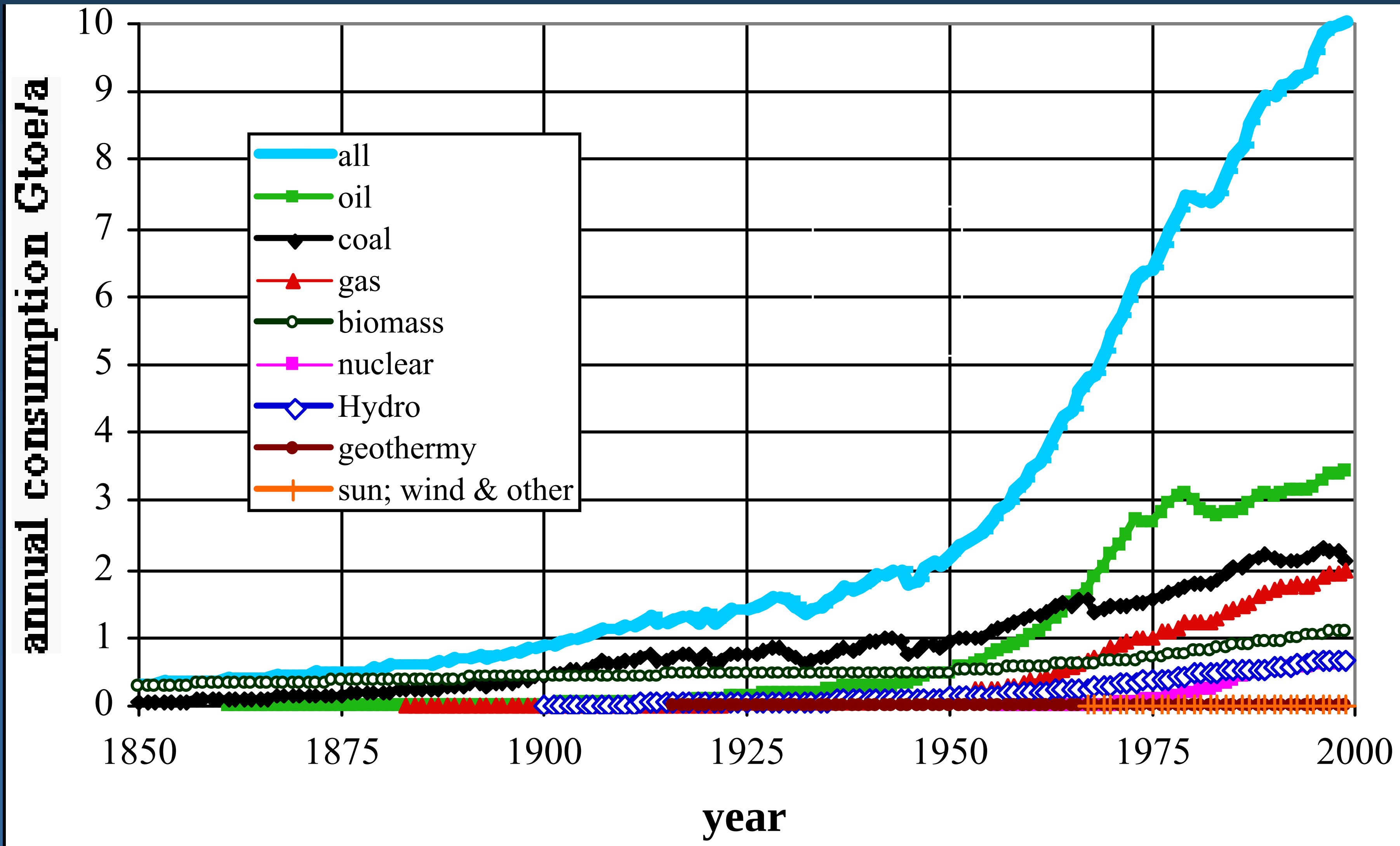
Energy: 1Mega$, 1Giga$, 1Tera$?

Jerry Seidler

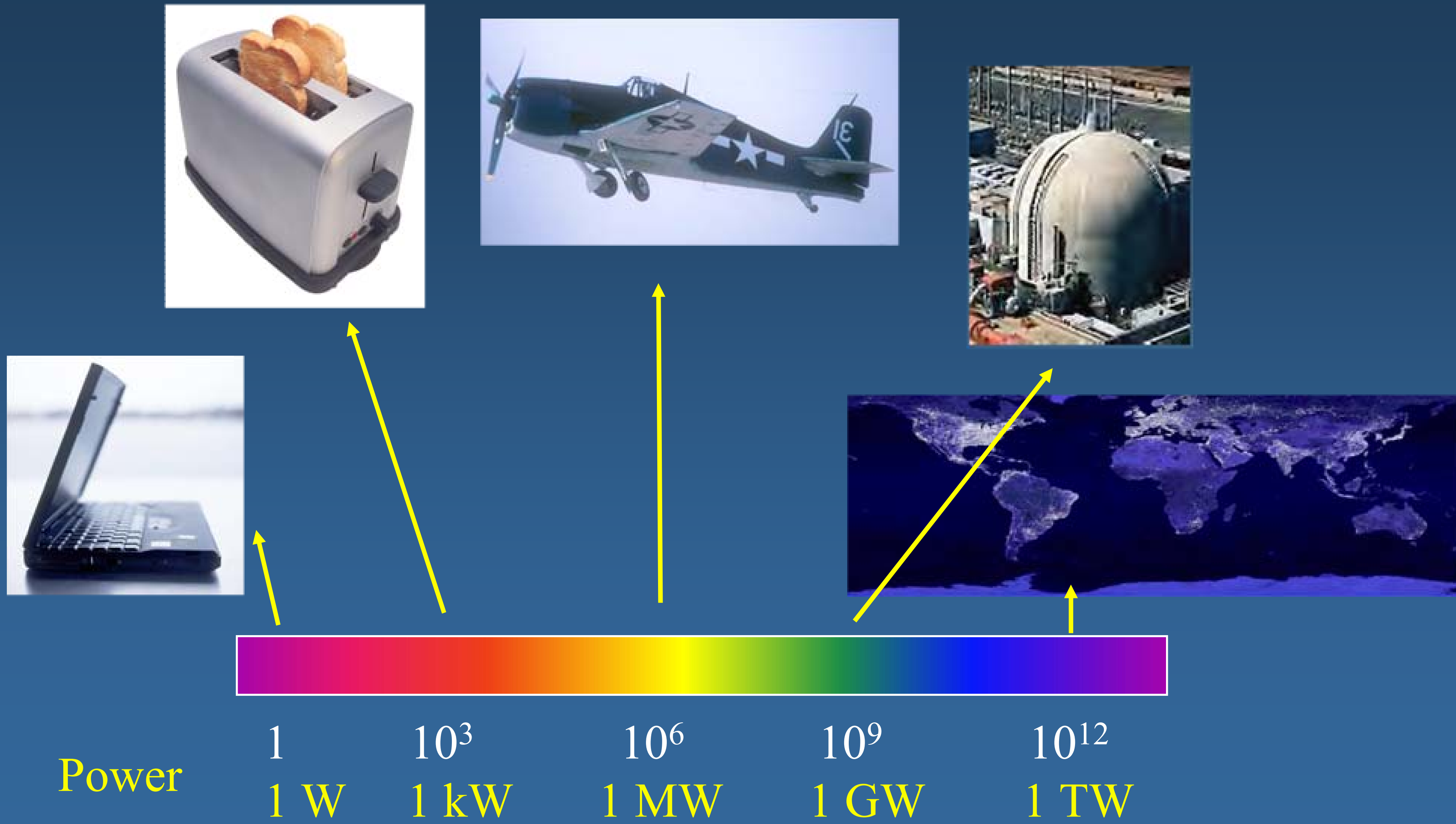
Energy Future Seminar Apr 1

This is intended as an overview of some of the largest technical and scientific problems in sustainable energy production… most of the slides are taken from Nate Lewis's (famous) "Powering the Planet" lecture

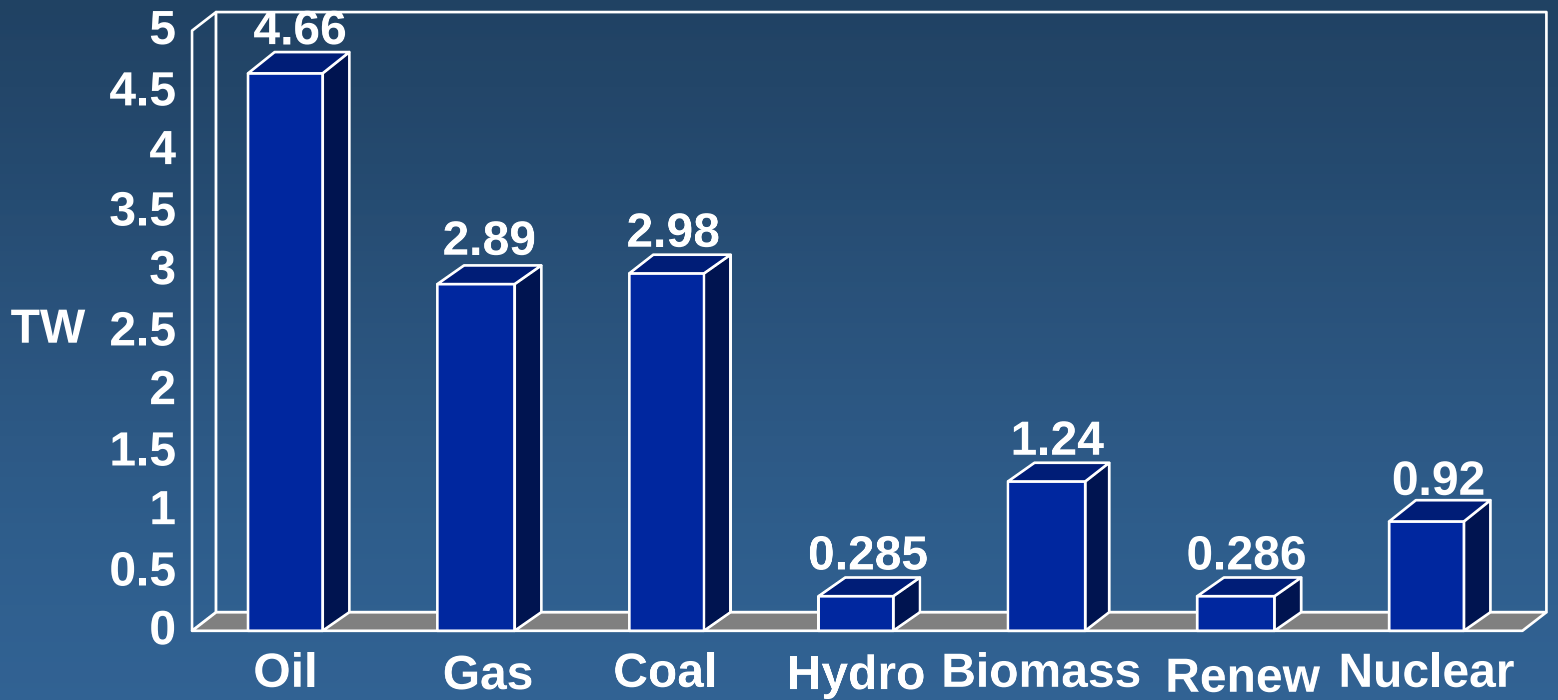
Global Energy Consumption



Power Units: The Terawatt Challenge

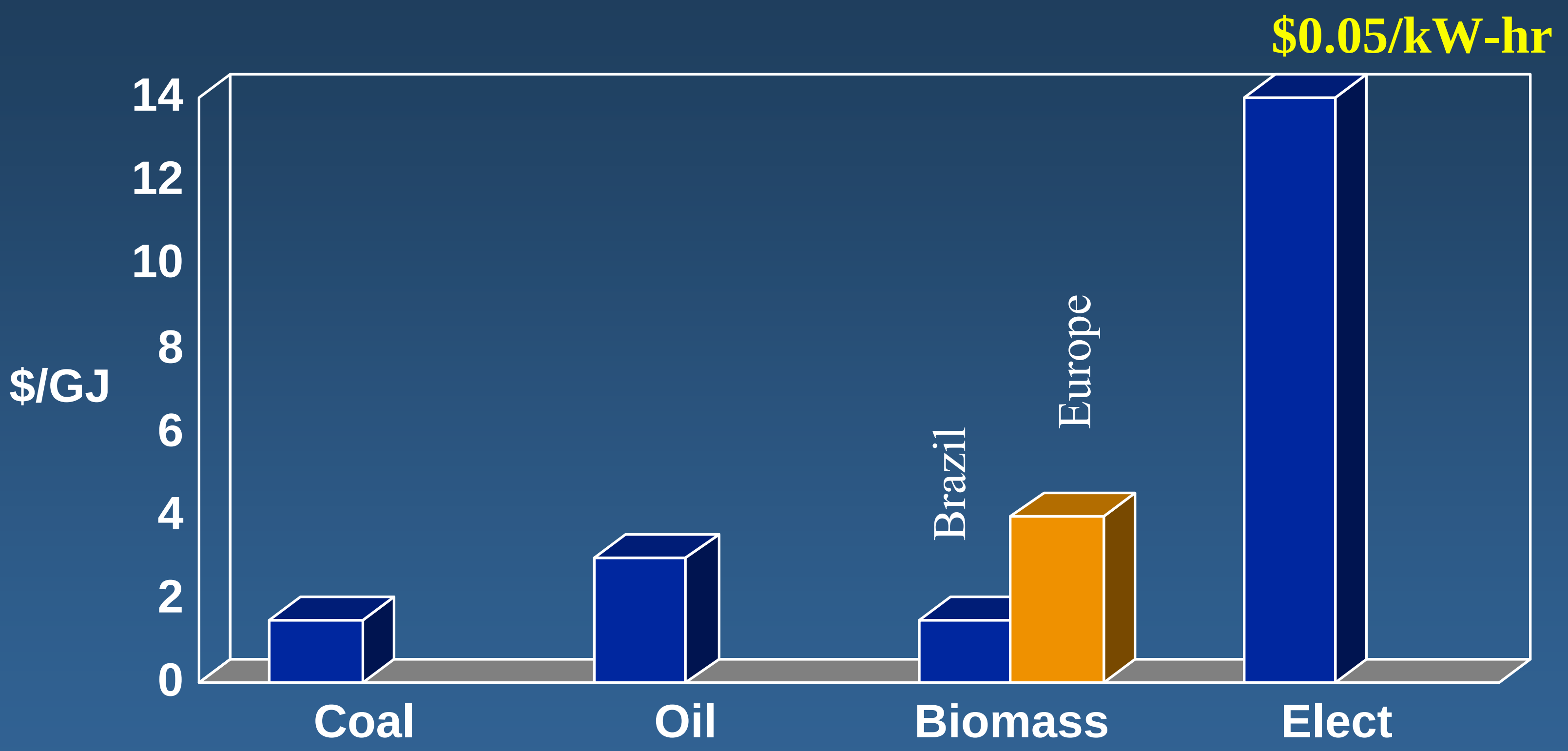


Global Energy Consumption, 2001



Total: 13.2 TW   U.S.: 3.2 TW (96 Quads)

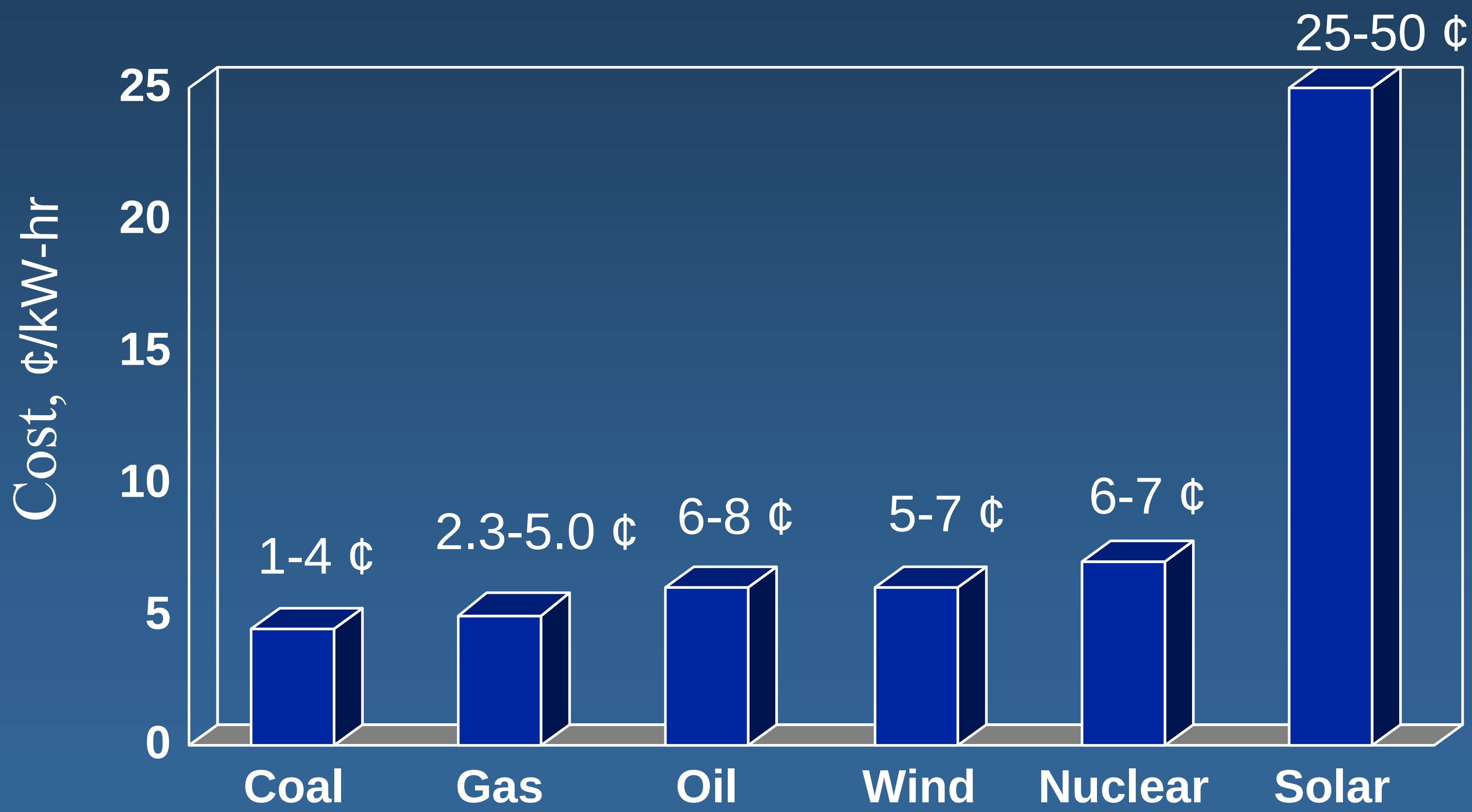
Energy Costs



www.undp.org/seed/eap/activities/wea

Today: Production Cost of Electricity

(in the U.S. in 2002)



What is annual global expenditure on purchasing energy?

What is annual global expenditure on purchasing energy?

More or less 1,000 Trillion$

(1 Terabuck)

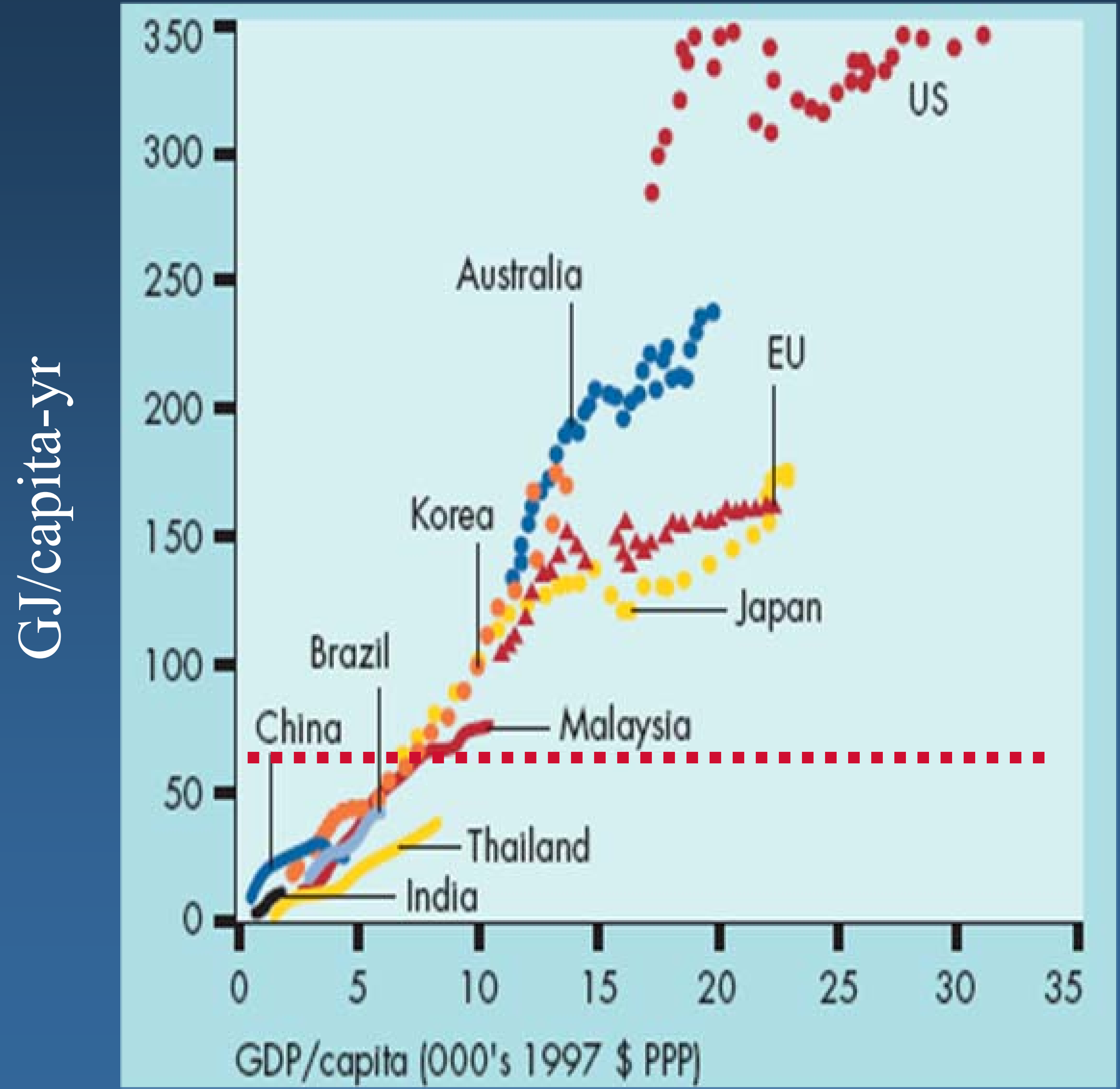
What is annual global expenditure on purchasing energy?

More or less 1,000 Trillion$

(1 Terabuck)

Upstream and downstream effects give big multipliers and expenditures and impacts

Energy Consumption vs GDP



Sources of Carbon-Free Power

- Nuclear fission
  - 10 TW = 10,000 new 1 GW reactors
  - i.e., a new reactor every other day for the next 50 years
  - ∏ 2.3 million tonnes proven reserves;
    1 TW-hr requires 22 tonnes of U
  - ∏ Hence at 10 TW, terrestrial resource base provides 10 years of energy
  - ∏ More energy in CH_4 than in ^{235}U
  - ∏ Would need to mine U from seawater
    (700 x terrestrial resource base;
    so needs 3000 Niagra Falls or breeders)
  - ∏ At $5/W, requires $50 Trillion (2006 GWP = $65 trillion)
- Carbon sequestration
- Renewables

Nuclear issues…

- Proliferation
  - Alternative fuel cycles: Th…
- Waste from fuel processing → radiation hazards & storage
- Waste fuel rods→radiation hazards & storage
- Land-based reserves of U are not plentiful on the ~50 yr time scale. Extraction from seawater is ‘obvious’ priority…. (but …)

5f-element Bonding is not Academic

Yucca mountain full with spent fuel by 2017, ***if opened…***

"***Yucca Mountain is not a workable option*** *and we will begin a thoughtful dialogue on a better solution for our nuclear waste storage needs.*"

Energy Secretary, Steven Chu, March 11 2009.

5f-element Bonding is not Academic

The Magic Number: 3 TW

This is the present US consumption rate for electricity (more or less)

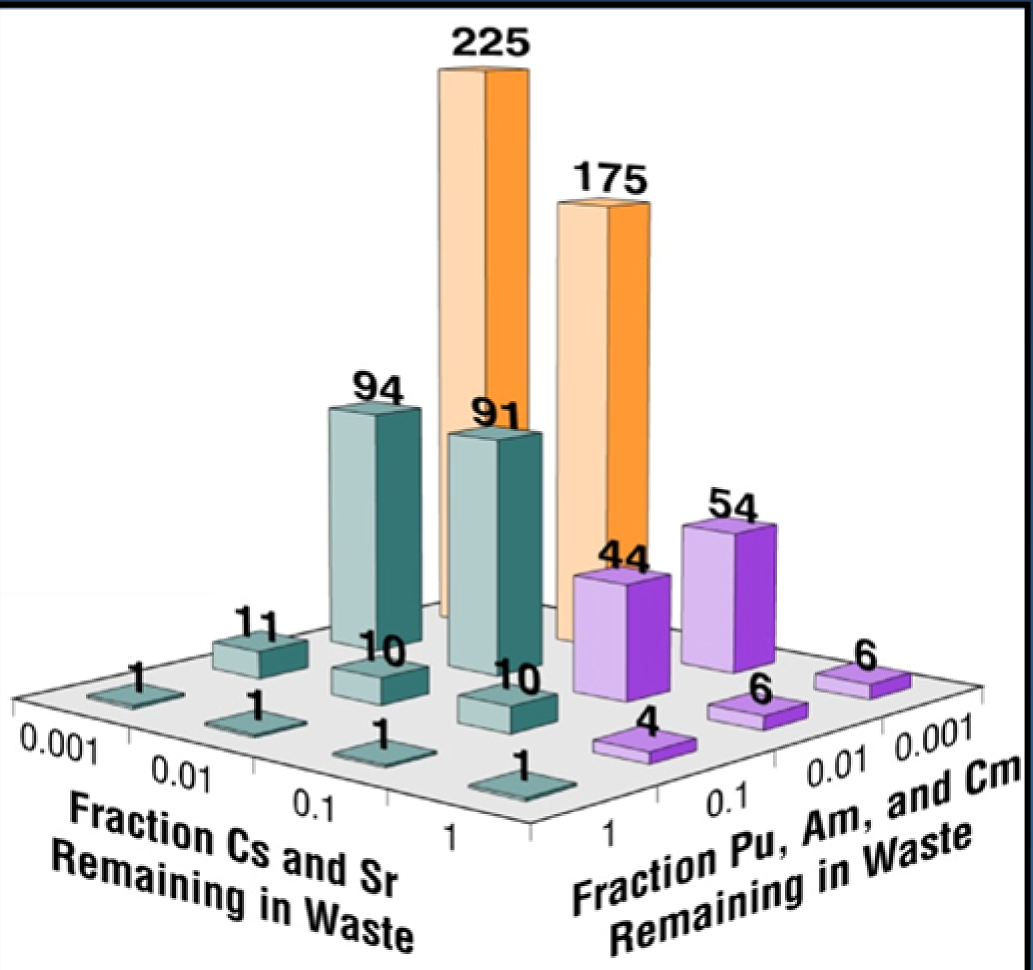
What sustainable (i.e., not petrochemical) energy generation channels exist on the scale of TW?

Nuclear: A few hundred reactors…

- What fuel cycle? (Th? Reprocessed?)
  - US running out of 'traditional' U reserves
  - Where to store spent rods?
- Fuel (re)processing
  - Reduce waste stream requiring storage
  - Nontraditional 'mining': seawater?

Actinide Separations Chemistry

RELATIVE INCREASE IN REPOSITORY BY REMOVING TRANSURANICS AND FISSION PRODUCTS



Wigelund, *Nuclear Technology*, (2006) 154 95-106.

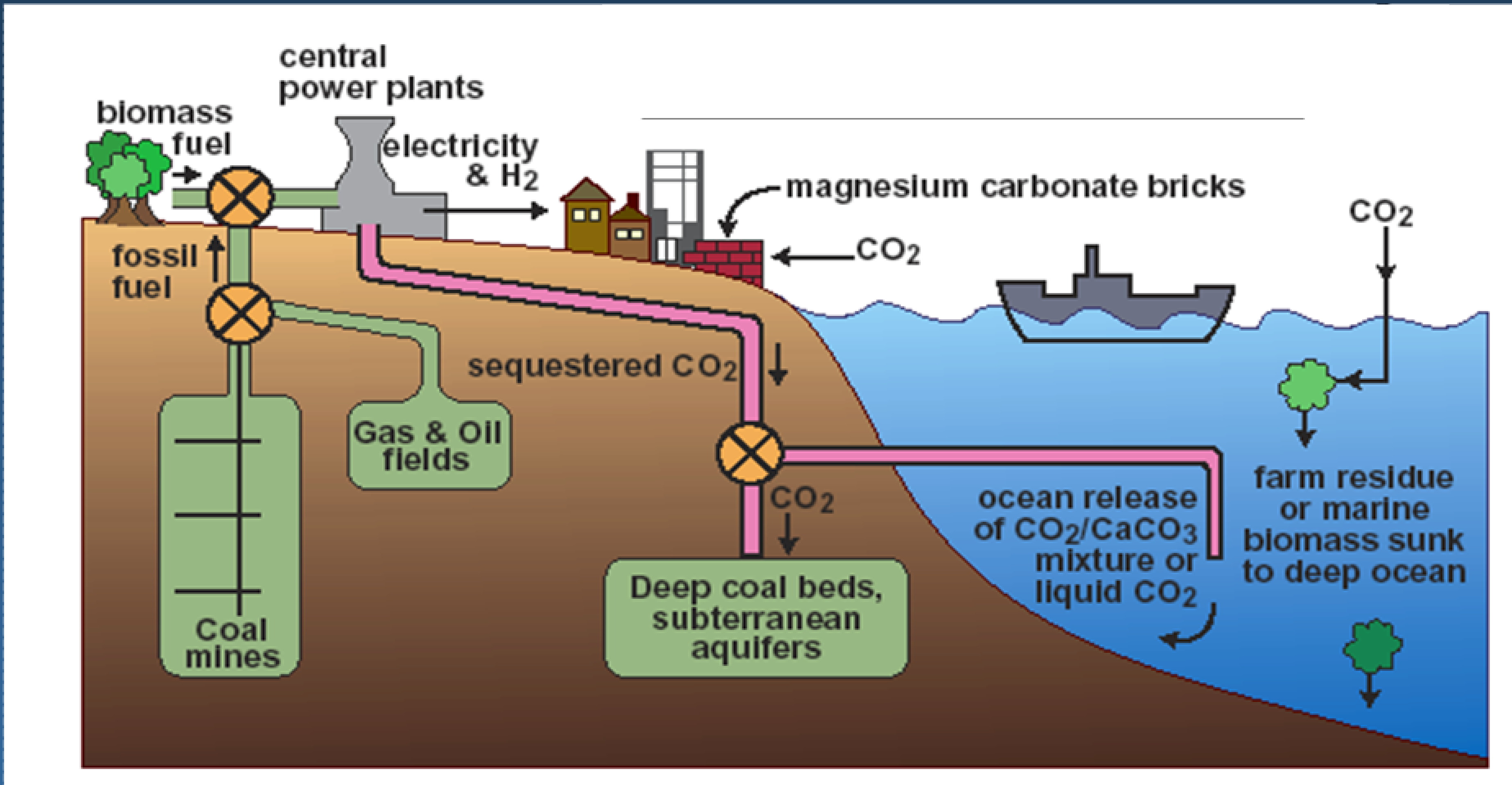
Vastly reduces waste volume

Factor of 100's gain in repository volume

Challenge: *An* must first be separated from *Ln*, which inhibit further separation

In particular, Ln(III) and An(III) are most difficult to separate.

Carbon Sequestration



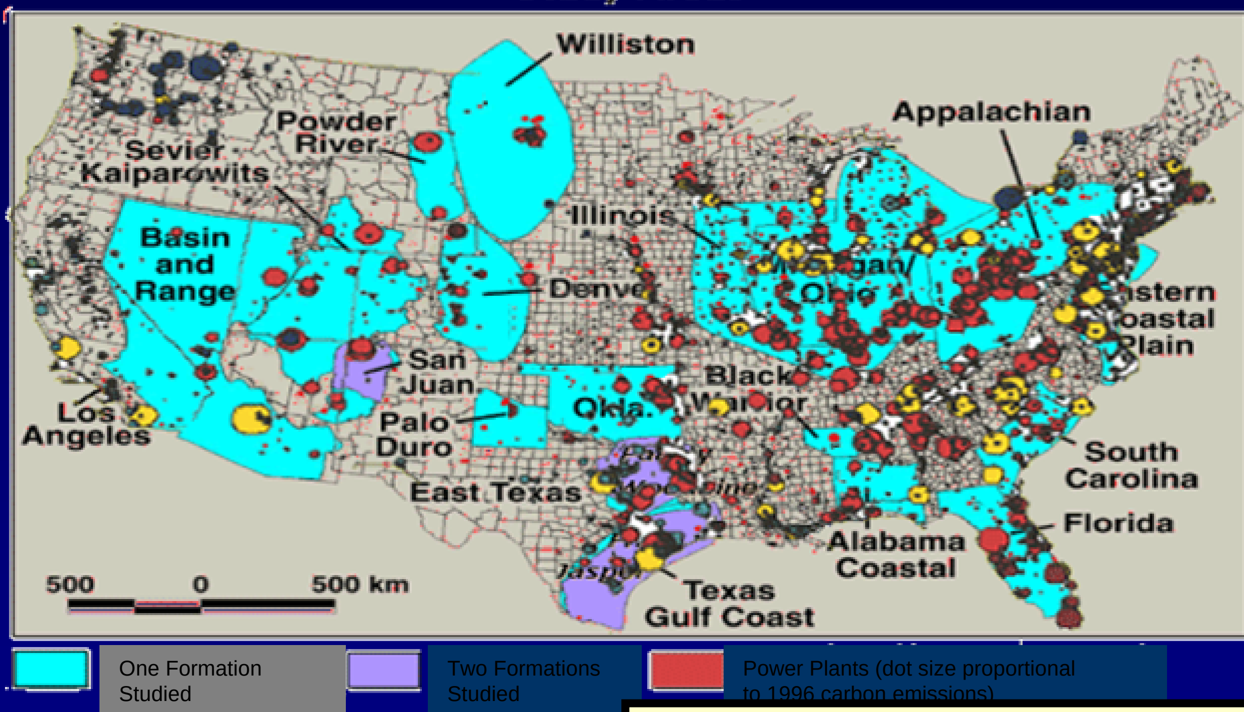
CO_2 Burial: Saline Reservoirs

130 Gt total U.S. sequestration potential

Global emissions 6 Gt/yr in 2002   Test sequestration projects 2002-2004

Study Areas

- **Near sources (power plants, refineries, coal fields)**
- **Distribute only H_2 or electricity**
- **Must not leak**
- **At 2 Gt/yr sequestration rate, surface of U.S. would rise 5 cm by 2100**

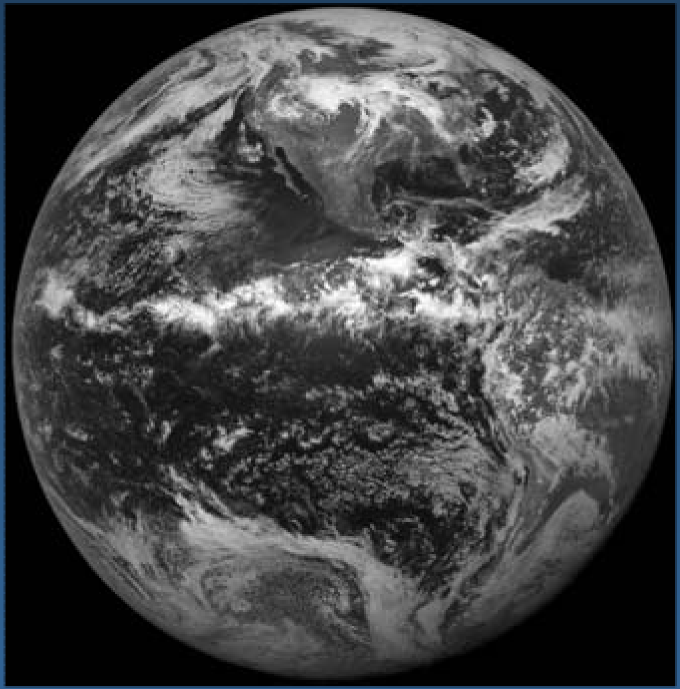


DOE Vision & Goal:
1 Gt storage by 2025, 4 Gt by 2050

Solar

Biomass

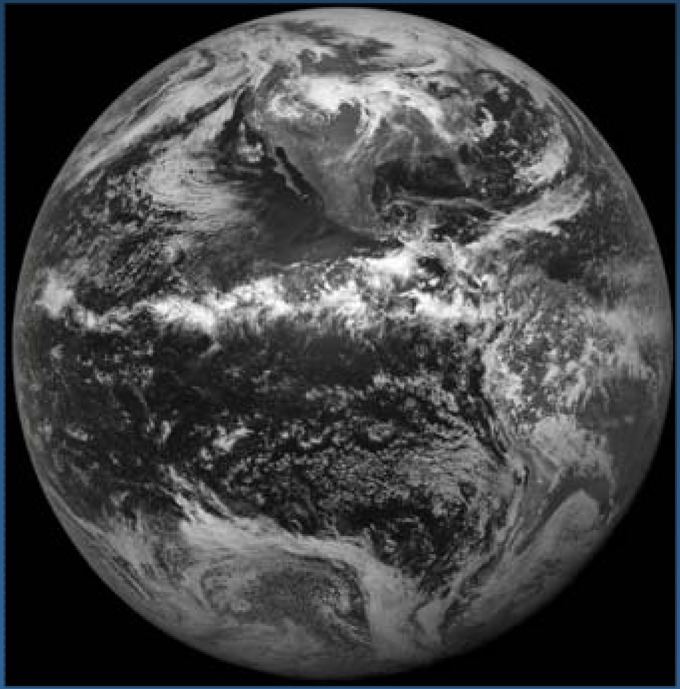
Ocean



Hydroelectric

Wind

Geothermal



Hydroelectric

Gross: 4.6 TW
Technically Feasible: 1.6 TW
Economic: 0.9 TW
Installed Capacity: 0.6 TW

Hydroelectric Energy Potential

Globally

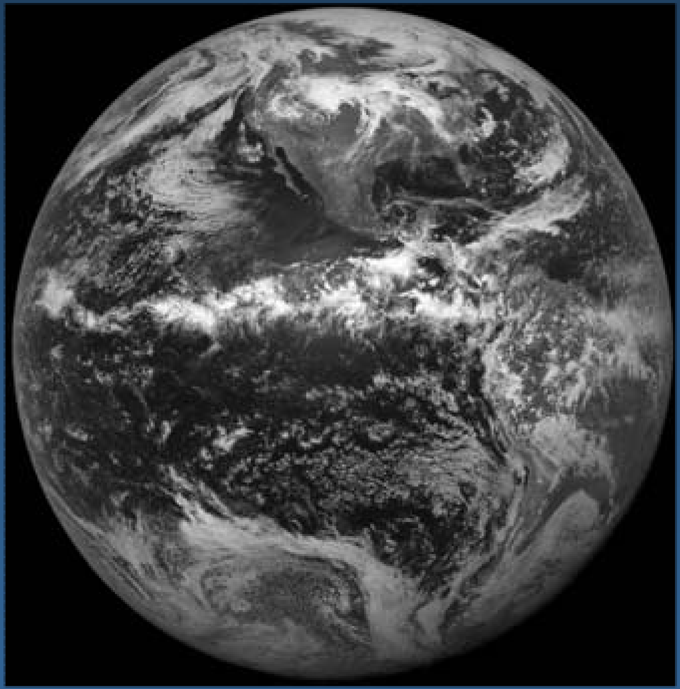
• Gross theoretical potential	4.6 TW
• Technically feasible potential	1.5 TW
• Economically feasible potential	0.9 TW
• Installed capacity in 1997	0.6 TW
• Production in 1997	0.3 TW

☐(can get to 80% capacity in some cases)

Source: WEA 2000

Three Gorges Dam

- Immense environmental and social impact
- 23 GW
- ~20B US$ (?)
- Largest single use of concrete and steel in the history of mankind
- Need 50 such dams to reach 1 TW



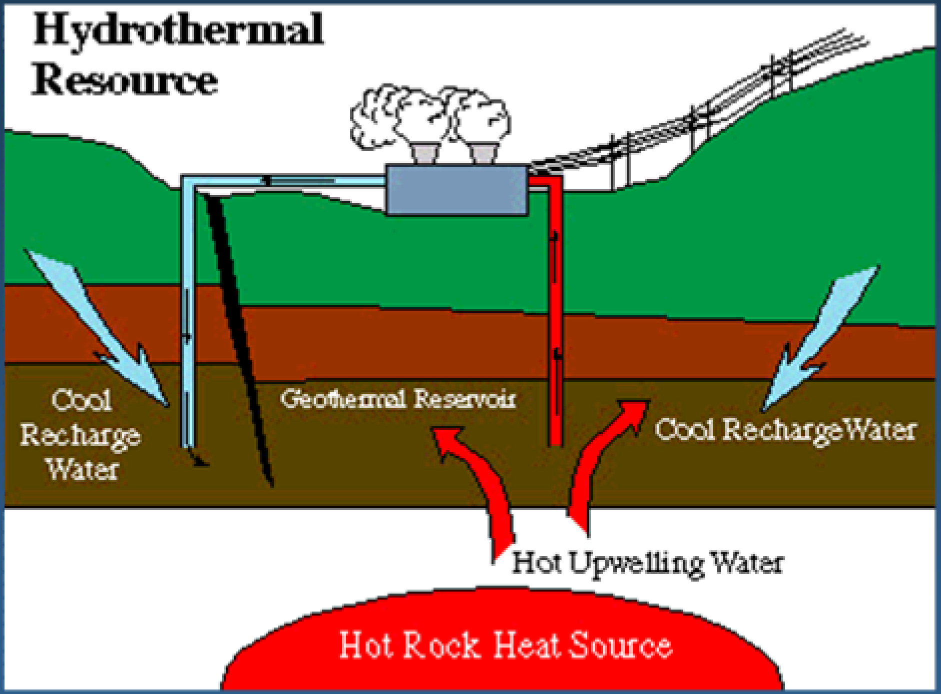
Geothermal

Mean flux at surface: 0.057 W/m^2

Continental Total Potential: 11.6 TW

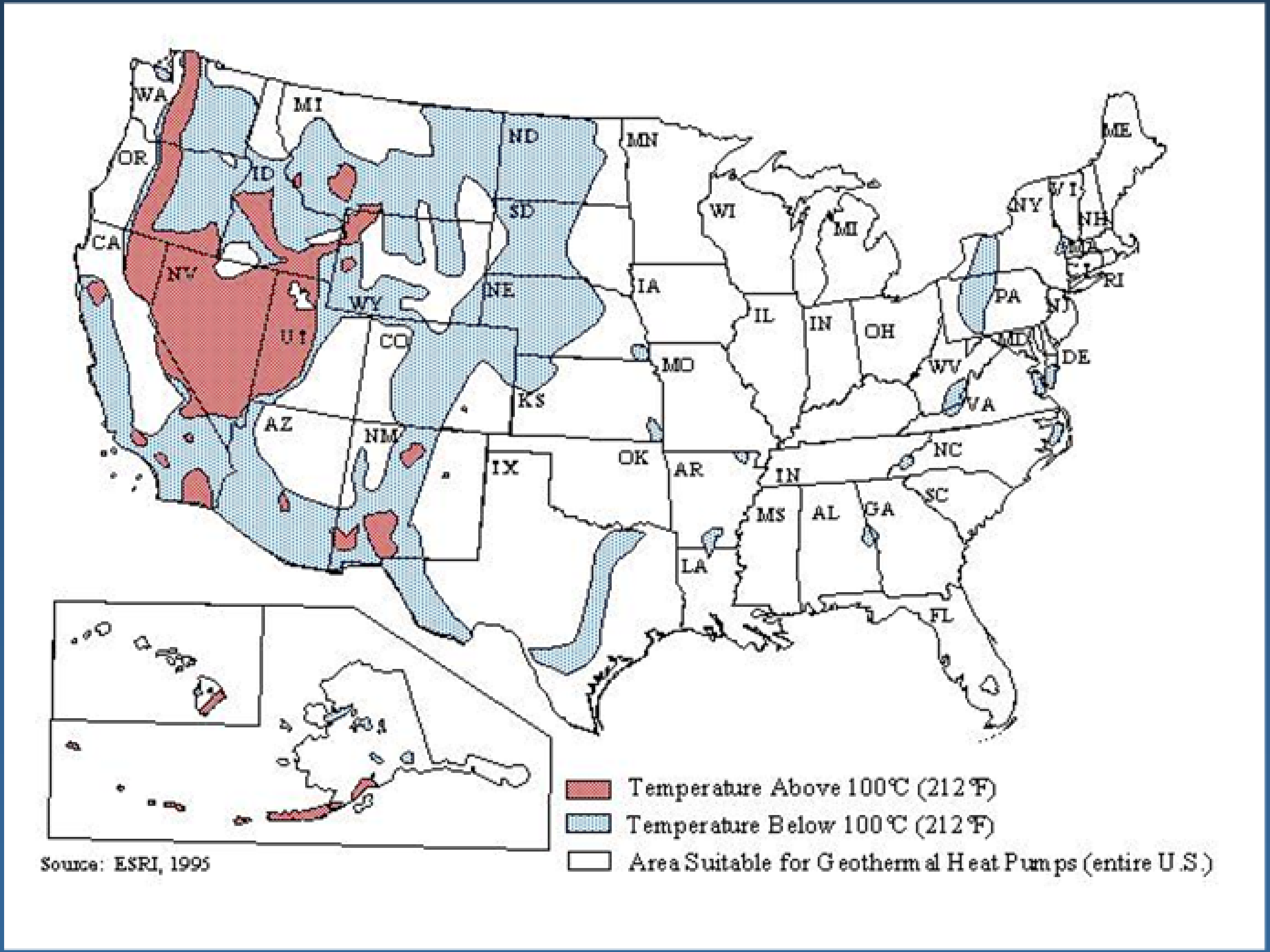
Geothermal Energy

1.3 GW capacity in 1985



Hydrothermal systems
Hot dry rock (igneous systems)
Normal geothermal heat (200 C at 10 km depth)

Geothermal Energy Potential



Geothermal Energy Potential

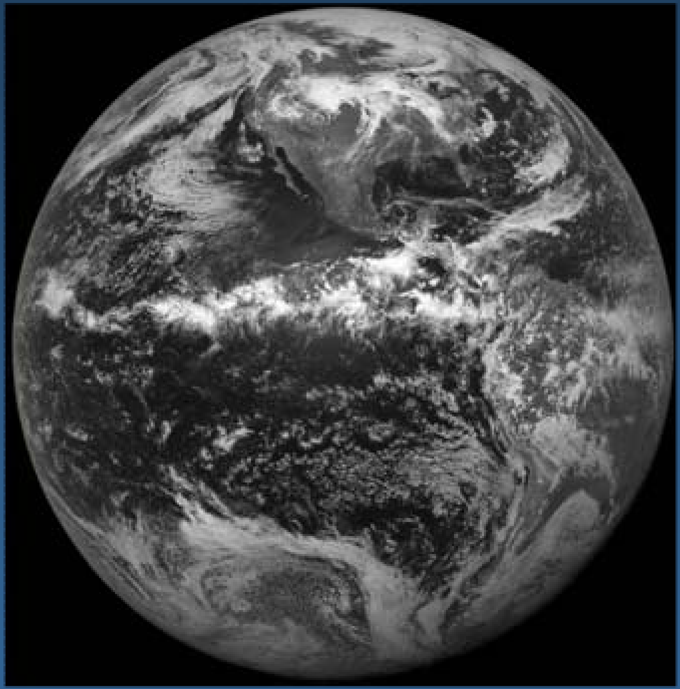
• Mean terrestrial geothermal flux at earth's surface	0.057 W/m^2
• Total continental geothermal energy potential	11.6 TW
• Oceanic geothermal energy potential	30 TW

• Wells "run out of steam" in 5 years	
• Power from a good geothermal well (pair)	5 MW
• Power from typical Saudi oil well	500 MW
• Needs drilling technology breakthrough (from exponential $/m to linear $/m) to become economical)	

Earthquakes and other problems…

- The two largest geothermal trial facilities (one US, one Europe) have just been shut down because of evidence that they caused numerous small earthquakes.

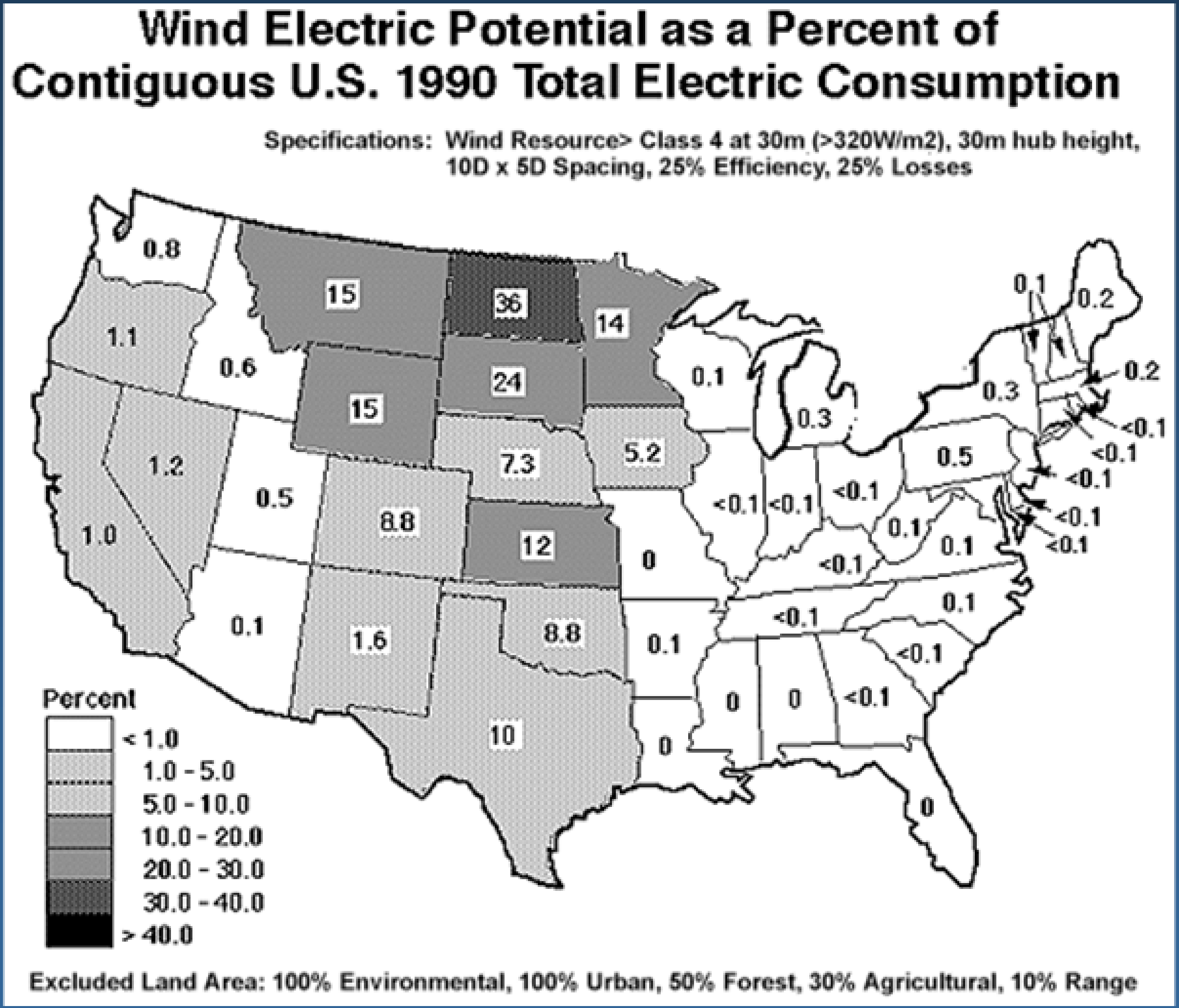
- Another geothermal trial facility has been cancelled in the drilling stages due to technical problems in reaching the target well depth.



Wind

4% Utilization
Class 3 and Above
2-3 TW

Electric Potential of Wind



In 1999, U.S consumed 3.45 trillion kW-hr of Electricity = 0.39 TW

http://www.nrel.gov/wind/potential.html

Global Potential of Terrestrial Wind

- **Top-down**:
  Downward kinetic energy flux: 2 W/m^2
  Total land area: $1.5x10^{14}$ m^2
  Hence total available energy = 300 TW
  Extract <10%, 30% of land, 30% generation efficiency:
  2-4 TW electrical generation potential

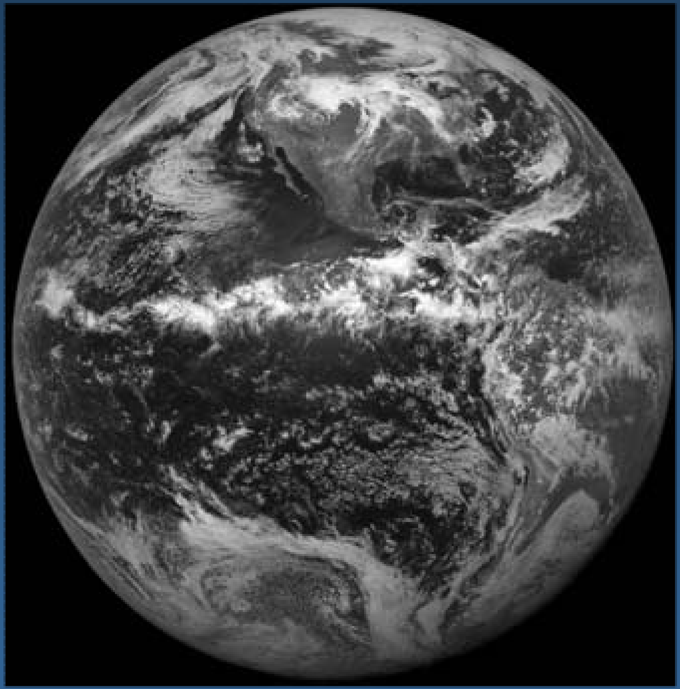
- **Bottom-Up**:
  Theoretical: 27% of earth's land surface is class 3 (250-300 W/m^2 at 50 m) or greater
  If use entire area, electricity generation potential of 50 TW
  Practical: 2 TW electrical generation potential (4% utilization of ≥class 3 land area, IPCC 2001)

  Off-shore potential is larger but must be close to grid to be interesting; (no installation > 20 km offshore now)

What is the economic scale of wind production?

- 1 TW is all US domestic steel and concrete for ~20 years.
- 2 MW peak = ~$4M (one modern on-shore turbine)
- 1 TW peak = $2B in ‘direct’ costs
- Competition for scarce resource? Minerals for magnets…
- Siting?
- Environmental impact
- Grid! Distribution….

Biomass



50% of all cultivatable land:
7-10 TW (gross)
1-2 TW (net)

Biomass Energy Potential

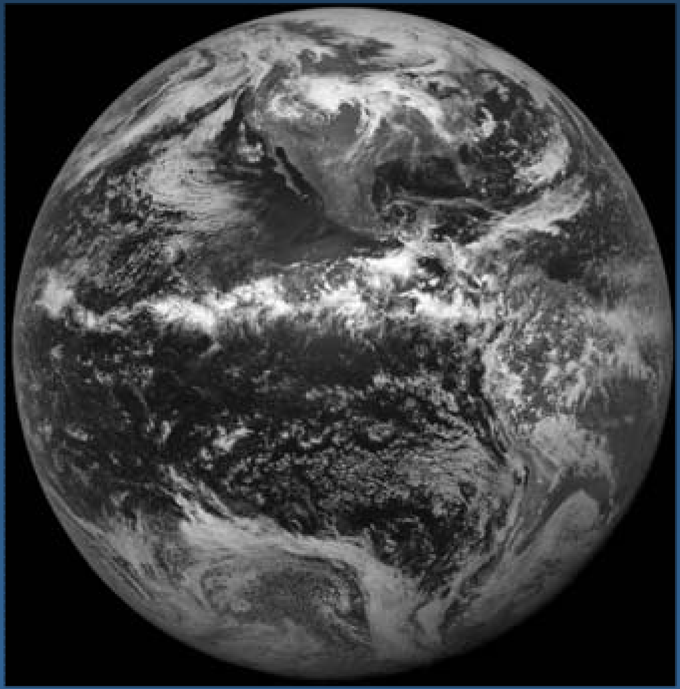
Global: Bottom Up

- Land with Crop Production Potential, 1990: 2.45×10^{13} m^2
- Cultivated Land, 1990: 0.897×10^{13} m^2
- Additional Land needed to support 9 billion people in 2050: 0.416×10^{13} m^2
- Remaining land available for biomass energy: 1.28×10^{13} m^2
- At 8.5-15 oven dry tonnes/hectare/year and 20 GJ higher heating value per dry tonne, energy potential is 7-12 TW
- Perhaps 5-7 TW by 2050 through biomass (less CO_2 displaced)
- Possible/likely that this is water resource limited
- 25% of U.S. corn provides 2% of transportation fuel

Food or Fuel … or Fertilizer?

- Large-scale use of biomass necessarily competes with food production.
- An additional competition: fuel versus fertilizer. Modern fertilizers, which increase crop yields by 5-20x and which help increase (effectively) arable land are fossil-fuel derived. Their price tracks oil prices. → massive impacts on developing countries
- Micro-algae to produce fertilizer? (Mayfield lecture!)

Solar: potential 1.2×10^5 TW; practical > 600 TW



Solar Energy Potential

- Theoretical: 1.2x10^5 TW solar energy potential

  (1.76 x10^5 TW striking Earth; 0.30 Global mean albedo)

  - Energy in 1 hr of sunlight ↔ 14 TW for a year

- Practical: > 600 TW solar energy potential

  (50 TW - 1500 TW depending on land fraction etc.; WEA 2000)

  Onshore electricity generation potential of ≈60 TW (10% conversion efficiency):

- *Photosynthesis*: 90 TW

U.S. Single Family Housing Roof Area

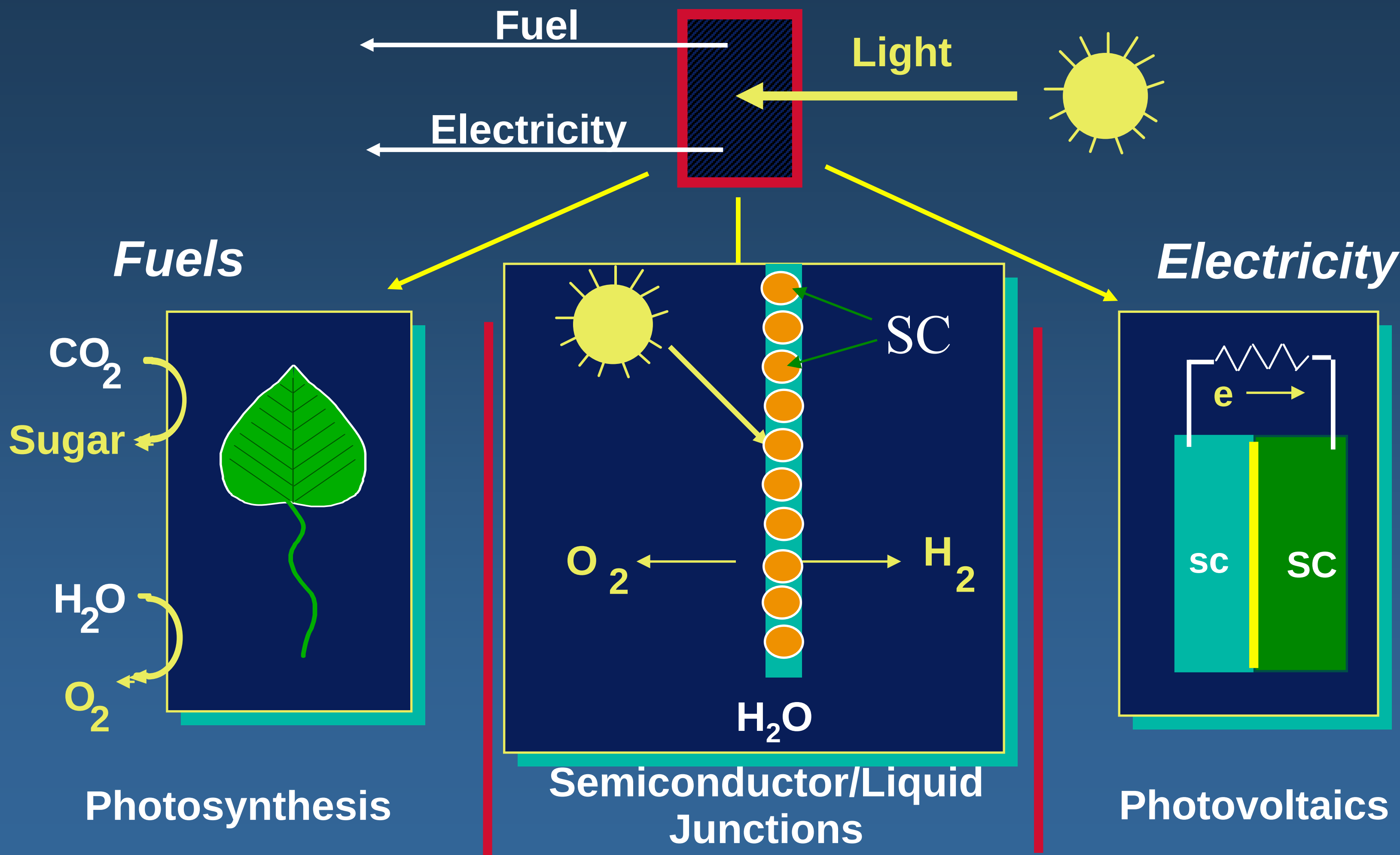
- 7×10^7 detached single family homes in U.S.
  $\approx$2000 sq ft/roof = 44ft x 44 ft = 13 m x 13 m = 180 m^2/home
  = 1.2×10^{10} m^2 total roof area

- Hence can (only) supply 0.25 TW, or $\approx$1/10th of 2000 U.S. Primary Energy Consumption

Solar Land Area Requirements

6 Boxes at 3.3 TW Each

Energy Conversion Strategies



Huge DOE funding and worldwide venture capital in all solar strategies

Solar thermal:
(Traditional)
Use concentrating mirrors to boil 'something' to turn turbines.
350 MW (peak)
Mojave Desert, CA

Proposed: PG&E 500MW (peak)

What about “solar thermal”?

- Large-scale installations with the most promising new technology (Sterling engines) cause massive competition for local water – has resulted in cancellations of large projects in the western US in the last few years.
- Overall warning: Land Use! All renewable energy is diffuse… how will you use land? Who has the rights to its use?

Almost all of above has been heavily focused on electricity… this leaves out:

- Distribution
- Policy & Land Use
  - Schwartz public lecture June 3
- Storage: batteries, altitude-wells, H2, other chemical….
- Efficiency!
  - Lighting, home & industrial heating, and another 800lb gorilla in the corner:
  - Transportation and its impact on demographics: suburbs versus high-density housing…

Transportation

- Demographics and mass transit
- Gasoline as a growing fractional cost on take-home salaries→impact on economic stability & growth
- Fossil fuels for transportation of food-stuffs and manufactured goods
- Electric cars?

Conclusion

- Global energy consumption is a 1Tera$/yr issue which impacts essentially all branches of the economies (and citizen lives) of all countries.
- Populations growth, climate change, increased demand from developing countries, peak production of fossil fuels (and more) all are aiming the world toward sustainable energy models.
- Basic and applied research at UW (and every other research university) is taking a steadily more invested look at energy production, consumption, distribution, policy and their impact on the environment…. And that's what we'll hear about in this seminar.