Renewable Energy

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Spring/Summer, 2010

Renewable Energy

A **quad** (one quadrillion BTU, 1,000,000,000,000,000 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 accounted for 100 quads in 2004)

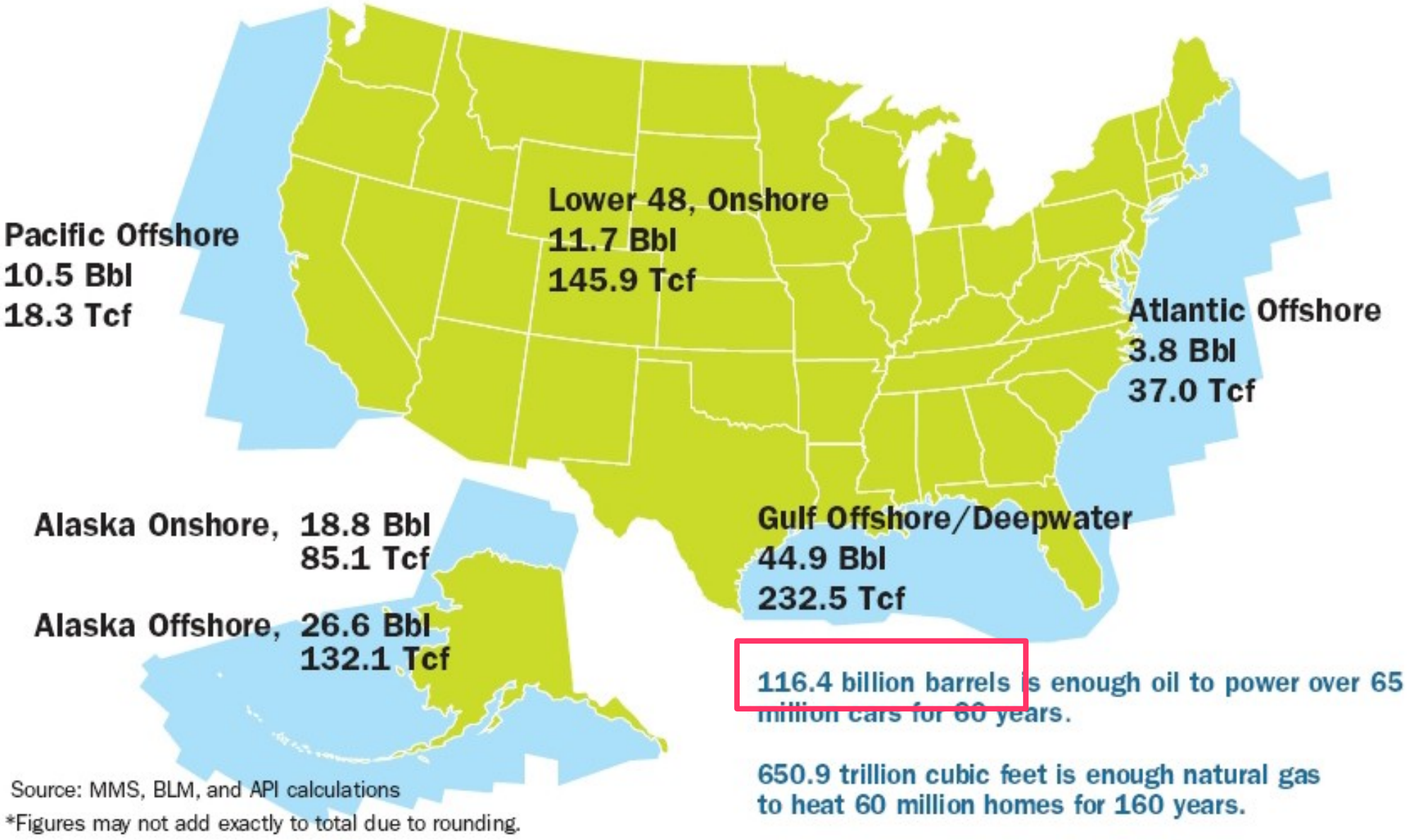
Why Renewable Energy?

- Finite fossil fuels
  - US estimated oil supply = 15 years
- Climate change
  - Warming, increasingly erratic
  - Rules out simple reliance on conventional coal
- 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

Natural gas extends the supply marginally, and is used for other needs

Why Renewable Energy?
Finite fossil fuels

- Using techniques that consume much of the available energy, oil also can be found in tar sands and shale.
- The US has lots of coal, but "clean coal" is a dream, and trapping the CO_2 consumes much of the energy
- "Clean coal" cannot compete economically with other renewable energy even if it can be done

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

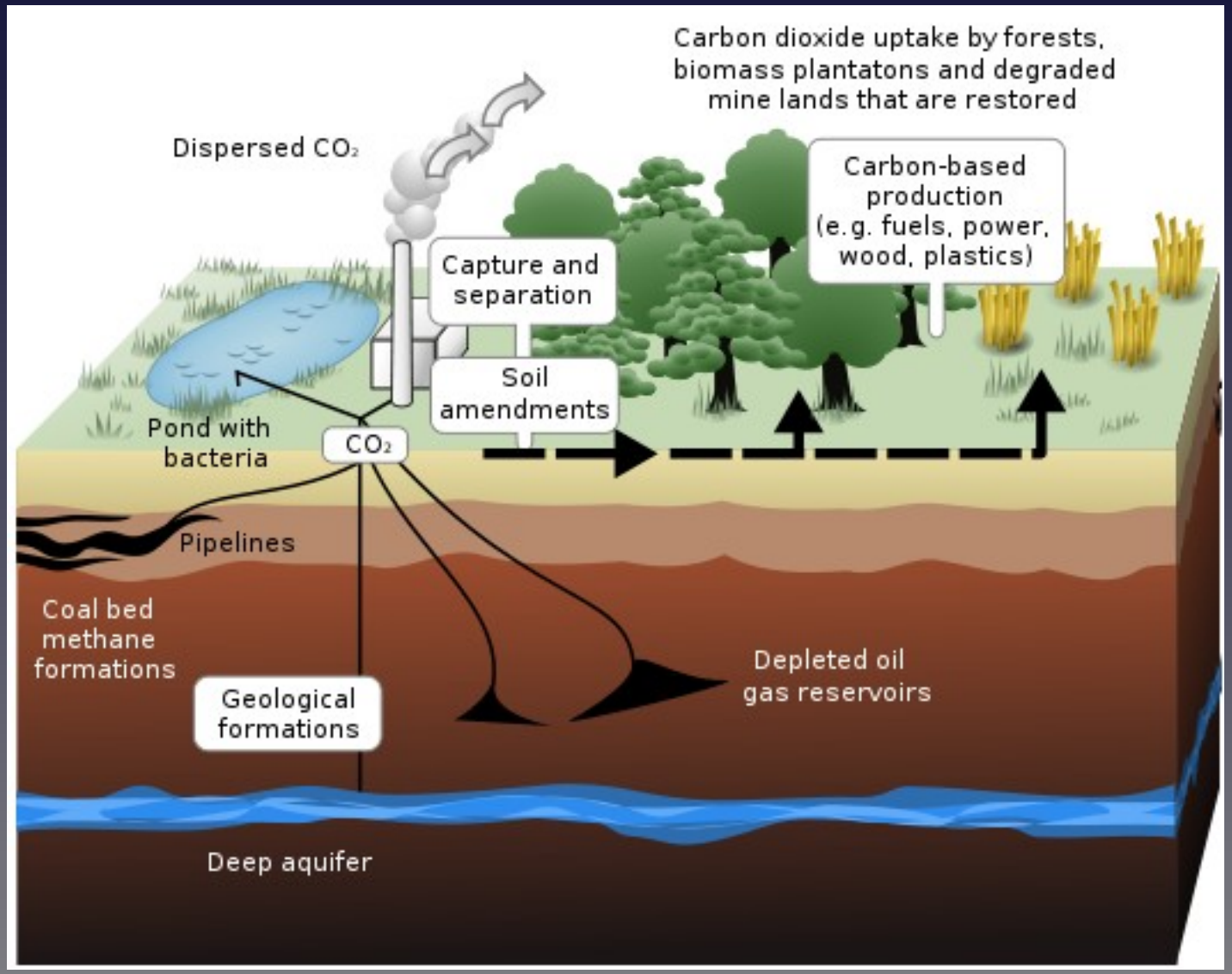
  Coal: 0.37 kg/kWh

  Natural gas: 0.23 kg/kWh

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

Why Renewable Energy?
Clean Coal

- Capturing the CO_2 requires burning up to 60% more coal
- Getting rid of the mercury and other toxins also adds cost
- We have no guarantee that CO_2 injected underground will stay permanently
- Study by Harvard University Belfer Center for Science and International Studies estimates carbon capture will cost $0.20/kWh



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
Wind Turbines

- The US consumes 4.18 Trillion kWh of electric power each year (average 477 Billion watts, or 477 Million KW)

- Do we have enough wind?

Wind Resource Map

Wind Resources in the US

- Assume that we get 400 W/m^2 in a fair area and 800 W/m^2 in a good area (offshore)
- Assume the windmill has blades 40 m long
- The area swept out by the blades is
  $A = \pi R^2 = 3.14 * (40m)^2 = 5024\ m^2$

$Power_{fair} = 5024 * 400 = 2{,}009{,}600$ watts

$Power_{good} = 5024 * 800 = 4{,}019{,}200$ watts

- 4 MW = 4,000 kW
  4,000 kW * 8760 hrs / year * \$0.04 = \$1.4 M - maint. - debt = ?

Wind Resources in the US

- 4.18 TWh = 477,000 MW * 8760 hours/year
- 477,000 MW / 2 MW = 238,500 wind turbines
- Considering offshore turbines (need fewer) and that a turbine runs only part time (need more), let's say we need 200,000 turbines

Wind Resources in the US

- 200,000 turbines / 50 states

  = 4000 windmills / state

- 200,000 turbines / 3,537,441 square miles

  = 1 windmill / 17.69 mi^2.

- Offshore Eastern US (10 mi * 1000 mi)

  = 10,000 mi^2

- An offshore turbine every ¼ mi. in each direction

  = 160,000 turbines

- 200,000 turbines * $2M each

  = $400 Billion

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

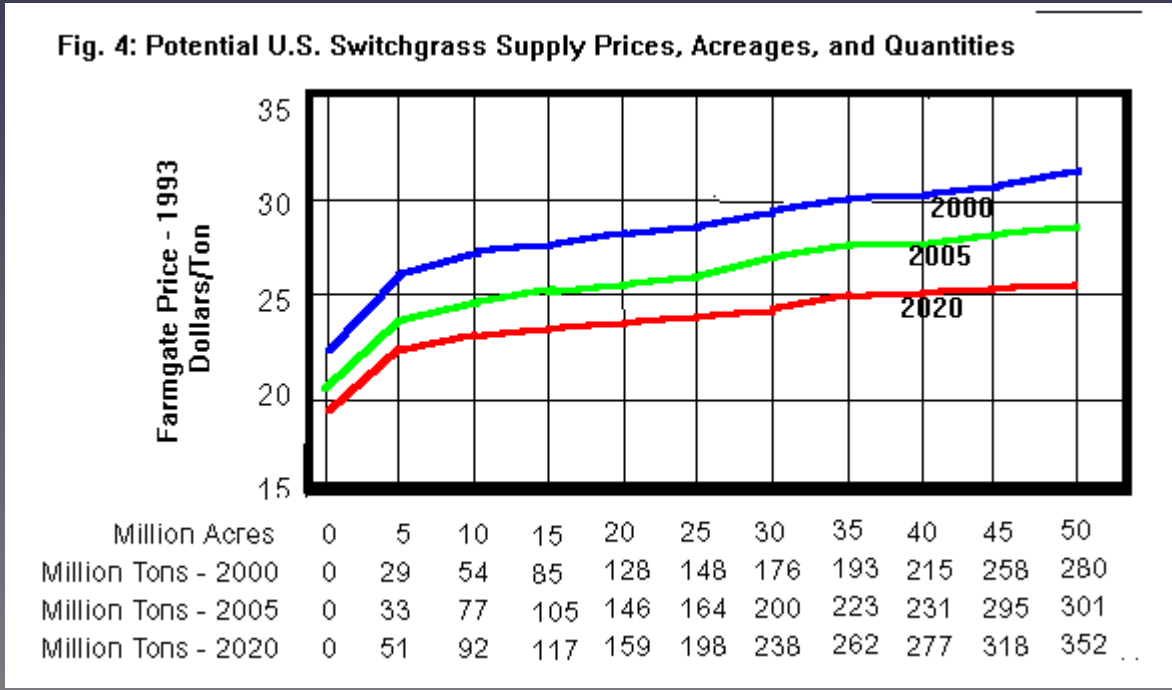
Renewable Energy
Biomass

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.

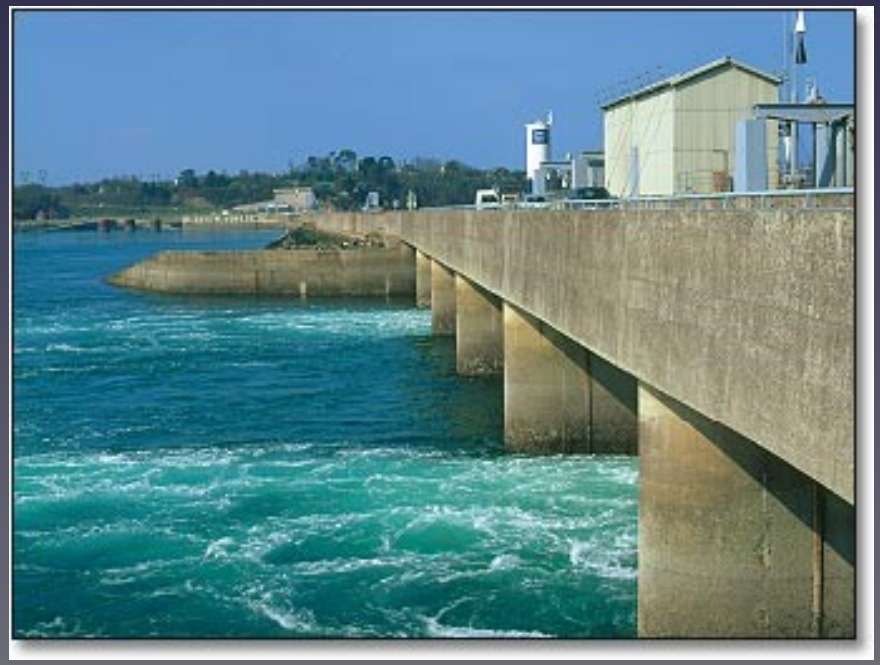
1 cord of very dry red oak firewood = 1 ton



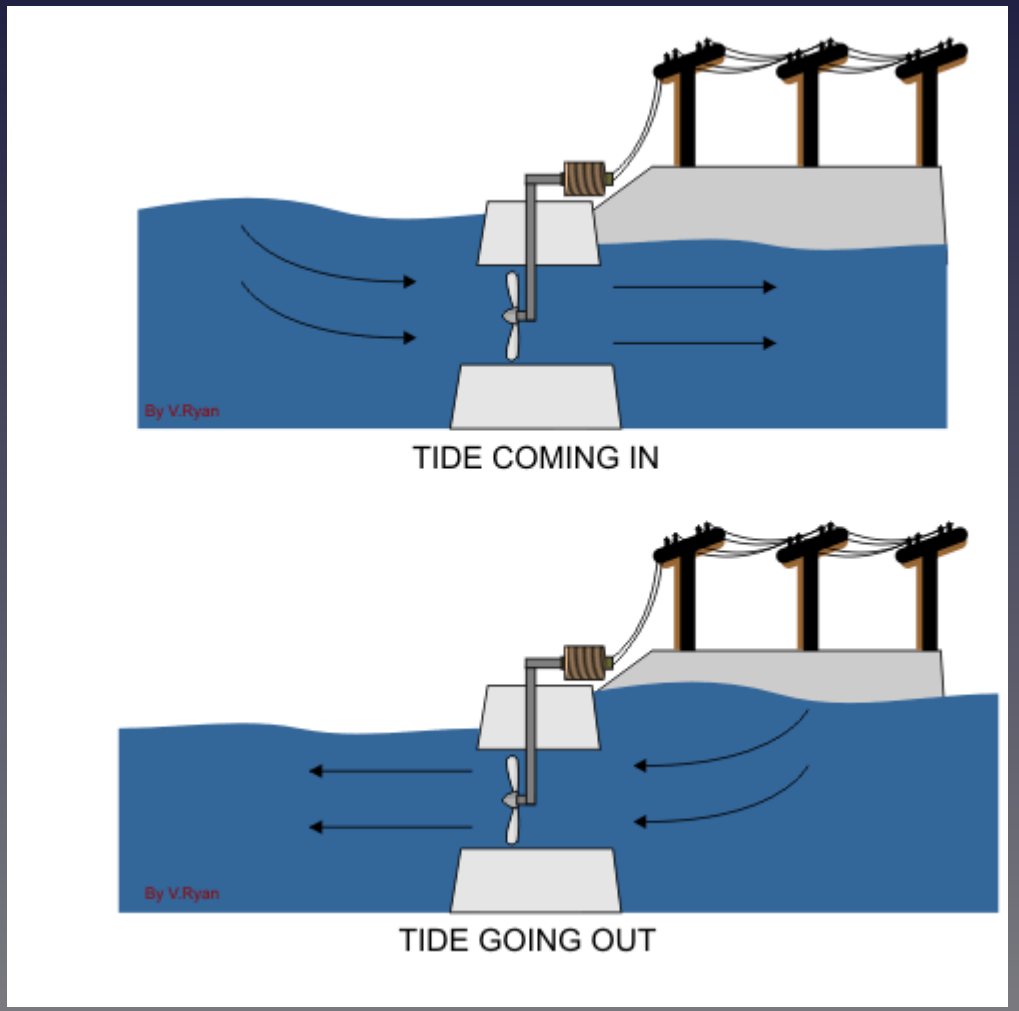
Million Acres	0	5	10	15	20	25	30	35	40	45	50
Million Tons - 2000	0	29	54	85	128	148	176	193	215	258	280
Million Tons - 2005	0	33	77	105	146	164	200	223	231	295	301
Million Tons - 2020	0	51	92	117	159	198	238	262	277	318	352

Renewable Energy
Tidal and River Motion

Like a windmill,
but under water

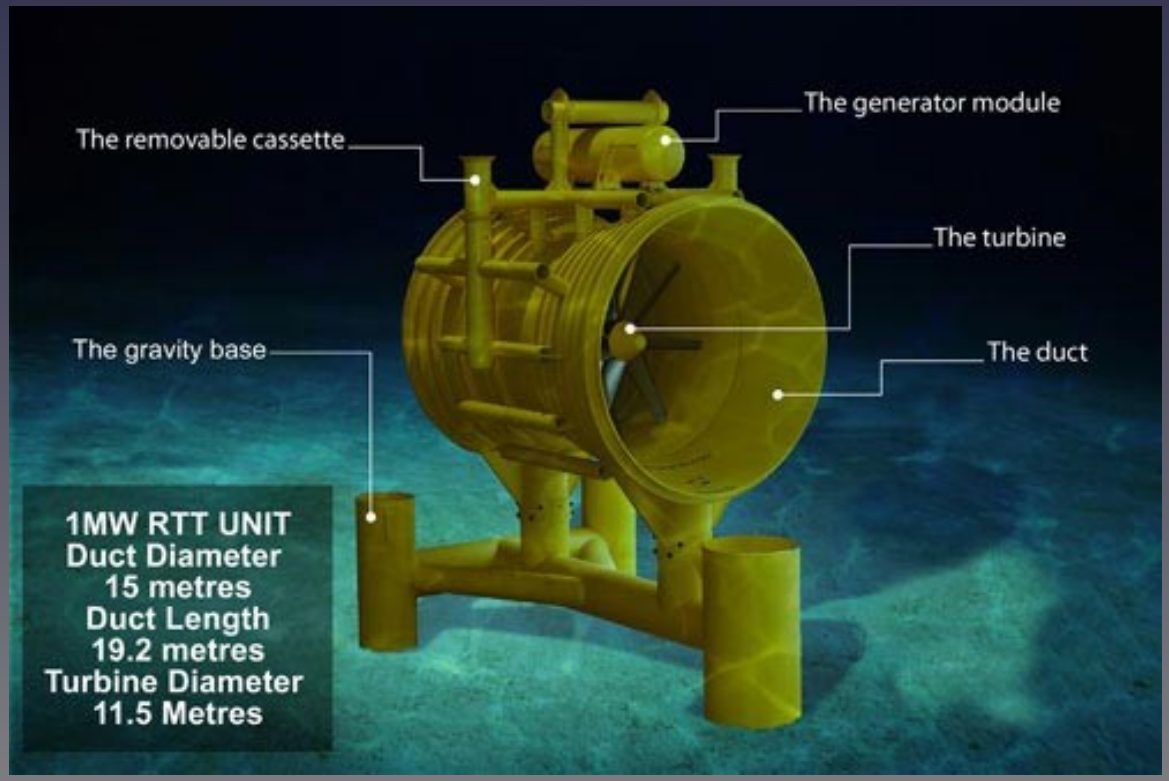


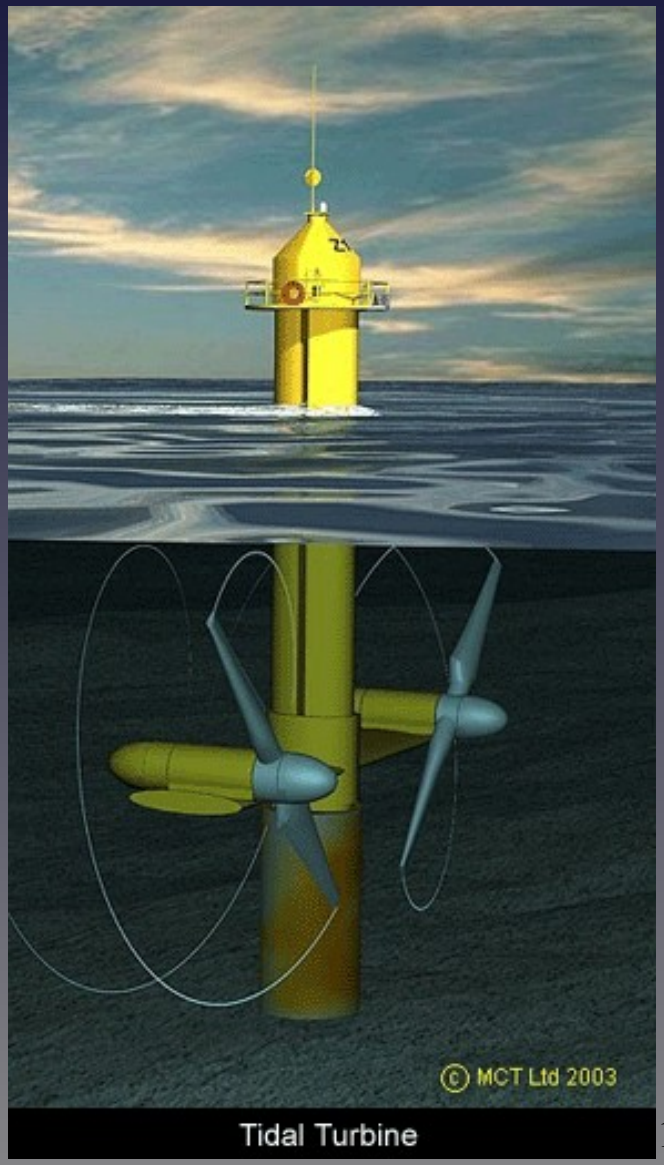
LaRance river estuary in France
240 MW



Renewable Energy
Tidal and River Motion

Like a windmill, but under water

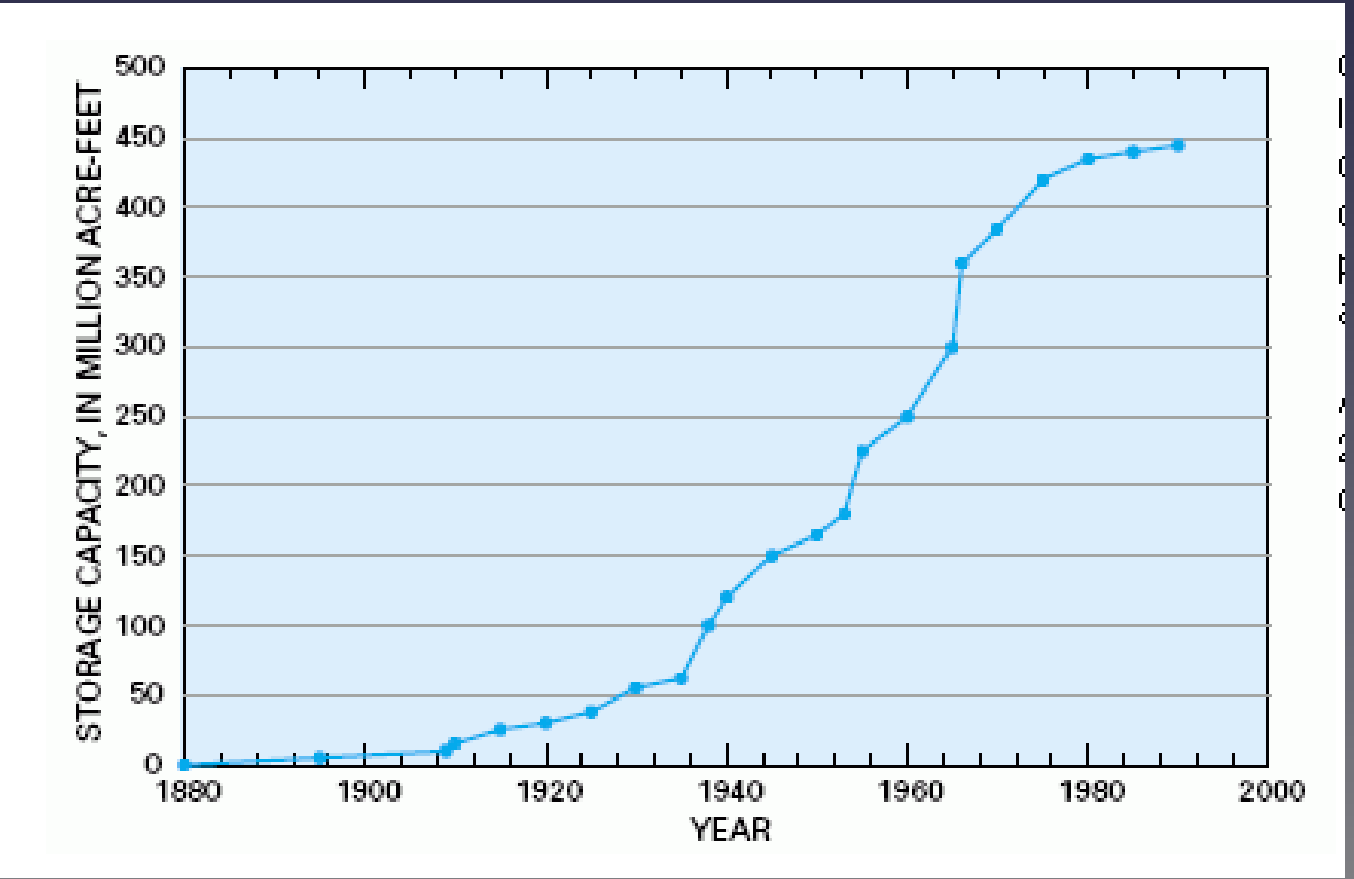




Renewable Energy
Conventional Hydroelectric

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

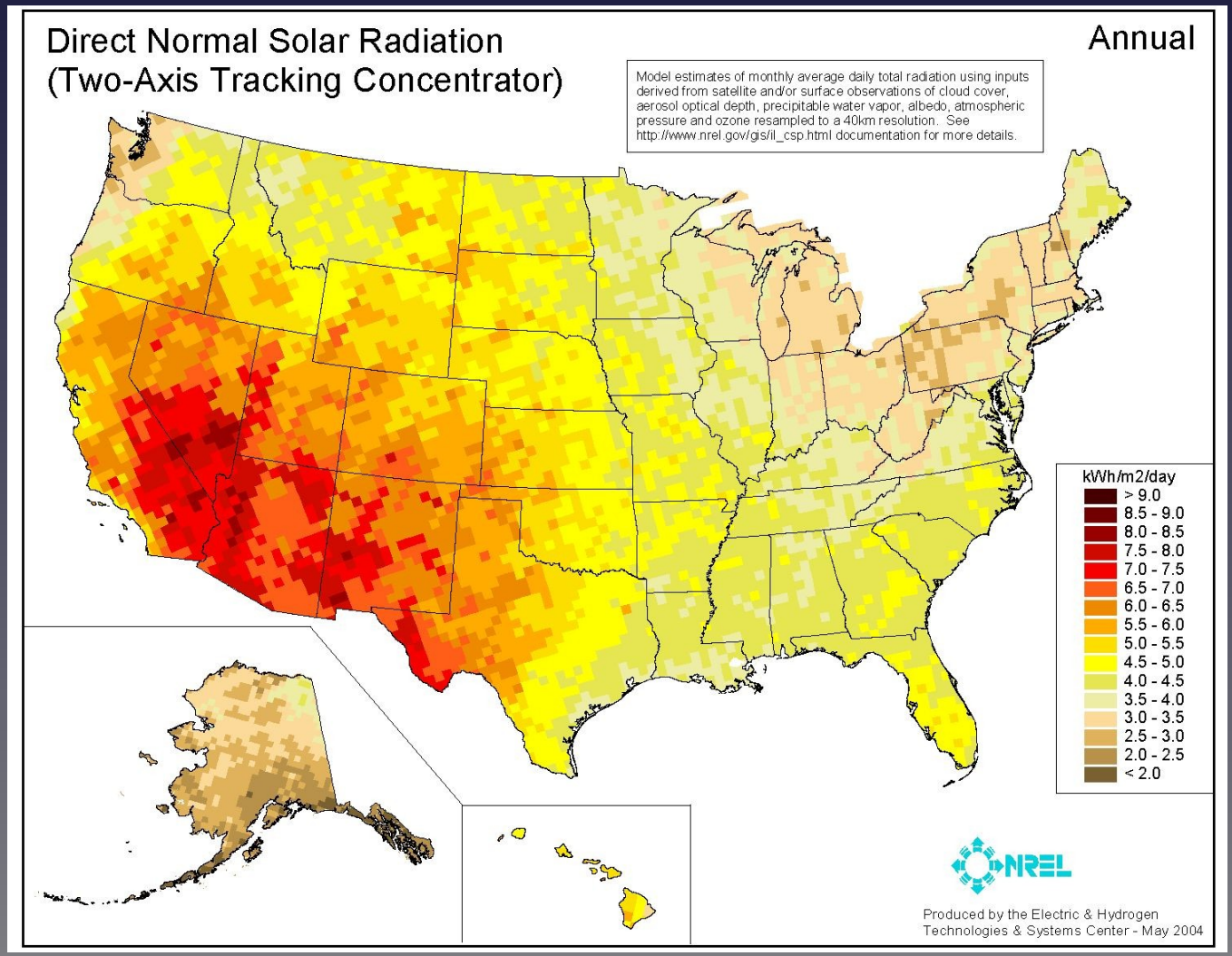
1 sq. mi yields 4,646 megawatt-hours per day

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

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 so 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

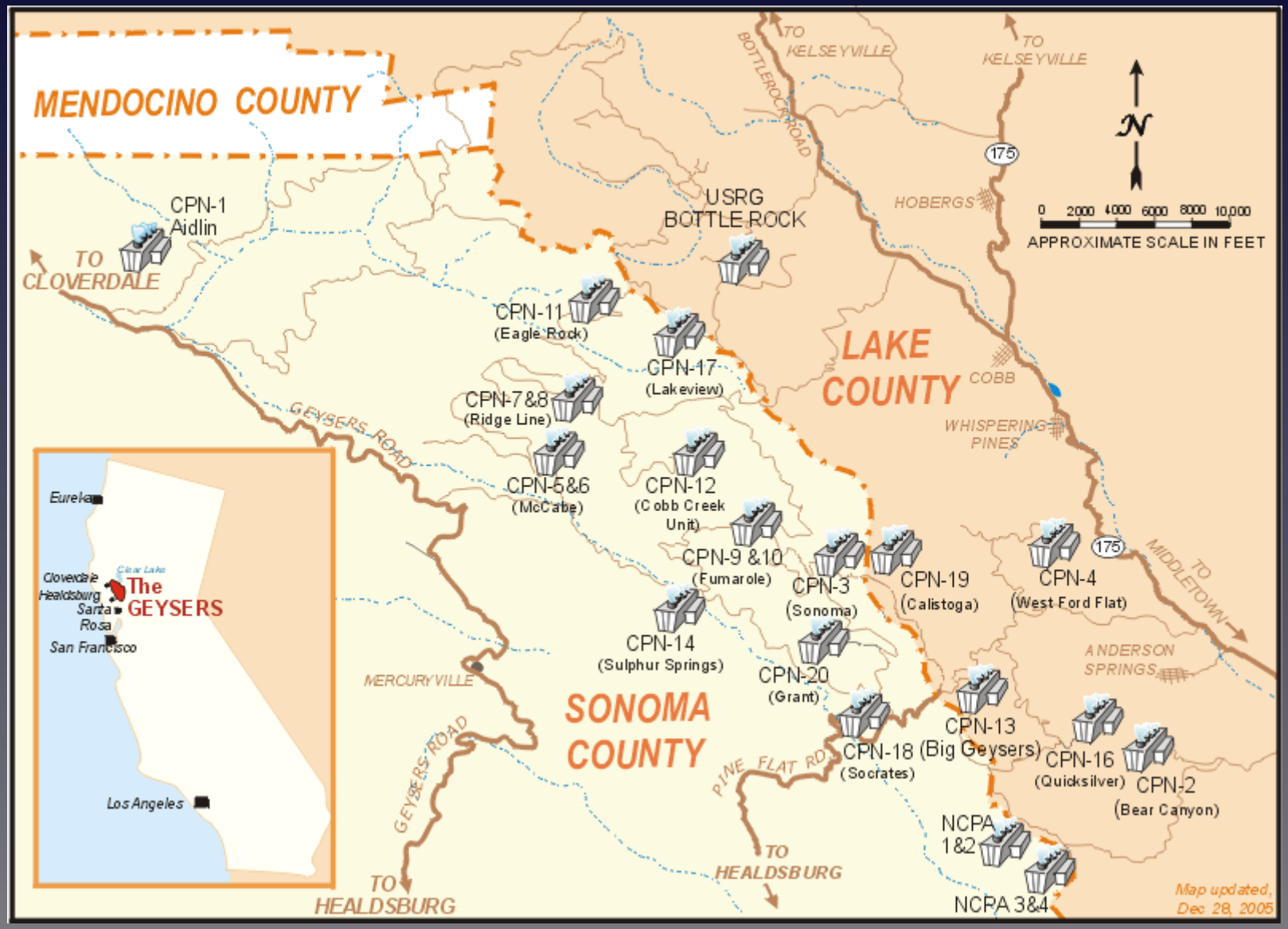
Renewable Energy
Geothermal

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

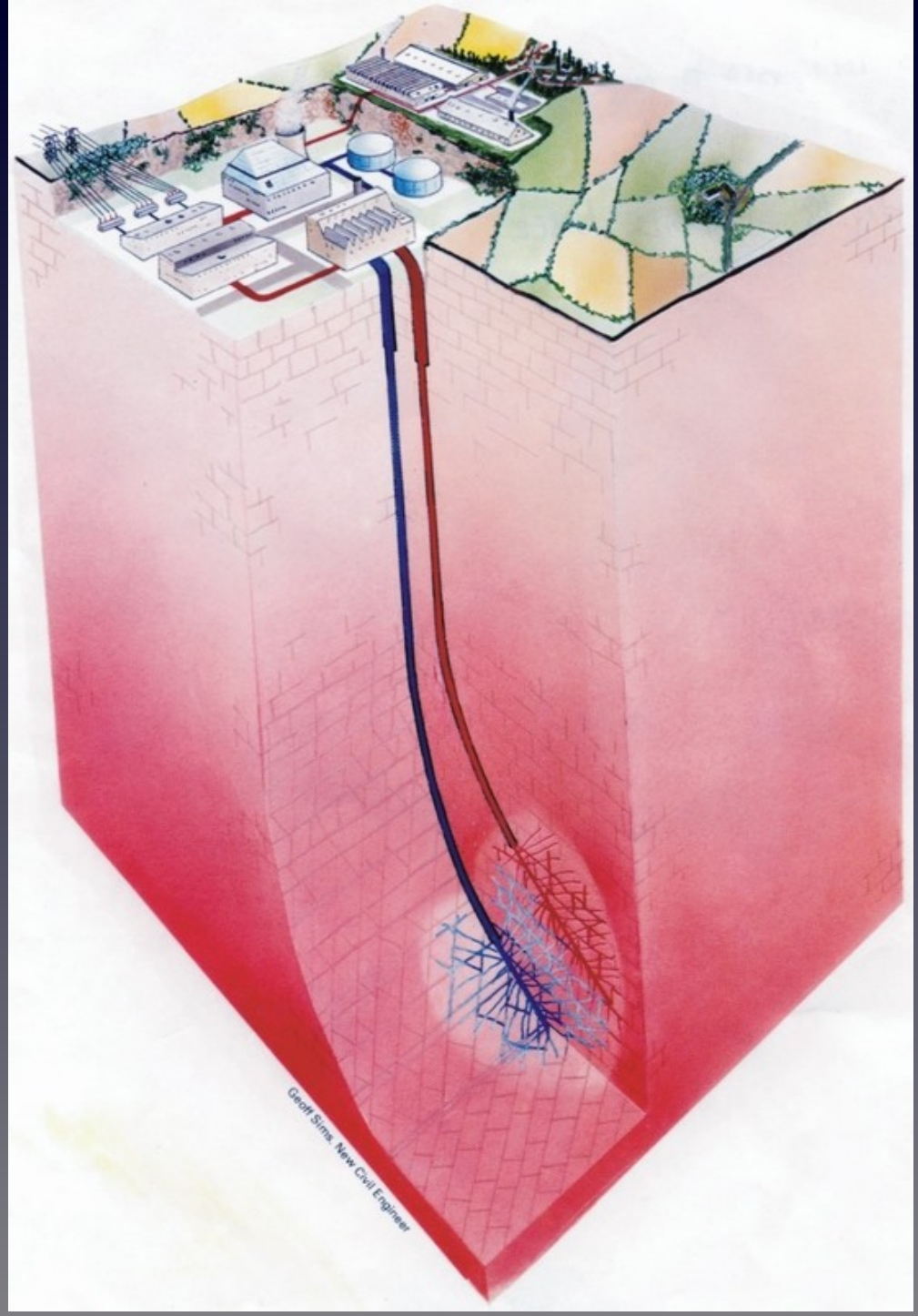
Renewable Energy
Geothermal

Modern plant at The Geysers

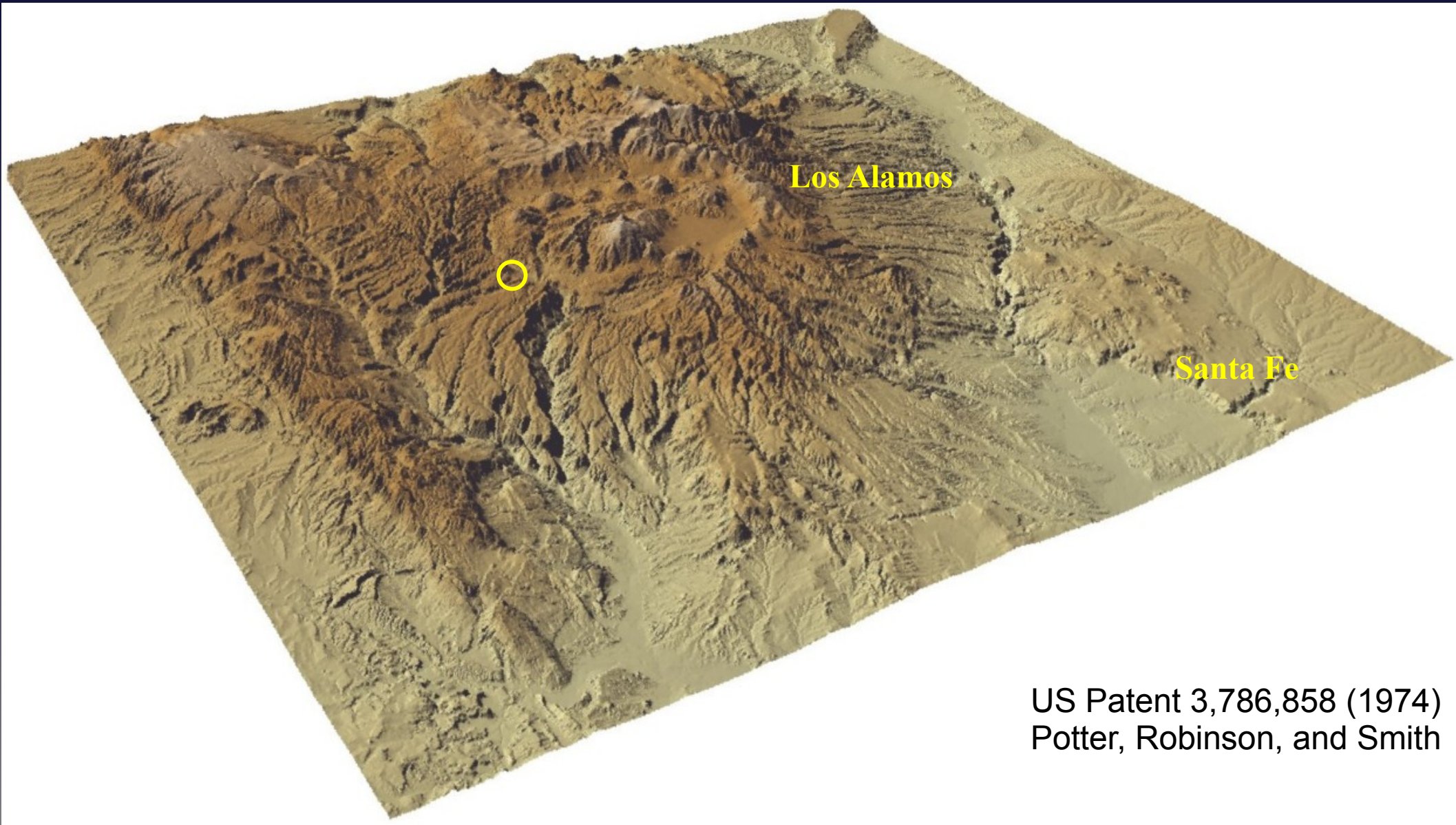
First generating plant, 1921

Renewable Energy

Hot Dry Rock
(now just Enhanced)
Geothermal Plant



Renewable Energy
Enhanced Geothermal: Valles Caldera, Fenton Hill



US Patent 3,786,858 (1974)
Potter, Robinson, and Smith

Renewable Energy
Geothermal

Renewable Energy

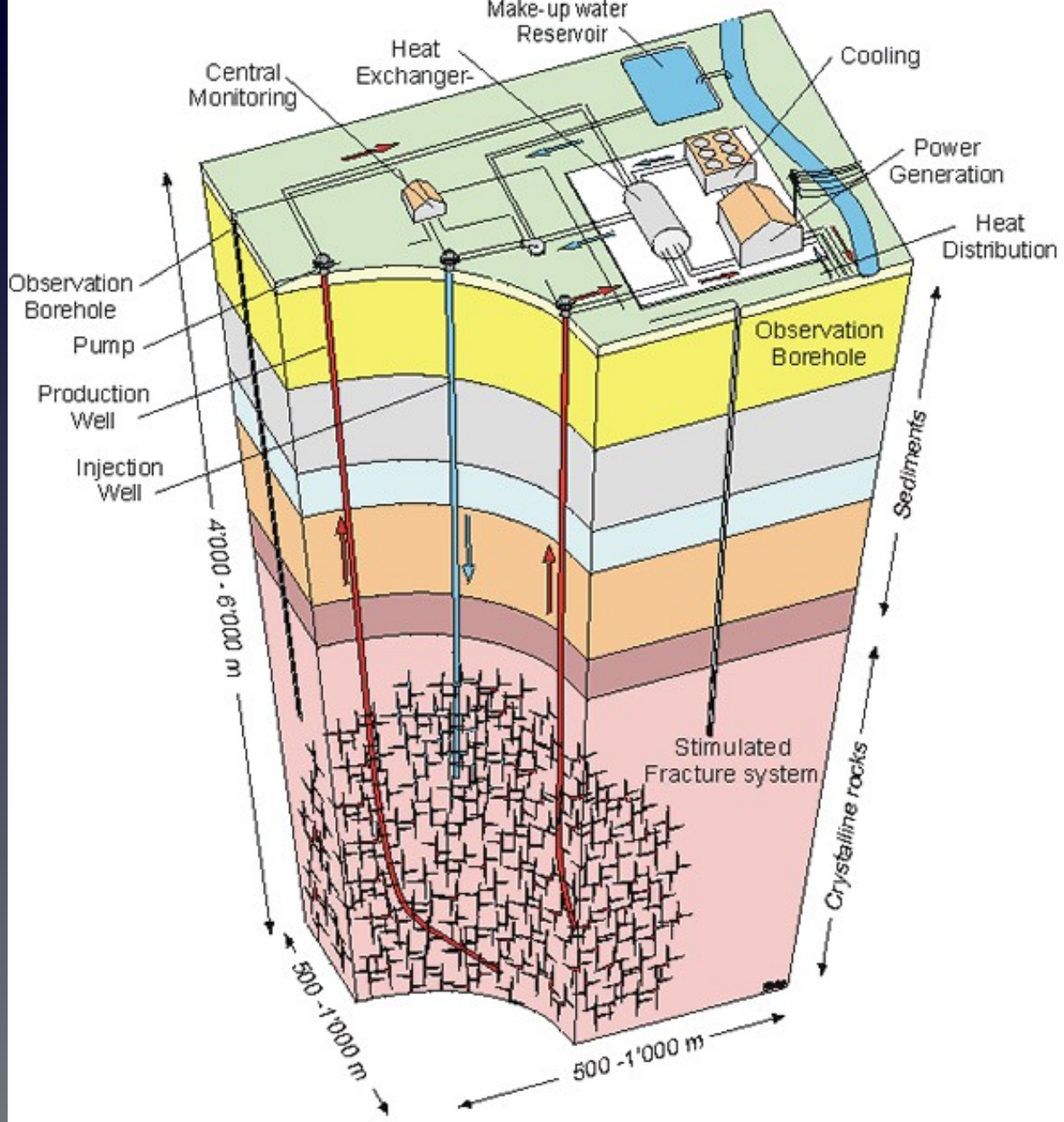
Valles Caldera, Fenton Hill

The Los Alamos Hot Dry Rock Project, 1974-1995

Renewable Energy

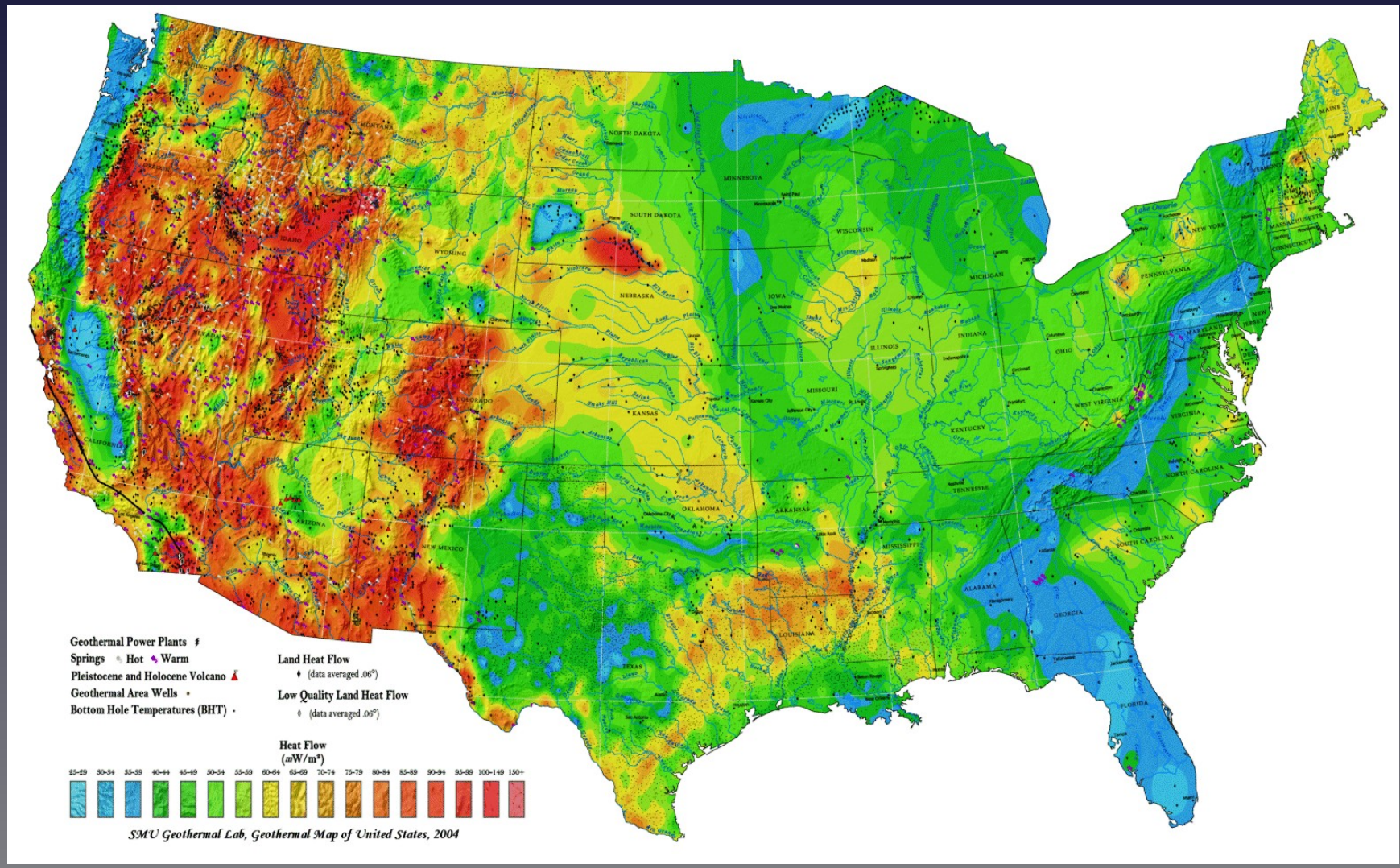
Hot Dry Rock (now just Enhanced) Geothermal Plant

The Haring Project in Switzerland Projected power was 3MW electricity and 20MW heat for buildings in Basel



Concept of the Deep Heat Mining System

Renewable Energy
Geothermal heat flow



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 the MIT report, only 2% of the heat beneath the continental US between 3 and 10 km (depths we can reach with current technology) is more than 2,500x the total energy use of the United States.

Renewable Energy
Geothermal risks

- The development and operation of EGS plants produces small earthquakes
- An earthquake during fracturing of the reservoir in Basel Switzerland in 2006 shut down that project
- Basel was seriously damaged by an earthquake in 1356
- Project will probably not be restarted
- EGS projects should not be placed near large natural faults
- A fund (estimated to cost a very small percent of revenues) can be established to insure EGS plants against seismic events

Renewable Energy
Gen 3 Nuclear Reactors

- Most of the nuclear power reactors (including TMI) we have are referred to as 2nd generation designs
- A newer generation of design is called 3rd generation, or Gen 3
- The Gen 3 reactors have economic and safety advantages

Renewable Energy
Gen 3 Nuclear Reactor Features

- a standardised design for each type to expedite licensing, reduce capital cost and reduce construction time,
- a simpler and more rugged design, making them easier to operate and less vulnerable to operational upsets,
- higher availability and longer operating life - typically 60 years, renewable to 120 years

Renewable Energy
Gen 3 Nuclear Reactor Features

- further reduced possibility of core melt accidents including passively safe designs,
- resistance to serious damage that would allow radiological release from an aircraft impact,
- higher burn-up to reduce fuel use and the amount of waste,
- burnable absorbers ("poisons") to extend fuel life,
- injectable, removable, solution poisons for safety.

Renewable Energy
Reactor waste disposal

- The only proposed waste disposal site in the US, at Yucca Mountain, Nevada has been ruled unacceptable by the current US administration
- Public opposition to using it is strong
- DOE Secretary Chu is recommending a new "Blue Ribbon Panel" to make recommendations
- The US will have no reactor waste disposal for the foreseeable future

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 fail catastrophically
- Windmills kill bats and birds (current designs)
- Tidal turbines kill fish, eels, etc.
- Hydroelectric dams destroy fish migration
- Geothermal plants produce small earthquakes
- 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 "one-and-only"
- 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

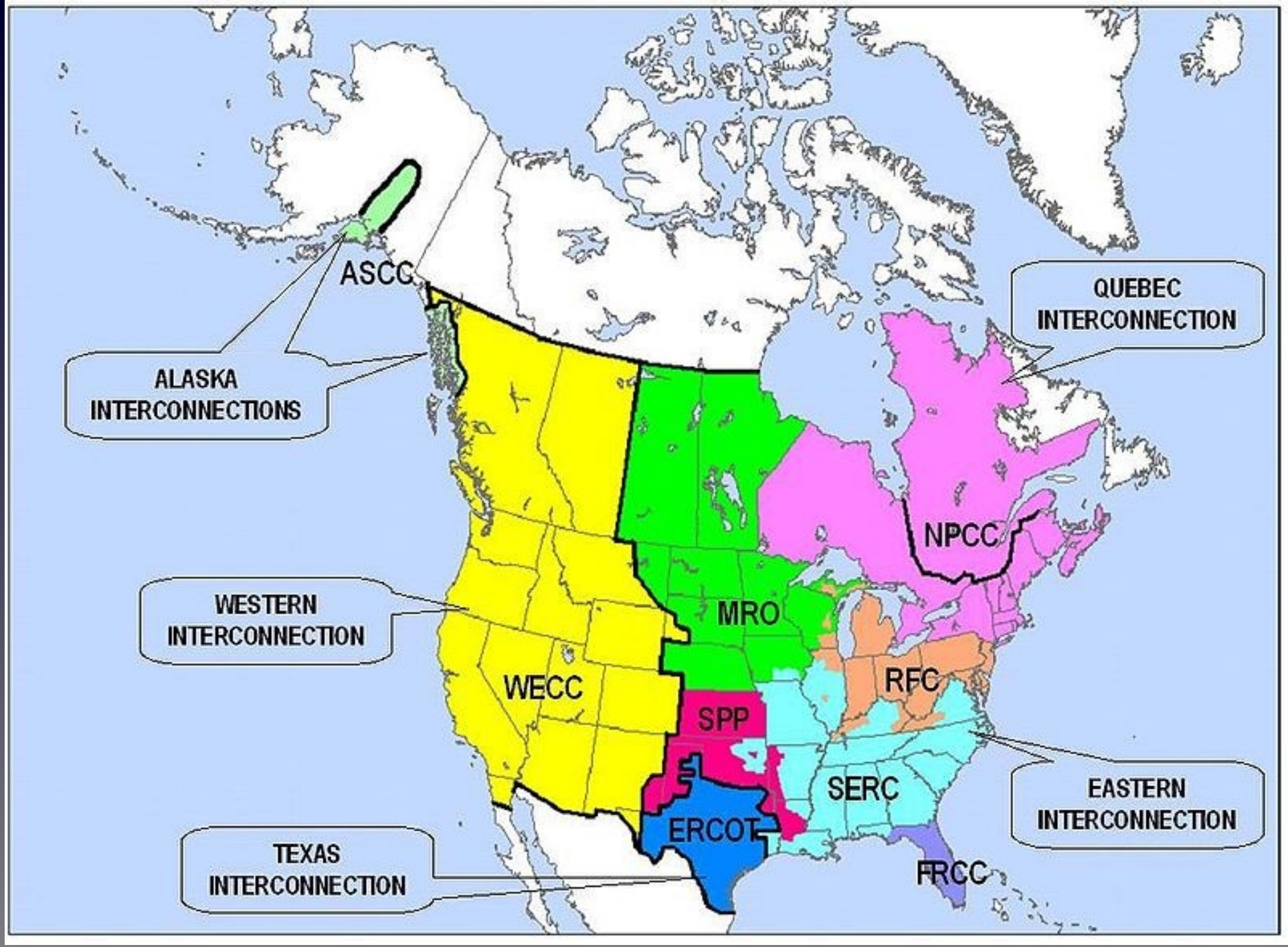
Renewable Energy
Development

Don't

- Drill, Baby, Drill

Instead

- Build, Baby, Build



Renewable Energy

Tres Amigas

Renewable Energy
Tres Amigas

A nationwide power sharing hub connecting the three regional interconnections

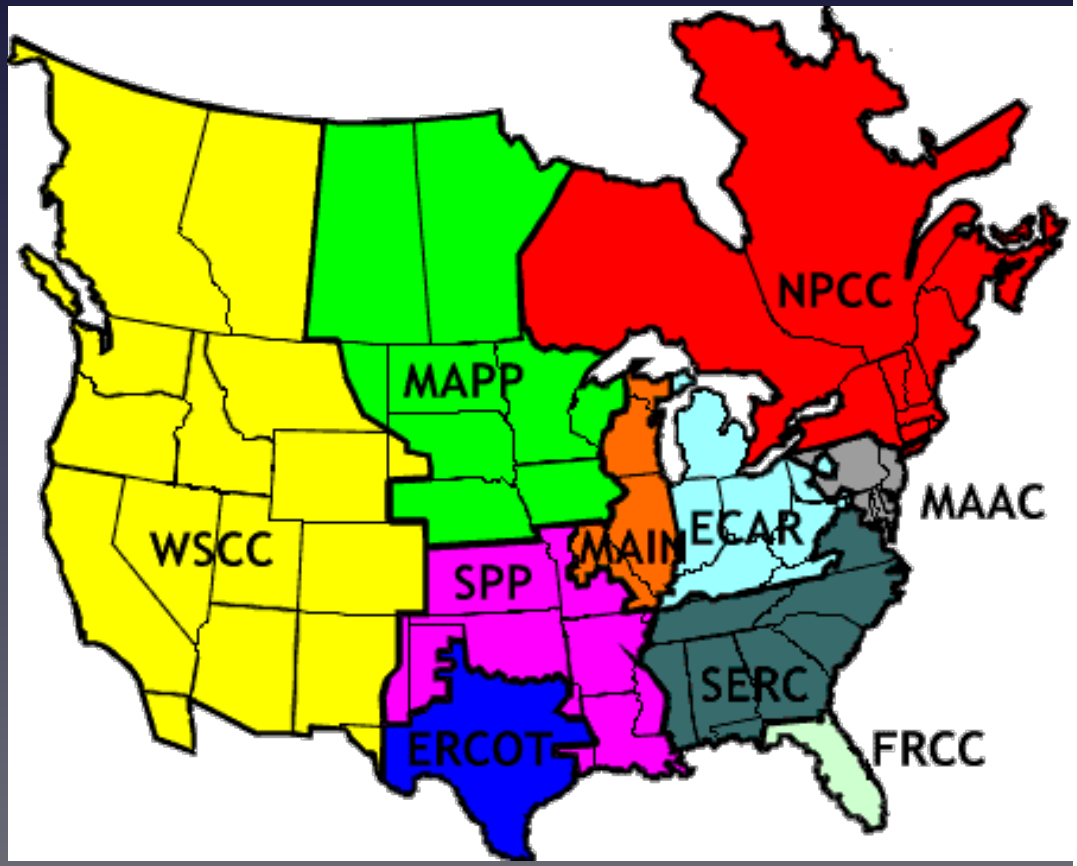
- Each regional interconnection requires every generator in it to spin at *exactly* the same speed
- The regional interconnections cannot trade electricity directly
- The electricity must first be converted to DC, piped across, then converted back to AC

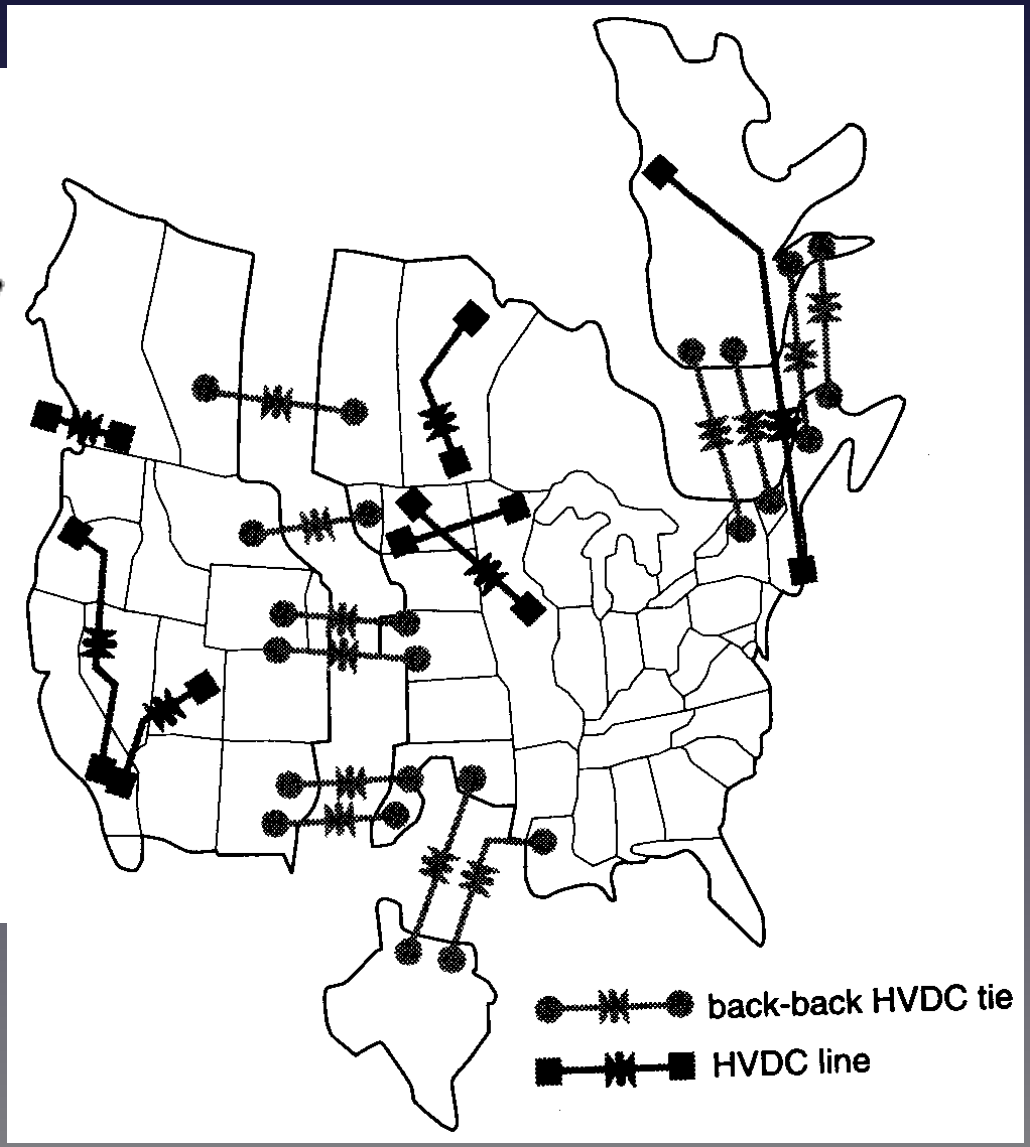
Tres Amigas will be the largest and only bridge connecting all three regions

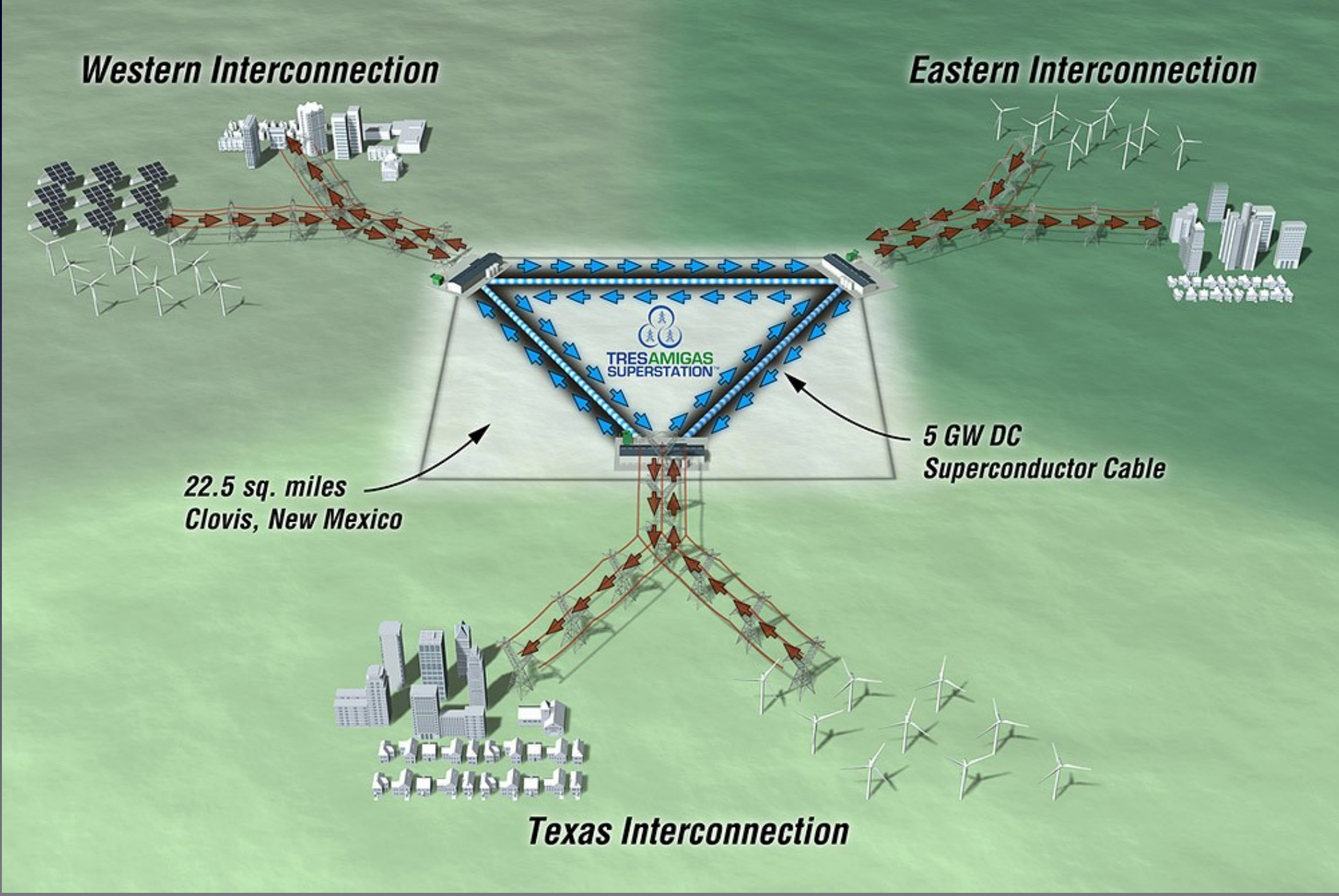
Renewable Energy
Tres Amigas

- Tres Amigas has been approved by the Federal Energy Regulatory Commission
- The majority of applicants to trade power so far are conventional coal-burning plants

Renewable Energy
Tres Amigas







Renewable Energy

Tres Amigas

Renewable Energy
Role of government

- Current policies give incentives to oil and gas production
- In 1931, the *Oil Depletion Allowance,* a large tax break, was introduced and lasted until the 1970s
- Current tax breaks are justified as enlarging domestic production

Renewable Energy
Role of government

- Tax breaks for alternative energy production are provided by the 2009 Recovery Act
- Investors want to be sure that the breaks will continue before committing to expenditures
- The ARRA provides a $0.021/kWh Production Tax Credit for ten years
- The Waxman-Markey bill passed by the USHR provided some most-needed features

Renewable Energy
Role of government

Waxman-Markey provisions

- a cap and trade program,
- a 20 percent renewable energy target by 2020,
- a program to upgrade the electric grid, and
- stronger energy efficiency standards

Renewable Energy
Cap and Trade

- The government sets a limit on how much CO_2 can be released by the whole country
- Each company or group is issued a permit to release a certain amount, and
- An allowance that may be smaller than the permit
- The releasing entity must buy additional allowances from another that does not need them
- For example, a coal-burning generator might buy the allowances from a solar generator
- Such a cap-and-trade system has worked well to reduce acid rain

Renewable Energy

Just do it already!!!