Geothermal
Topics included to the second midterm examination (4 Dec. 2013):
  Food
  Solar (thermal, biomass, photovoltaic)
  Lighting
  Tide
  Hydroelectricity
  Geothermal
  Waves
Figure 16.1. An earth in section.
Radioactive decay in the crust

Heat in the core

Figure 16.4. Temperature profile in a typical continent.
Geothermal energy comes from two sources: Radioactive decay in the crust of the earth, and heat trickling through the mantle from the earth’s core.

The heat in the core is there because the earth used to be red-hot, and it’s still cooling down and solidifying; the heat in the core is also being topped up by tidal friction: the earth flexes in response to the gravitational fields of the moon and sun, in the same way that an orange changes shape if you squeeze it and roll it between your hands.
The Geothermal energy of the Earth's crust originates from the original formation of the planet (20%) and from radioactive decay of minerals (80%).

The geothermal gradient, which is the difference in temperature between the core of the planet and its surface, drives a continuous conduction of thermal energy in the form of heat from the core to the surface.

The adjective geothermal originates from the Greek roots γη (ge), meaning earth, and θερμός (thermos), meaning hot.

At the core of the Earth, temperatures may reach over 5000 degrees Celsius.

Heat conducts from the core to surrounding cooler rock. The high temperature and pressure cause some rock to melt, creating magma convection upward since it is lighter than the solid rock. The magma heats rock and water in the crust, sometimes up to 370 degrees Celsius (700 degrees Fahrenheit).
History

The oldest known pool fed by a hot spring, built in the Qin dynasty in the 3rd century BCE.
Hot springs have been used for bathing at least since paleolithic times. The oldest known spa is a stone pool on China’s Lisan mountain built in the Qin dynasty in the 3rd century BC, at the same site where the Huaqing Chi palace was later built.
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In the first century AD, Romans conquered Aquae Sulis, now Bath, Somerset, England, and used the hot springs there to feed public baths and underfloor heating. The admission fees for these baths probably represent the first commercial use of geothermal power. The world's oldest geothermal district heating system in Chaudes-Aigues, France, has been operating since the 14th century.
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Charlie Lieb developed the first downhole heat exchanger in 1930 to heat his house. Steam and hot water from geysers began heating homes in Iceland starting in 1943.
Electricity Production

How can we produce electricity using geothermal energy?

Any suggestions?
Figure 16.5. Enhanced geothermal extraction from hot dry rock. One well is drilled and pressurized to create fractures. A second well is drilled into the far side of the fracture zone. Then cold water is pumped down one well and heated water (indeed, steam) is sucked up the other.

There are three designs for geothermal power plants, all of which pull hot water and steam from the ground, use it, and then return it as warm water to prolong the life of the heat source.

In the simplest design, the steam goes directly through the turbine, then into a condenser where the steam is condensed into water.
In a second approach, very hot water is depressurized or "flashed" into steam which can then be used to drive the turbine.

In the third approach, called a binary system, the hot water is passed through a heat exchanger, where it heats a second liquid—such as isobutane—in a closed loop. The isobutane boils at a lower temperature than water, so it is more easily converted into steam to run the turbine. The three systems are shown in the diagrams below.
In the 20th century, demand for electricity led to the consideration of geothermal power as a generating source. Prince Piero Ginori Conti tested the first geothermal power generator on 4 July 1904, at the same Larderello (Italy) dry steam field where geothermal acid extraction began. It successfully lit four light bulbs. Later, in 1911, the world's first commercial geothermal power plant was built there. It was the world's only industrial producer of geothermal electricity until New Zealand built a plant in 1958.
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Lord Kelvin invented the heat pump in 1852, and Heinrich Zoelly had patented the idea of using it to draw heat from the ground in 1912. But it was not until the late 1940s that the geothermal heat pump was successfully implemented. The earliest one was probably Robert C. Webber's home-made 2.2 kW direct-exchange system, but sources disagree as to the exact timeline of his invention. J. Donald Kroeker designed the first commercial geothermal heat pump to heat the Commonwealth Building (Portland, Oregon) and demonstrated it in 1946. Professor Carl Nielsen of Ohio State University built the first residential open loop version in his home in 1948. The technology became popular in Sweden as a result of the 1973 oil crisis, and has been growing slowly in worldwide acceptance since then. The 1979 development of polybutylene pipe greatly augmented the heat pump’s economic viability.
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In 1960, Pacific Gas and Electric began operation of the first successful geothermal electric power plant in the United States at The Geysers in California. The original turbine lasted for more than 30 years and produced 11 MW net power. The binary cycle power plant was first demonstrated in 1967 in the U.S.S.R. and later introduced to the U.S. in 1981. This technology allows the generation of electricity from much lower temperature resources than previously. In 2006, a binary cycle plant in Chena Hot Springs, Alaska, came on-line, producing electricity from a record low fluid temperature of 57 °C (135 °F).
Global geothermal electric capacity. Upper red line is installed capacity; lower green line is realized production.

http://en.wikipedia.org/wiki/Geothermal_energy
Geothermal power plants are used all over the world, but can not be located just anywhere. They are located where tectonic plates collide and generate volcanic activity.

http://academic.evergreen.edu/g/grossmaz/heidtken.html
This map shows where plate boundaries are located.

http://academic.evergreen.edu/g/grossmaz/heidtken.html
This map illustrates the general location of geothermal power plants being used around the world.
http://academic.evergreen.edu/g/grossmaz/heidtken.html
## Installed geothermal electric capacity

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<td>Thailand</td>
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<td><strong>9,981.9</strong></td>
<td><strong>10,959.7</strong></td>
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Steam rising from the Nesjavellir Geothermal Power Station in Iceland.

Figure 16.3. Geothermal power in Iceland. Average geothermal electricity generation in Iceland (population, 300,000) in 2006 was 300 MW (24 kWh/d per person). More than half of Iceland’s electricity is used for aluminium production. Photo by Gretar Ívarsson.
Youtube movies

How a Geothermal Plant Works
Geothermal Energy
Iceland-Geothermal

In a typical continent, the heat flow from the centre coming through the mantle is about 10 mW/m². The heat flow at the surface is 50 mW/m². So the radioactive decay has added an extra 40 mW/m² to the heat flow from the centre.

So at a typical location, the maximum power we can get per unit area is 50 mW/m².

Figure 16.4. Temperature profile in a typical continent.
The temperature increases with depth as shown in figure 16.4, reaching a temperature of about 500 °C at a depth of 40 km. Between depths of 0 km where the heat flow is biggest but the rock temperature is too low, and 40 km, where the rocks are hottest but the heat flow is 5 times smaller (because we’re missing out on all the heat generated from radioactive decay) there is an optimal depth at which we should suck. The exact optimal depth depends on what sort of sucking and powerstation machinery we use.
For the temperature profile shown in figure 16.4, I calculated that the optimal depth is about 15 km. Under these conditions, an ideal heat engine would deliver 17 mW/m². At the world population density of 43 people per square km, that’s 10 kWh per person per day, if all land area were used. In the UK, the population density is 5 times greater, so wide-scale geothermal power of this sustainable-forever variety could offer at most 2 kWh per person per day.
Transporting stuff: 12 kWh/d

Stuff: 48+ kWh/d

Food, farming, fertilizer: 15 kWh/d

Gadgets: 5

Light: 4 kWh/d

Heating

Geothermal: 1 kWh/d

Tide: 11 kWh/d

Wave: 4 kWh/d

Deep offshore wind: 32 kWh/d

Shallow offshore wind: 16 kWh/d

Biomass: food, biofuel, wood, waste incin’n, landfill gas: 34 kWh/d

Hydro: 1.5 kWh/d