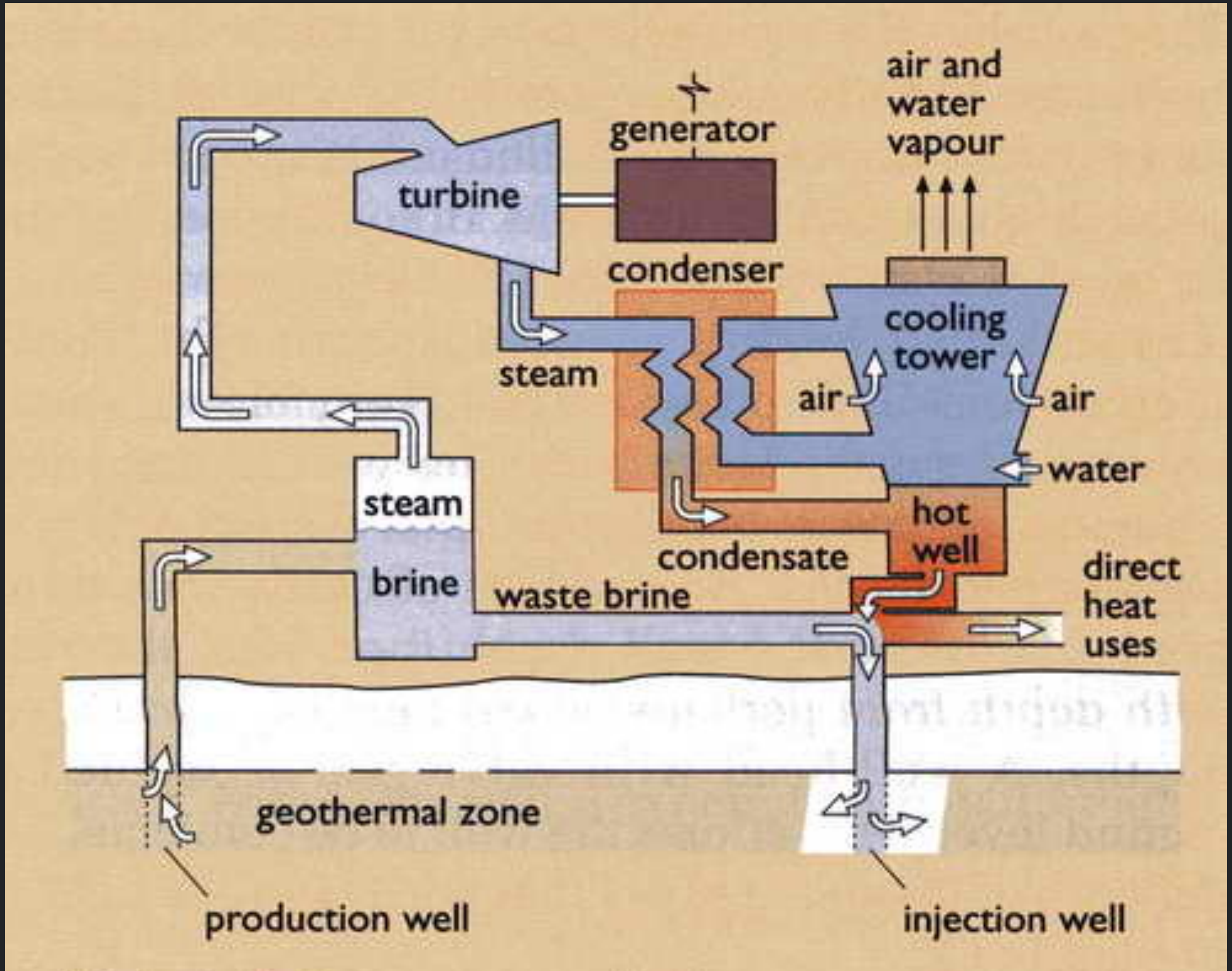
(a) dry steam power plant

Boyle, *Renewable Energy*, 2nd edition, 2004

Single Flash Steam Schematic

- Steam with water extracted from ground
- Pressure of mixture drops at surface and more water “flashes” to steam
- Steam separated from water
- Steam drives a turbine
- Turbine drives an electric generator
- Generate between 5 and 100 MW
- Use 6 to 9 tonnes of steam per hour

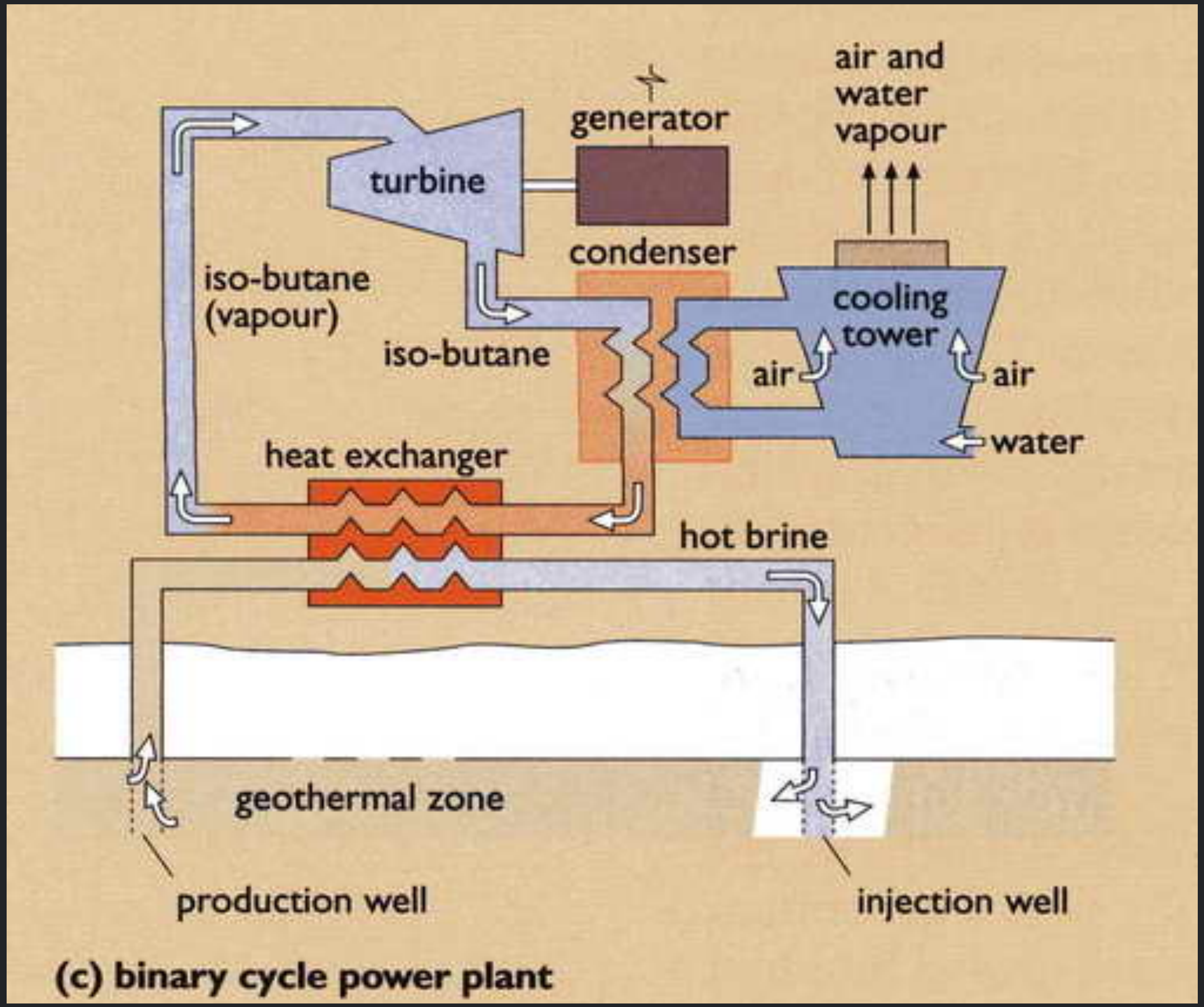
Boyle, *Renewable Energy*, 2nd edition, 2004



(b) single flash steam power plant

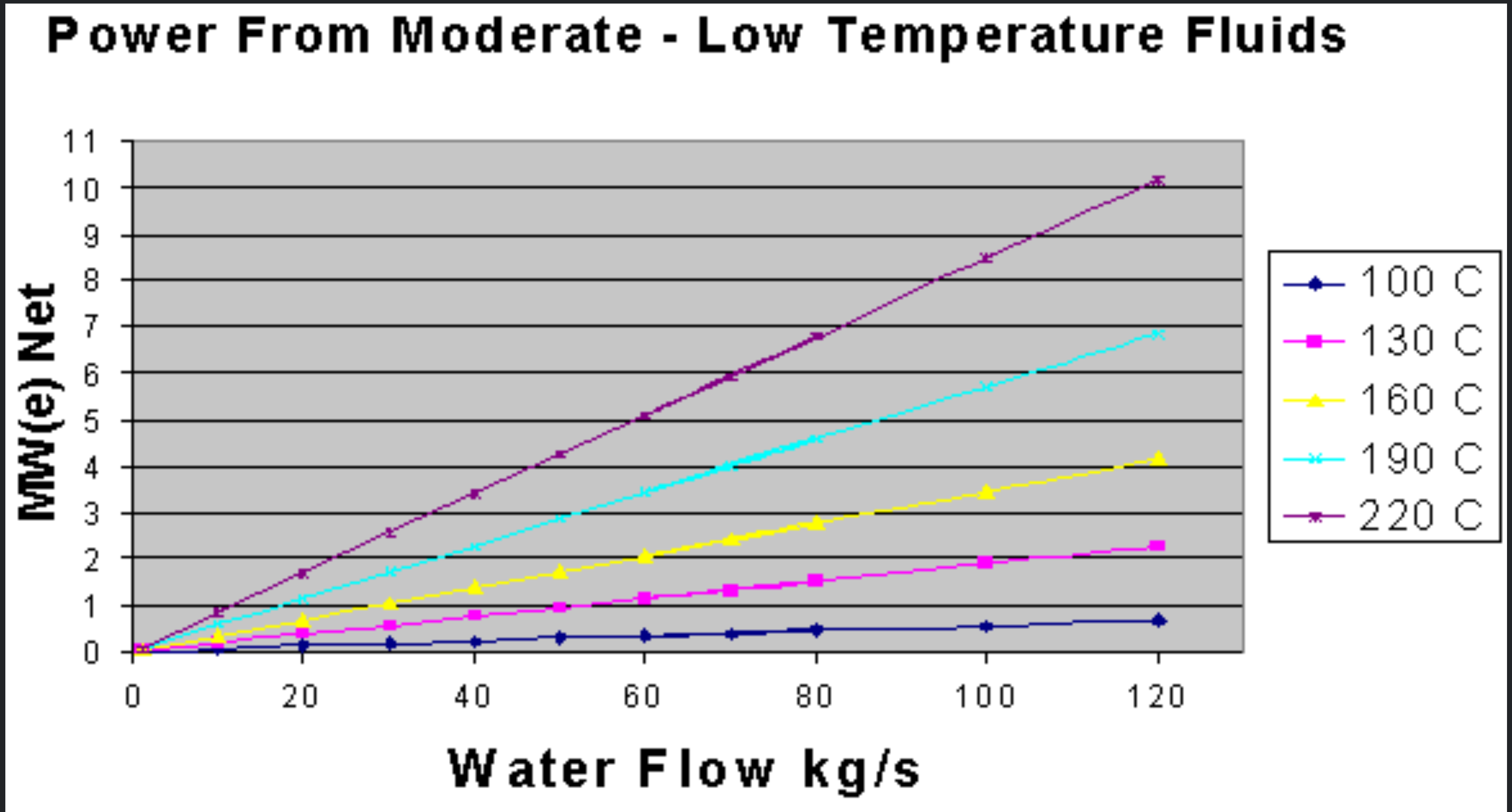
Binary Cycle Schematic

- Low temps – 100º and 150ºC
- Use heat to vaporize organic liquid
    - E.g., iso-butane, iso-pentane
- Use vapor to drive turbine
    - Causes vapor to condense
    - Recycle continuously
- Typically **7 to 12 %** efficient
- 0.1 – 40 MW units common



Boyle, *Renewable Energy*, 2nd edition, 2004

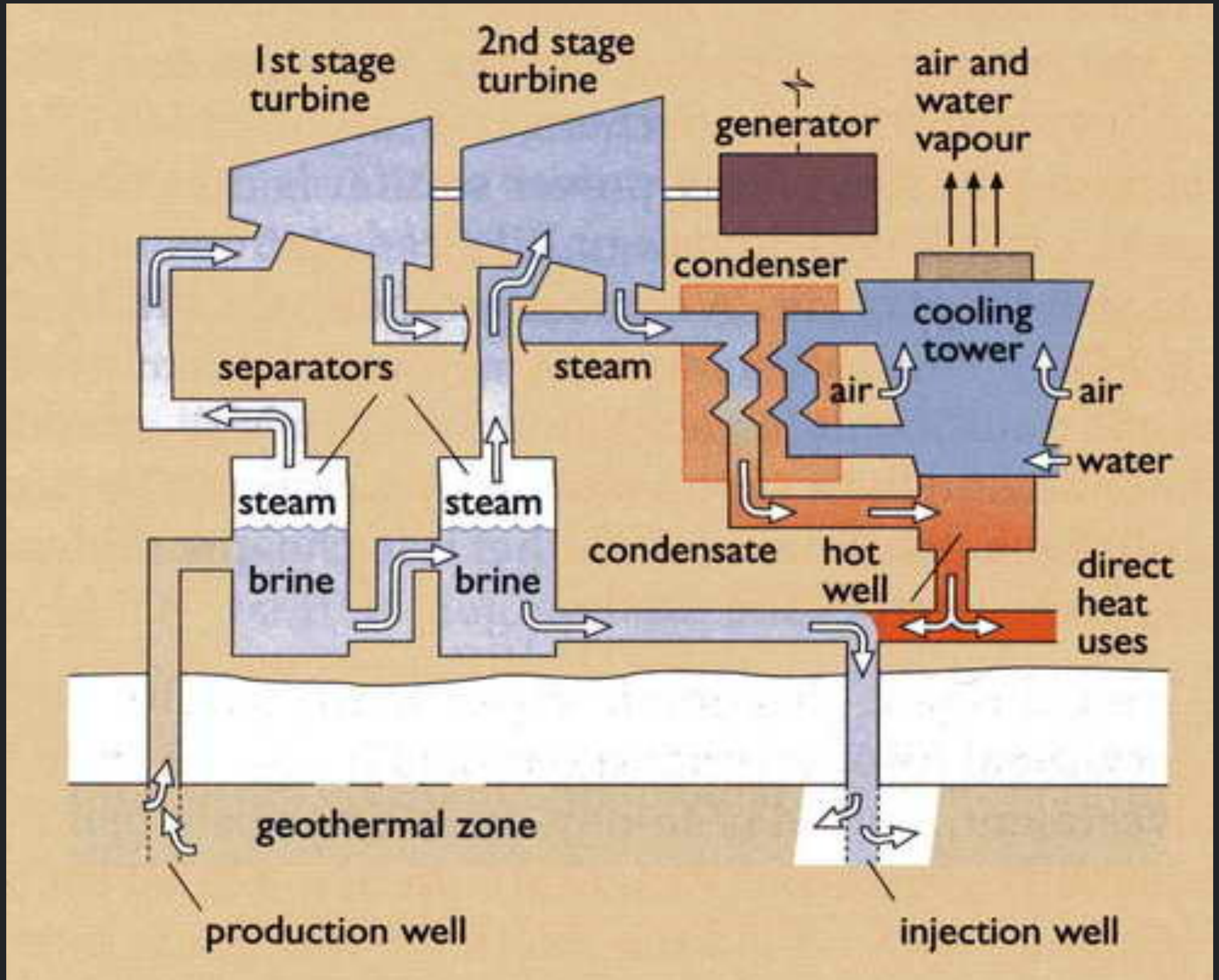
Binary Plant Power Output



http://www.worldbank.org/html/fpd/energy/geothermal/technology.htm

Double Flash Schematic

- Similar to single flash operation
- Unflashed liquid flows to low-pressure tank – flashes to steam
- Steam drives a second-stage turbine
  - Also uses exhaust from first turbine
- **Increases output 20-25% for 5% increase in plant costs**



(d) double flash power plant

Boyle, *Renewable Energy*, 2nd edition, 2004

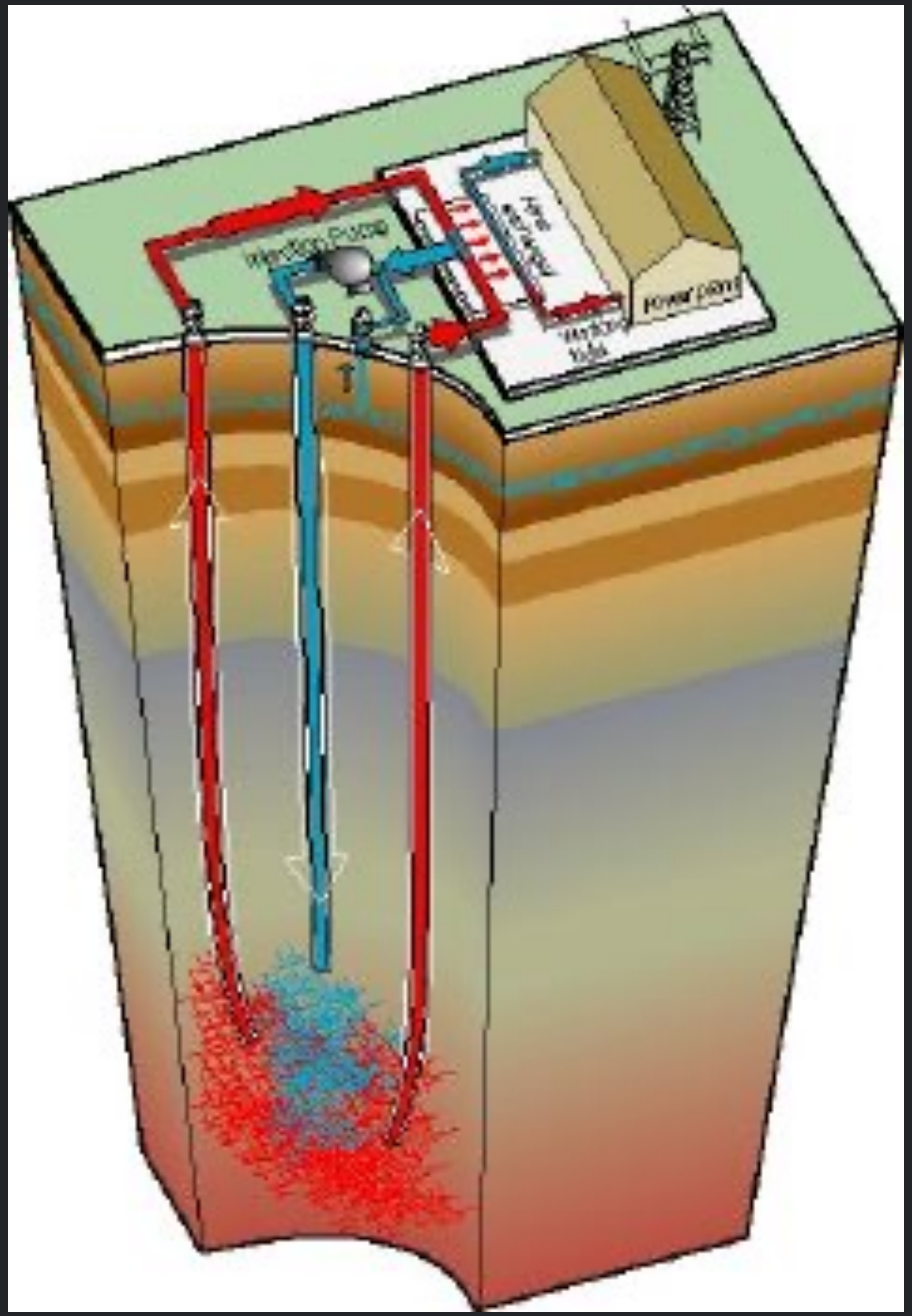
Combined Cycle Plants

- Combination of conventional steam turbine technology and binary cycle technology
  - Steam drives primary turbine
  - Remaining heat used to create organic vapor
  - Organic vapor drives a second turbine
- Plant sizes ranging between 10 to 100+ MW
- Significantly greater efficiencies
  - Higher overall utilization
  - Extract more power (heat) from geothermal resource

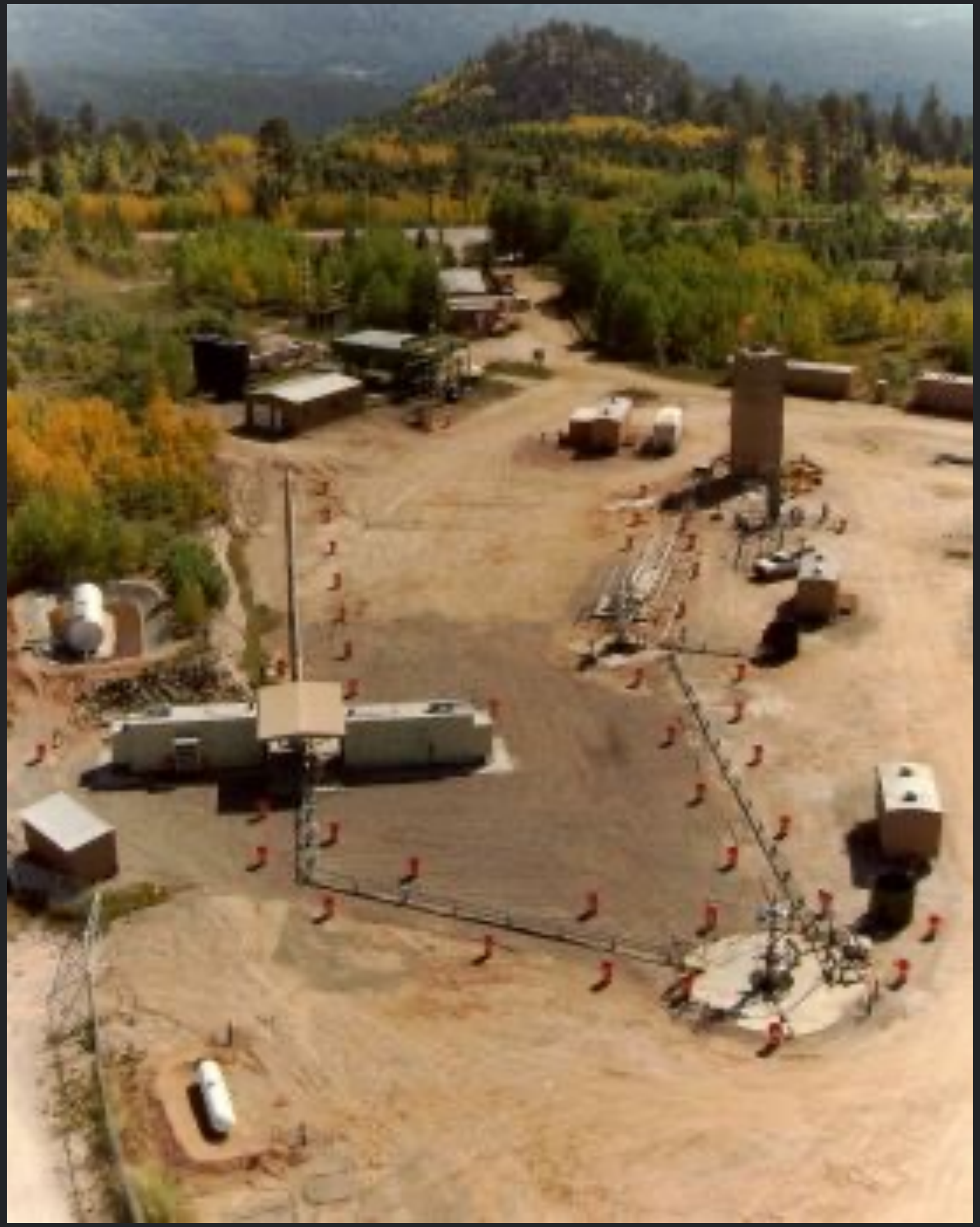
http://www.worldbank.org/html/fpd/energy/geothermal/technology.htm

Hot Dry Rock Technology

- Wells drilled 3-6 km into crust
  - Hot crystalline rock formations
- Water pumped into formations
- Water flows through natural fissures picking up heat
- Hot water/steam returns to surface
- Steam used to generate power



http://www.ees4.lanl.gov/hdr/



Fenton Hill plant

Soultz Hot Fractured Rock

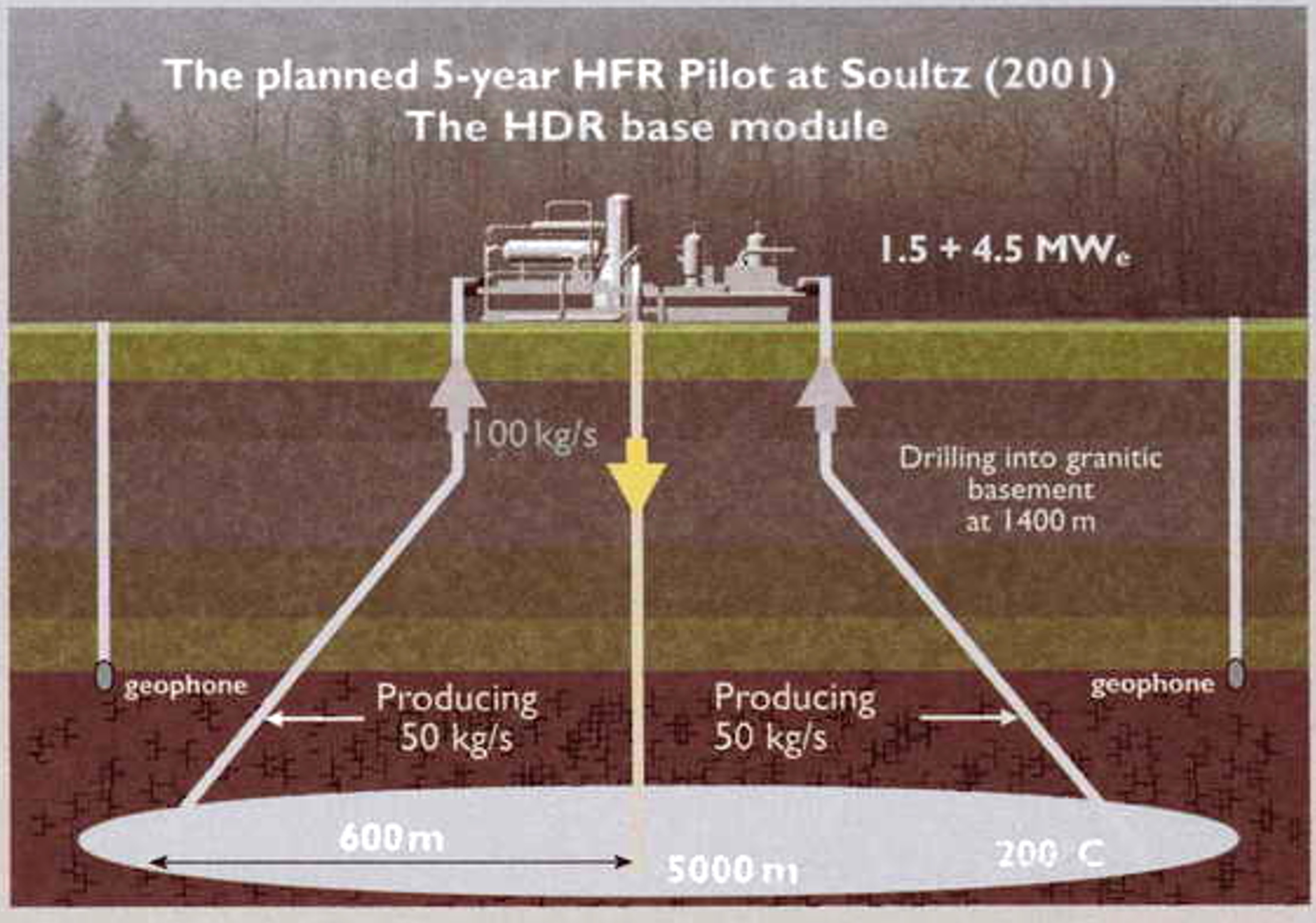


Figure 9.14 The planned 5-year HFR Pilot at Soultz. Note: the term HFR refers to Hot Fractured Rock – a specific type of hot dry rock

Boyle, *Renewable Energy*, 2nd edition, 2004

Direct Use Technologies

Geothermal heat is used directly rather than for power generation

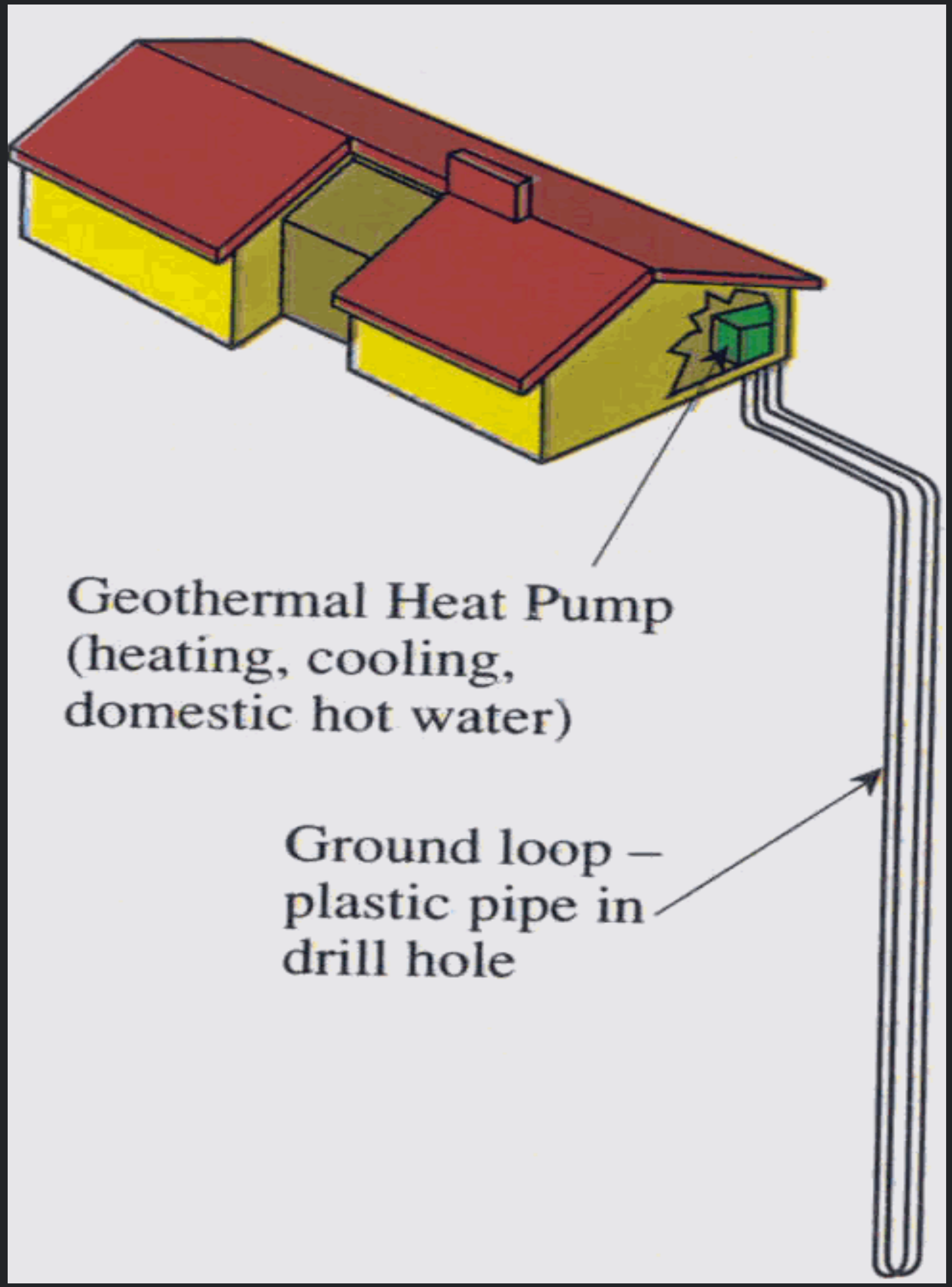
Extract heat from low temperature geothermal resources

< 150 °C or 300 °F.

Applications sited near source (<10 km)

http://www.worldbank.org/html/fpd/energy/geothermal/technology.htm

Geothermal Heat Pump



http://www.worldenergy.org/wec-geis/publications/reports/ser/geo/geo.asp

Heat vs. Depth Profile

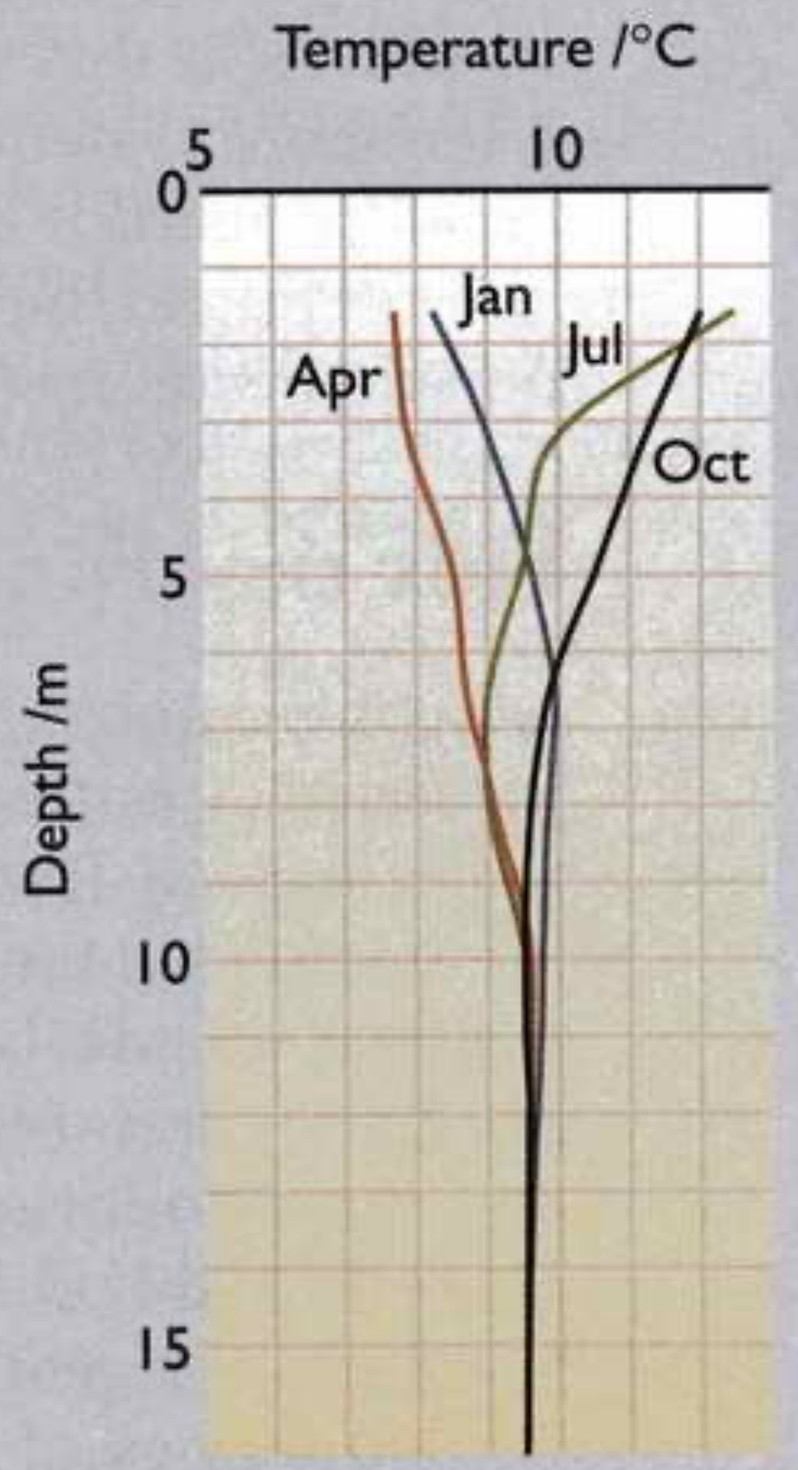
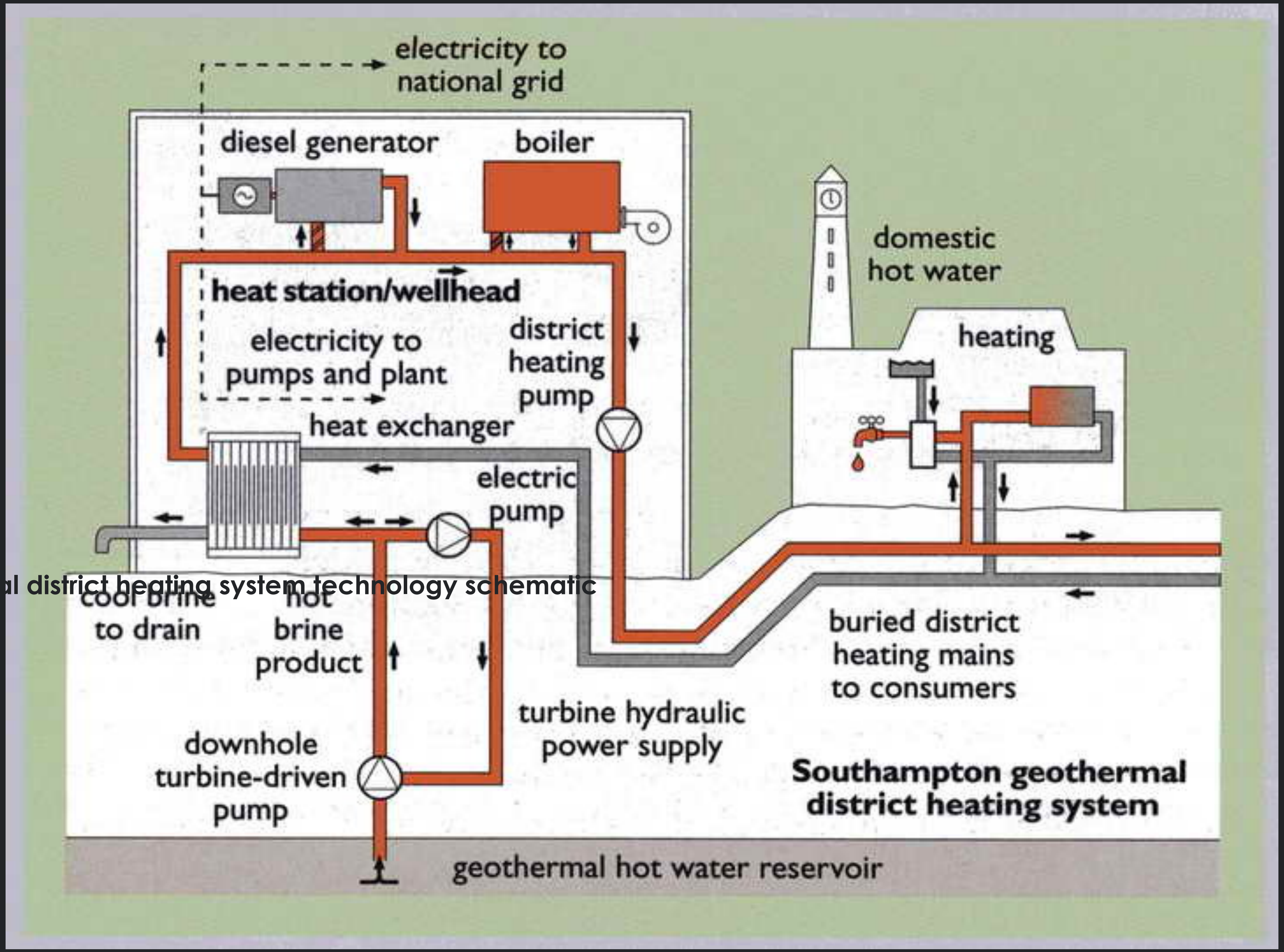


Figure 9.12 Ground temperatures typical of northern Europe, as a function of depth for different periods of the year

Boyle, *Renewable Energy*, 2nd edition, 2004

Geothermal District Heating



Boyle, *Renewable Energy*, 2nd edition, 2004

Technological Issues

- Geothermal fluids can be corrosive
  - Contain gases such as hydrogen sulphide
  - Corrosion, scaling
- Requires careful selection of materials and diligent operating procedures
- Typical capacity factors of 85-95%

http://www.worldbank.org/html/fpd/energy/geothermal/technology.htm

Technology vs. Temperature

Reservoir Temperature	Reservoir Fluid	Common Use	Technology commonly chosen
High Temperature >220°C (>430°F).	Water or Steam	Power Generation Direct Use	• Flash Steam • Combined (Flash and Binary) Cycle • Direct Fluid Use • Heat Exchangers • Heat Pumps
Intermediate Temperature 100-220°C (212 - 390°F).	Water	Power Generation Direct Use	• Binary Cycle • Direct Fluid Use • Heat Exchangers • Heat Pumps
Low Temperature 50-150°C (120-300°F).	Water	Direct Use	• Direct Fluid Use • Heat Exchangers

http://www.worldbank.org/html/fpd/energy/geothermal/technology.htm

Environmental Implications

Environmental Impacts

- Land
  - Vegetation loss
  - Soil erosion
  - Landslides
- Air
  - Slight air heating
  - Local fogging
- Ground
  - Reservoir cooling
  - Seismicity (tremors)
- Water
  - Watershed impact
  - Damming streams
  - Hydrothermal eruptions
  - Lower water table
  - Subsidence
- Noise
- **Benign overall**

http://www.worldbank.org/html/fpd/energy/geothermal/assessment.htm

Economics of Geothermal

Cost Factors

- Temperature and depth of resource
- Type of resource (steam, liquid, mix)
- Available volume of resource
- Chemistry of resource
- Permeability of rock formations
- Size and technology of plant
- Infrastructure (roads, transmission lines)

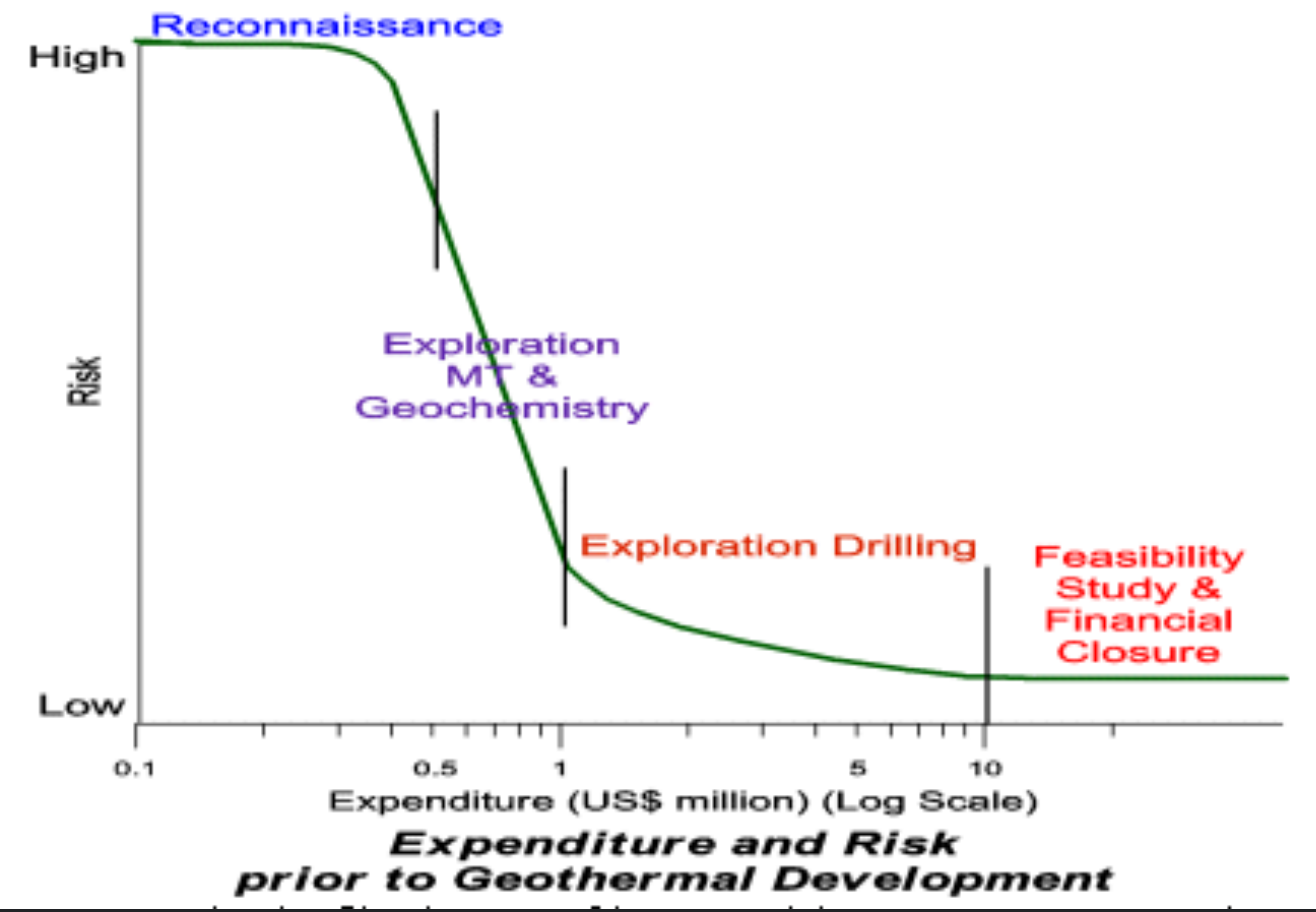
http://www.worldbank.org/html/fpd/energy/geothermal/cost_factor.htm

Costs of Geothermal Energy

- Costs highly variable by site
  - Dependent on many cost factors
- High exploration costs
- High initial capital, low operating costs
  - Fuel is “free”
- Significant exploration & operating risk
  - Adds to overall capital costs
  - “Risk premium -> high return”

http://www.worldbank.org/html/fpd/energy/geothermal/

Risk Assessment



http://www.worldbank.org/html/fpd/energy/geothermal/assessment.htm

Cost of Water & Steam

	Cost (US $/ tonne of steam)	Cost (US ¢/tonne of hot water)
High temperature (>150^{o}C)	3.5-6.0	
Medium Temperature (100-150^{o}C)	3.0-4.5	20-40
Low Temperature (<100^{o}C)		10-20

Table Geothermal Steam and Hot Water Supply Cost where drilling is required

http://www.worldbank.org/html/fpd/energy/geothermal/assessment.htm

Cost of Geothermal Power

	Unit Cost (US ¢/kWh) High Quality Resource	Unit Cost (US ¢/kWh) Medium Quality Resource	Unit Cost (US ¢/kWh) Low Quality Resource
Small plants (<5 MW)	5.0-7.0	5.5-8.5	6.0-10.5
Medium Plants (5-30 MW)	4.0-6.0	4.5-7	Normally not suitable
Large Plants (>30 MW)	2.5-5.0	4.0-6.0	Normally not suitable

http://www.worldbank.org/html/fpd/energy/geothermal/assessment.htm

Direct Capital Costs

Plant Size	High Quality Resource	Medium Quality Resource	Low Quality Resource
Small plants (<5 MW)	Exploration : US$400-800 Steam field:US$100-200 Power Plant:US$1100-1300 **Total: US$1600-2300**	Exploration : US$400-1000 Steam field:US$300-600 Power Plant:US$1100-1400 **Total: US$1800-3000**	Exploration : US$400-1000 Steam field:US$500-900 Power Plant:US$1100-1800 **Total:US$2000-3700**
Med Plants (5-30 MW)	Exploration : US$250-400 Steamfield:US$200-US$500 Power Plant: US$850-1200 **Total: US$1300-2100**	Exploration: : US$250-600 Steam field:US$400-700 Power Plant:US$950-1200 **Total: US$1600-2500**	Normally not suitable
Large Plants (>30 MW)	Exploration:: US$100-200 Steam field:US$300-450 Power Plant:US$750-1100 **Total: US$1150-1750**	Exploration : US$100-400 Steam field:US$400-700 Power Plant:US$850-1100 **Total: US$1350-2200**	Normally not suitable

Direct Capital Costs (US $/kW installed capacity)

http://www.worldbank.org/html/fpd/energy/geothermal/assessment.htm

Indirect Costs

- Availability of skilled labor
- Infrastructure and access
- Political stability
- Indirect Costs
  - Good: 5-10% of direct costs
  - Fair: 10-30% of direct costs
  - Poor: 30-60% of direct costs

http://www.worldbank.org/html/fpd/energy/geothermal/assessment.htm

Operating/Maintenance Costs

	O&M Cost (US c/KWh) Small plants (<5 MW)	O&M Cost (US c/KWh) Medium Plants (5-30 MW)	O&M Cost (US c/KWh) Large Plants(>30 MW)
Steam field	0.35-0.7	0.25-0.35	0.15-0.25
Power Plant	0.45-0.7	0.35-0.45	0.25-0.45
Total	**0.8-1.4**	**0.6-0.8**	**0.4-0.7**

Operating and Maintenance Costs

http://www.worldbank.org/html/fpd/energy/geothermal/assessment.htm

Geothermal Installations

Examples

Geothermal Power Examples

Table 9.1 Geothermal power generation around the end of the twentieth century

Nation	1995 MW_e	2000 MW_e	2005 (est. MW_e)
Argentina	0.67	0	n/a
Australia	0.17	0.17	n/a
China	28.78	29.17	n/a
Costa Rica	55.0	142.5	161.5
El Salvador	105.0	161	200
Ethipoia	0	8.52	8.52
France	4.2	4.2	20
Guatemala	0	33.4	33.4
Iceland	50.0	170	186
Indonesia	309.75	589.5	1987.5
Italy	631.7	785	946
Japan	413.7	546.9	566.9
Kenya	45.0	45	173
Mexico	753.0	755	1080
New Zealand	286.0	437	437
Nicaragua	70.0	70	145
Philippines	1227.0	1909	2673
Portugal	5.0	16	45
Russia	11.0	23	125
Thailand	0.3	0.3	0.3
Turkey	20.4	20.4	250
USA	2816.7	2228	2376
Totals	**6833**	**7974**	**11 414**

(from Huttrer, 2000)

Boyle, *Renewable Energy*, 2nd edition, 2004

Geothermal Power Generation

- World production of 8 GW
  - 2.7 GW in US
- The Geyers (US) is world's largest site
  - Produces 2 GW
- Other attractive sites
  - Rift region of Kenya, Iceland, Italy, France, New Zealand, Mexico, Nicaragua, Russia, Phillippines, Indonesia, Japan

http://en.wikipedia.org/wiki/Geothermal

Geothermal Energy Plant

Geothermal energy plant in Iceland

http://www.wateryear2003.org/en/

Geothermal Well Testing

http://www.geothermex.com/es_resen.html

Geothermal well testing,
Zunil, Guatemala

Heber Geothermal Power Station

52kW electrical generating capacity

http://www.ece.umr.edu/links/power/geotherm1.htm

Geysers Geothermal Plant

The Geysers is the largest producer of geothermal power in the world.

http://www.ece.umr.edu/links/power/geotherm1.htm

Geyers Cost Effectiveness

Table 9.5 The Geysers field: improvements in cost-effectiveness

	Capital cost per kW of capacity	Operational / maintenance costs (US¢/kWh)	Overall energy production cost (US¢/kWh)
1981	$3000	4.0	8.5
1991	$2600	2.2	5.7

Boyle, *Renewable Energy*, 2nd edition, 2004

Geothermal Summary

Geothermal Prospects

- Environmentally very attractive
- Attractive energy source in right locations
- Likely to remain an adjunct to other larger energy sources
    - Part of a portfolio of energy technologies
- Exploration risks and up-front capital costs remain a barrier

END