Renewable Energy

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Spring/Summer, 2009

Renewable Energy

A **quad** (one quadrillion BTU, 1,000,000,000,000 BTU) of energy equals:

8,007,000,000 Gallons (US) of gasoline
293,071,000,000 Kilowatt hours
36,000,000 Tonnes of coal
970,434,000,000 Cubic feet of natural gas
5,996,000,000 UK gallons of diesel oil
25,200,000 Tonnes of oil

The world produces 446 quads of energy per year (the US accounts for 100 quads)

Why Renewable Energy?

- Finite fossil fuels
  US estimated oil supply = 15 years

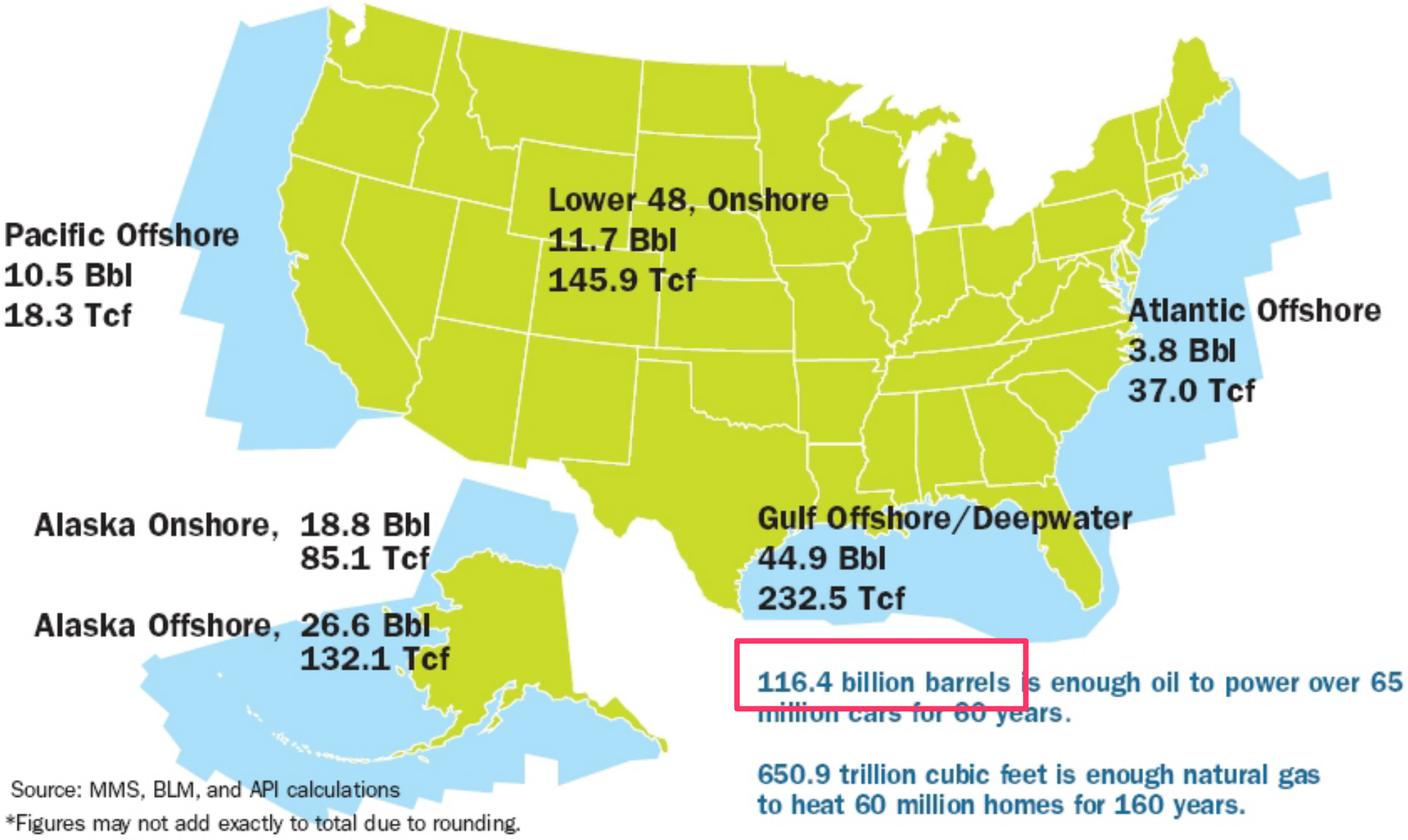
- Climate change
  Warming, increasingly erratic

- Politics and economics
  Oil must be imported for $$$
  Revenues finance unstable people/countries
  We are losing ownership of our country

Why Renewable Energy?
Finite fossil fuels

U.S. daily consumption (2007) = 20,680,000 barrels per day

Source: DOE Energy Information Administration
(http://tonto.eia.doe.gov/dnav/pet/pet_cons_psup_dc_nus_mbblpd_a.htm)



Source: The Truth About Oil and Gasoline: An API Primer (American Petroleum Institute) October 10, 2008

Why Renewable Energy?
Finite fossil fuels

116.4 Billion barrels

divided by

20.68 Million barrels/day =

15.42 years

Why Renewable Energy?
Climate change

- Sea level is rising (6 inches in 20th century)
- Arctic ice is melting
- More intense hurricanes
- Reefs are dying
- More intense droughts
- Migration or extinction of sensitive species
- Seawater is becoming more acidic

Why Renewable Energy?
Climate change

- Natural gas = Methane = CH_4

  $CH_4 + 2O_2 \Rightarrow CO_2 + 2H_2O$ + energy

- Coal = Carbon = C

  $C + O_2 \Rightarrow CO_2$ + energy

- Carbon dioxide emissions

  Coal: 0.37 kg/kWh

  Natural gas: 0.23 kg/kWh

- Other coal pollutants: nitrogen and sulfur acids, mercury, radioactives, other

Why Renewable Energy?
Politics and economics

- Our oil imports cost the US approximately $2.2B per day (22MB @ $100/bbl), $803 B per year
- US GDP is $13,843 B per year (2007)
- Thus, we send nearly 6% of our wealth away each year
- Much of it goes to people who do not share our ideals

Why Renewable Energy?
Politics and economics

- Renewable energy is renewable wealth
- Renewable energy is intrinsically free, so the money spent on it goes to support the people who build and maintain it and to enrich the people who own it
- Most renewable energy can be produced locally, by local workers
- Local energy production can be owned much more easily than some fossil fuels, but it may not be locally owned if the local people are not capable and knowledgeable.

Renewable Energy

- Nuclear reactors
- Wind turbines
- Conventional hydroelectric
- Tidal and river motion devices
- Biomass
- Geothermal
- Direct solar collection as:
  - heat
  - electricity
  - hydrogen
  - other chemical

Renewable Energy
Biomass

Biomass: living and recently dead biological material that can be used as fuel or for industrial production.

Corn → ethanol
Trees → firewood, paper
Sugar cane → ethanol, plastics
Cotton, flax, wool → clothing, carpets, etc

Using biomass for fuel competes with other uses

Renewable Energy
Biomass

Biomass is renewable only if it is managed properly

- Clear-cutting of forests causes erosion and deterioration of the soil
- Conventional agriculture consumes oil-based fertilizers and fuel
- Insects and other beneficial organisms are deprived of their habitat in dead wood
- Current use of biomass supplies about 0.5% of US electricity

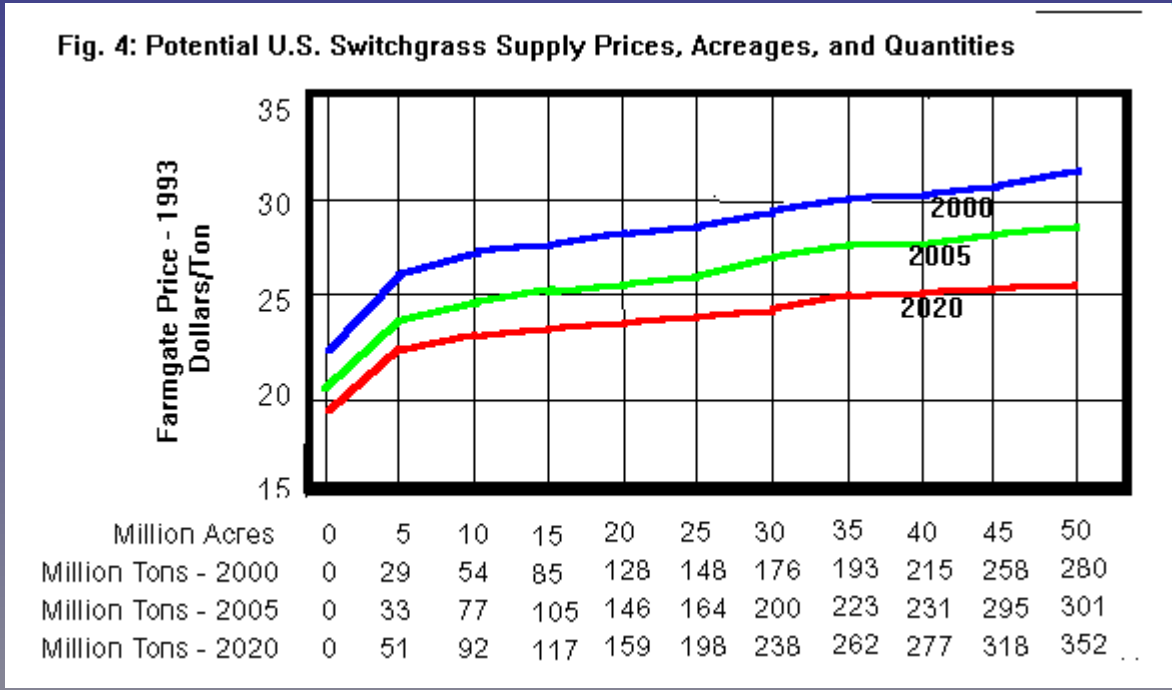
Renewable Energy
Biomass

The US has 2.5 Billion acres of land.

50 Million acres is 2% of our land.

50 million acres might produce 5 quads of energy, 5% of US consumption.

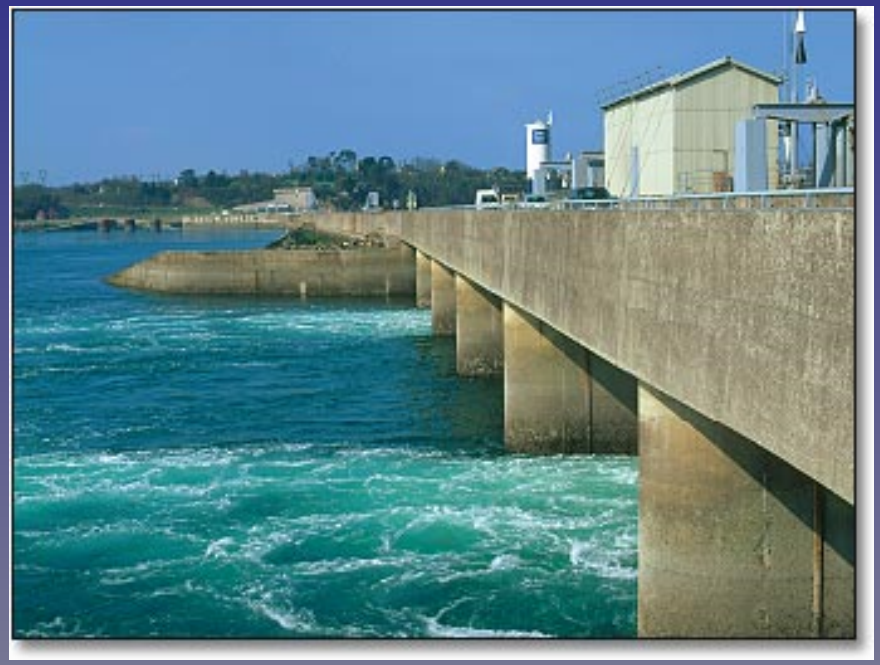
1 cord of very dry red oak firewood = 1 ton



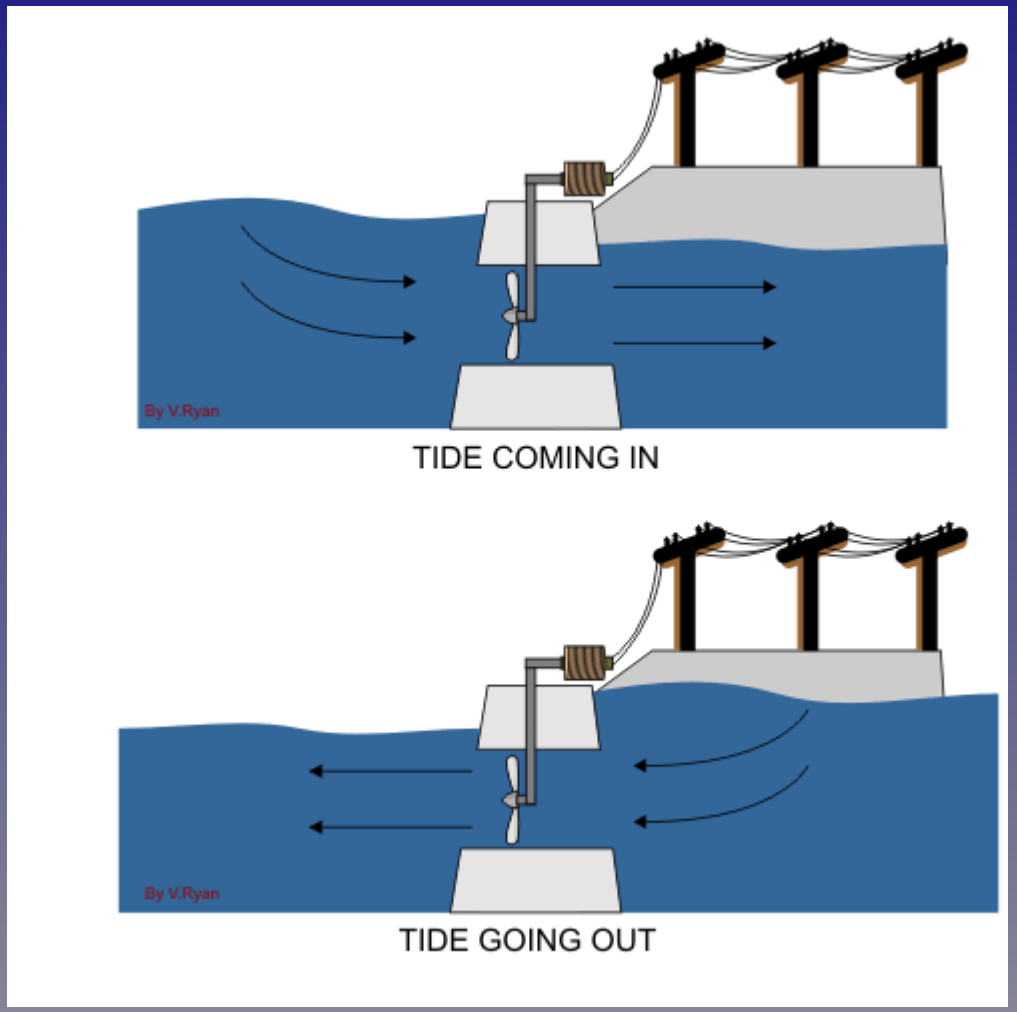
Million Acres	0	5	10	15	20	25	30	35	40	45	50
Million Tons - 2000	0	29	54	85	128	148	176	193	215	258	280
Million Tons - 2005	0	33	77	105	146	164	200	223	231	295	301
Million Tons - 2020	0	51	92	117	159	198	238	262	277	318	352

Renewable Energy
Tidal and River Motion

Like a windmill,
but under water

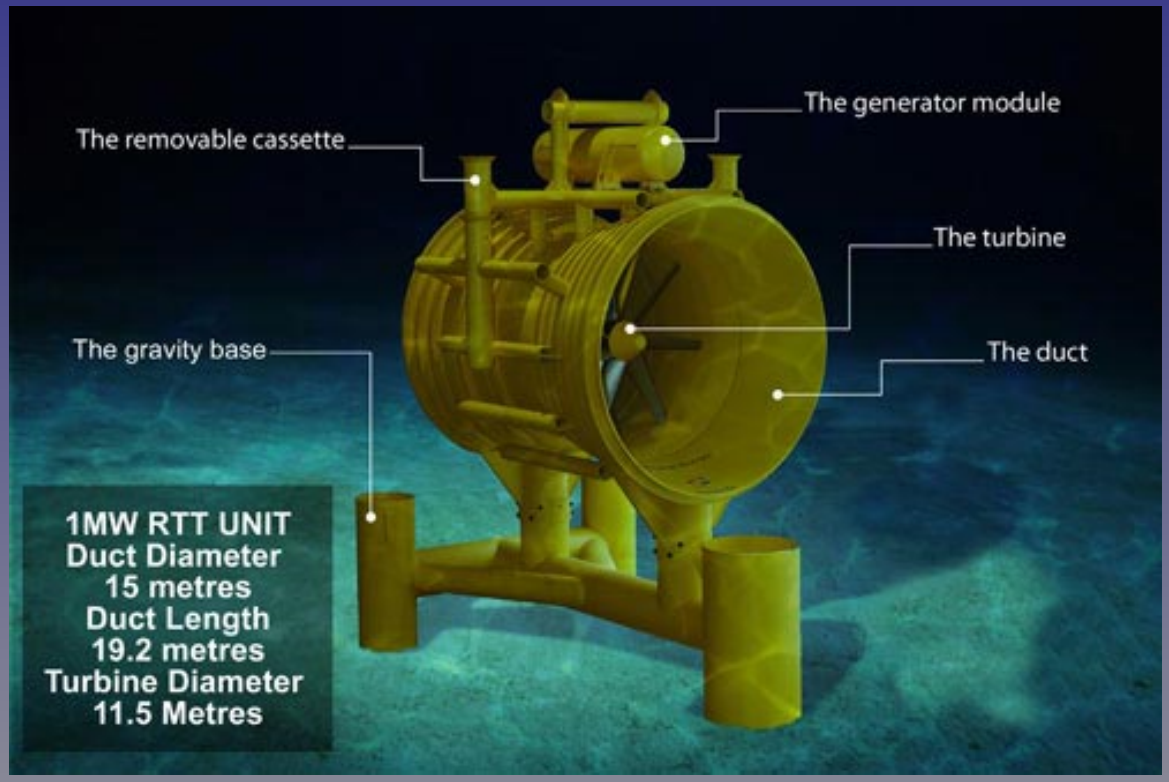


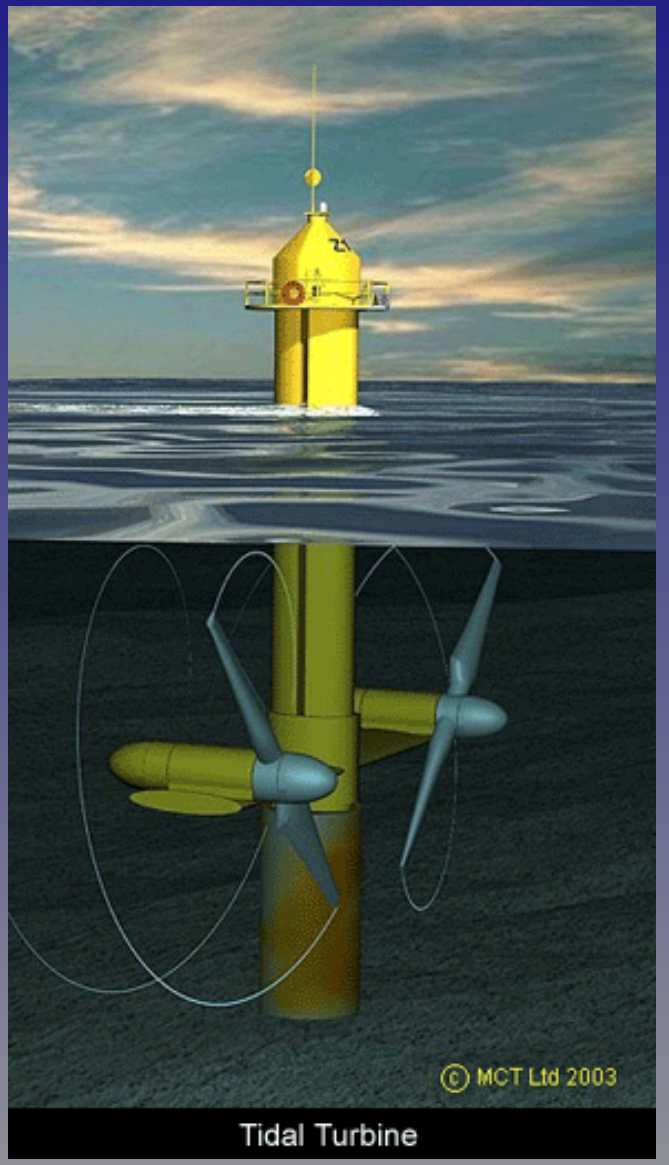
LaRance river estuary in France
240 MW



Renewable Energy
Tidal and River Motion

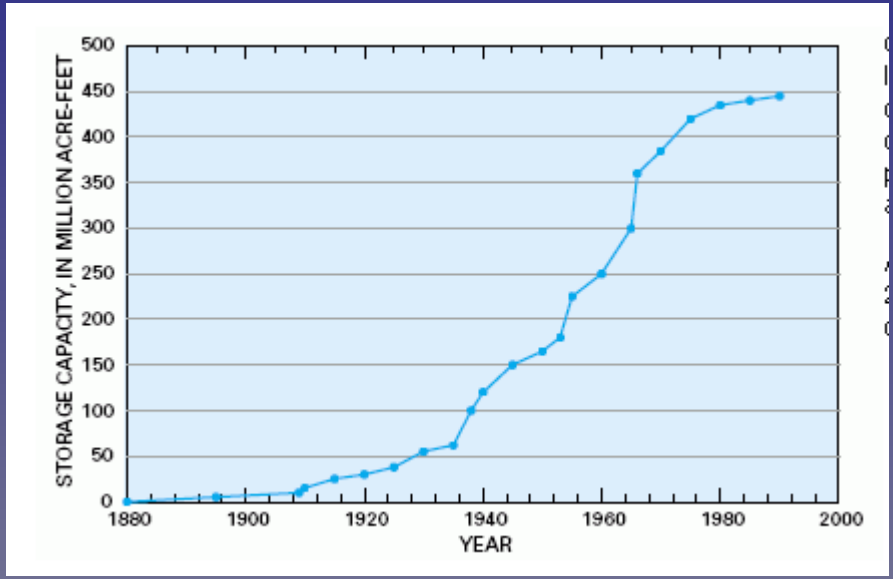
Like a windmill, but under water





Renewable Energy
Conventional Hydroelectric

In 2006, the US obtained 7% of its electricity from hydroelectric dams.



We have used up most of the *politically acceptable* opportunities for large-scale hydroelectric power.

Renewable Energy
Direct Solar Collection

Sunlight heats a central tower

Direct midday sunlight provides about 1000W per square meter

1 sq. mi yields 4,646 megawatt-hours per day

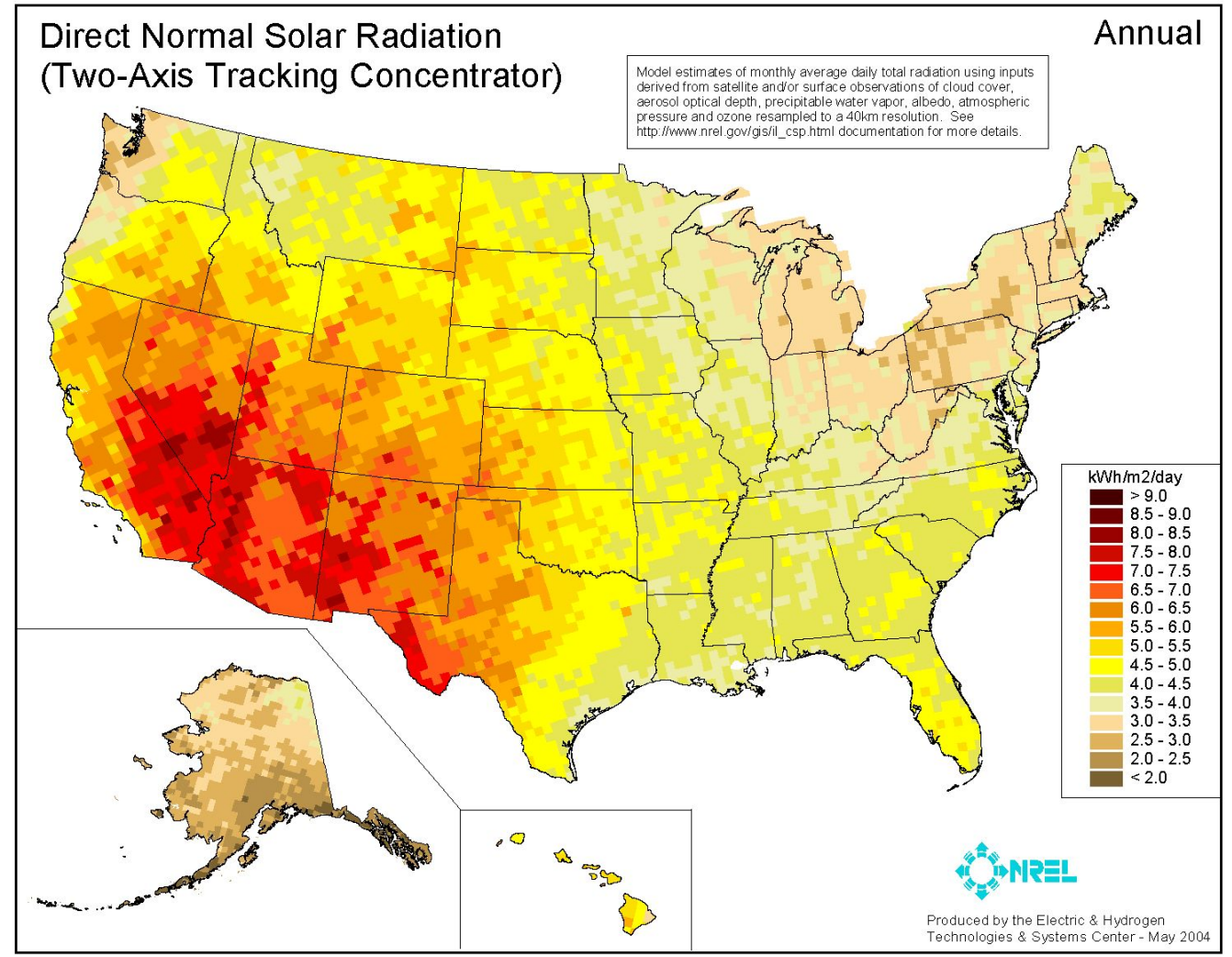
18,000 sq. mi provides the total US energy consumption (131 x 131 mi)

Renewable Energy
Direct Solar Collection

Sunlight hits semiconductor panels and pumps electrons through them to make electricity

Science and Society

Renewable Energy
Solar Energy Potential



Renewable Energy
Geothermal

The center of the earth is about 3000 to 5000 deg. C

Why is the interior of the earth hot?

The exact proportions are not known, but the heat comes from two sources:

- The original heat produced when small orbiting bodies collided and pulled together
- Decay of radioactive elements

Renewable Energy
Geothermal

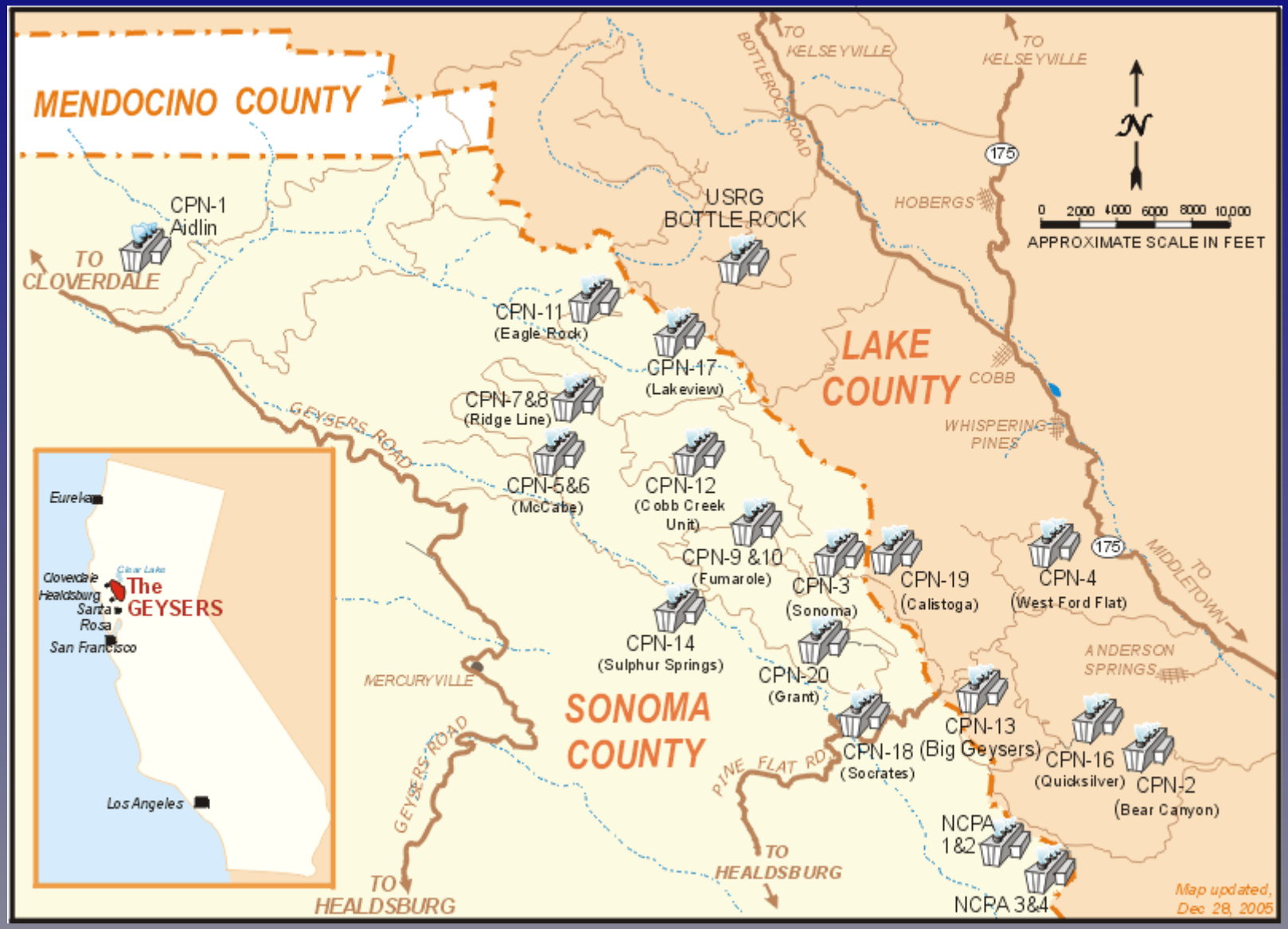
The earth's heat can be extracted by pumping water from deep wells and used to generate electricity and/or to directly heat buildings.

The circulating water becomes toxic as it dissolves minerals from the rocks and must be pumped back into other wells.

Icelandic geothermal plant

Renewable Energy

Geothermal



The Geysers plants produce approx. enough electricity for San Francisco

Science and Society

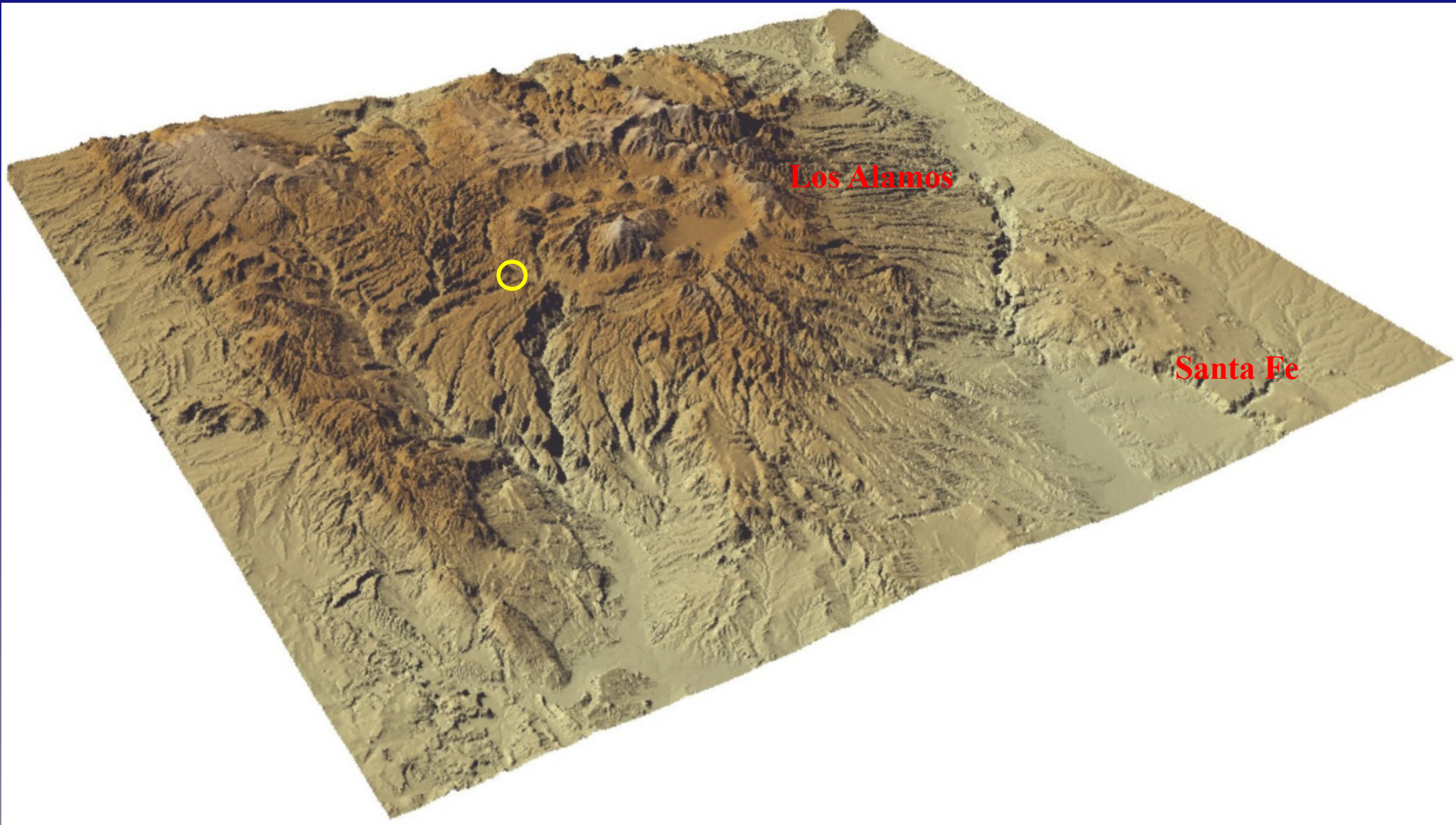
Renewable Energy
Geothermal

Modern plant at The Geysers

First generating plant, 1921

Renewable Energy

Enhanced Geothermal: Valles Caldera, Fenton Hill



Renewable Energy
Geothermal

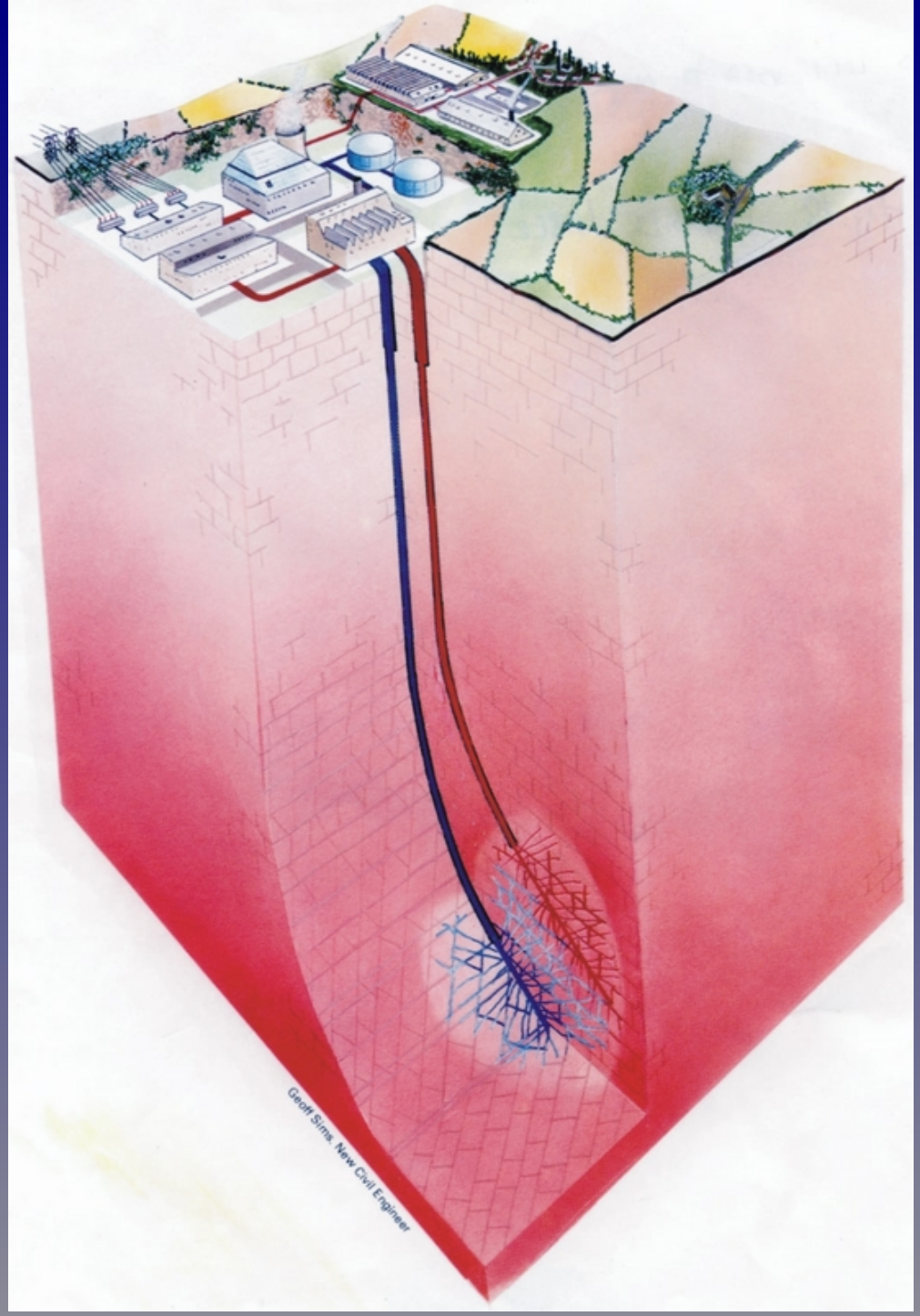
Renewable Energy

Valles Caldera, Fenton Hill

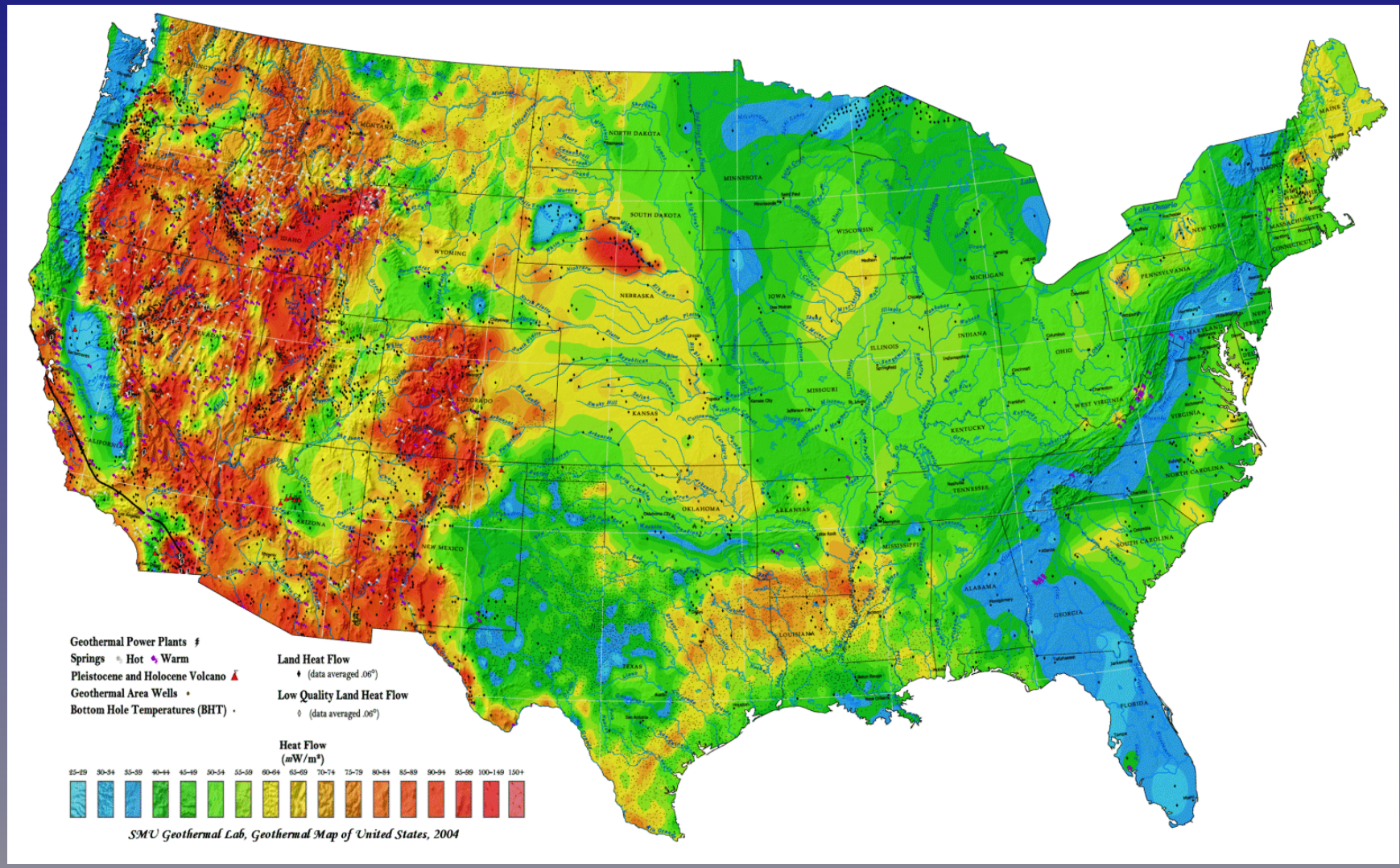
The Los Alamos Hot Dry Rock Project, 1974-1995

Renewable Energy

Hot Dry Rock
(now just Enhanced)
Geothermal Plant



Renewable Energy
Geothermal heat flow



Science and Society

Renewable Energy
Geothermal

An MIT estimate is that an investment of $15B in Enhanced Geothermal Systems(EGS) would yield 100GW of electric power, or about 20% of the current US consumption.

According to an MIT report on EGS, only 2% of the heat beneath the continental US between 3 and 10 kilometers (depths we can reach with current technology) is more than 2,500x the annual energy use of the United States.

The latest DOE plan,

"**Geothermal Technologies Program**
Multi-Year Research, Development and Demonstration Plan 2009-2015 with program activities to 2025,"

projects only one 5MW pilot plan by 2015.

The Geysers geothermal plants already produce 725 MW of geothermal energy.

Renewable Energy Costs

	2001 energy costs	Potential future energy cost
Electricity		
Wind	4–8 ¢/kWh	3–10 ¢/kWh
Solar photovoltaic	25–160 ¢/kWh	5–25 ¢/kWh
Solar thermal	12–34 ¢/kWh	4–20 ¢/kWh
Large hydropower	2–10 ¢/kWh	2–10 ¢/kWh
Small hydropower	2–12 ¢/kWh	2–10 ¢/kWh
Geothermal	2–10 ¢/kWh	1–8 ¢/kWh
Biomass	3–12 ¢/kWh	4–10 ¢/kWh
Coal (comparison)	4 ¢/kWh	
Heat		
Geothermal heat	0.5–5 ¢/kWh	0.5–5 ¢/kWh
Biomass — heat	1–6 ¢/kWh	1–5 ¢/kWh
Low temp solar heat	2–25 ¢/kWh	2–10 ¢/kWh
All costs are in 2001 US$-cent per kilowatt-hour.		
Source: World Energy Assessment, 2004 update[29]		

Renewable Energy
Environmental damage

- Nuclear reactors generate radioactive waste and can explode
- Windmills kill bats and birds
- Tidal turbines kill fish, eels, etc.
- Hydroelectric dams destroy fish migration
- Geothermal plants produce toxic water
- Biomass production displaces food production
- Solar farms destroy desert habitat
- All large-scale methods occupy land or water

Renewable Energy
Development

- No single method appears the “best”
- Some methods are capable of supplying **all** our energy needs
- Environmental problems must be solved
- Initial cost is high, but feasible
- Maintenance cost is comparable to current methods
- The supply is never exhausted
- Most countries have usable resources

Renewable Energy
Development

The societal will to move from fossil fuels to renewable energy before we suffer a calamity is the biggest obstacle to be overcome

The longer we wait, the more expensive the transition becomes

Renewable Energy
More to come

We will discuss

- Nuclear power
- Wind turbines

and

- Power transmission

in more detail