The Future of Energy

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How Much Energy Do We Use?

- More appropriate question:
  - At what *rate* do we use energy?
  - That rate is called *power*
  - Energy is "stuff," power is the *rate* at which it's used or generated
- Alternate version of question:
  - At what rate do you, as a resident of twenty-first century industrialized society, use energy?
  - How's that compare with the rate at which your own body uses energy?

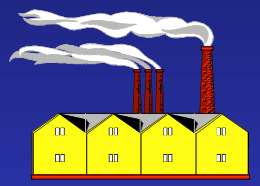
Your Body's Power: 100 watts

Credits
Left: Tad Merrick Photography, from *Energy, Environment, and Climate*
Right: http://www.abcbodybuilding.com/exercise3/deepkneebends.htm

Your Energy Use

- Your own body
  - Produces energy at the rate of 100 watts
- You (average U.S. citizen)
  - Use energy at the rate of about 10,000 watts
  - 10 kilowatts (kW)
  - 100 “energy servants”

Your Energy Use



You

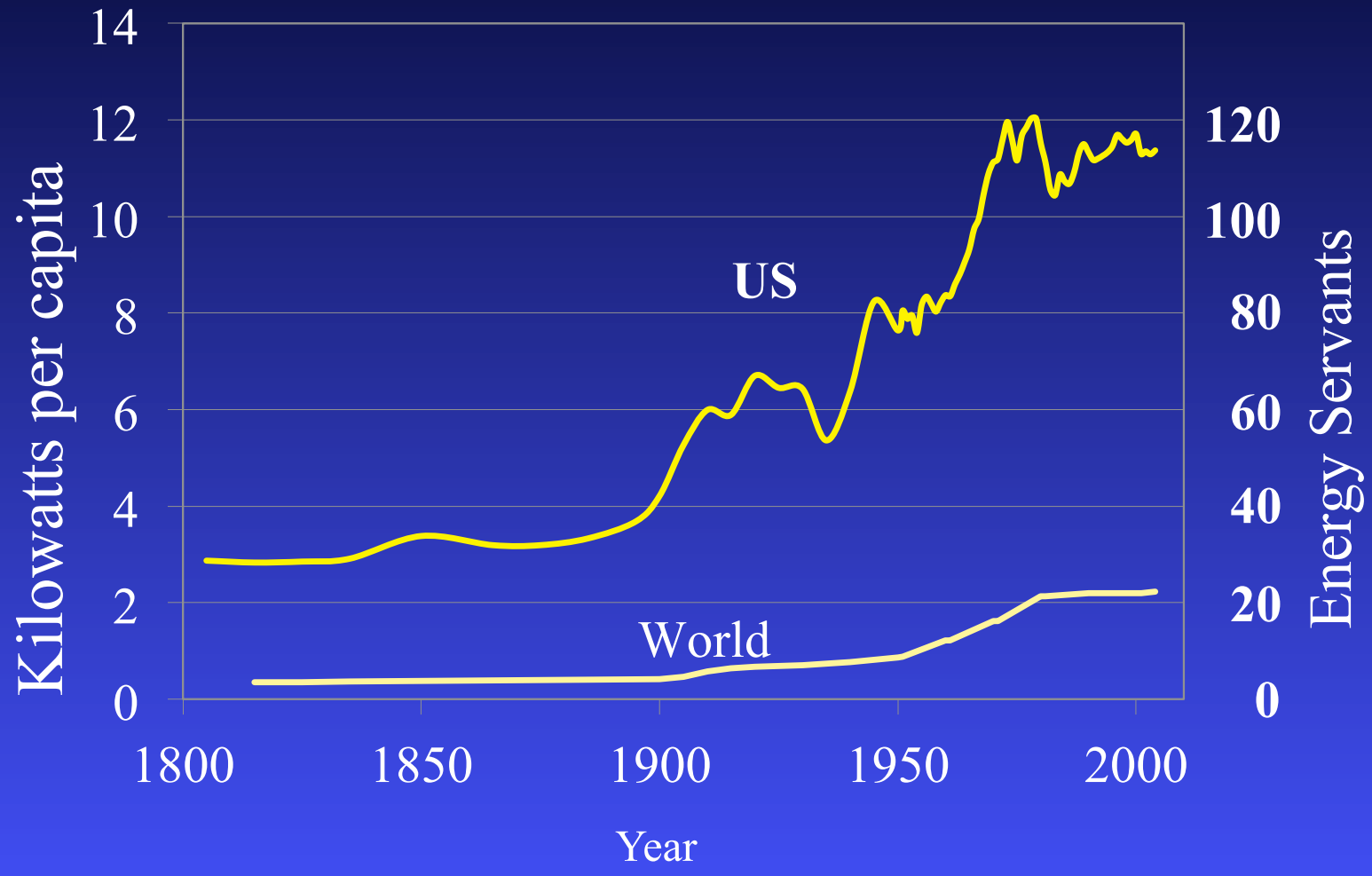
Some of your energy uses

Your “energy servants”

Energy and Power

- Energy: the amount of "stuff"
  - kilowatt-hours, joules, calories, ergs, electron volts, British thermal units, barrels of oil equivalent,…
- Power: the rate at which it's used, generated, lost, transferred, converted…
  - watts, kilowatts, megawatts, gigawatts, terawatts, joules/second, boe/year, btu/hour,…
- What's wrong with "this power plant will produce 500 megawatts every hour…"?

It hasn't always been like this…



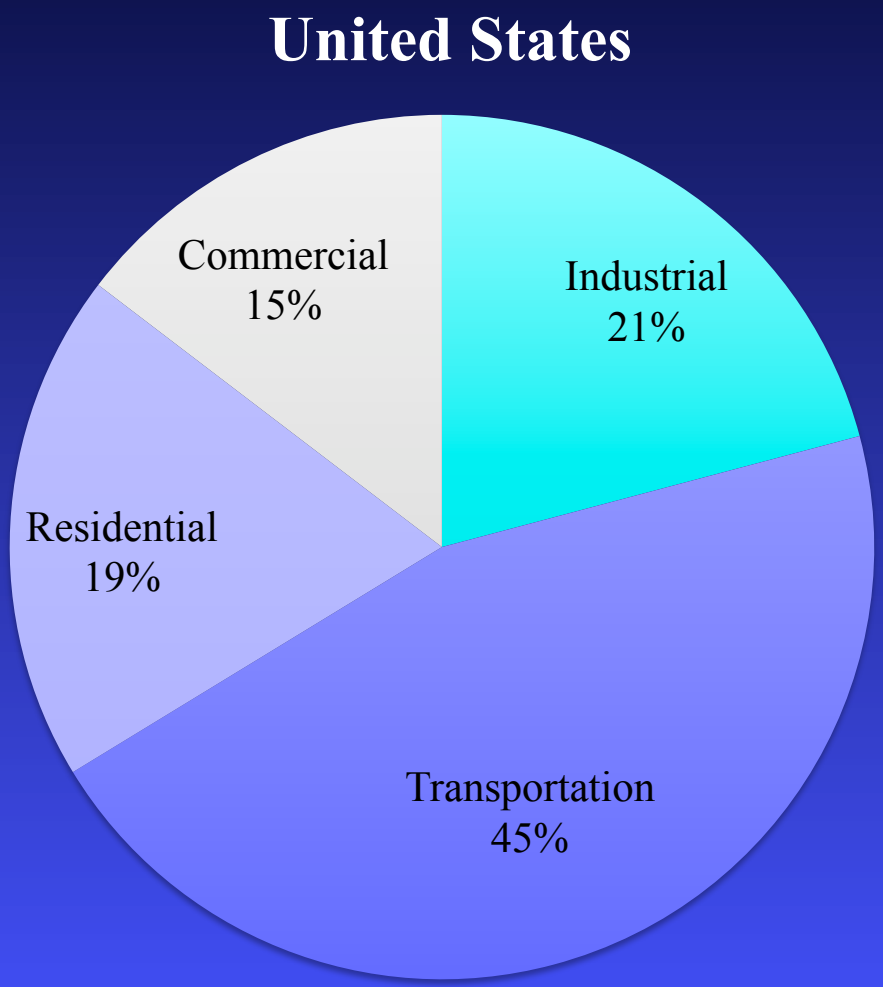
Some Small Energy Numbers

- Desk lamp: 60 W
- Laptop computer: 60 W
- TV: 250 W
- Stove burner: 1,500 W
- Clothes dryer: 5,000 W
- Home heat/cool: 10,000 - 40,000 W
- Prius hybrid, 60 mph: 50,000 W
- Hummer H2, 60 mph: 200,000 W
- ms Eurodam: 56 MW = 56 million watts
- Solar energy on 1 square meter, noon Sun: 1000 W
- Guayama solar farm, PR: 24 MW peak
- Santa Isabel wind farm, PR: 101 MW peak
- Turkey Point Nuclear Plant, FL: 1.4 GW =1.4 billion watts
- Hoover dam, AZ/NV: 2 GW
- Churchill Falls, Canada: 5.4 GW
- 3 Gorges Dam, China: 23 GW

Some Big Energy Numbers

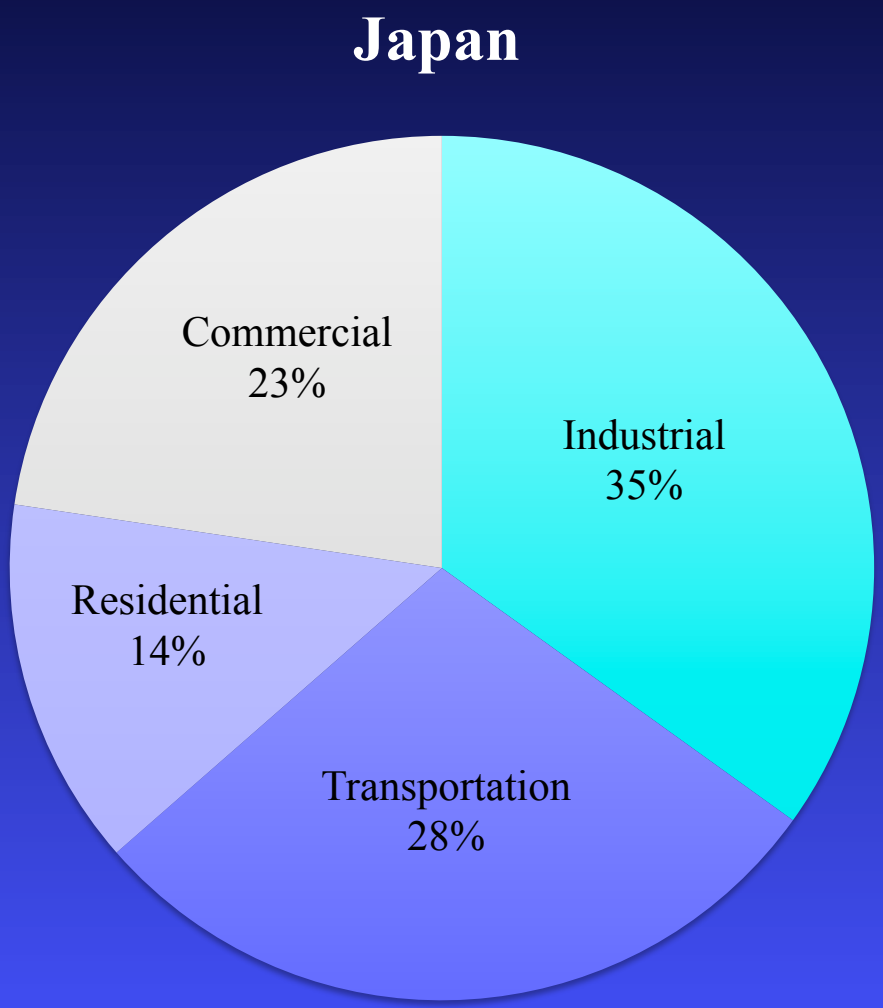
- US oil consumption:
  1.5 trillion W (1.5 TW)
  (21 million barrels/day;
  8 billion barrels/year)
- US oil imports:
  ~2/3 of consumption
- U.S. energy consumption:
  3.4 trillion W (3.4 TW)
- World energy consumption:
  16 trillion W (16 TW)
- Oil reserves, ANWR:
  6-16 billion barrels
- Oil reserves, offshore US:
  20 billion barrels
- World oil reserves:
  1 trillion barrels
- Solar energy falling on entire Earth:
  174 quadrillion W
  (174,000 TW;
  2.5 trillion barrels of oil equivalent per day)

Energy: What Do We Do With It?



End use energy from : International Energy Agency: http://www.iea.org/stats/index.asp

Energy: What Do We Do With It?



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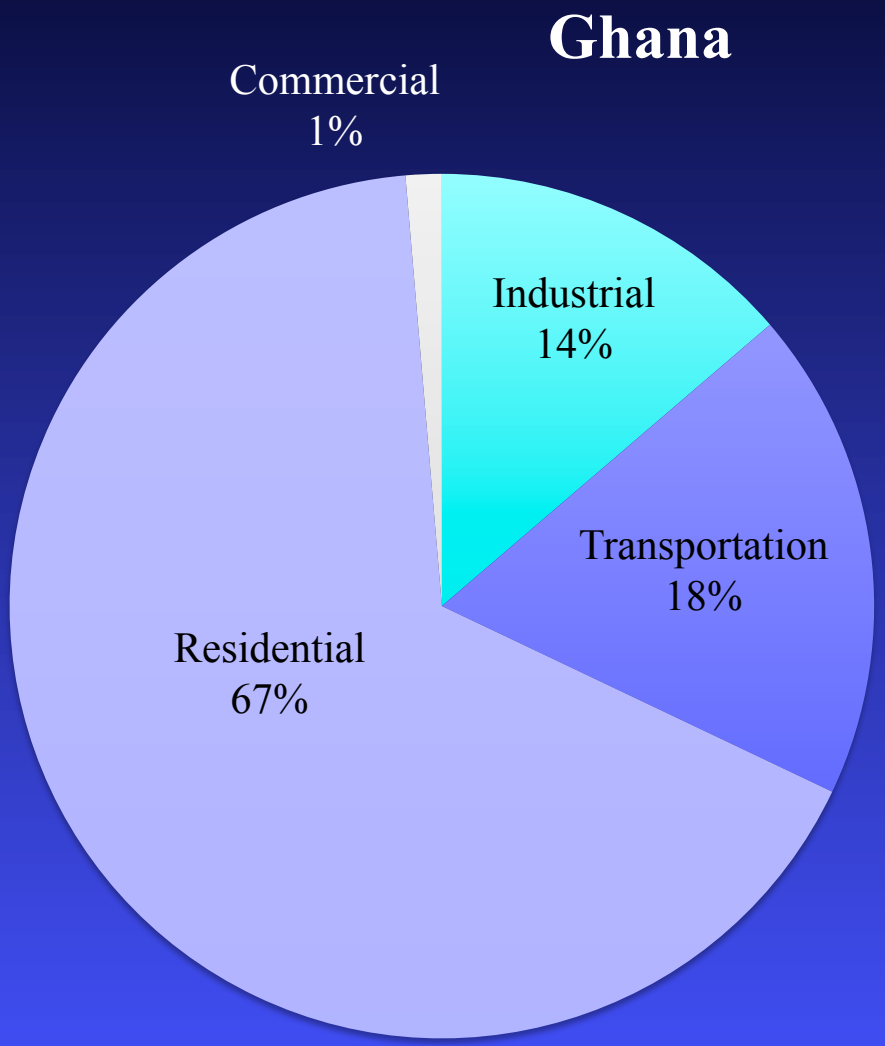
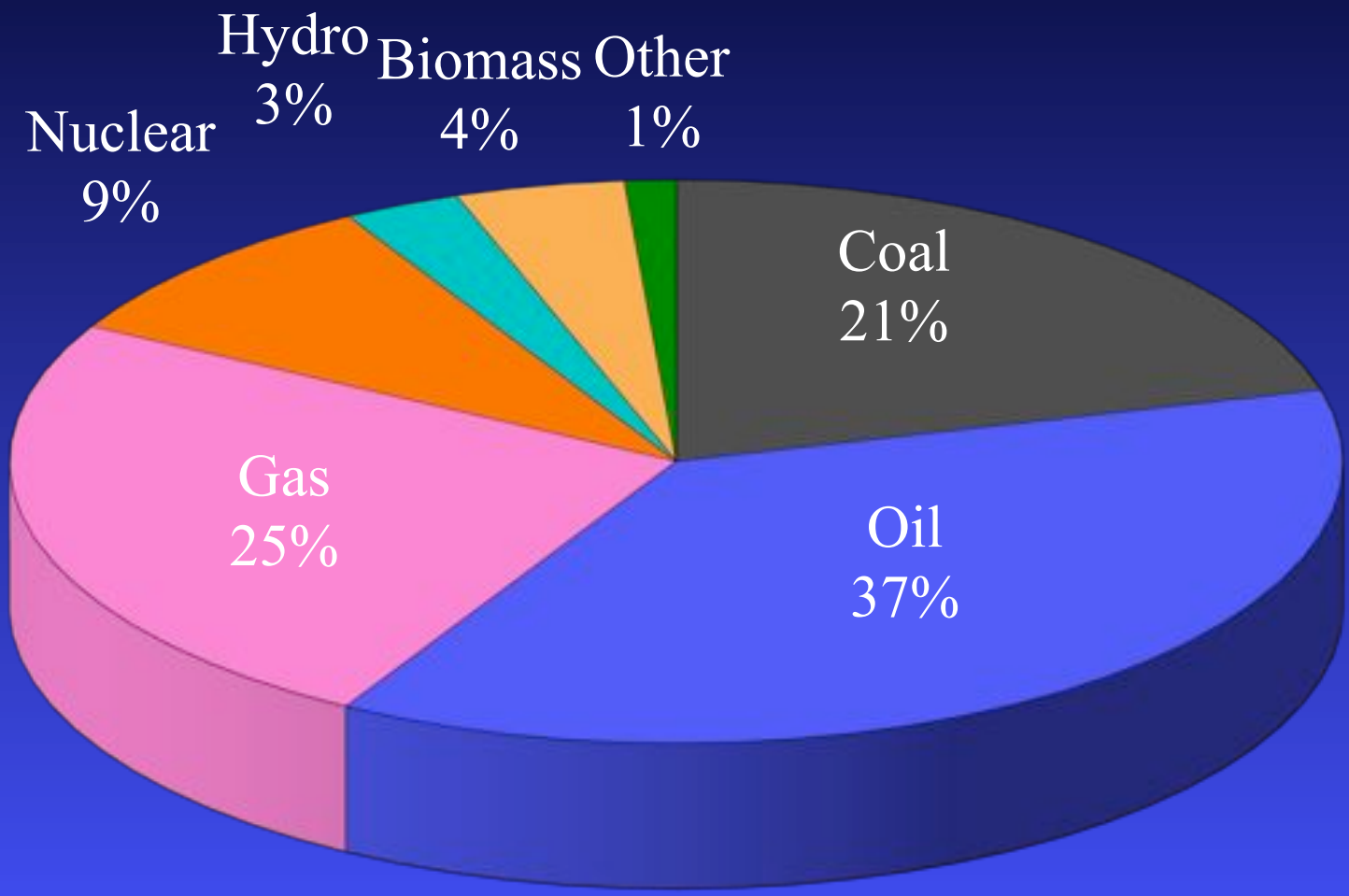
Energy: What Do We Do With It?



End use energy from : International Energy Agency: http://www.iea.org/stats/index.asp

Energy: Where's it Come From?

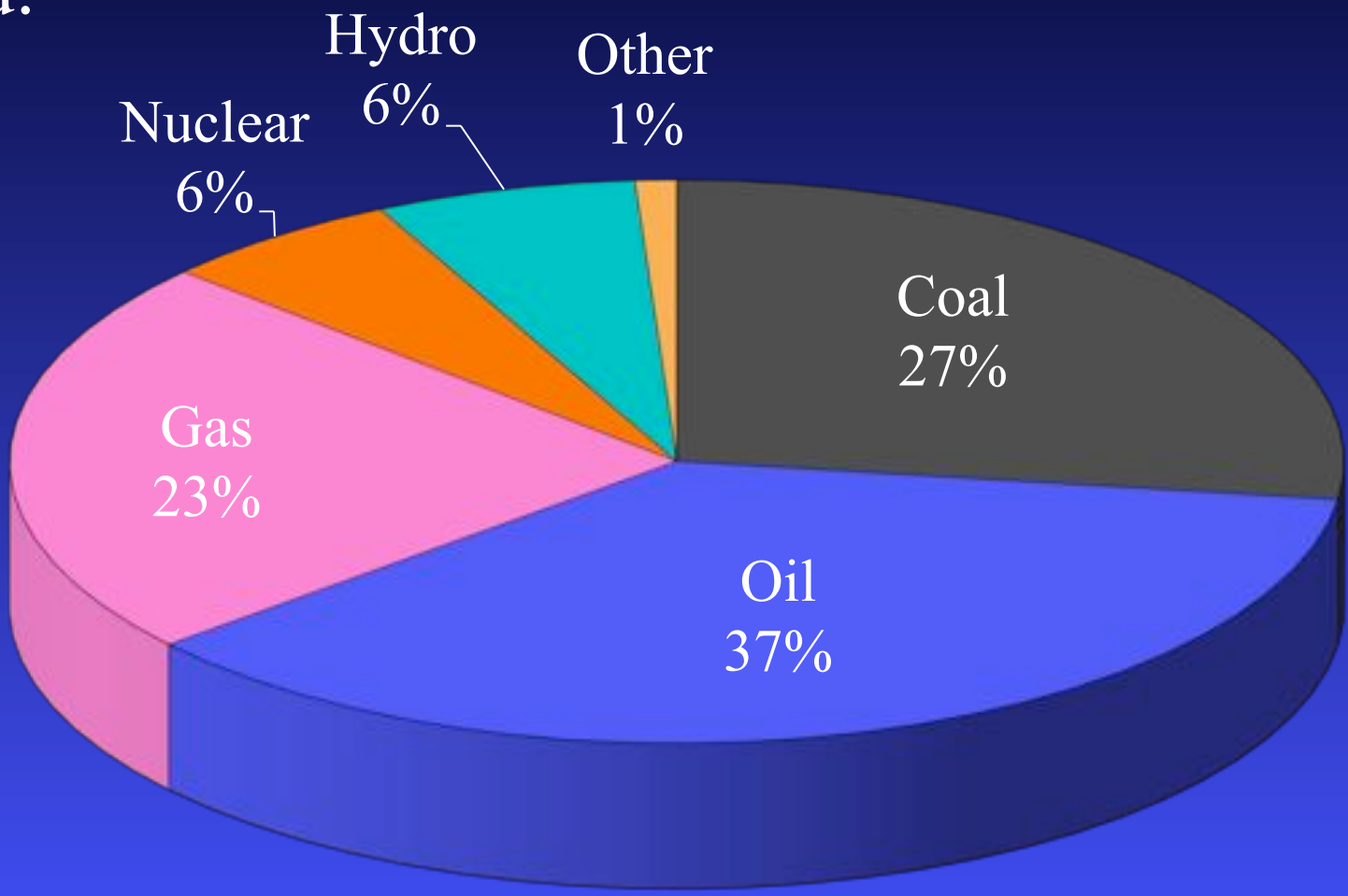
United States:



U.S. Energy end uses; Source: EIA/DOE Annual Energy Review 2009 Table 1.3

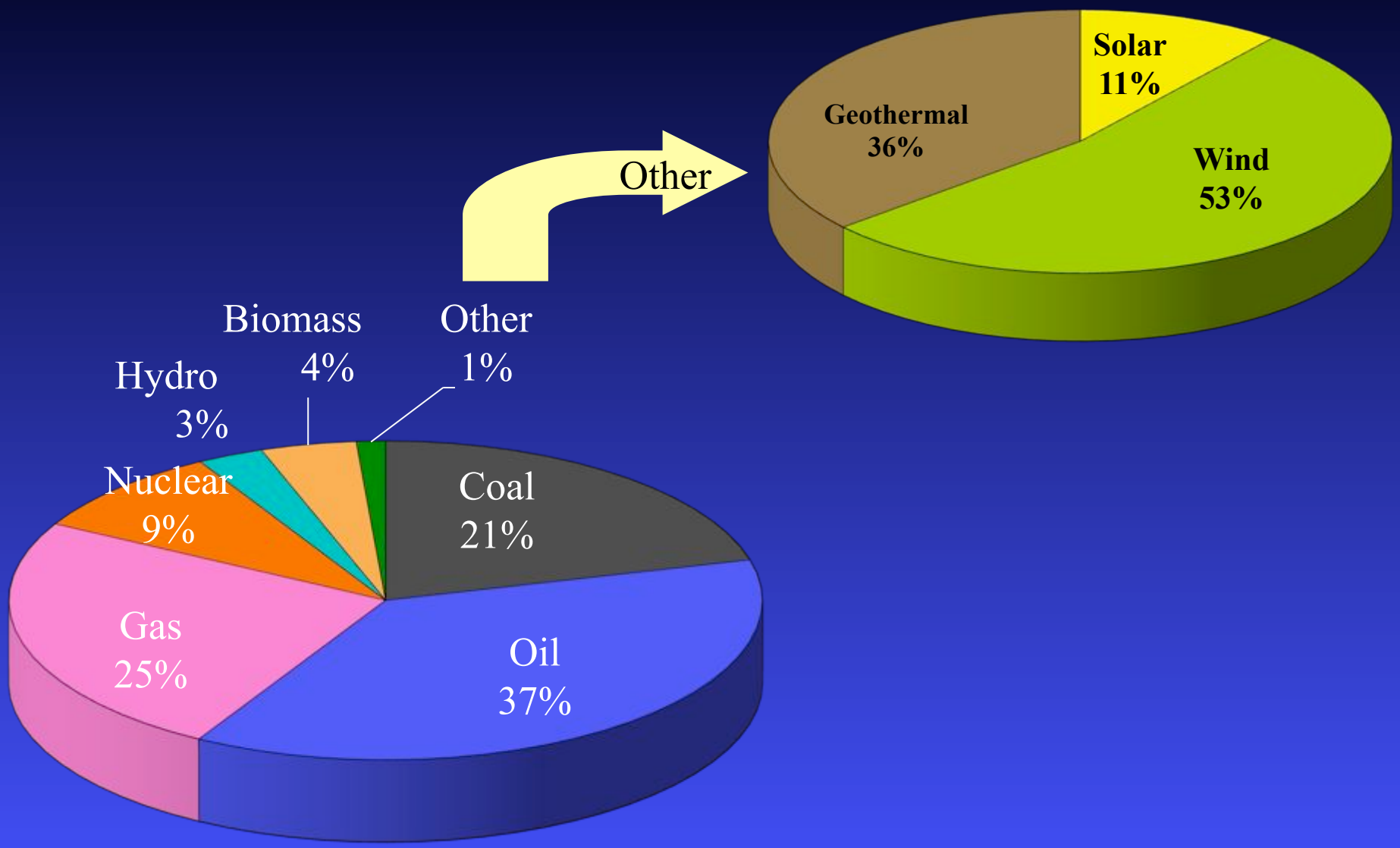
Energy: Where's it Come From?

World:



Source: EIA International Energy Annual 2010 Table 1.8 (2006 data)

US Energy Sources: Not Much "Other"

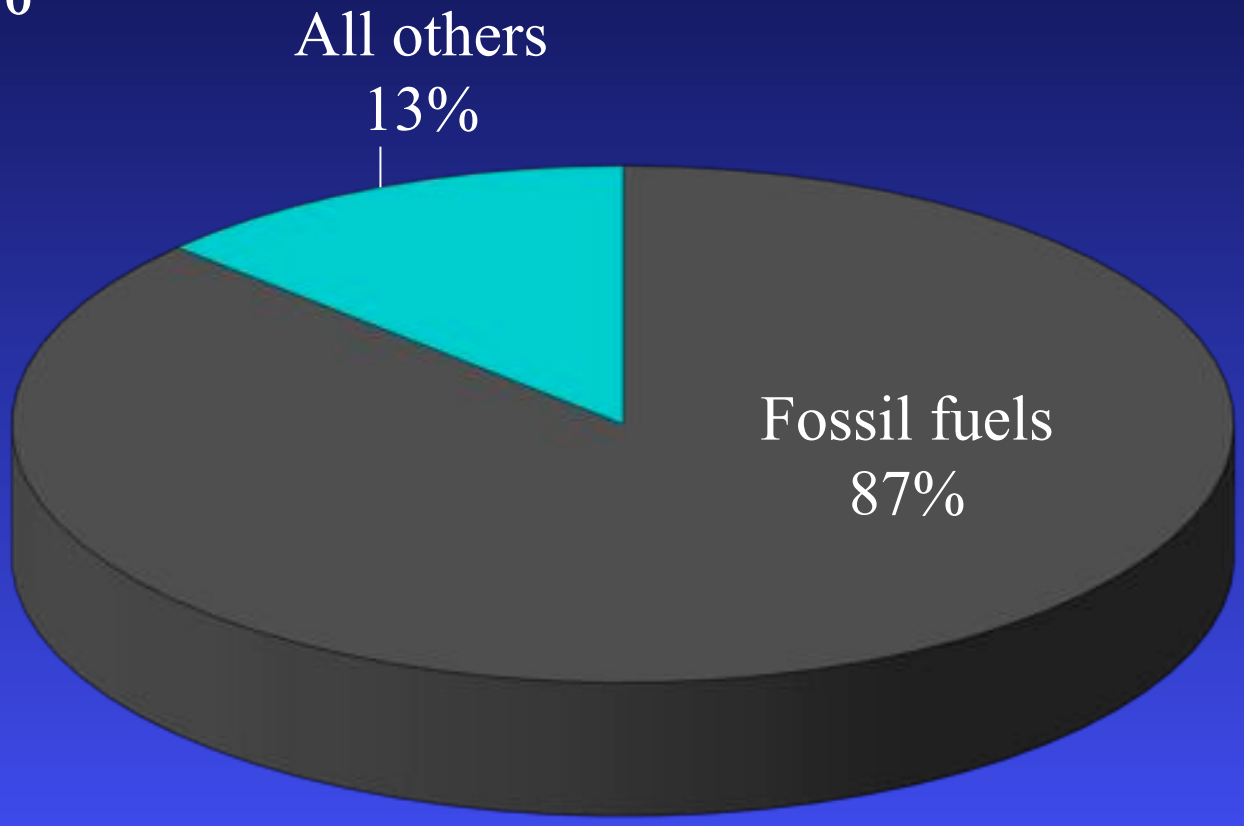


U.S. Energy end uses; Source: Source: EIA/DOE Annual Energy Review 2009 Table 1.3

Energy Sources: Mostly Fossil Fuels

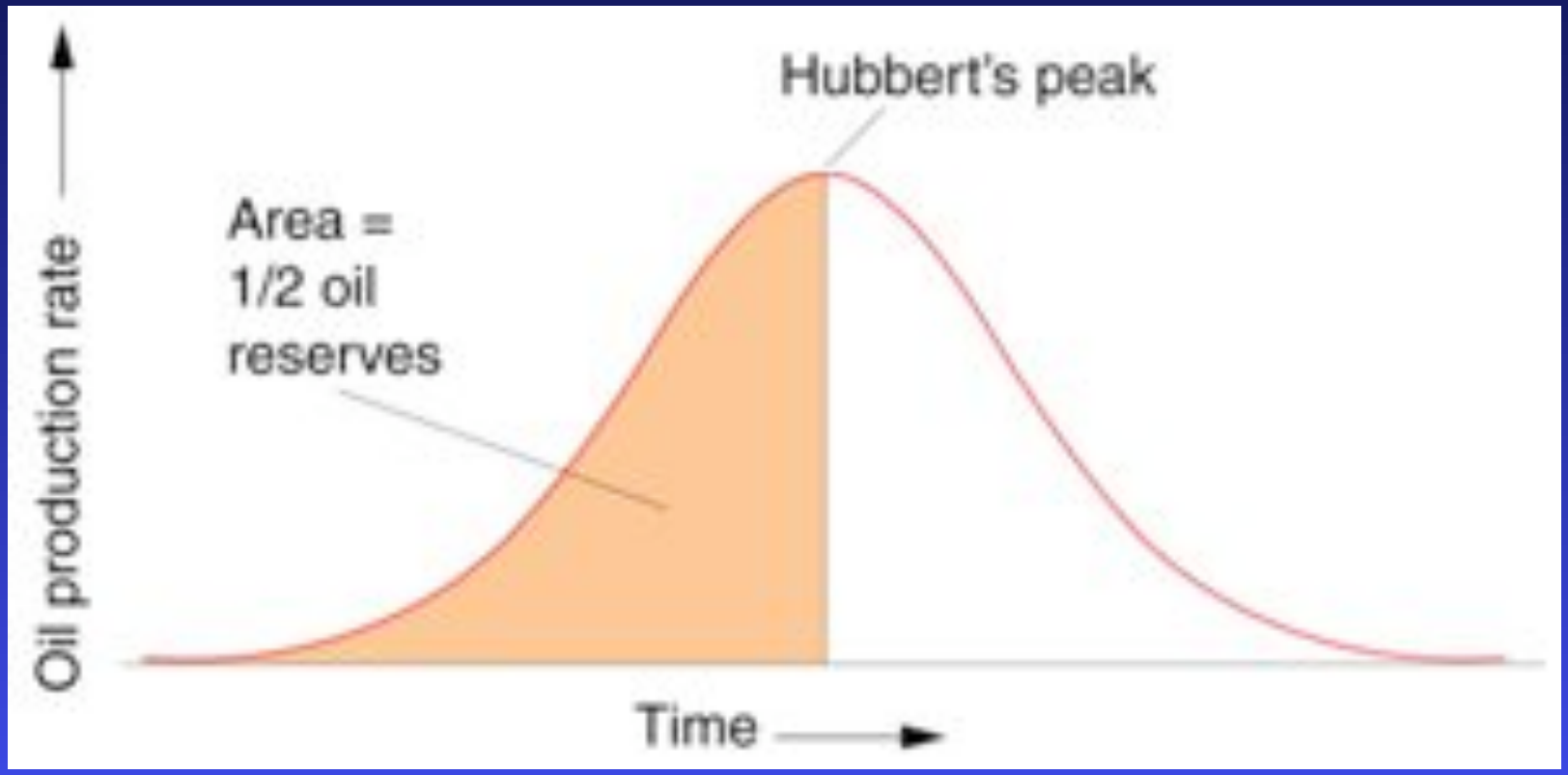
United States: 83%

World: 87%



Why Wean Ourselves from Fossil Fuels?

1) We're running out:



EE&C Fig 5.24

Why Wean Ourselves from Fossil Fuels?

2) We're wrecking our planet:

- Oil spills

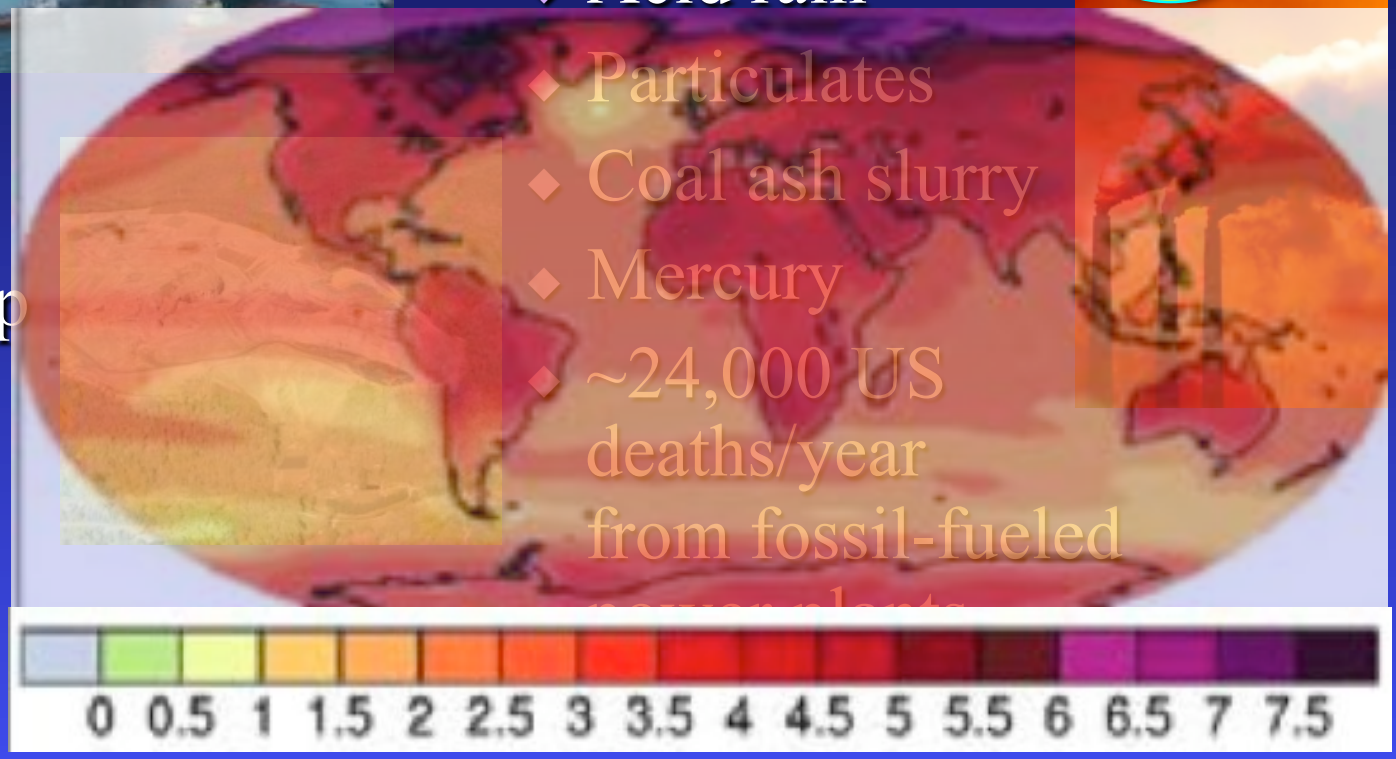
- Air pollution
  - Smog

- Acid rain
- Particulates
- Coal ash slurry
- Mercury
- ~24,000 US deaths/year from fossil-fueled power plants

- Mining
  - Strip/mountaintop
  - Acid mine drainage

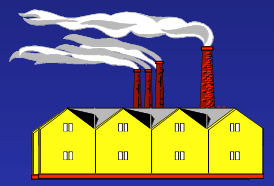
  - Black lung disease

Climate Change



Our Energy Future:
The First Step



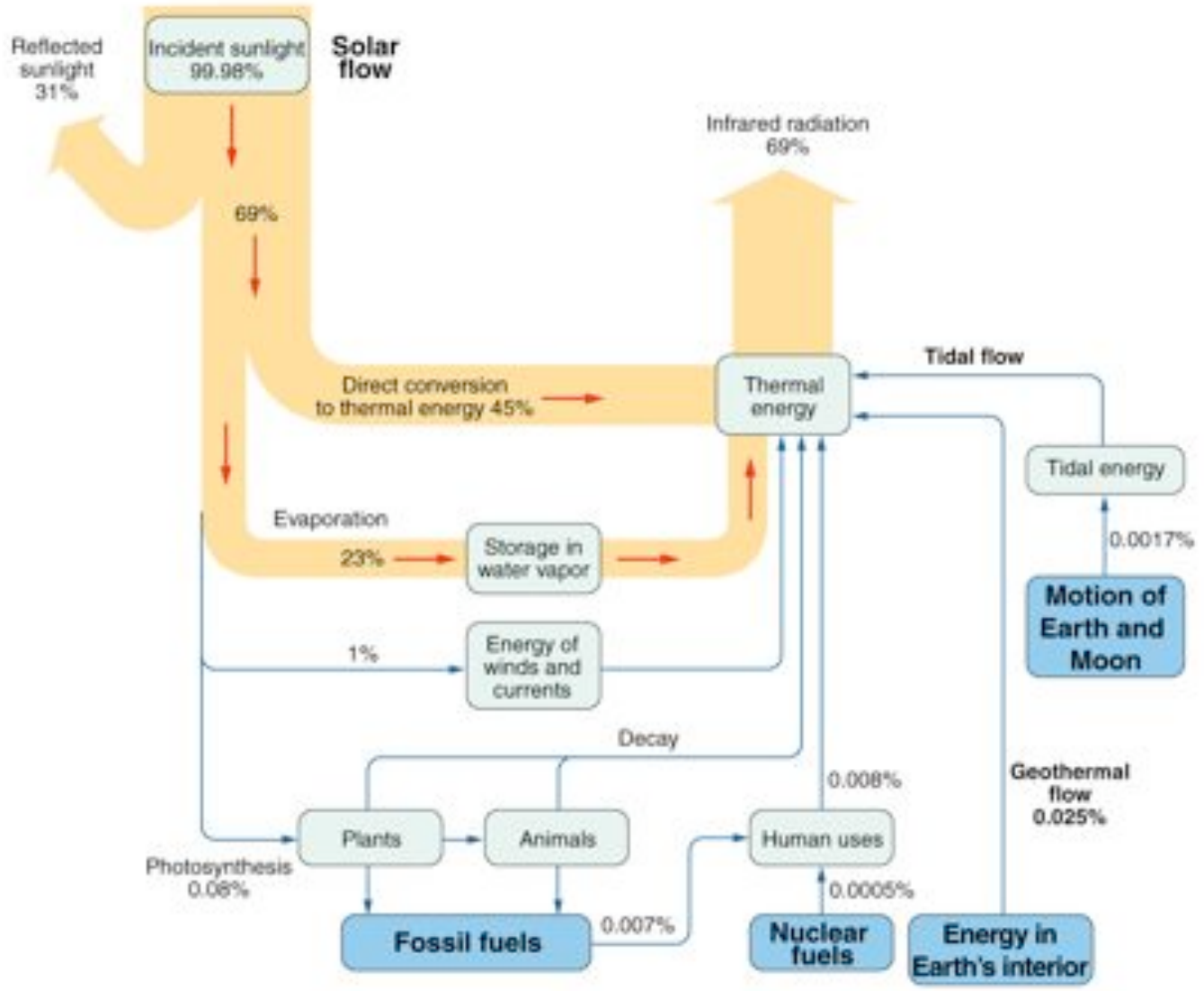



You

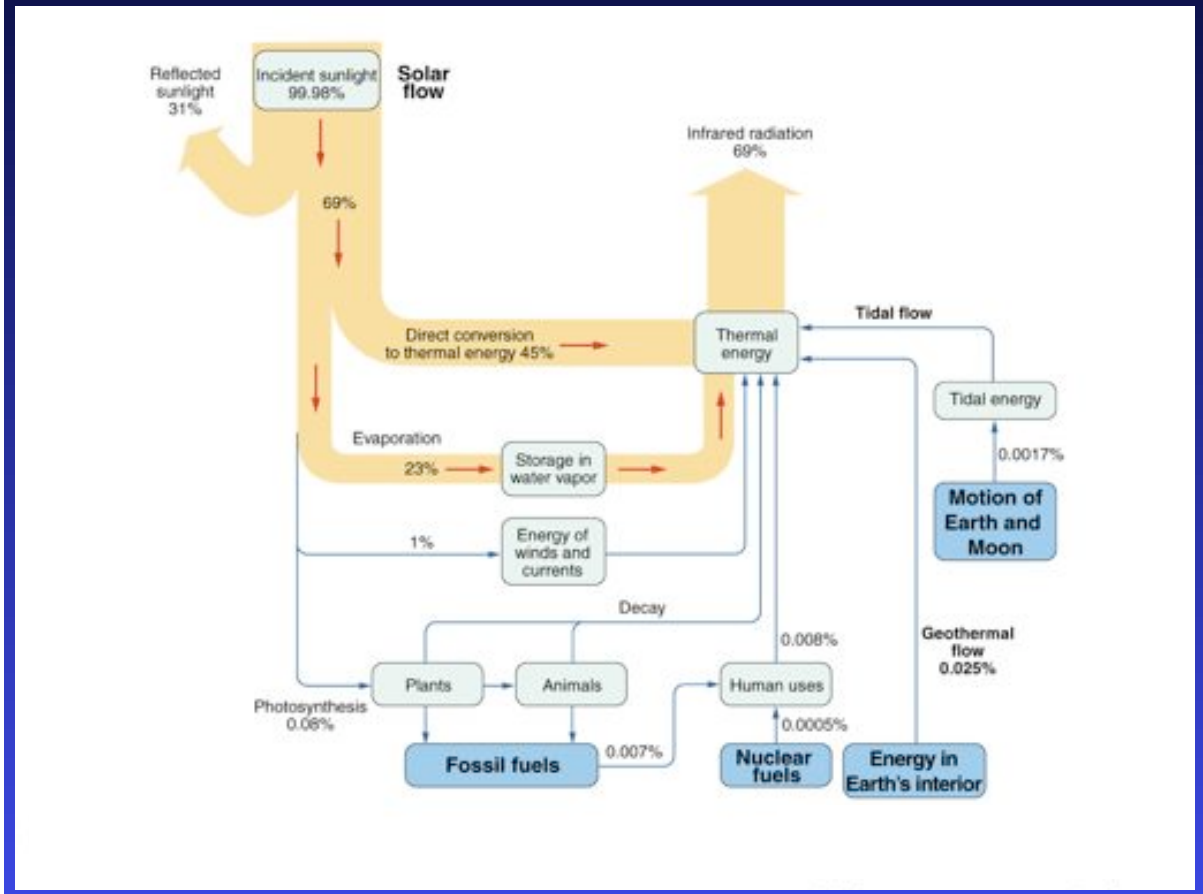
Some of your energy uses

Your “energy servants”

Earth's Energy Endowment



Doing the Numbers



Solar flow: 174,000 TW

Geothermal flow: 40 TW

Tidal flow: 3 TW

Human energy consumption rate: 16 TW

Fossil reserves: ~1200 TW-year

Nuclear fission reserves: ~50-7000 TW-year

Nuclear fusion reserves: 500 billion TW-year

Tidal Energy

Rate: 3 TW global; Humanity: 16 TW

Old way:
La Rance River estuary, France
240 MW

New way:
Verdant Energy's Roosevelt Island Tidal Energy project, East River, NY
1 MW

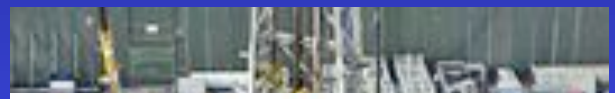
Geothermal Energy

Rate: 40 TW global; Humanity: 16 TW

Old: Geysers, California
17 units; 1.4 GW total

New: Mammoth Lakes, California
40-MW closed-cycle binary plant

Future? Basel, Switzerland
Deep Heat Mining Project

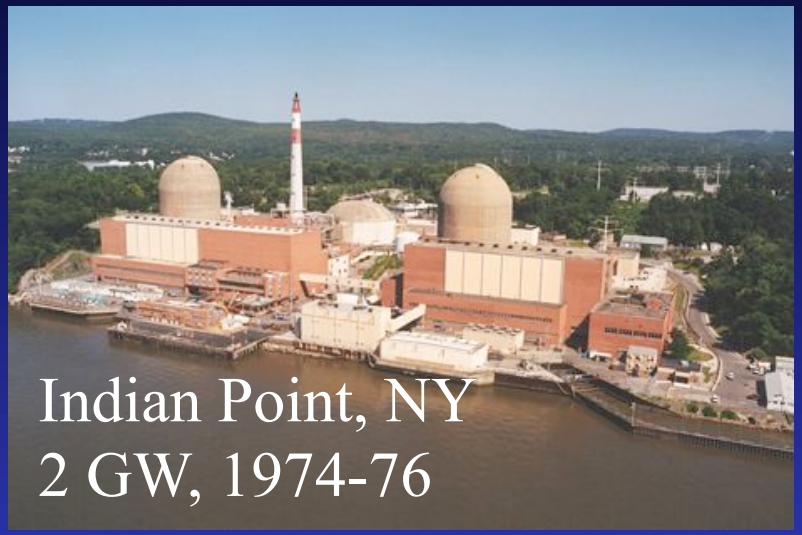


Swiss halt geothermal experiment after tremor

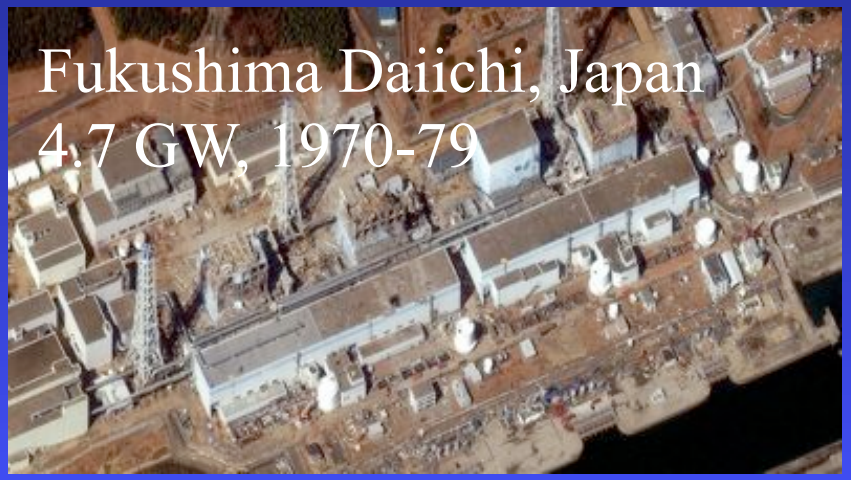
09 Dec 2006 22:41:21 GMT
Source: Reuters

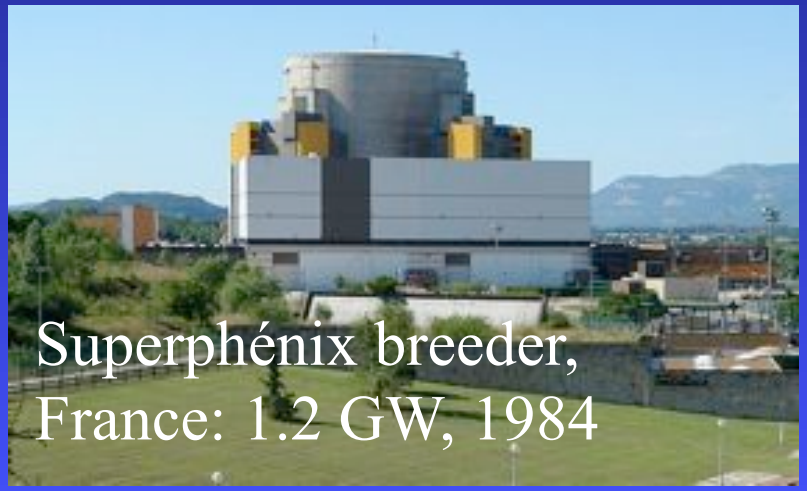
Nuclear Fission

Reserves: 50-7000 TW-year; Humanity: 16 TW-year/year


Indian Point, NY
2 GW, 1974-76

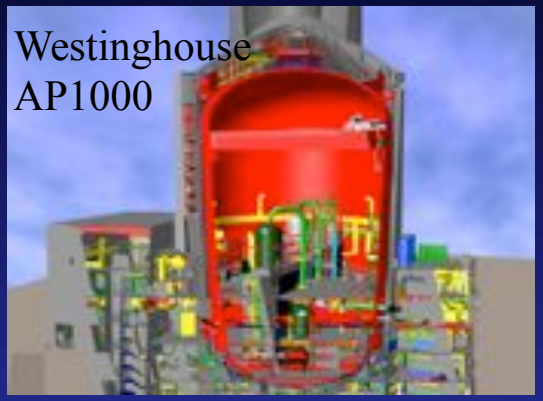

Shin-Kori, Korea
6.8 GW, 2010-13


Fukushima Daiichi, Japan
4.7 GW, 1970-79

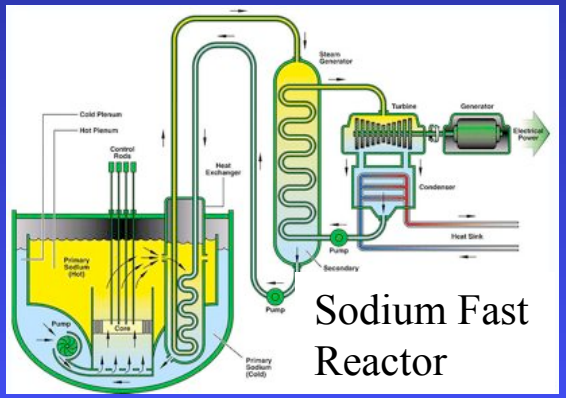

Superphénix breeder,
France: 1.2 GW, 1984

Nuclear Fission: Safer Reactors?

Reserves: 50-7000 TW-year; Humanity: 16 TW-year/year



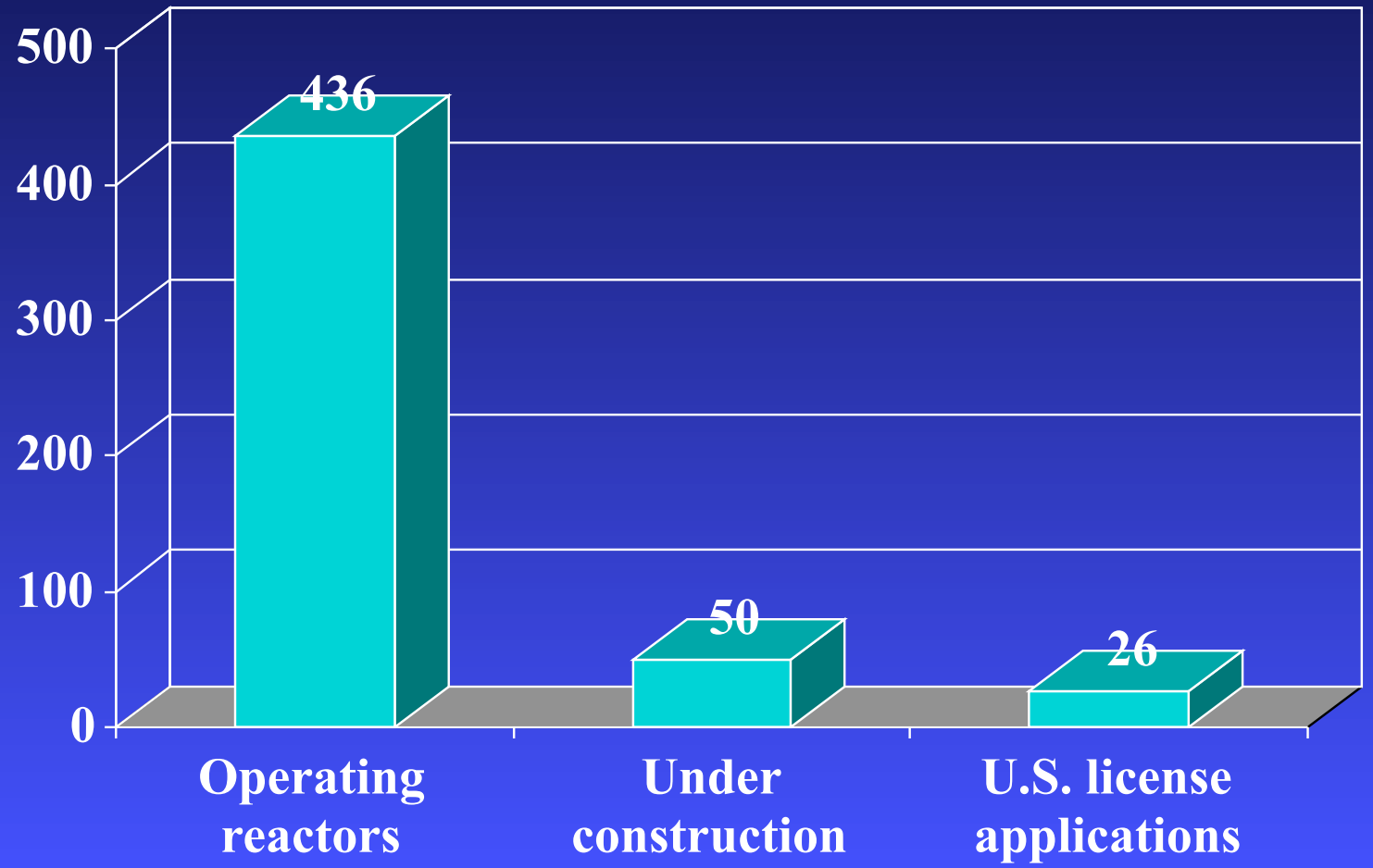
- Generation III+
  - Passive safety systems
  - Standardized construction
  - Under construction in Asia; licensed in US
- Generation IV
  - Radically new designs; faster, hotter
  - "Burn" long-lived nuclear waste
  - Still decades away



Nuclear Fission: A Renaissance?

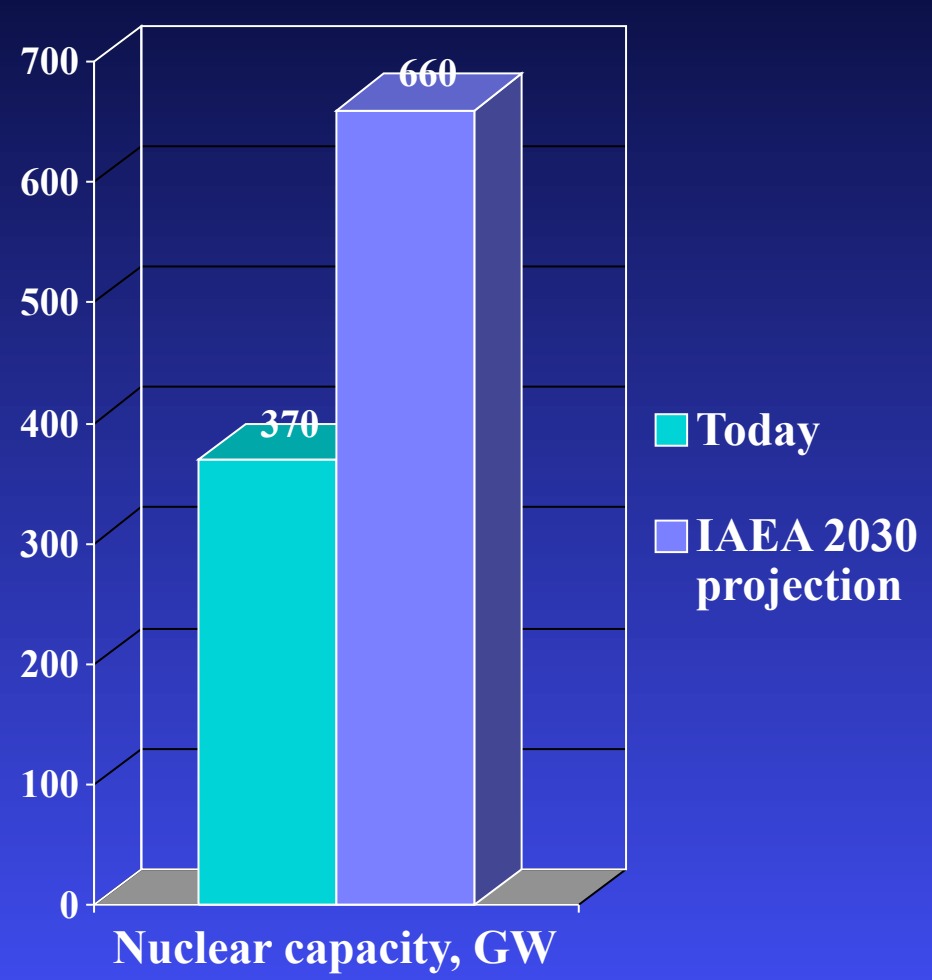
Reserves: 50-7000 TW-year; Humanity: 16 TW-year/year

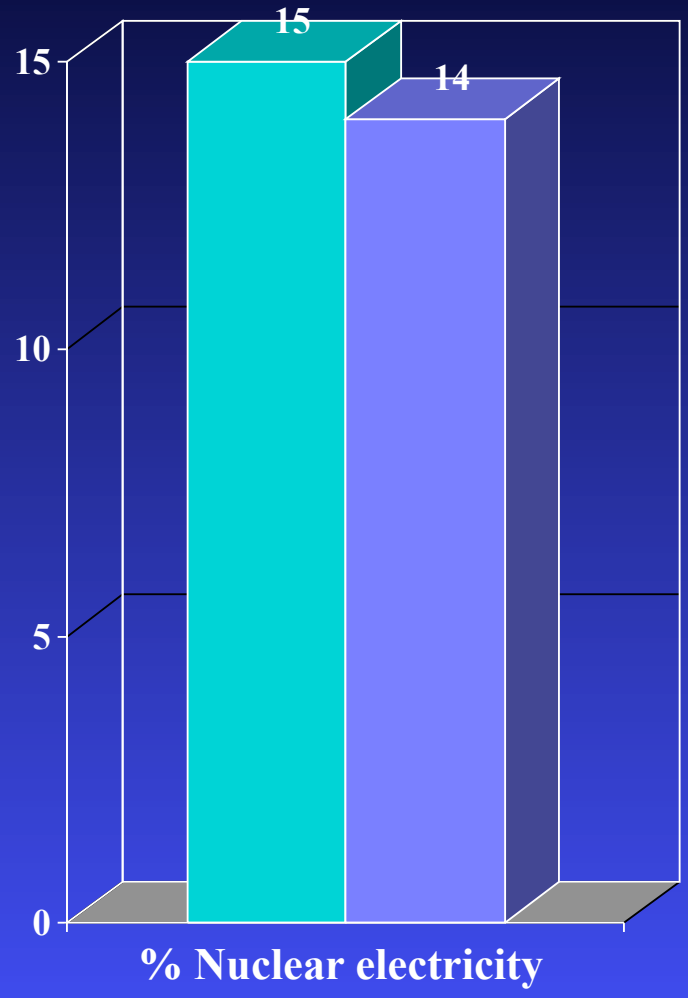
Nuclear power reactors, worldwide
Total capacity: 0.38 TW, 14% of world electrical energy



Nuclear Fission: A Renaissance?

Reserves: 50-7000 TW-year; Humanity: 16 TW-year/year



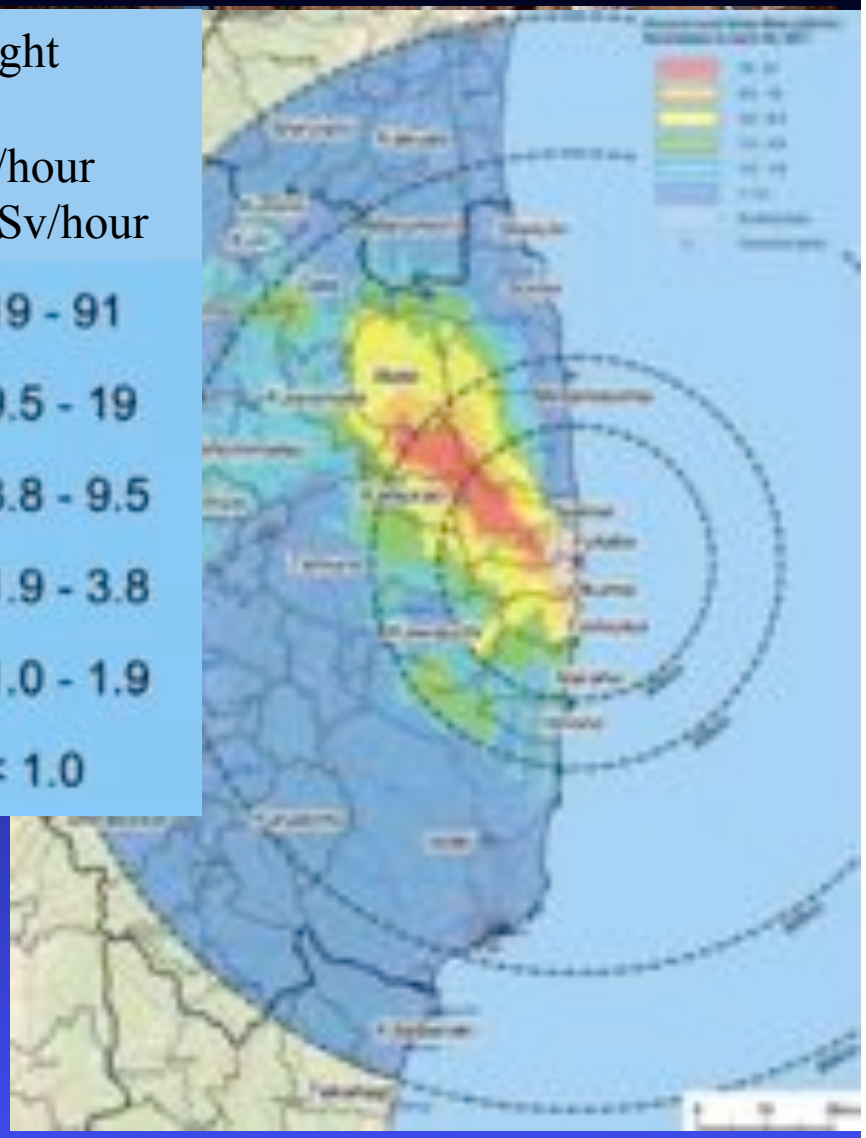


Data source: World Nuclear Association

Digression:
Nuclear Energy after Fukushima

What Went Wrong at Fukushima

- Earthquake: reactor damage?
- Tsunami: Damaged backup cooling
- Hydrogen buildup: explosions
- Fuel meltdowns
- Damage to spent fuel pools
- Radiation releases



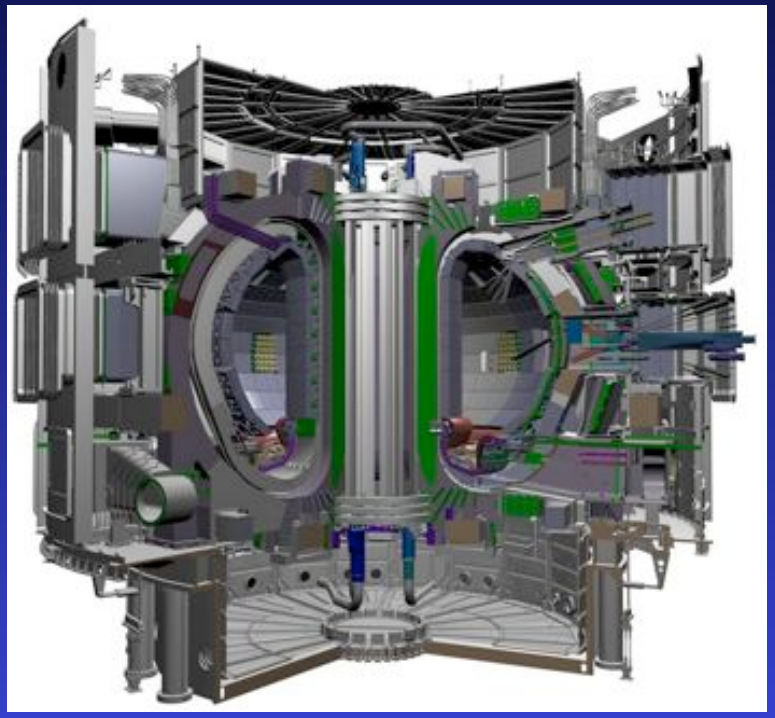
Fukushima-Inspired Thoughts

- ~1.5% of the world's commercial power reactors have now melted down
  - Comparable to Space Shuttle accident rate
- Was Fukushima the worst credible accident?
  - 3-4 reactors; 40% of Chernobyl radiation
  - Safety of light water reactors?
    - Vindicated? Unacceptable risks?
  - Implications for multiple-reactor power stations?
- Is Fukushima over?
  - "Cold shutdown" 16 December 2011
  - 40-year cleanup
  - Long-term land contamination?

Nuclear Fusion

Reserves: 500 billion TW-year; Humanity: 16 TW-year/year

Magnetic confinement



ITER Experimental
fusion reactor:
50 MW in, 500 MW out
2019 (?)

Inertial confinement

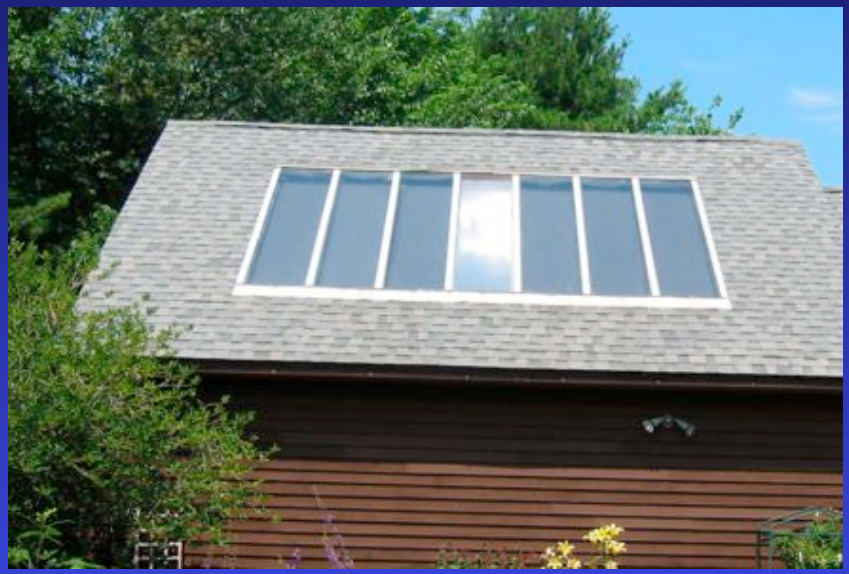
National Ignition Facility,
LLNL: 2010
Scientific breakeven (?)

Direct Solar Energy

Rate: 174,000 TW global*; Humanity: 16 TW

*~100,000 TW at surface

Passive heating



Active hot-water heating

Direct Solar Energy

Rate: 174,000 TW global*; Humanity: 16 TW

*~100,000 TW at surface

Concentrated solar-thermal,
2-axis tracking (90 MW, CA)

Suncatcher concentrated solar-thermal, 3-axis tracking, (25 kW each, 1.5 MW total, Arizona); 1.5 GW planned

Concentrated solar-thermal,
power towers
(30 MW, Spain)

Direct Solar Energy

Rate: 174,000 TW global*; Humanity: 16 TW

Photovoltaic power

*~100,000 TW at surface

China: 200 MW, 2011

Maine: 4 kW, 1996

Germany: 53 MW, 2009

Spain: 60 MW, 2008

Ontario: 97 MW, 2010

Nevada: 14 MW, 2007

Indirect Solar Energy: Hydropower

Rate: 200 TW global; Humanity: 16 TW

Hoover Dam
Colorado River
AZ/NV
1935; 2.1 GW

3 Gorges, China
2003-2010; 23 GW

John Jay Dam
Columbia River, WA
1971; 2.2 GW

Belden's Falls, VT
1913; 1.6 MW
1988: 4.1 MW

Indirect Solar Energy: Wind

Rate: 200 TW global; Humanity: 16 TW

Carleton College
2004; 1.65 MW

Offshore wind
farm, Denmark
2009; 209 MW

Enercon
E-126
2008
7 MW

Alta, CA 720 MW in 2011;
ultimately 1.4 GW

Gansu wind farm
China: 2020; 20 GW

Indirect Solar Energy: Oceans

Rate: ~10 TW global; Humanity: 16 TW

Wave power,
Portugal 2008; 3×750 kW

Ocean Thermal
Energy Conversion
(OTEC) concept

Ocean current
turbines concept

Indirect Solar Energy: Biomass

Rate: 133 TW global; Humanity: 16 TW

McNeil generating station, VT
1954; 54 MW

Middlebury College biomass boiler
2009; 5 MW thermal

Corn ethanol

Biodiesel

Algae

Hydrogen!

Reserves: 0

Humanity: 16 TW-year/year

Electricity!

Reserves: 0

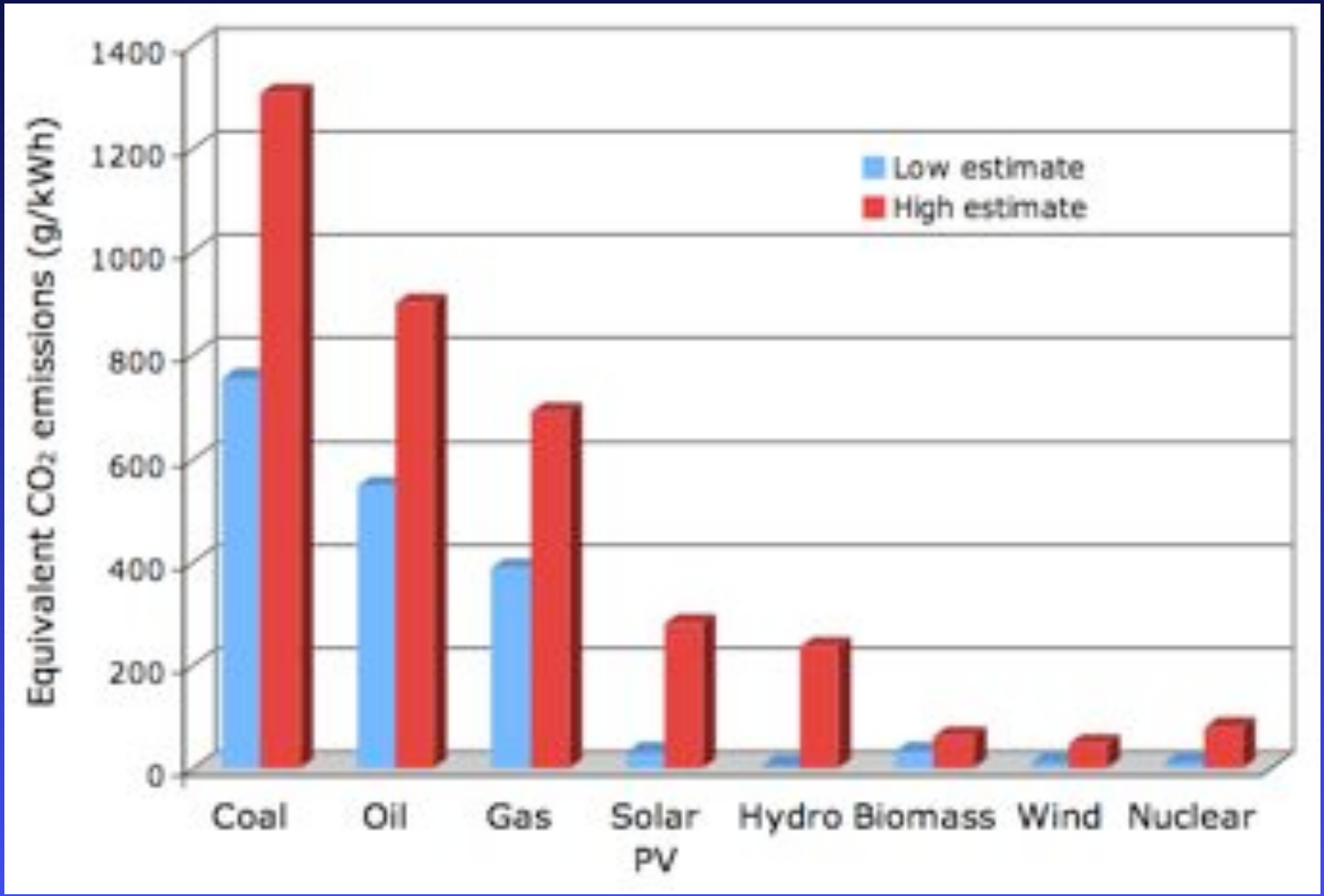
Humanity: 16 TW-year/year

Energy & Environment

No energy source is environmentally benign!

- Wind
  - Aesthetics
  - Noise
  - Bird & bat kills
- Solar
  - Toxic substances
  - Climate-change potential (albedo)
- Geothermal
  - Air & water pollution
  - Land subsidence
  - Damage to scenic areas
  - Earthquakes
- Biomass
  - Air pollution
  - Toxins (dioxin, etc)
- Hydro
  - Land inundation
  - Population displacement
  - Greenhouse gas emissions
- Nuclear
  - Radioactive waste
  - Catastrophic accidents
  - Terrorism
  - Lung cancer in miners

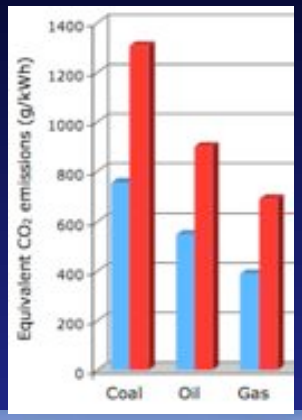
No energy source is greenhouse-emission free

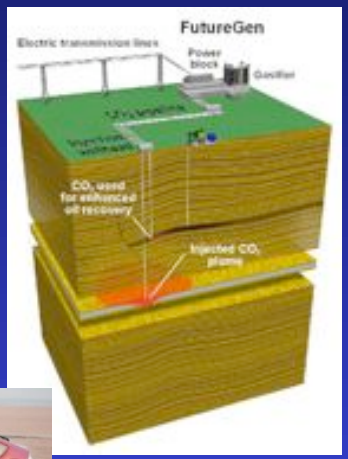


Wolfson, *Energy Environment and Climate* 2e Fig. 16.4

Future of Energy: Near Term

- Fossil fuels continue
  - Gas substitutes for coal
  - Coal with CCS
  - Higher CAFE standards
  - Carbon tax (?)



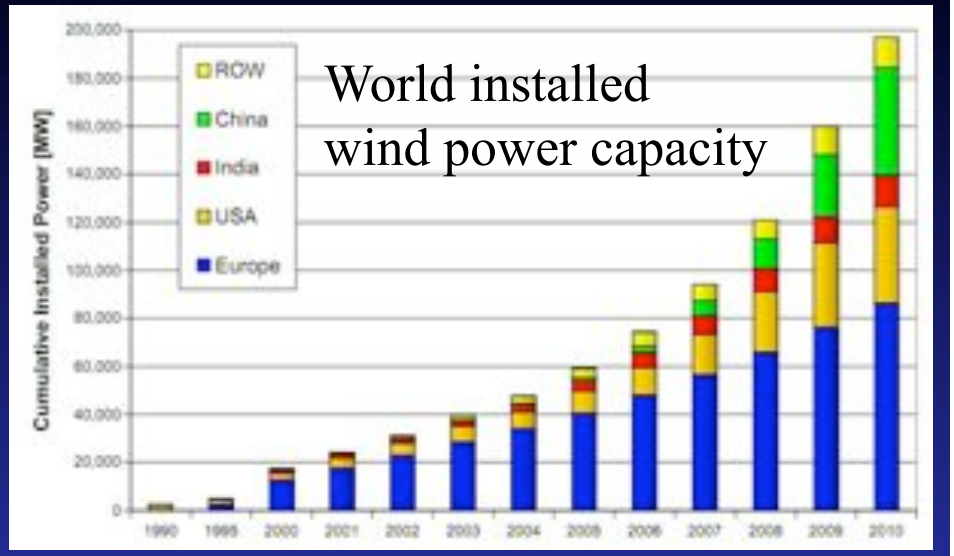


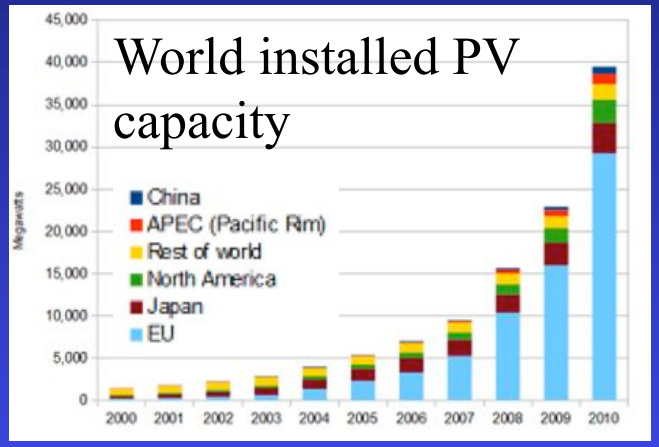
New Federal CAFE standards officially released, 34.1 mpg by 2016

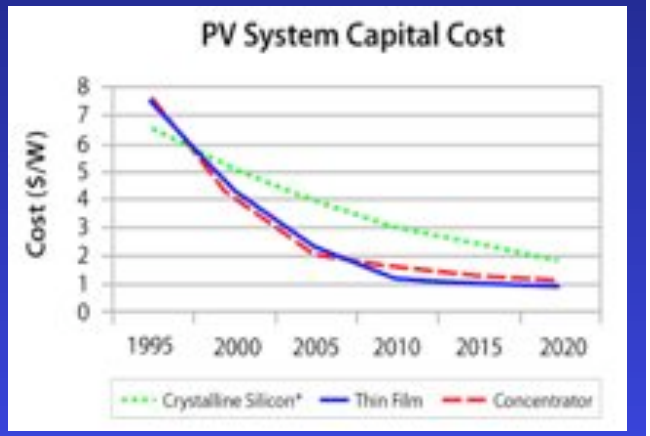
U.S. Senate Climate Bill 'Dead' for 2010
Senator Harry Reid

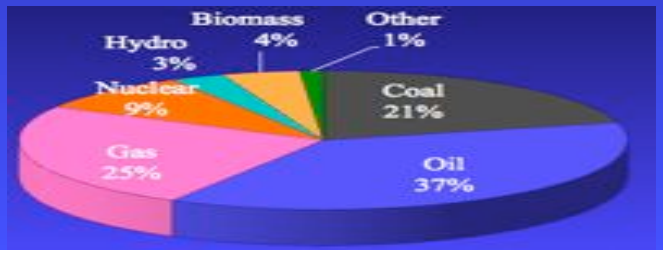
Future of Energy: Near Term

- Growth in renewables
  - Wind 32%/year
    - 200 GW
    - 16 TW in 14 years!
  - Solar
    - 40 GW
- But a long way to go…



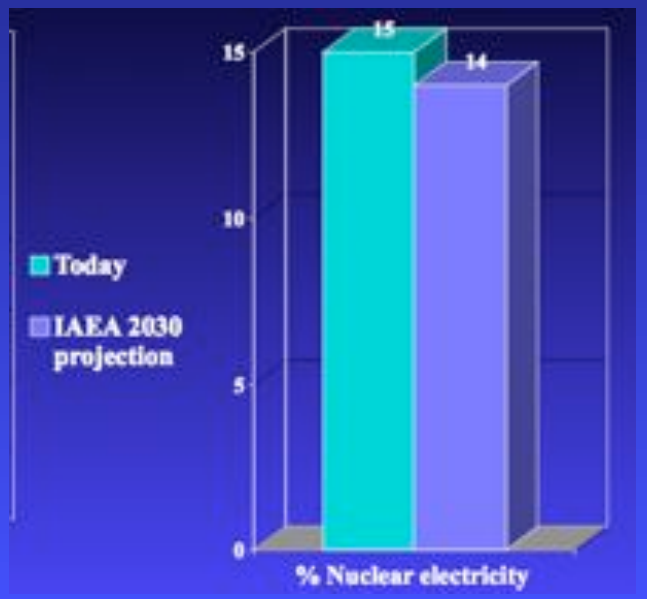






Future of Energy: Near Term

- Nuclear fission
  - New reactors, especially Asia and E. Europe
  - Gradual advances in LWRs
  - Little or no increase in nuclear contribution to world energy supply

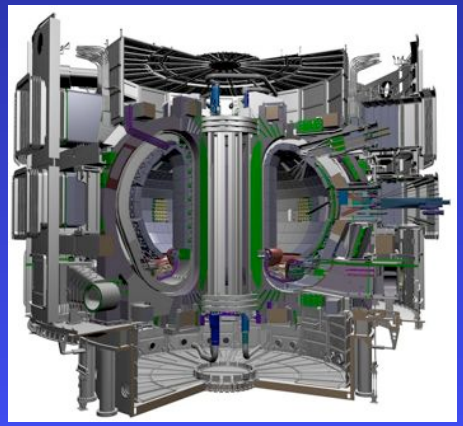


Future of Energy: Near Term

- Energy infrastructure
  - Smart grids
    - Load control
    - Net metering
    - Instantaneous pricing
    - Lower losses
  - Feed-in tariffs
  - More CHP/cogeneration
  - Distributed generation

Future of Energy: Long Term

- Dominated by direct solar and/or fusion
  - Hydrogen or synfuels for vehicles
    - Hydrolysis or photolysis of water
    - Bioengineering for fuel production
  - Increased electrical energy use
    - Superconducting power transmission
- More limited roles for
  - Indirect solar (wind, currents, waves)
  - Advanced fission, breeders, fission/fusion hybrids



Future of Energy: Long Term

Solar flow: 174,000 TW

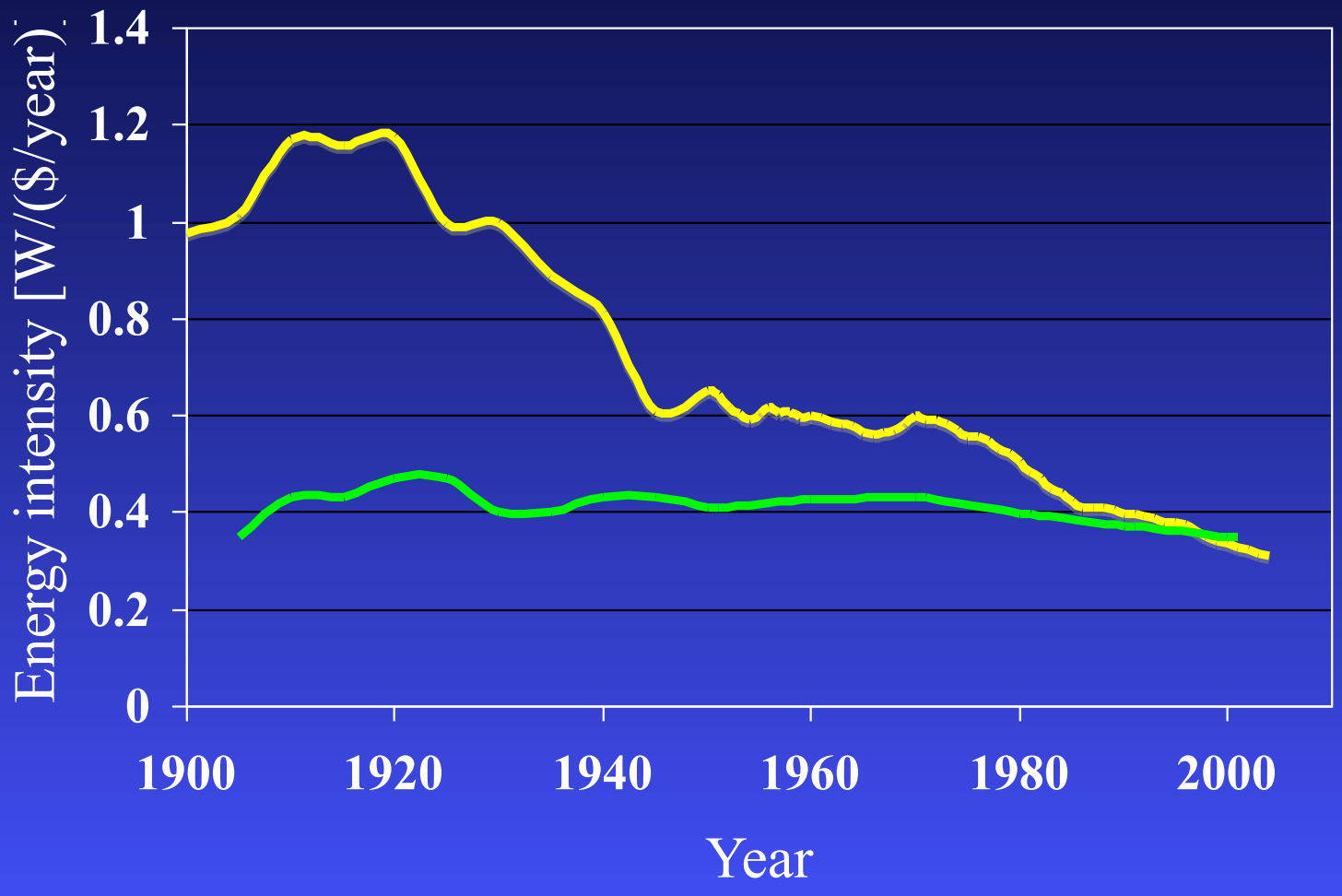
Human consumption: 16 TW

Bonus Material

Energy & Prosperity

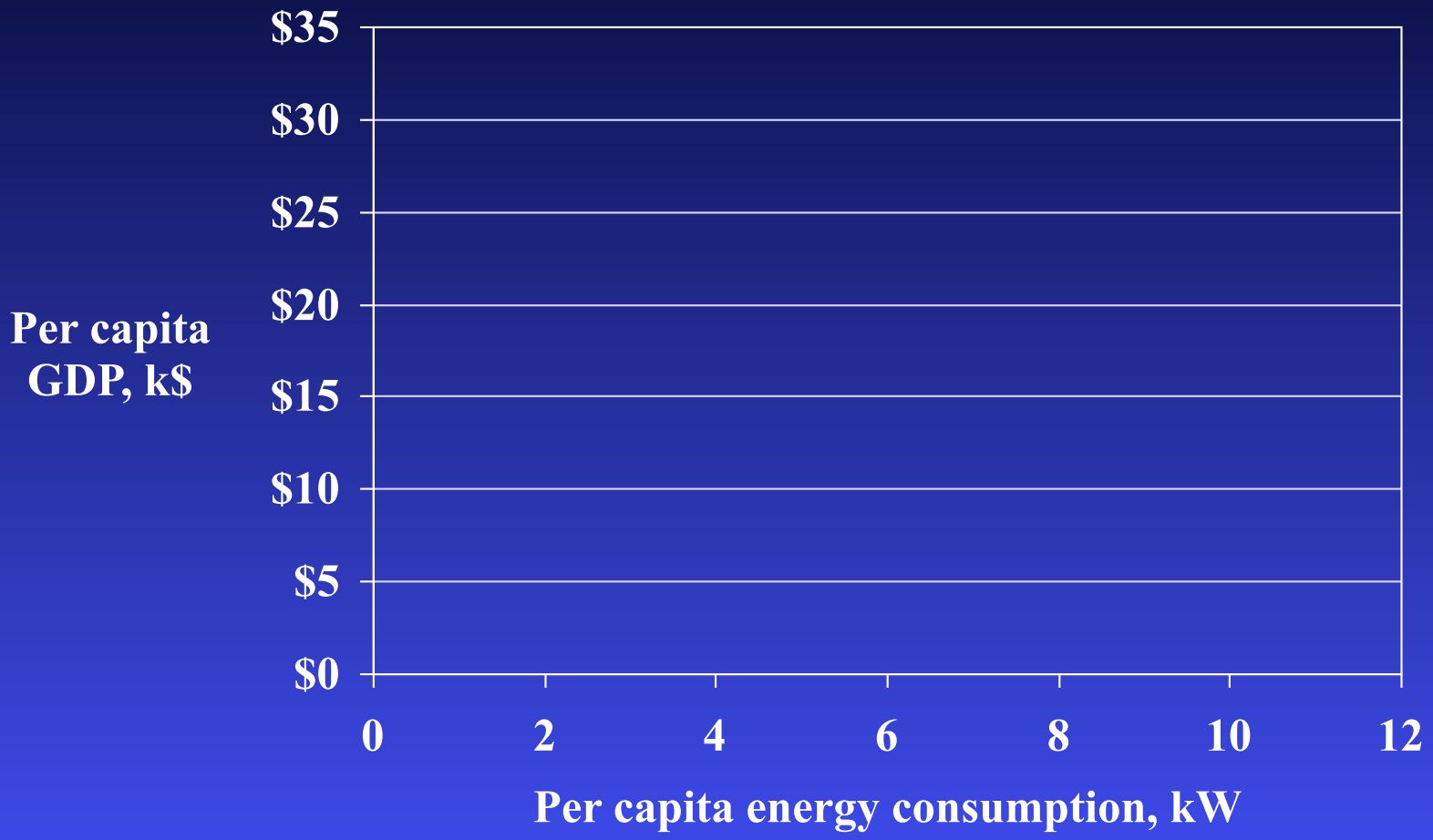
Energy Intensity

How much energy does it take to make $1 of GDP?



Source: Wolfson, *Energy, Environment, and Climate*, Fig. 2-8

Energy & Prosperity



Source: International Energy Agency, Key World Energy Statistics, Section 8: Selected Energy Indicators for 2002

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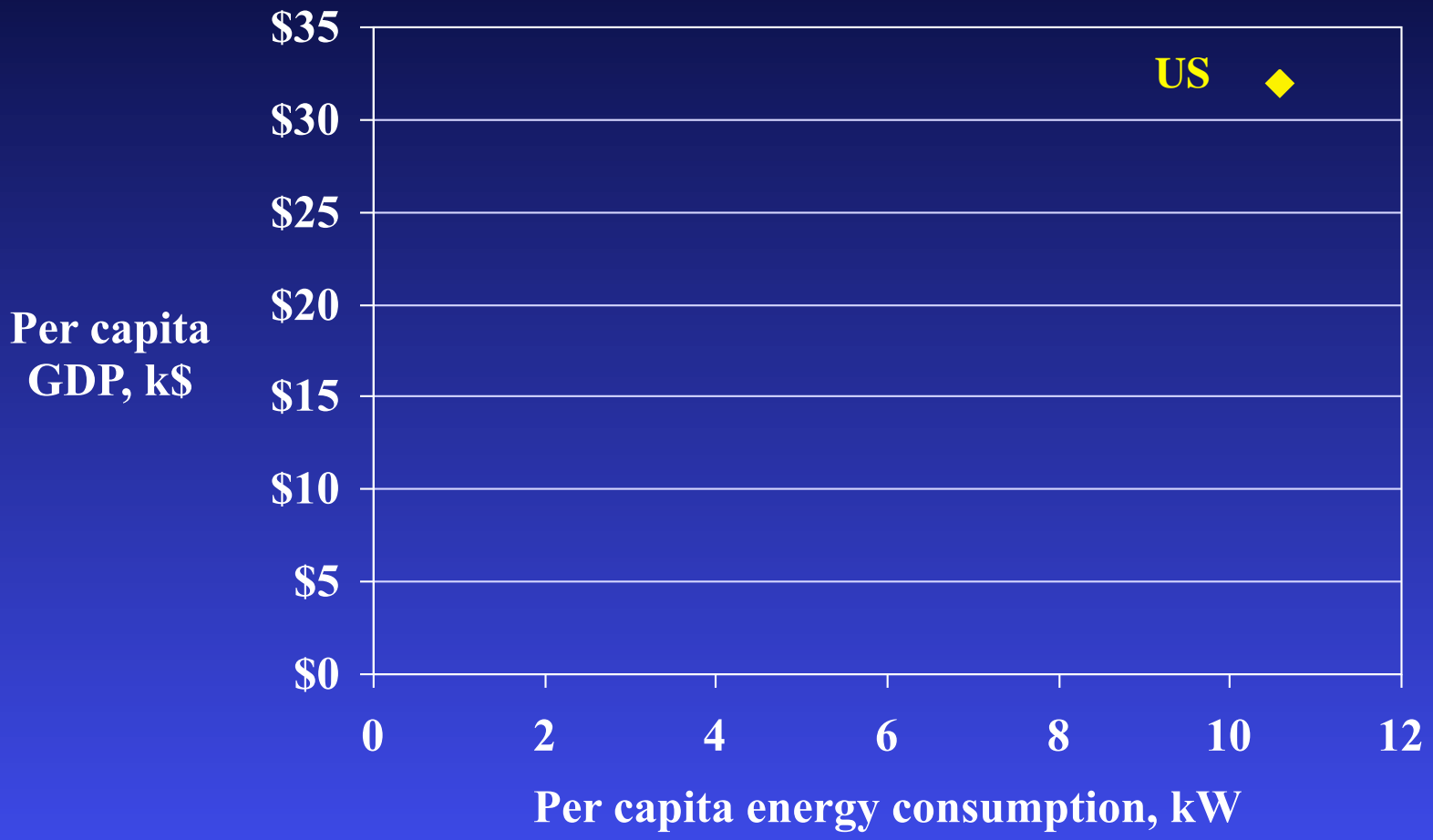

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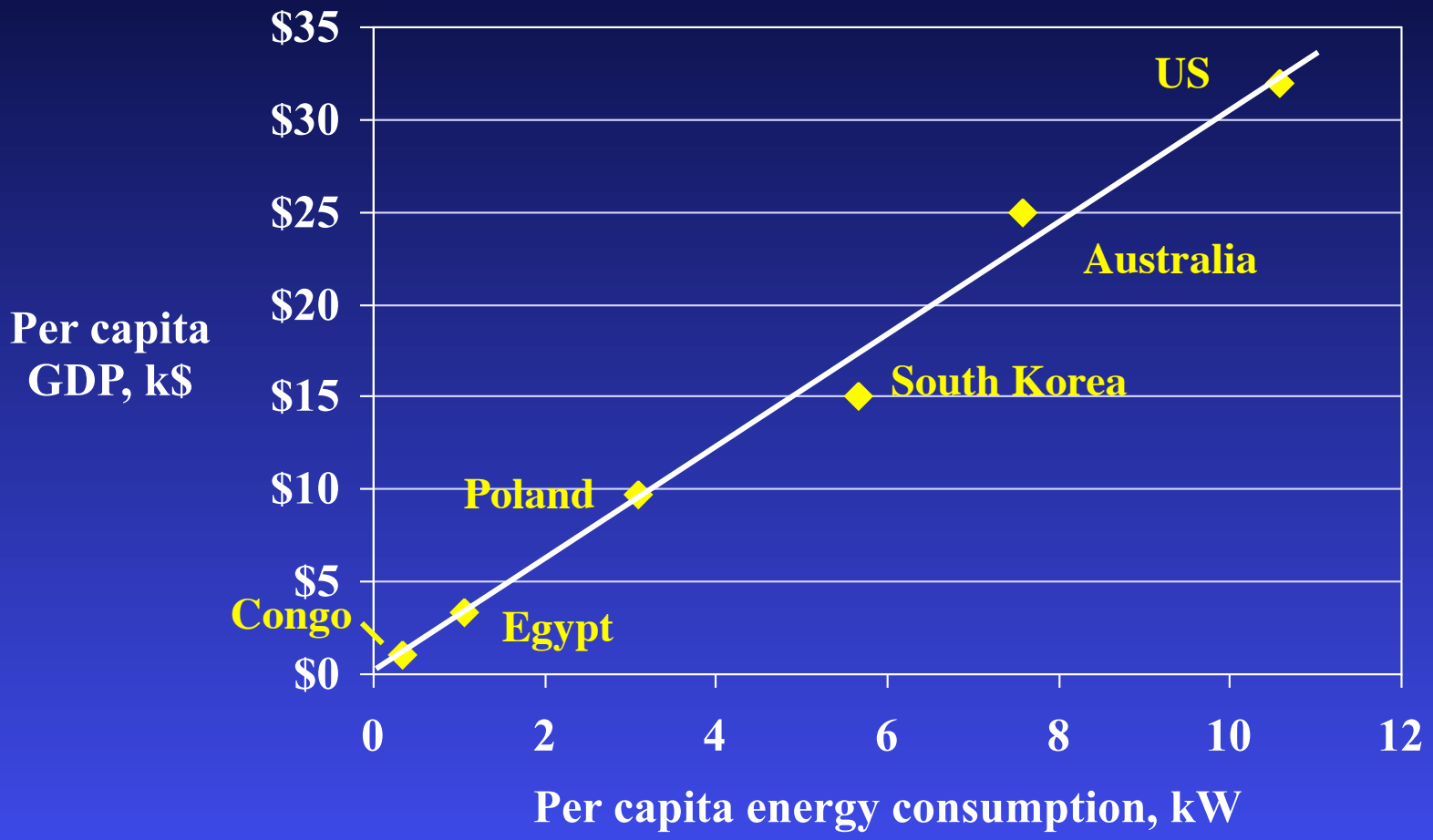

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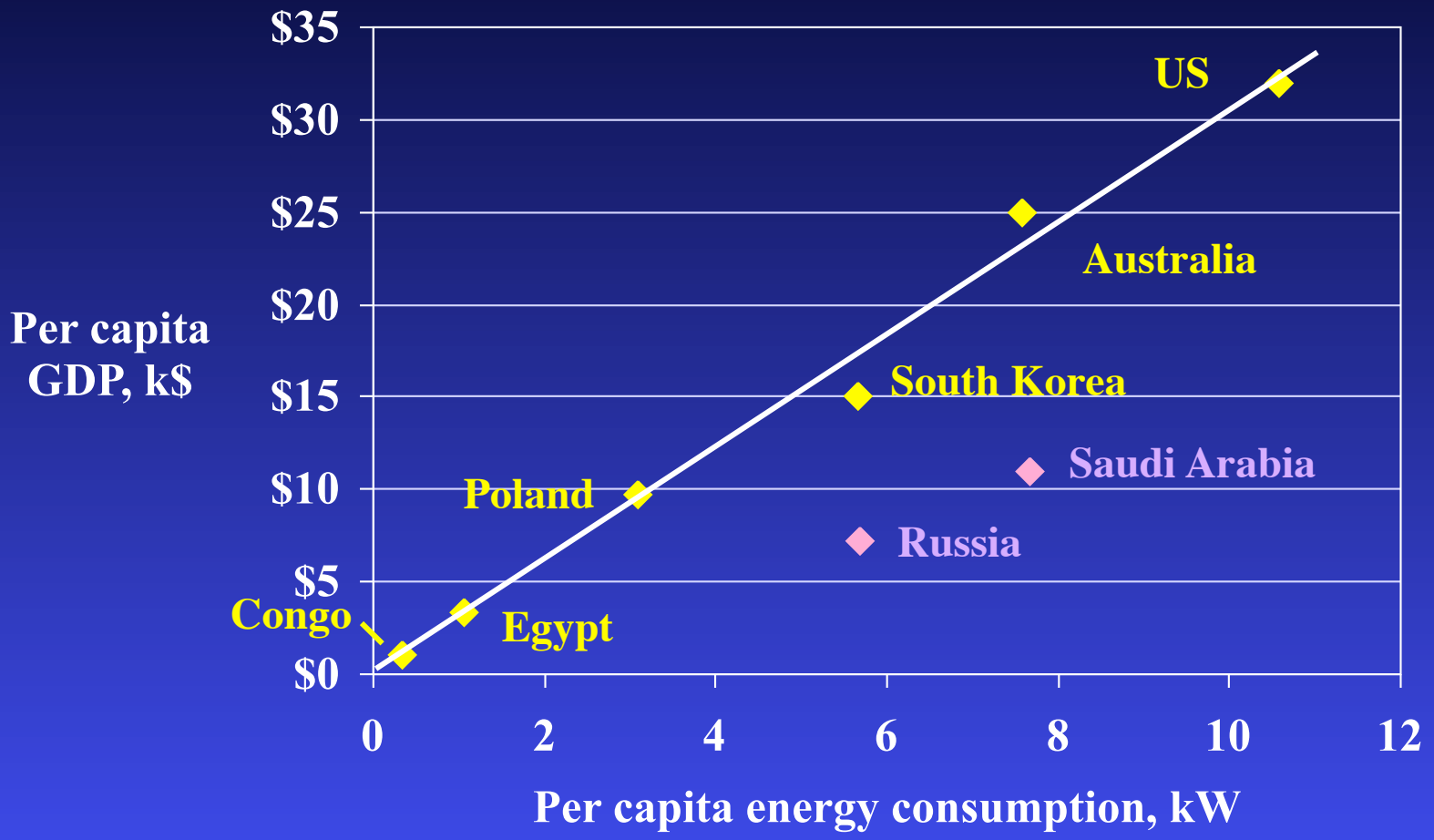
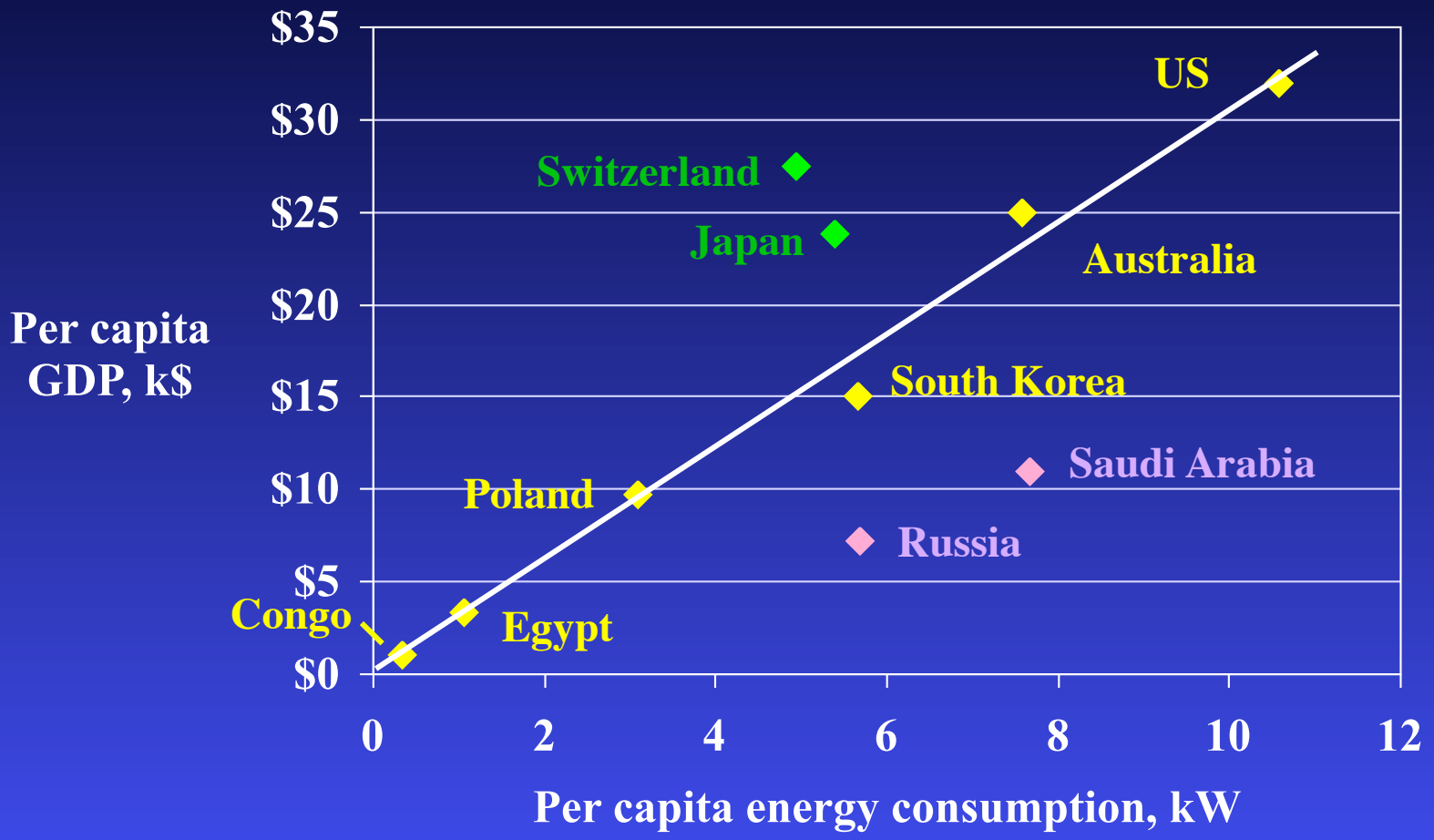
Energy & Prosperity



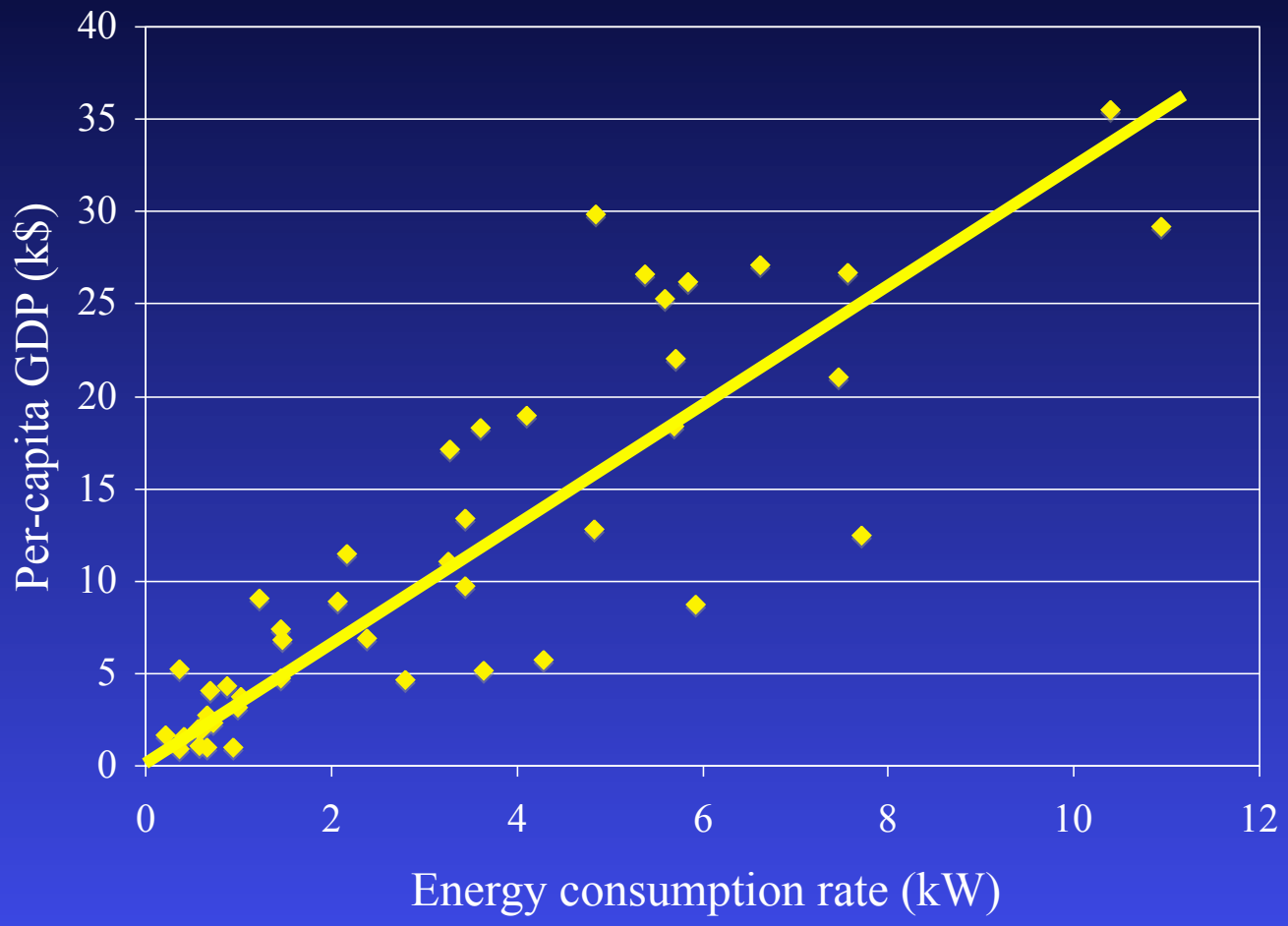
Source: International Energy Agency, Key World Energy Statistics, Section 8: Selected Energy Indicators for 2002

Energy & Prosperity



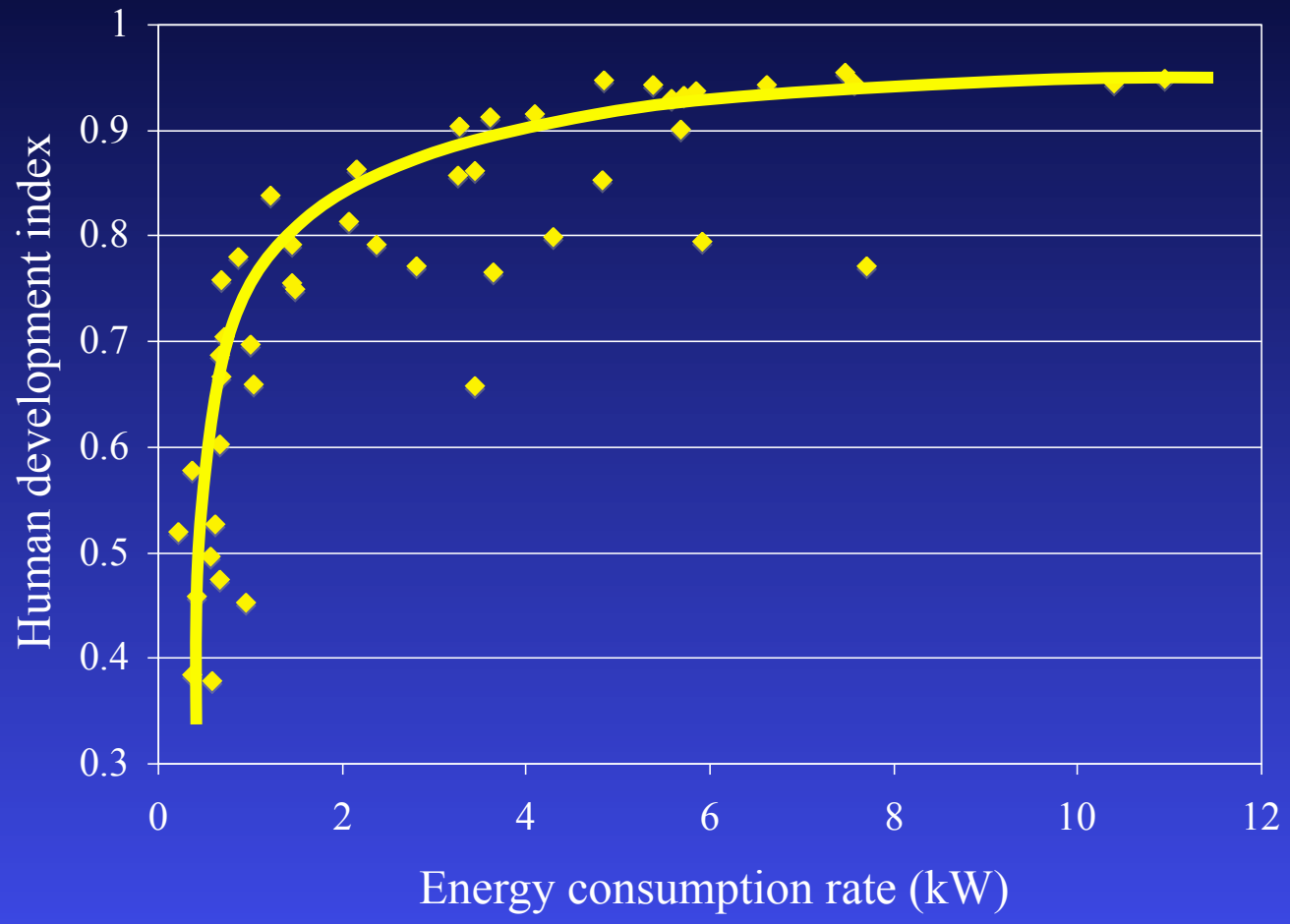
Source: International Energy Agency, Key World Energy Statistics, Section 8: Selected Energy Indicators for 2002

Energy and Prosperity?



Source: International Energy Agency, Key World Energy Statistics, Section 8: Selected Energy Indicators for 2002

Energy and Prosperity?



Source: IEA as in previous slide; HDI from UN Human Development Report 2005, Table 1