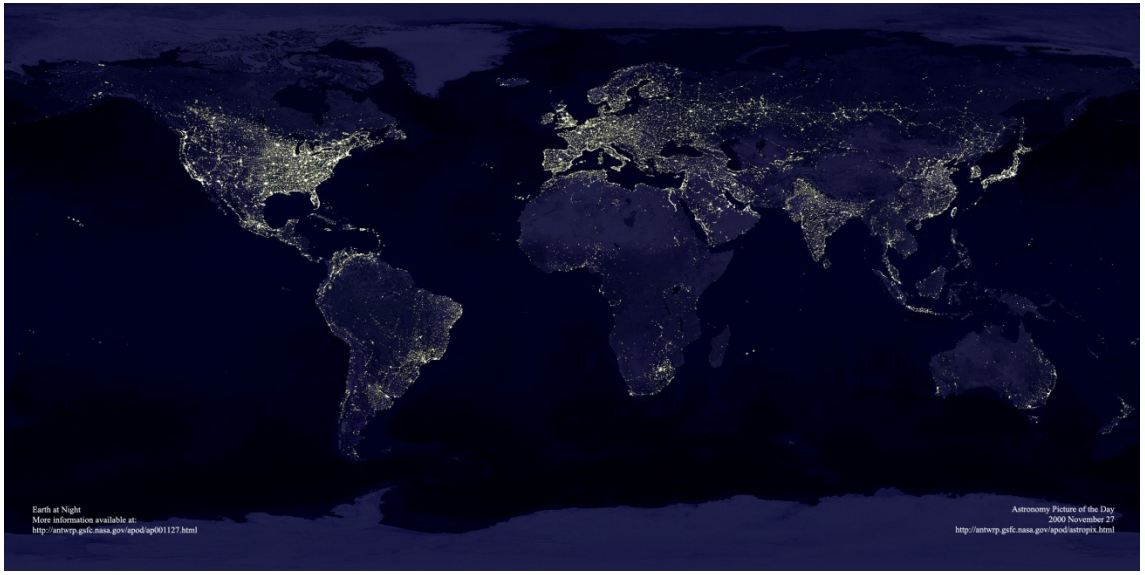
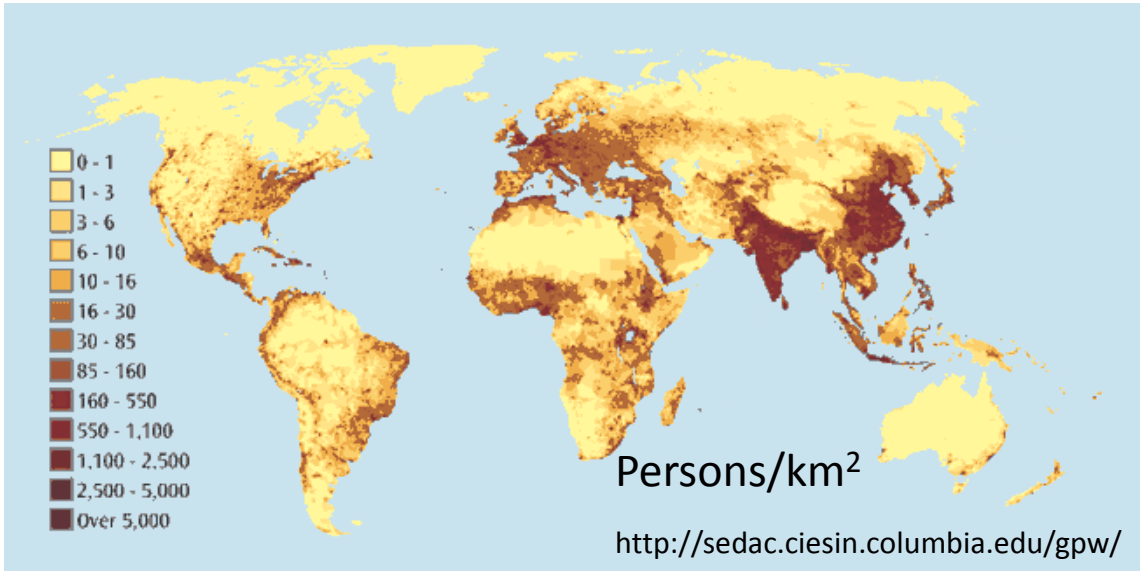
Introduction to Alternative and Renewable Energy

EST1830

Who has the energy?





1. Introductory Section

1.1 Overview
1.1.1 Energy Definition and Units
1.1.2 US Energy Consumption Statistics
1.1.3 World Energy Consumption Statistics
1.1.4 Alternative and Renewable Energy Statistics

1.1.1 Energy Definition and Units

What is Energy?

A thermodynamic quantity which is essentially equivalent to the capacity of a physical system to do work.

What is Renewable Energy?

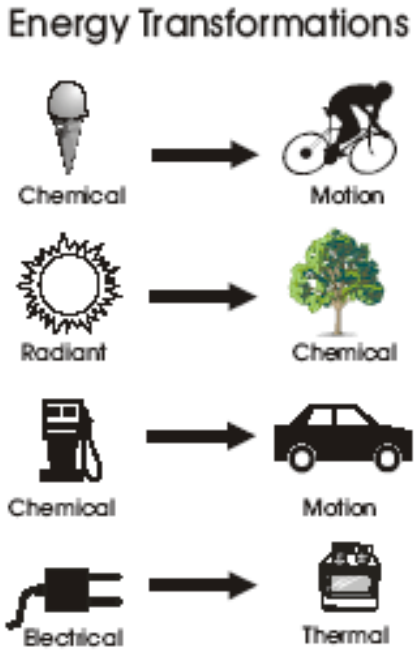
Energy produced through a renewable source that is replaced by natural processes at a rate comparable or faster than its rate of consumption.

What is Sustainability?

The capacity to endure. Means using less than is renewed.

Forms of Energy

Potential Energy Potential energy is stored energy and the energy of position — gravitational energy. There are several forms of potential energy.	Kinetic Energy Kinetic energy is motion — of waves, molecules, objects, substances, and objects.
Chemical Energy is energy stored in the bonds of atoms and molecules. Biomass, petroleum, natural gas, and coal are examples of stored chemical energy. Chemical energy is converted to thermal energy when we burn wood in a fireplace or burn gasoline in a car's engine.	**Radiant Energy** is electromagnetic energy that travels in transverse waves. Radiant energy includes visible light, x-rays, gamma rays and radio waves. Light is one type of radiant energy. Sunshine is radiant energy, which provides the fuel and warmth that make life on Earth possible.
Mechanical Energy is energy stored in objects by tension. Compressed springs and stretched rubber bands are examples of stored mechanical energy.	**Thermal Energy**, or heat, is the vibration and movement of the atoms and molecules within substances. As an object is heated up, its atoms and molecules move and collide faster. Geothermal energy is the thermal energy in the Earth.
Nuclear Energy is energy stored in the nucleus of an atom — the energy that holds the nucleus together. Very large amounts of energy can be released when the nuclei are combined or split apart. Nuclear power plants split the nuclei of uranium atoms in a process called fission. The sun combines the nuclei of hydrogen atoms in a process called fusion.	**Motion Energy** is energy stored in the movement of objects. The faster they move, the more energy is stored. It takes energy to get an object moving and energy is released when an object slows down. Wind is an example of motion energy. A dramatic example of motion is a car crash, when the car comes to a total stop and releases all its motion energy at once in an uncontrolled instant.
Gravitational Energy is energy stored in an object's height. The higher and heavier the object, the more gravitational energy is stored. When you ride a bicycle down a steep hill and pick up speed, the gravitational energy is being converted to motion energy. Hydropower is another example of gravitational energy, where the dam "piles" up water from a river into a reservoir.	**Sound** is the movement of energy through substances in longitudinal (compression/rarefaction) waves. Sound is produced when a force causes an object or substance to vibrate — the energy is transferred through the substance in a wave. Typically, the energy in sound is far less than other forms of energy.
Electrical Energy is what is stored in a battery, and can be used to power a cell phone or start a car. Electrical energy is delivered by tiny charged particles called electrons, typically moving through a wire. Lightning is an example of electrical energy in nature, so powerful that it is not confined to a wire.	



http://www.need.org/EnergyInfobooks.php

http://www.eia.doe.gov/kids/energy.cfm?page=about_forms_of_energy-forms

Law of Conservation of Energy: Energy cannot be created or destroyed. But it can change from one form to another. (First Law of Thermodynamics)

Energy and Power

- Energy is the capacity of a system to do work.
  - Its SI unit is the Joule (J)
  - From the traditional sense of force acting over a distance derived from Newton's 2nd law of motion.
    - Force (N) = mass (kg) x acceleration (m/s^2) [F=ma]
    - Energy (J) = force (N) x distance (m)
- Power is the **rate** at which energy is converted from one form to another. So units are in energy converted per time.
  - SI unit is the Watt (W), which is defined as one Joule per second (J/s).
- In practice, we measure energy in terms of power used over a period of time. So a dimensional analysis of the commonly used kilowatt-hour (kW-hr) yields units of energy (J).

Begin with basics: Energy Units

Energy

- 1 BTU = 1055 Joules (J)
- 1 kWh = 3.61 million J
- 1 kWh = 3412 BTU
- 1 Quad = 10^{15} BTU
- J= 778 ft-lbs= 252 calories
- 1 exaJoule = 10^{18} J = 4 days of energy use in the US
- 1 burning match = 1000 J

Power

- 1 Watt (W) = 1 J/s
- 1 Watt (W) = 3.41 BTU/hr
- 1 horsepower (hp) =550 ft-lbs/s
- 1 horsepower (hp) =746 W

- 1 kWh = amount of energy converted if work is done at an average rate of 1000 Watts for one hour.
  - Ex1: Using a 60 W incandescent light bulb for one hour consumes 0.06 kWh of electricity.
  - Ex2: Using a 100W bulb for one hour a day for 30 days consumes 100W x 30 h = 3000 Wh = 3kWh.

Source: Wikipedia

Scalings

Energy

- 1bbl oil= 42 gallons
  - = 5.6×10^6 BTU
  - = 5.9×10^9 J
- 1 bbl hot water cooled by 100 deg C
  - = 8900 BTU
  - = 9.4×10^6 J
  - = 0.00159 bbl of oil

Energy Rate (power)

- Candy Bar: 25kcal
- Avg Daily Req: 2000-3000 kcal = 100W
- Human heart: 2 W
- Cell phone: 2 W
- Laptop: 10 W
- Running: 500W
- 1 hp: 746 W
- Car 100 kW
- Typical Wind turbine 1-3 MW
- 747 Jet 250 MW
- Typical electrical plant: 1000 MW
- Space Shuttle [w/boosters]: 1 GW [14GW]

1.1.2 US Energy Consumption Statistics

Energy Consumption

- US Energy consumption per year
  - 100,000,000,000,000,000,000 J ~ 100 Quads = 3.5 TW
- Worldwide energy consumption per year
  - 400,000,000,000,000,000,000 J ~ 400 Quads = 15 TW

Currently about 25% of energy consumption in the world comes from the US.

- Average US household consumes about 10,655 kWh of electricity each year. *(source: AWEA)*

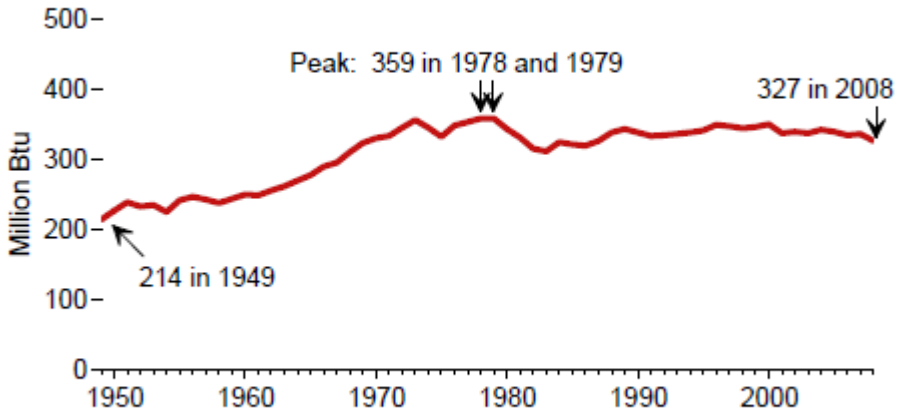
US Energy Consumption

Source: Annual Energy Review 2008, http://www.eia.doe.gov/aer

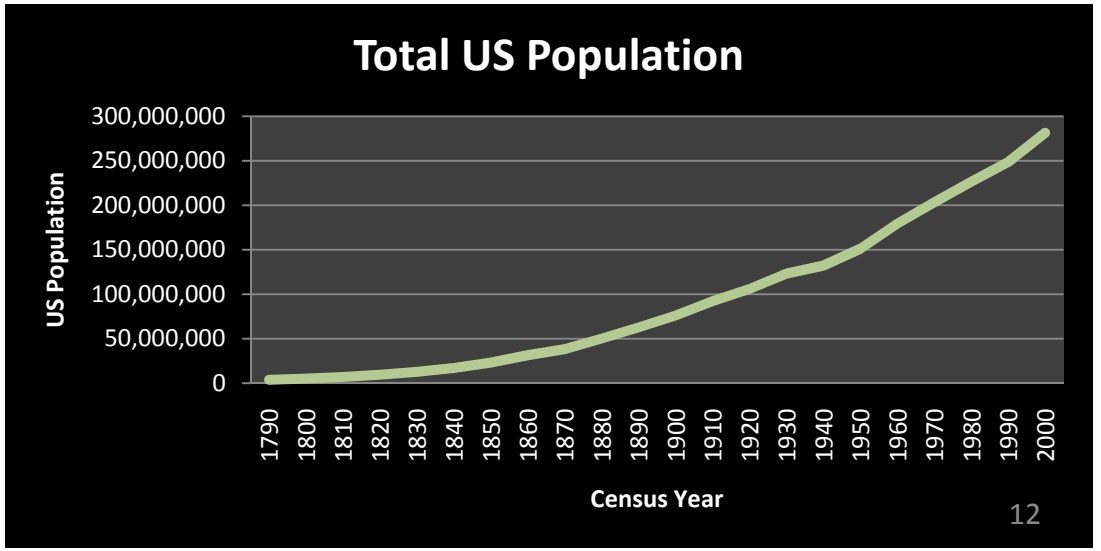
Census Year	Total US Population
1790	3,929,214
1800	5,308,483
1810	7,239,881
1820	9,638,453
1830	12,860,702
1840	17,063,353
1850	23,191,876
1860	31,443,321
1870	38,558,371
1880	50,189,209
1890	62,979,766
1900	76,212,168
1910	92,228,496
1920	106,021,537
1930	123,202,624
1940	132,164,569
1950	151,325,798
1960	179,323,175
1970	203,302,031
1980	226,542,199
1990	248,709,873
2000	281,421,906

Source: US Census Bureau

Figure 2. Energy Consumption per Person

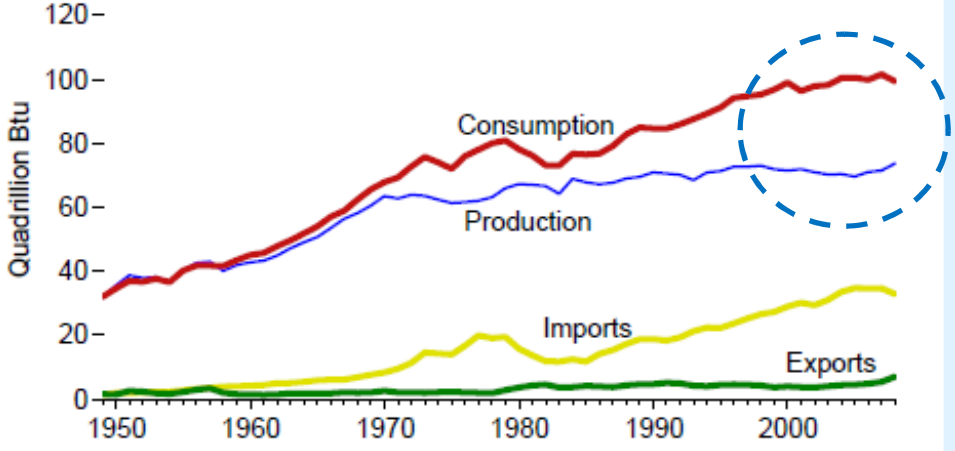


Energy use per person stood at 214 million British thermal units (Btu) in 1949. The rate generally increased until the oil price shocks of the mid-1970s and early 1980s when the trend reversed for a few years. From 1988 on, the rate held fairly steady. In 2008, 327 million Btu of energy were consumed per person, 52 percent above the 1949 rate.



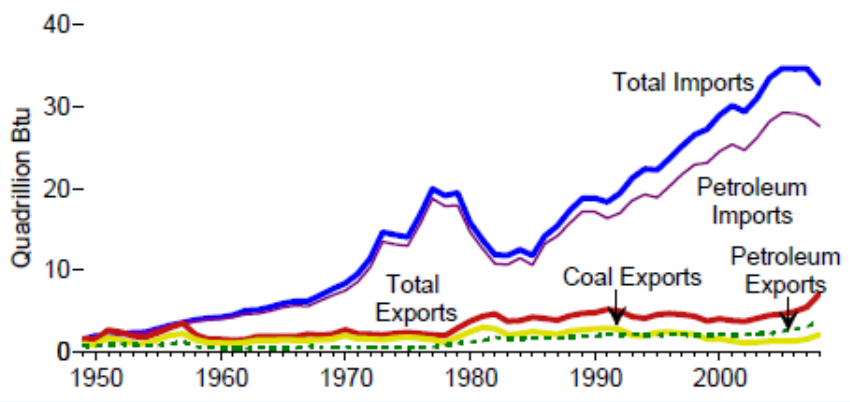
US Energy Consumption

Figure 1. Primary Energy Overview



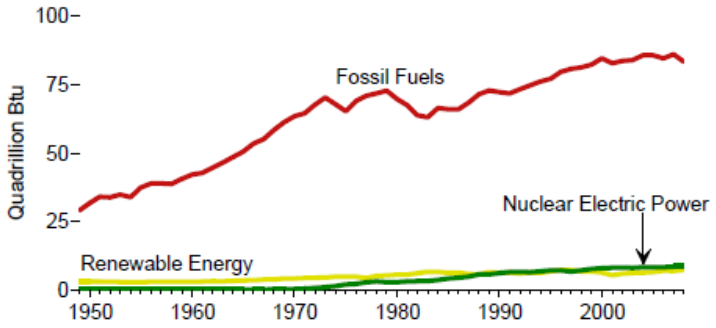
The United States was self-sufficient in energy until the late 1950s when energy consumption began to outpace domestic production. At that point, the Nation began to import more energy to fill the gap. In 2008, net imported energy accounted for 26 percent of all energy consumed.

Figure 13. Primary Energy Imports and Exports



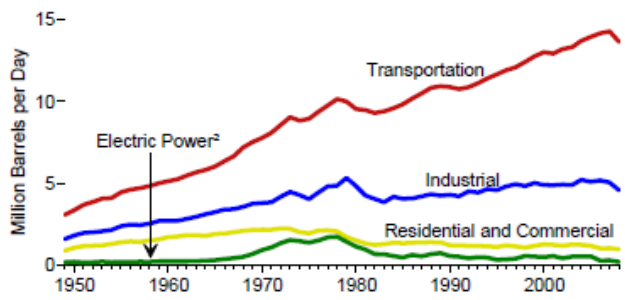
Since the mid-1950s, the Nation imported more energy than it exported. In 2008, the United States imported 33 quadrillion Btu of energy and exported 7 quadrillion Btu. Most imported energy was in the form of petroleum; since 1986, natural gas imports expanded rapidly as well. Through 1992, most exported energy was in the form of coal; after that, petroleum exports often exceeded coal exports.

Figure 4. Primary Energy Consumption by Source



Most energy consumed in the United States comes from fossil fuels. Renewable energy resources supply a relatively small but steady portion. In the late 1950s, nuclear fuel began to be used to generate electricity, and in most years since 1988, nuclear electric power surpassed renewable energy.

Figure 18. Petroleum Consumption[1] by Sector



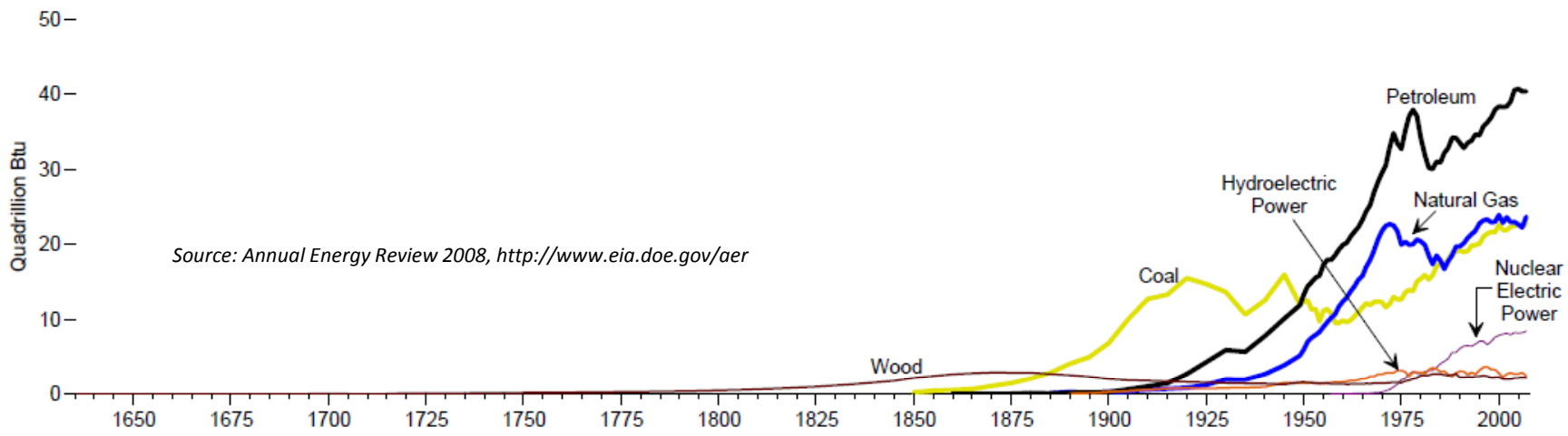
[1] Petroleum products supplied is used as an approximation for consumption.
[2] Through 1988, electric utilities only; after 1988, also includes independent power producers.

Transportation was the largest consuming sector of petroleum and the one showing the greatest expansion. In 2008, 13.7 million barrels per day of petroleum products were consumed for transportation purposes, accounting for 70 percent of all petroleum used.

Source: Annual Energy Review 2008, http://www.eia.doe.gov/aer

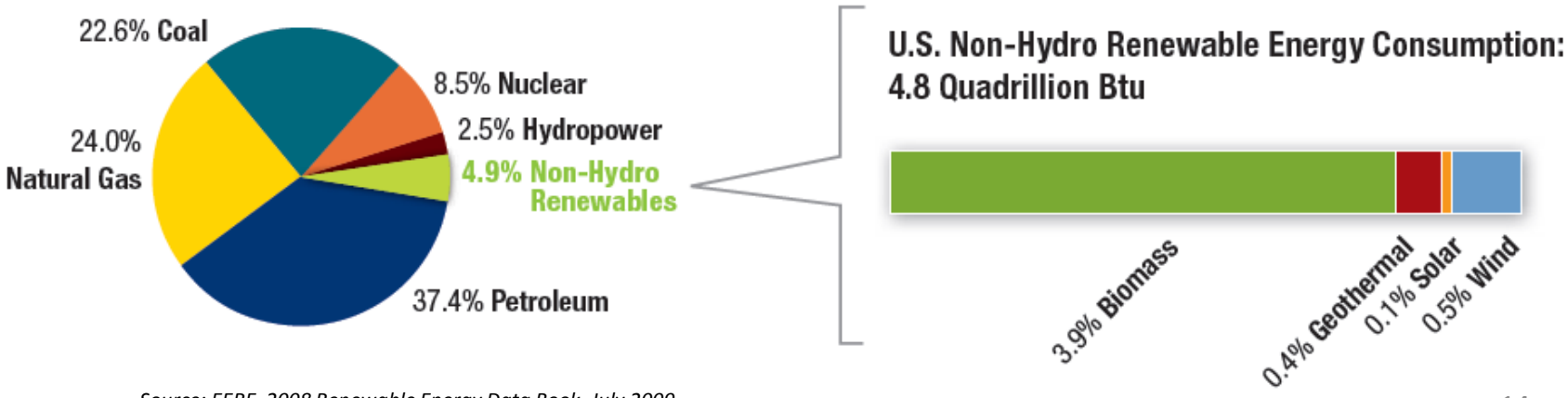
US Energy Consumption for all sectors

Figure 5. Primary Energy Consumption by Source, 1635-2008



Source: Annual Energy Review 2008, http://www.eia.doe.gov/aer

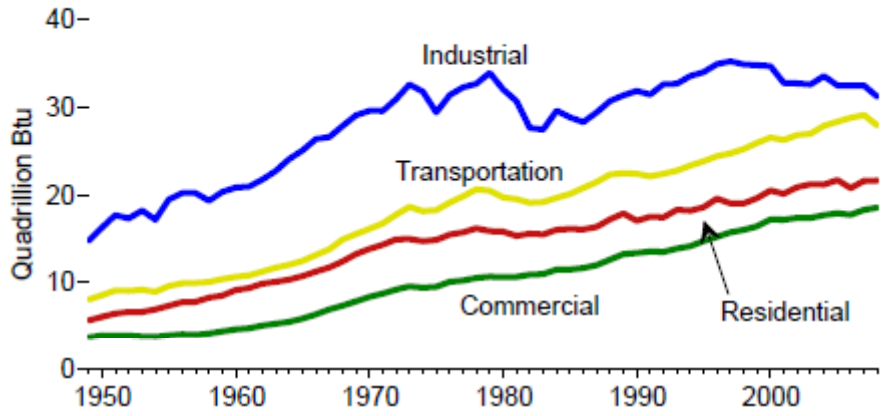
U.S. Energy Consumption (2008): 99.3 Quadrillion Btu



Source: EERE, 2008 Renewable Energy Data Book, July 2009.

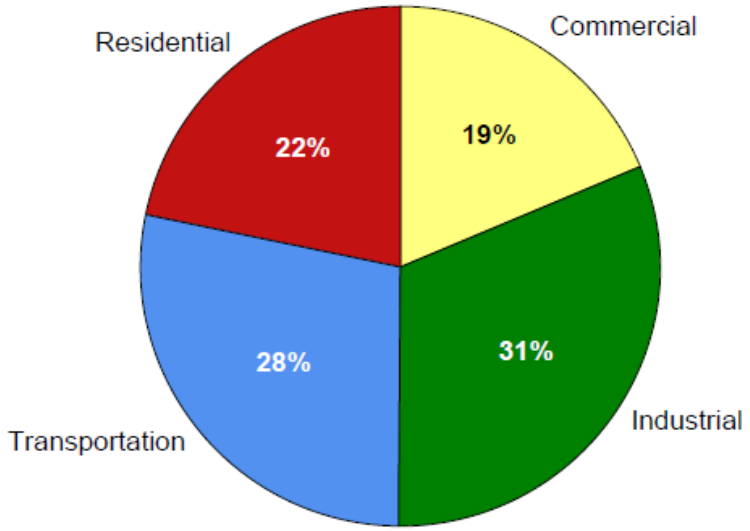
US Energy Consumption

Figure 7. Total Energy Consumption by End-Use Sector



All four major economic sectors of the economy recorded tremendous growth in their use of energy. The industrial sector used the biggest share of total energy and showed the greatest volatility; in particular, steep drops occurred in the sector in 1975, 1980-1982, 2001, 2005, and 2008 largely in response to high oil prices and economic slowdown.

End-Use Sector Shares of Total Consumption, 2008

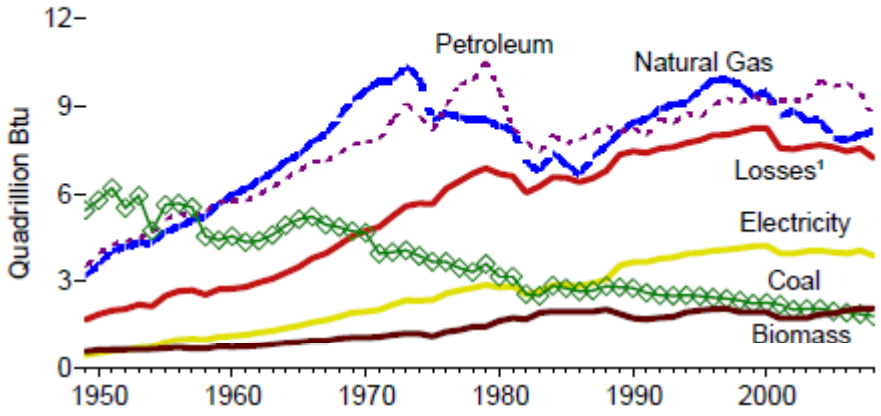


Consumption includes allocated electrical systems energy losses.

Source: Annual Energy Review 2008, http://www.eia.doe.gov/aer

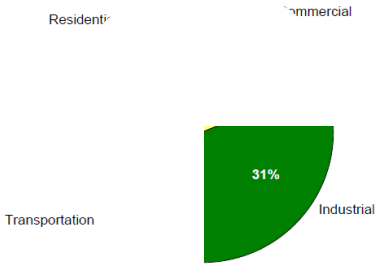
US Industrial Consumption

Figure 9. Industrial Total Energy Consumption, Major Sources



¹ Energy lost during generation, transmission, and distribution of electricity.

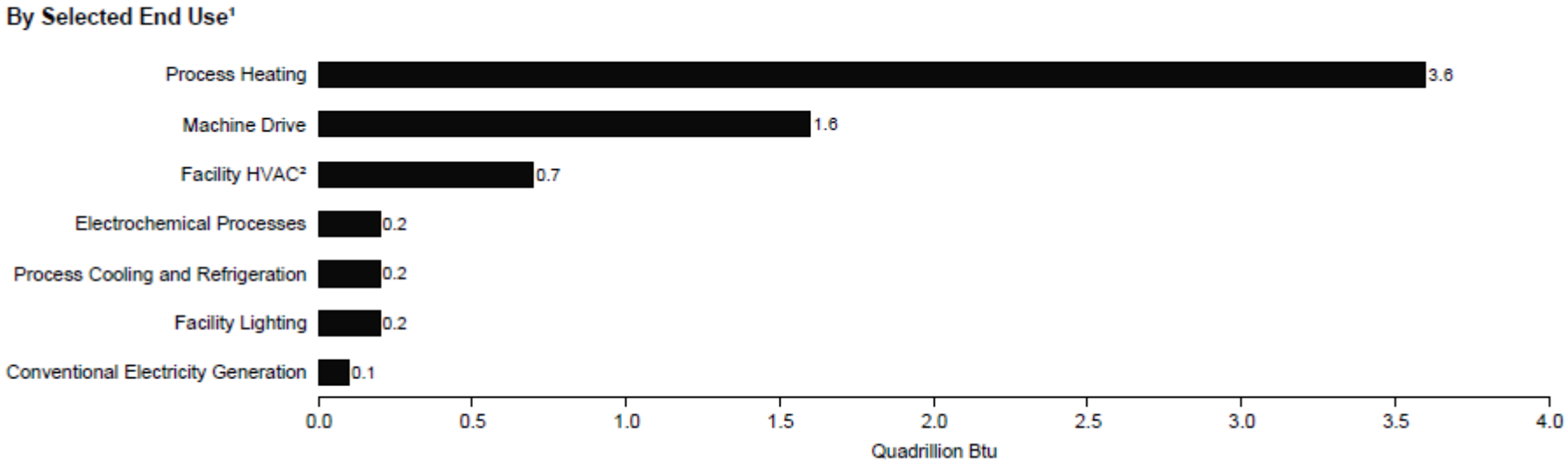
Coal, once the predominant form of energy in the industrial sector, gave way to natural gas and petroleum in the late 1950s. Both natural gas and petroleum use expanded rapidly until the early 1970s, and then fluctuated widely over the following decades. Use of electricity and biomass trended upward.



Source: Annual Energy Review 2008, http://www.eia.doe.gov/aer

Industrial Consumption End Use

Figure 2.3 Manufacturing Energy Consumption for Heat, Power, and Electricity Generation, 2002



Top Energy Consuming Industries

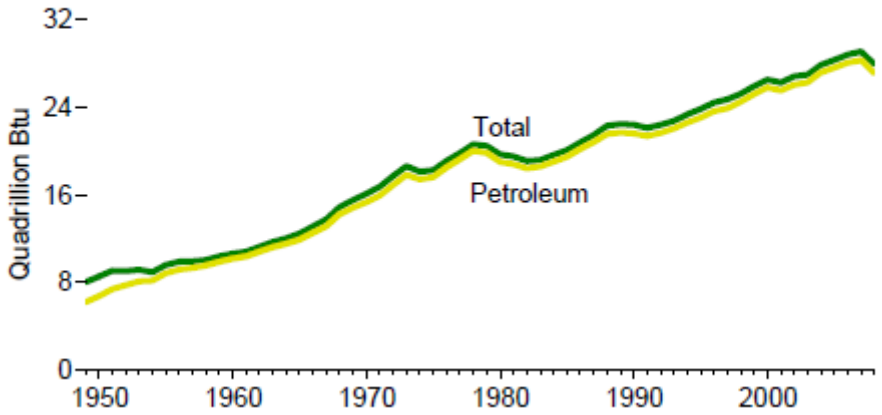
2002 total energy consumption: 22.7 Quad

- Petroleum/coal products: 6.8 Quads (30%)
- Chemicals: 6.5 Quads (29%)
- Paper: 2.4 Quads (11%)
- Primary Metals: 2.1 Quads (9%)
- Food: 1.1 Quads (5%)
- Mineral Products: 1.1 Quads (5%)

Source: Annual Energy Review 2008, http://www.eia.doe.gov/aer

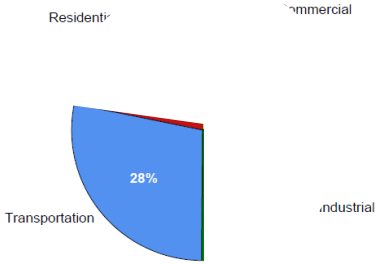
US Transportation Consumption

Figure 10. Transportation Total Energy Consumption



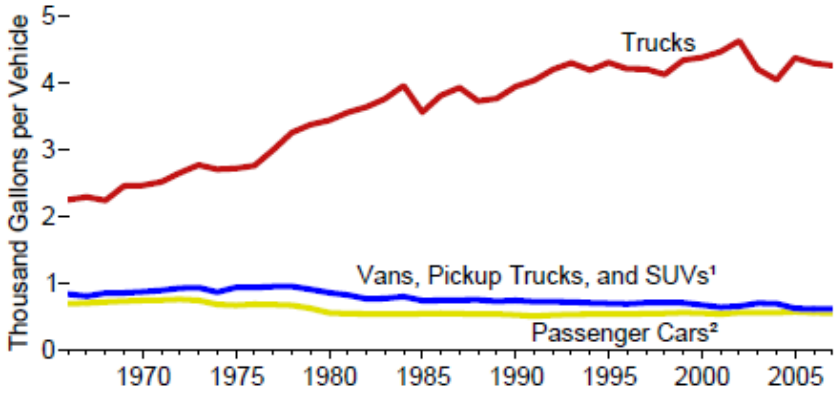
Transportation sector use of energy experienced tremendous growth overall but registered noticeable pauses in 1974, 1979-1982, 1990 and 1991, 2001 and 2008. In 2008, petroleum accounted for 94 percent of the transportation sector's total use of energy. In Btu, motor gasoline accounted for 62 percent of all petroleum used in the sector; in barrels, motor gasoline accounted for 64 percent .

Notice the trend in Trucks!!



Source: Annual Energy Review 2008, http://www.eia.doe.gov/aer

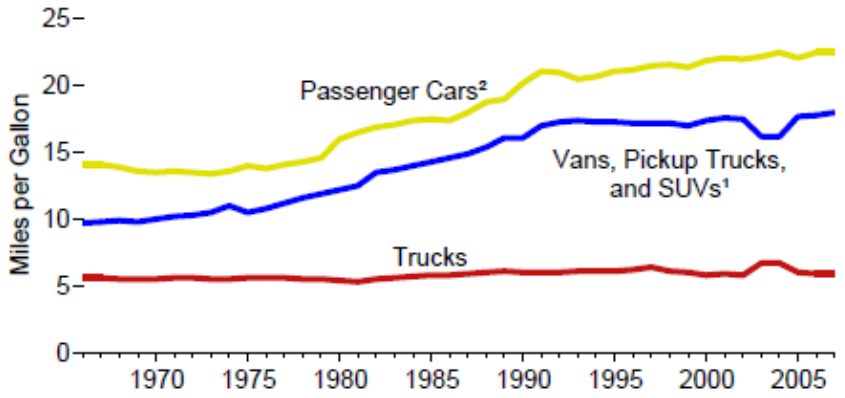
Figure 31. Motor Vehicle Fuel Consumption



¹ Sport utility vehicles. ² Motorcycles are included through 1989.

Average fuel consumption rates for trucks greatly exceeded those for other vehicles, and trended upward over time—doubling from 2.3 thousand gallons per truck in 1966 to 4.6 thousand gallons per truck in 2002. Average fuel consumption rates for passenger cars, and vans, pickup trucks, and sport utility vehicles were much lower and generally trended downward.

Figure 33. Motor Vehicle Fuel Rates

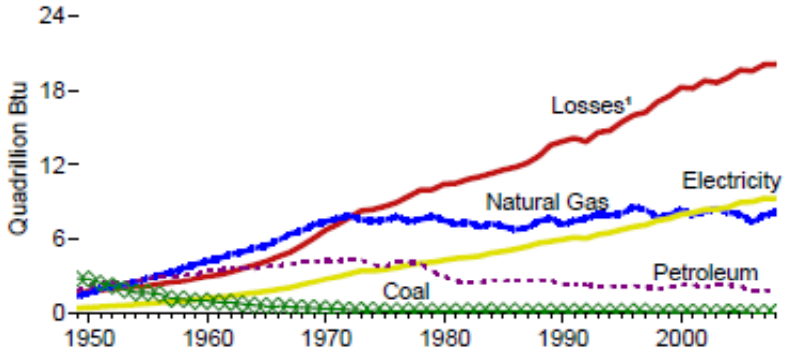


¹ Sport utility vehicles. ² Motorcycles are included through 1989.

Fuel rates (miles per gallon) for passenger cars, and vans, pickup trucks, and sport utility vehicles (SUVs), improved noticeably from the late 1970s through the early 1990s. Fuel rates for passenger cars improved further in subsequent years; rates for vans, pickup trucks, and SUVs fell in 2002 and 2003, but increased in 2005 through 2007. Fuel rates for trucks, which were much lower than for other vehicles, showed far less change over time.

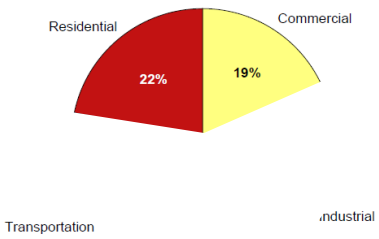
US Residential and Commercial Consumption

Figure 8. Residential and Commercial Total Energy Consumption, Major Sources



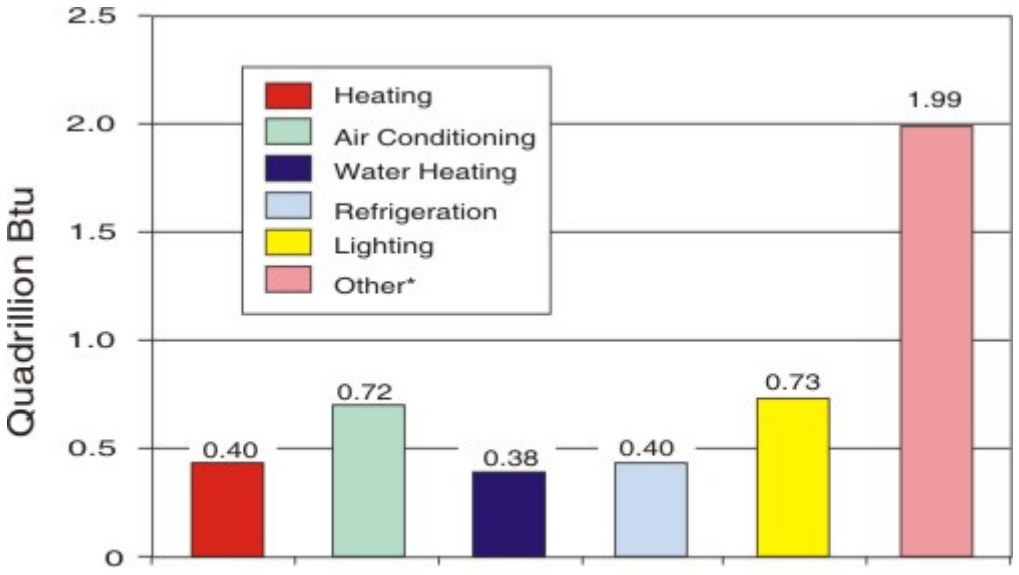
* Energy lost during generation, transmission, and distribution of electricity.

In the 1950s and 1960s, coal, which had been important to residential and commercial consumers, was gradually replaced by other forms of energy. Petroleum consumption peaked in the early 1970s. Natural gas consumption grew fast until the early 1970s, and then, with mild fluctuations, held fairly steady in the following years. Meanwhile, electricity use (and related losses) expanded dramatically.



Source: Annual Energy Review 2008, http://www.eia.doe.gov/aer

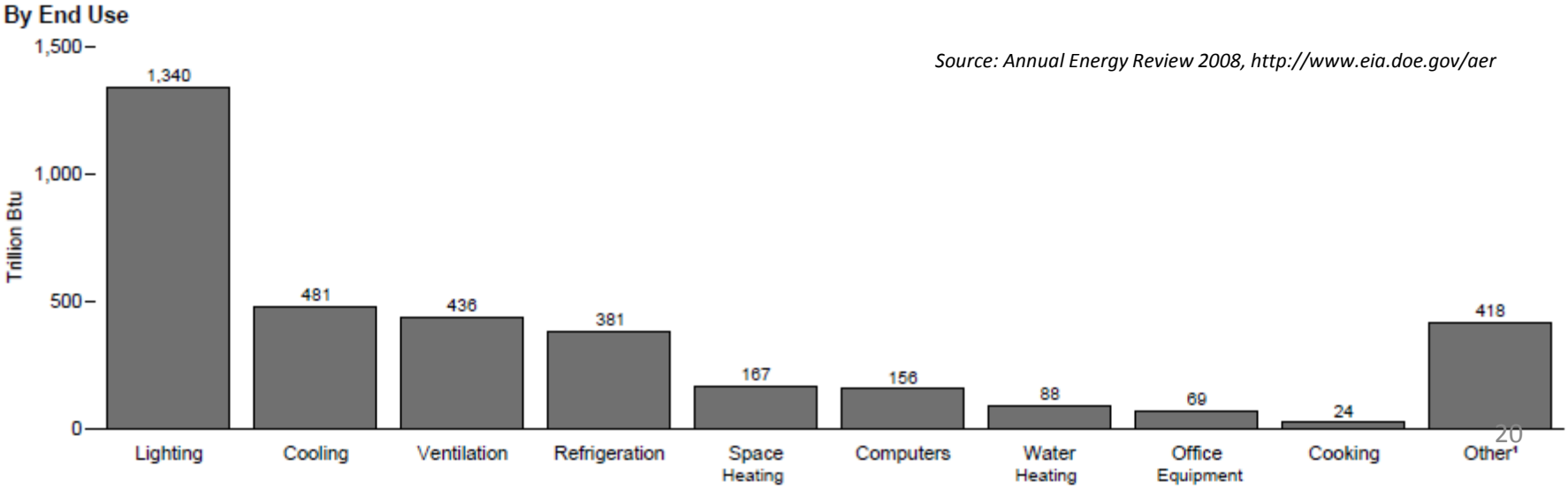
US Residential and Commercial Consumption: Buildings!



*Other includes small electric devices, heating elements, and motors not listed. It also includes color televisions, cooking stoves, clothes dryers, freezers, clothes washers, dishwashers, personal computers and furnace fans.
Source: Energy Information Administration, *Annual Energy Outlook 2008*, Table A4.

US Residential Electricity Consumption, 2006

Figure 2.11 Commercial Buildings Electricity Consumption by End Use, 2003

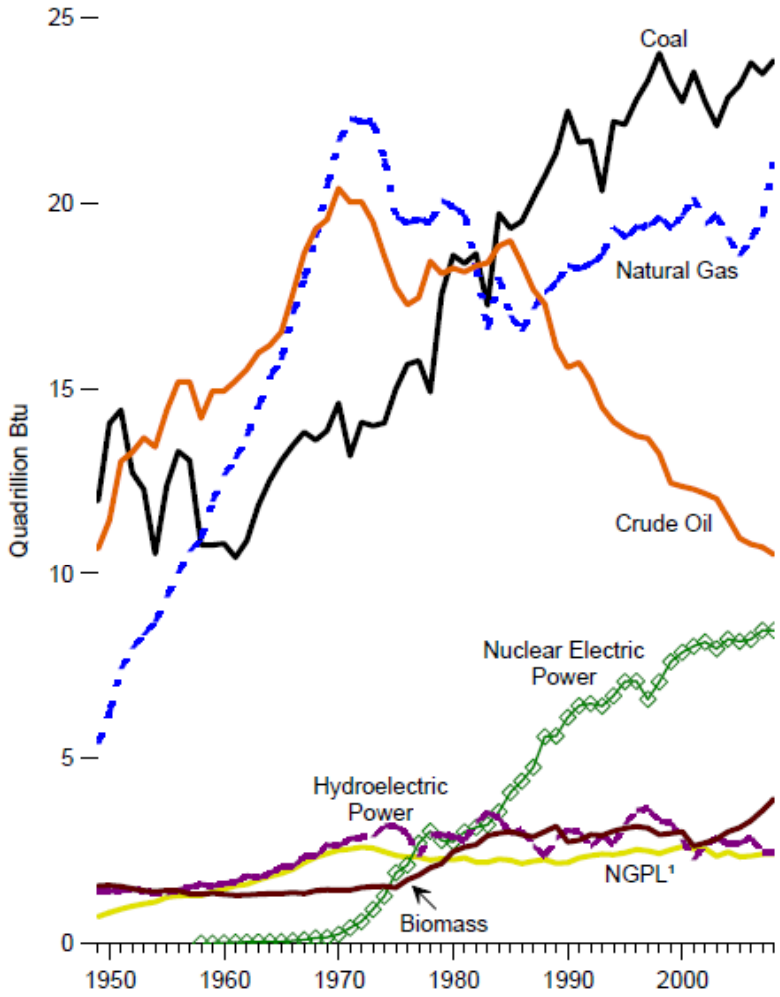


Source: Annual Energy Review 2008, http://www.eia.doe.gov/aer

US Energy Production

Data for all US energy uses.

Figure 11. Primary Energy Production by Major Source

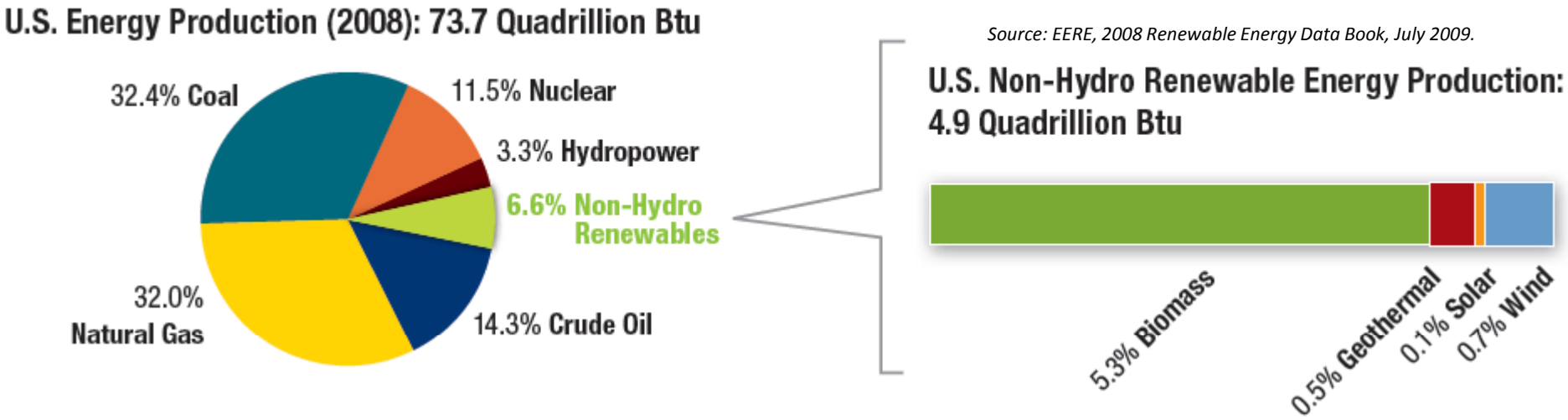


¹ Natural gas plant liquids.

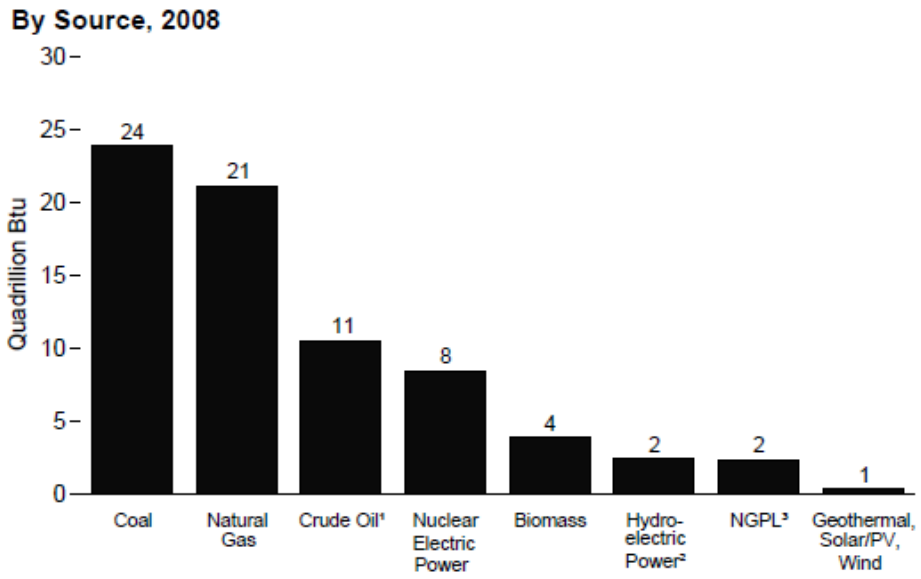
Most energy produced in the United States came from fossil fuels—coal, natural gas, and crude oil. Coal, the leading source at the middle of the 20th century, was surpassed by crude oil and then by natural gas. By the mid-1980s, coal again became the leading energy source produced in the United States, and crude oil declined sharply. In the 1970s, electricity produced from nuclear fuel began to make a significant contribution and expanded rapidly in the following decades.

Source: Annual Energy Review 2008, http://www.eia.doe.gov/aer

US Energy Production



Source: EERE, 2008 Renewable Energy Data Book, July 2009.

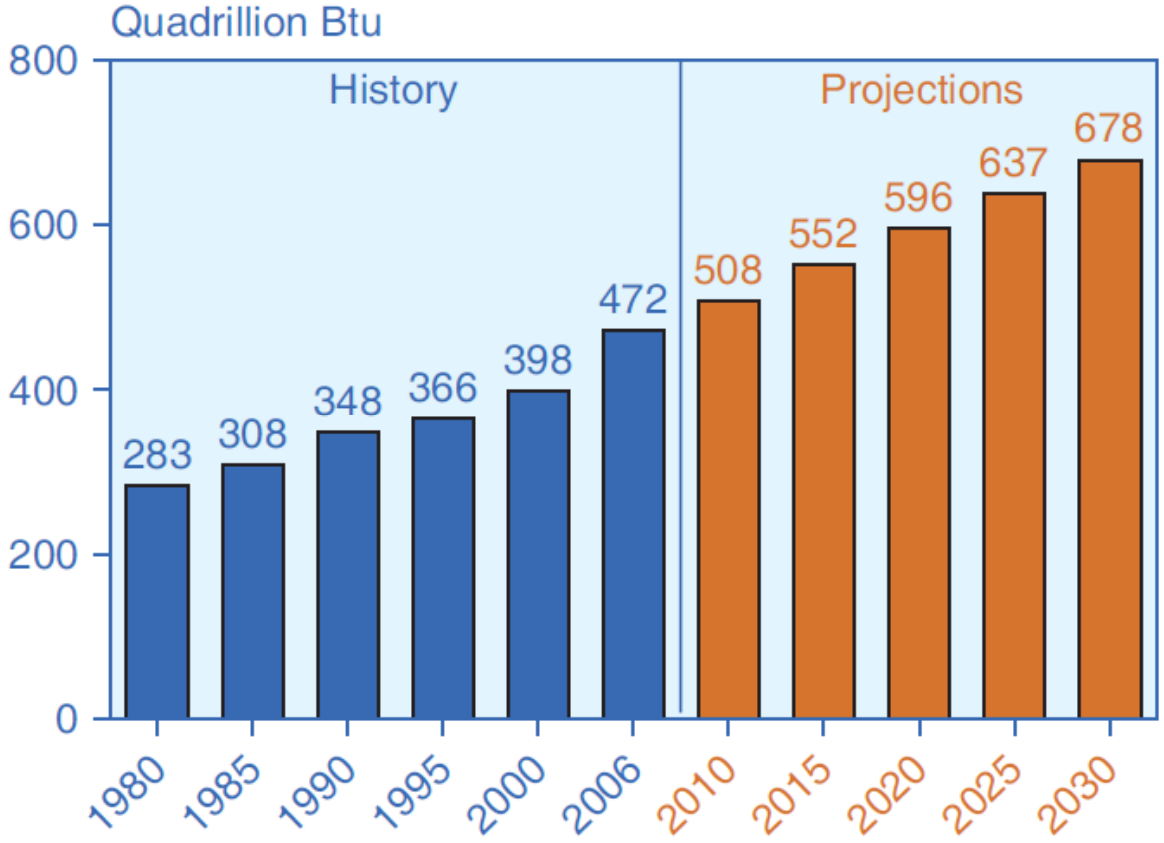


Source: Annual Energy Review 2008, http://www.eia.doe.gov/aer

1.1.3 World Energy Consumption Statistics

World Energy Consumption

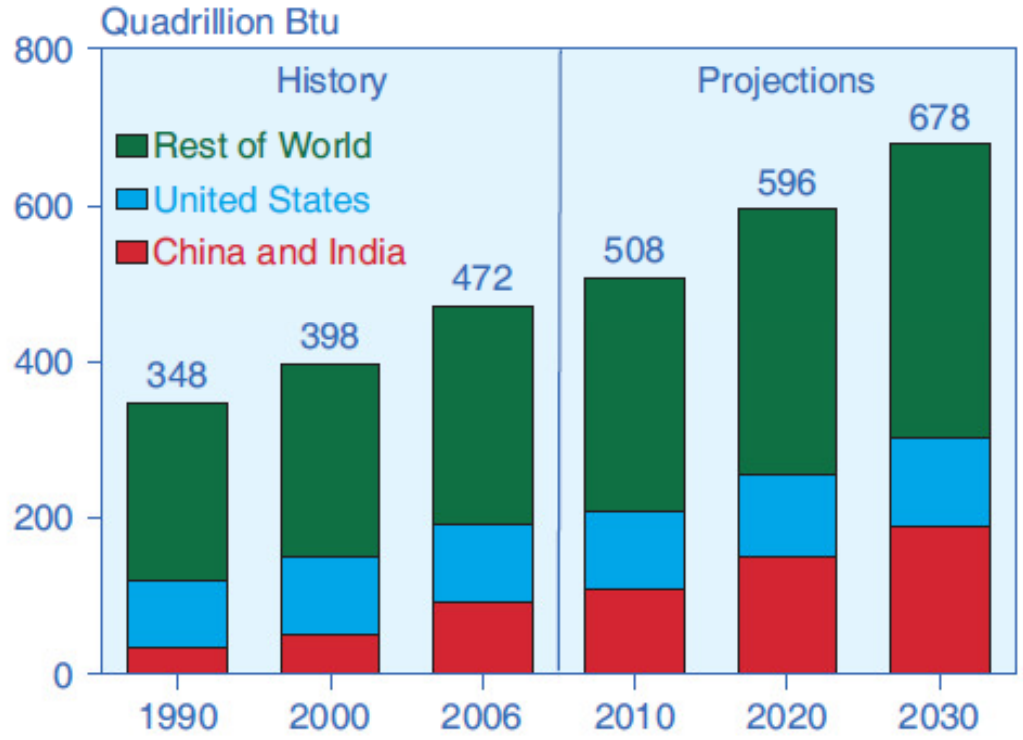
Figure 10. World Marketed Energy Consumption, 1980-2030



Sources: **History:** Energy Information Administration (EIA), *International Energy Annual 2006* (June-December 2008), web site www.eia.doe.gov/iea. **Projections:** EIA, World Energy Projections Plus (2009).

World Energy Consumption

Figure 12. Marketed Energy Use by Region, 1990-2030



Sources: **History:** Energy Information Administration (EIA), *International Energy Annual 2006* (June-December 2008), web site www.eia.doe.gov/iea. **Projections:** EIA, World Energy Projections Plus (2009).

World population

Figure 1. Long-term world population growth, 1750 to 2050

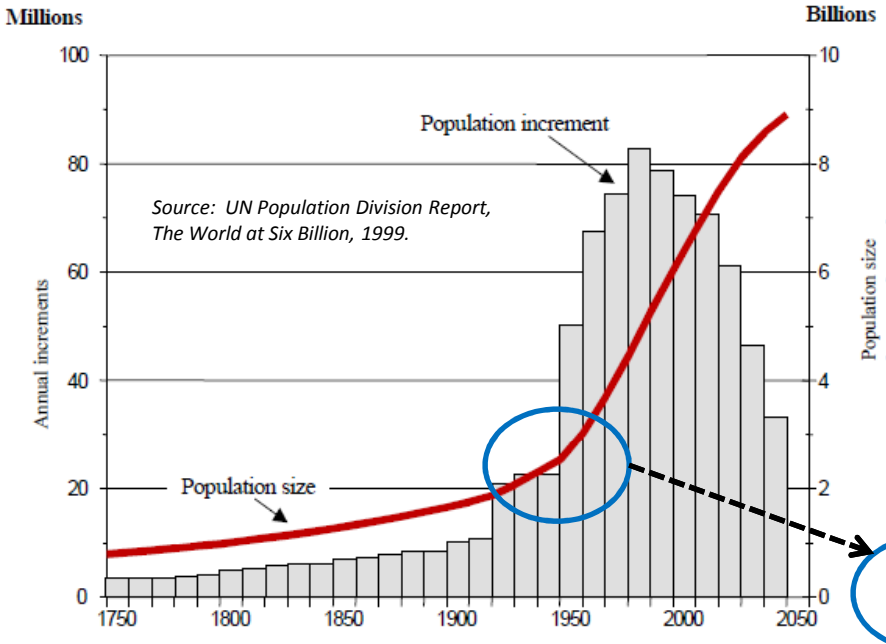
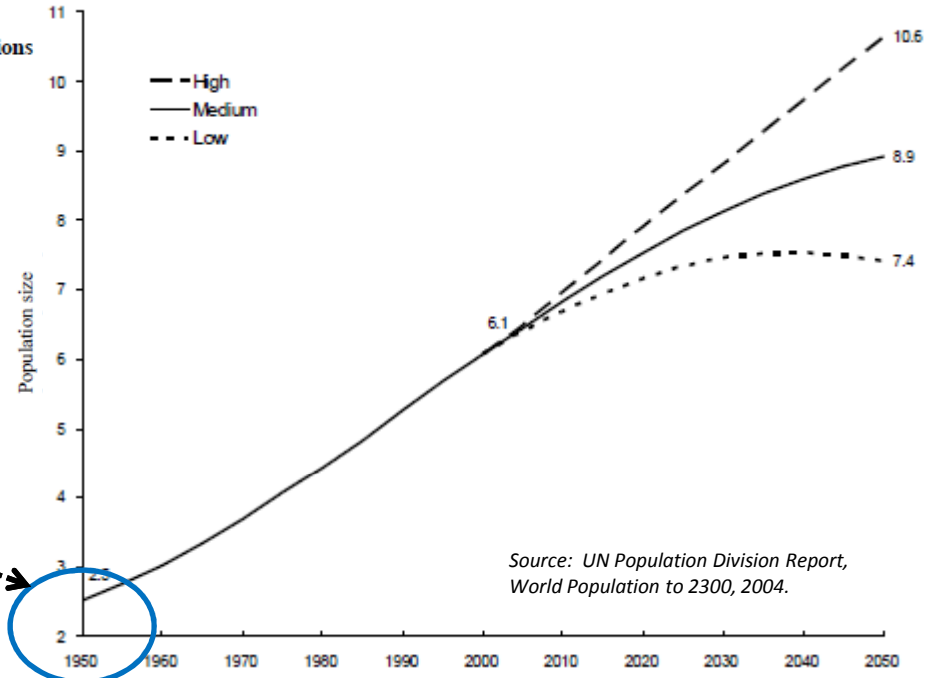


Figure 1. Estimated world population, 1950-2000, and projections: 2000-2050

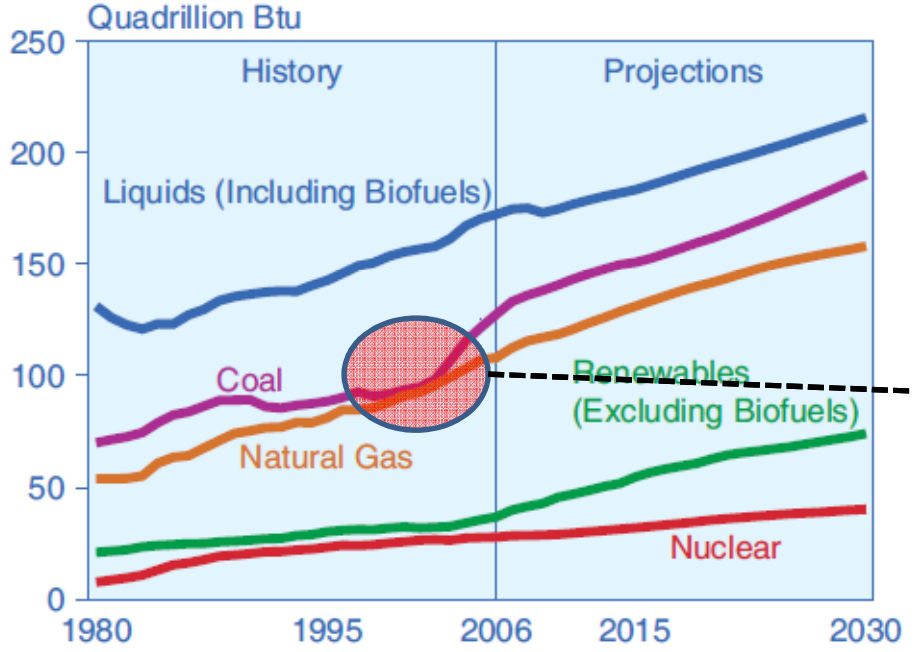


Country	% of World Population 2001	% of World GDP 2002	% of World Energy Consumption 2002
United States	4.6%	32%	24%
Japan	2.0%	12%	5%
France	0.9%	4%	3%
Germany	1.4%	6%	4%
United Kingdom	1.0%	5%	2%
China	20%	4%	11%
India	17%	2%	4%

Source: 2005, OCW MIT

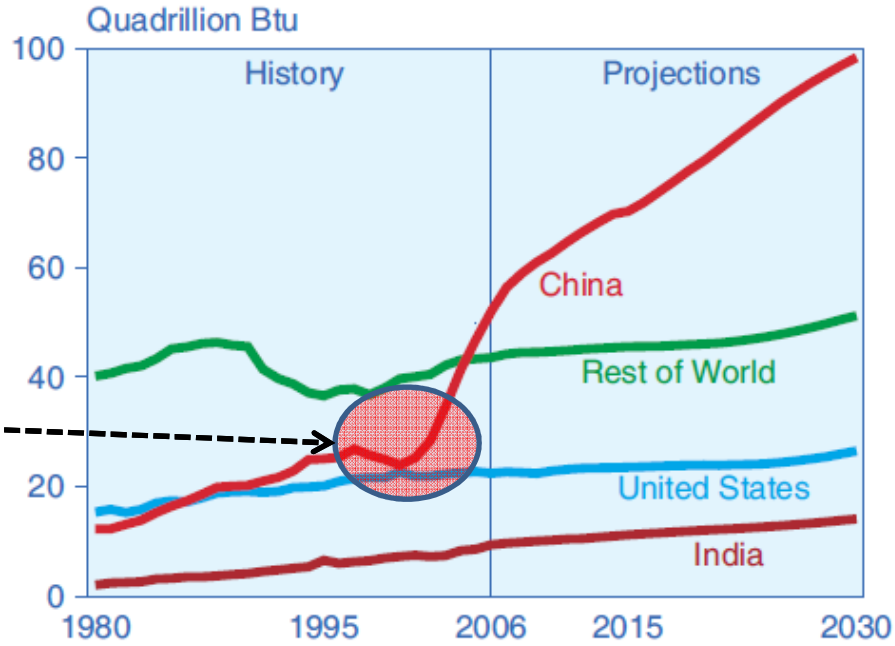
The China effect

Figure 2. World Marketed Energy Use by Fuel Type, 1980-2030



Sources: **2006:** Energy Information Administration (EIA), *International Energy Annual 2006* (June-December 2008), web site www.eia.doe.gov/iea. **Projections:** EIA, World Energy Projections Plus (2009).

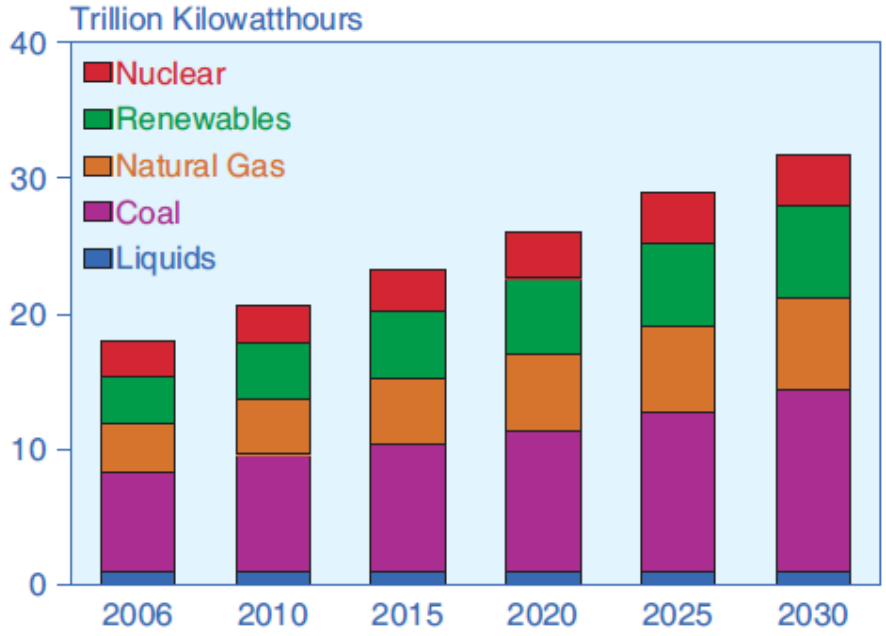
Figure 15. Coal Consumption in Selected World Regions, 1980-2030



Sources: **History:** Energy Information Administration (EIA), *International Energy Annual 2006* (June-December 2008), web site www.eia.doe.gov/iea. **Projections:** EIA, World Energy Projections Plus (2009).

World Electricity Generation

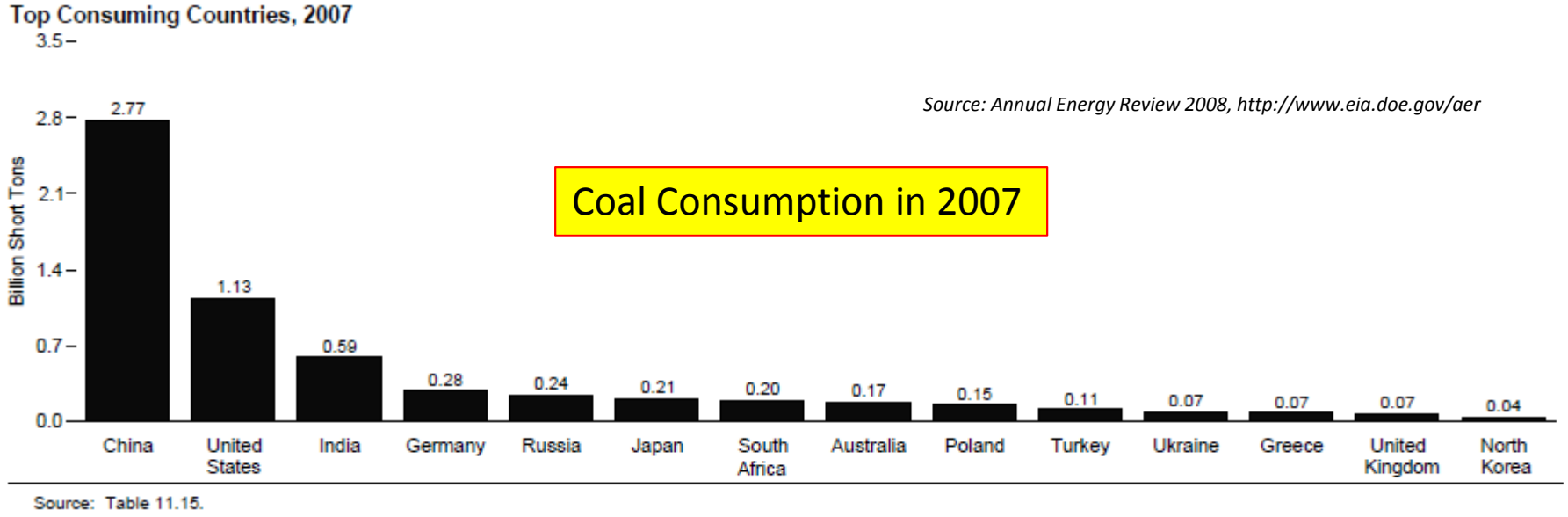
Figure 6. World Electricity Generation by Fuel, 2006-2030



Sources: **2006:** Energy Information Administration (EIA), *International Energy Annual 2006* (June-December 2008), web site www.eia.doe.gov/iea. **Projections:** EIA, World Energy Projections Plus (2009).

US, China, India are expected to account for 88% of the projected net increase in coal consumption from 2006-2030.

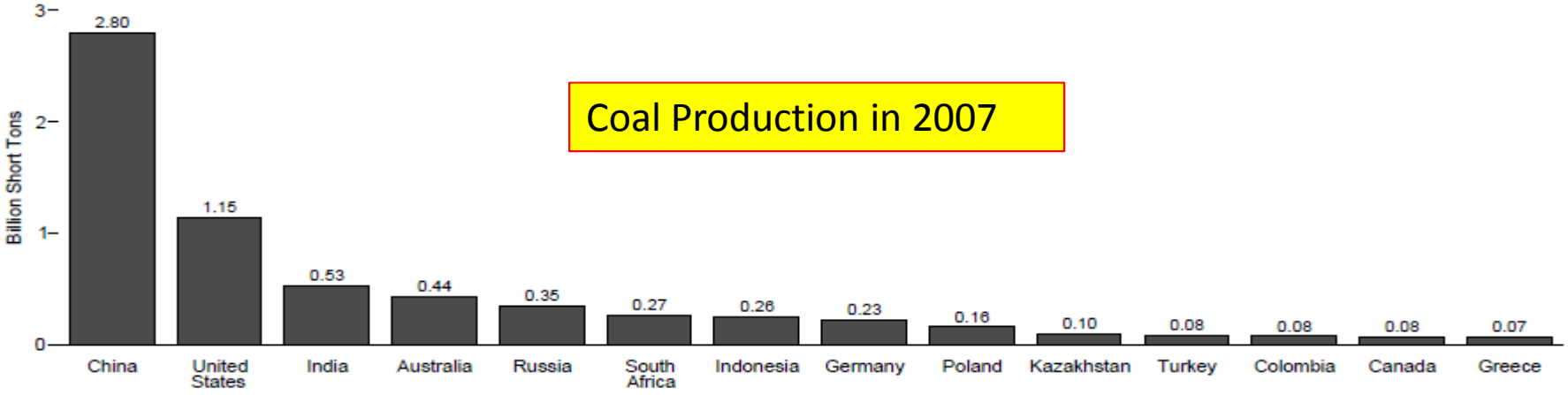
World Coal Consumption/Production



Source: Annual Energy Review 2008, http://www.eia.doe.gov/aer

Coal Consumption in 2007

Source: Table 11.15.



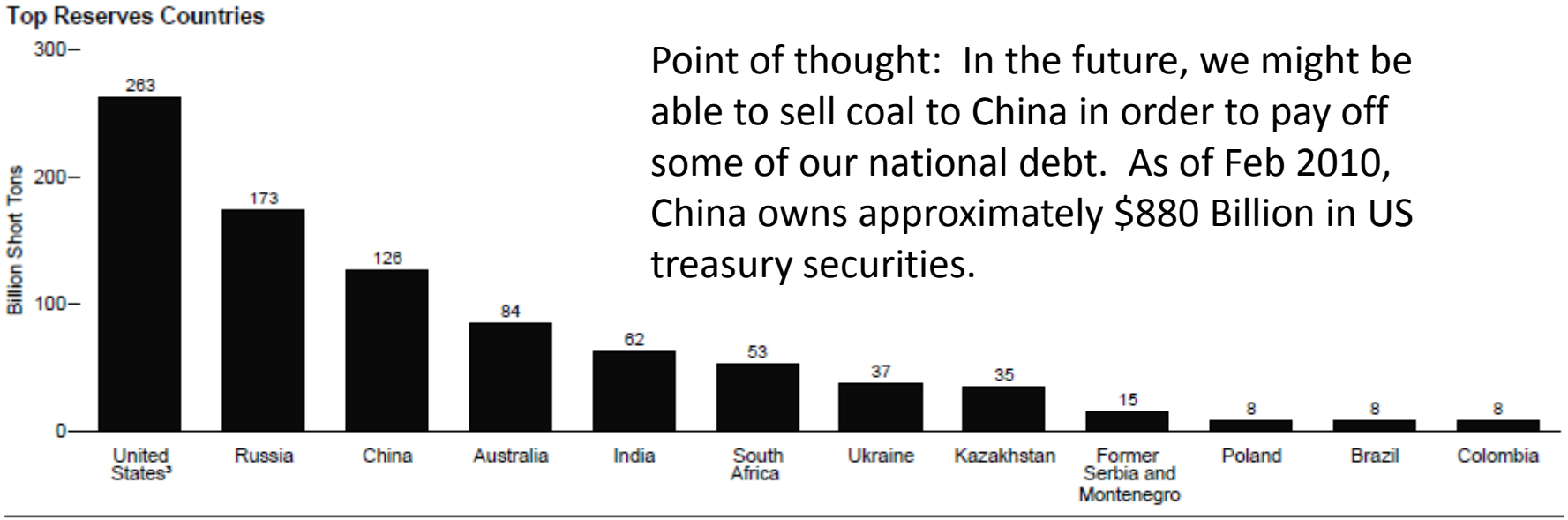
Coal Production in 2007

[1] Excludes countries that were part of the former U.S.S.R. See "U.S.S.R." in Glossary.
[2] Includes only countries that were part of the former U.S.S.R. See "U.S.S.R." in Glossary.

Source: Table 11.14.

World Coal Reserves

Coal Reserves in 2005 (US: 2007)



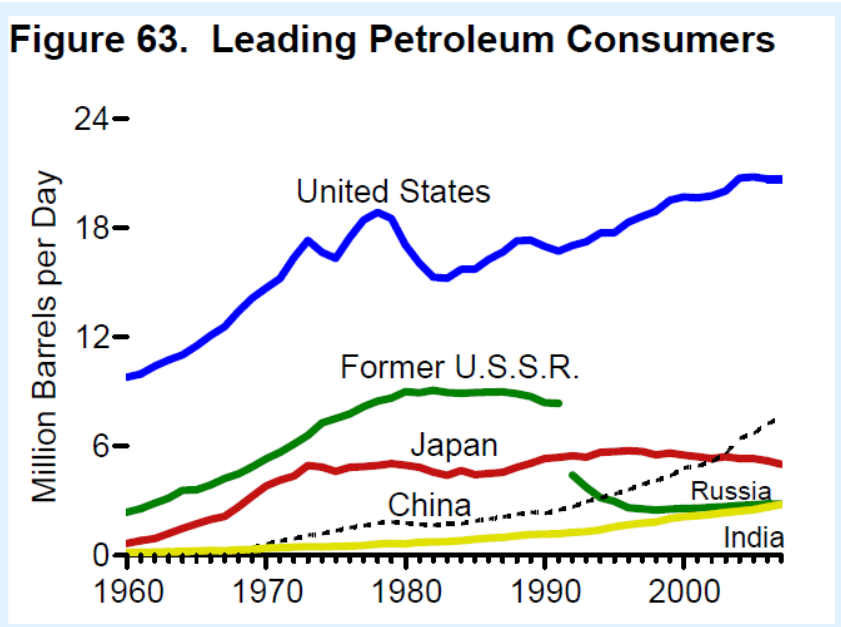
¹ Excludes countries that were part of the former U.S.S.R. See "U.S.S.R." in Glossary.
² Includes only countries that were part of the former U.S.S.R. See "U.S.S.R." in Glossary.
³ U.S. reserves are at end of 2007, 2 years later than other data in this figure.

Note: Data are at end of year.
Source: Table 11.13.

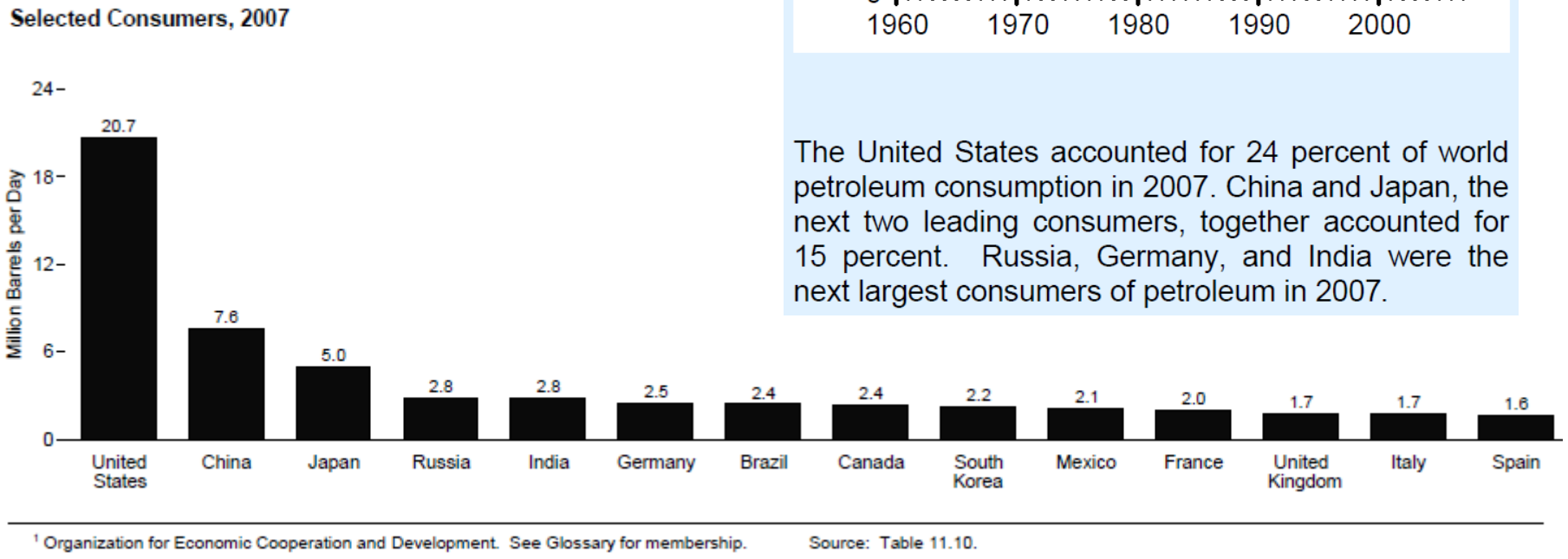
Point of thought: In the future, we might be able to sell coal to China in order to pay off some of our national debt. As of Feb 2010, China owns approximately $880 Billion in US treasury securities.

Source: Annual Energy Review 2008, http://www.eia.doe.gov/aer

World Petroleum Consumption



The United States accounted for 24 percent of world petroleum consumption in 2007. China and Japan, the next two leading consumers, together accounted for 15 percent. Russia, Germany, and India were the next largest consumers of petroleum in 2007.



[1] Organization for Economic Cooperation and Development. See Glossary for membership. Source: Table 11.10.

Source: Annual Energy Review 2008, http://www.eia.doe.gov/aer

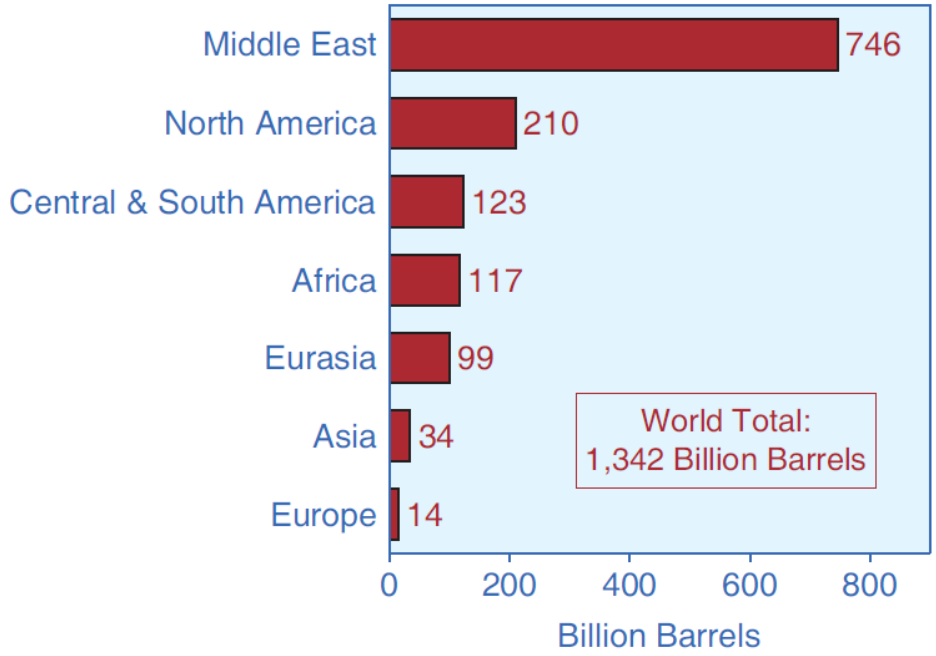
China

Credit: Xiayang Liu/Corbis

Nearly 1,500 cars are added to Beijing's roads daily.

World Petroleum Reserves

Figure 32. World Proved Oil Reserves by Geographic Region as of January 1, 2009



Source: "Worldwide Look at Reserves and Production," *Oil & Gas Journal*, Vol. 106, No. 48 (December 22, 2008), pp. 23-24.

China

- In 2006, China passed the United States as the world's top emitter of greenhouse gases.
- In 2009 it exceeded U.S. investment in clean energy for the first time, with a total of $34.6 billion.
- Driving that investment
  - air pollution, which has reached choking levels in Chinese cities
  - strong desire to meet a voracious energy demand through domestic sources.
- Not only is the country adding nuclear, hydroelectric, wind, and solar power at an unrivaled pace, but it's fast becoming a proving ground for next--generation energy technologies that have stalled elsewhere.

Source: Fairley, Peter, *Technology Review*, Vol. 113, No. 3, pp. 36-43, May/June 2010.

China

- Coal meets 70 % of China's energy needs, but
- Claims to have shut down 60 gigawatts' worth of inefficient coal-fired plants since 2005.
- This one was demolished in Henan province in 2009.

Credit: Chinatopix/AP

Source: Fairley, Peter, *Technology Review*, Vol. 113, No. 3, pp. 36-43, May/June 2010.

China

- China has 22 nuclear reactors under construction.
- Combined: 23 gigawatts.
- Two-thirds of these, including this one at Fuqing on China's southeastern coast, use a homegrown design based on France's existing light-water reactors.

Credit: Zheng Shuai/ChinaFotoPress/Getty Images

Source: Fairley, Peter, *Technology Review*, Vol. 113, No. 3, pp. 36-43, May/June 2010.

Credit: Siemens AG

China

The Jinanqiao hydroelectric dam, nearing completion, is one of a dozen installed or under construction on the Jinsha River.

•Beijing-based Sinovel Wind erected a 34th wind turbine beside Shanghai's 32.5 km Donghai Bridge in February.

• Several 3MW turbines will power over 200,000 Shanghai households.

•China has doubled its installed wind-power capacity every year for the past five years, and last year it supplanted the United States as the world's largest market for wind power

Credit: Nelson Ching/Bloomberg via Getty Images

Source: Fairley, Peter, *Technology Review*, Vol. 113, No. 3, pp. 36-43, May/June 2010.

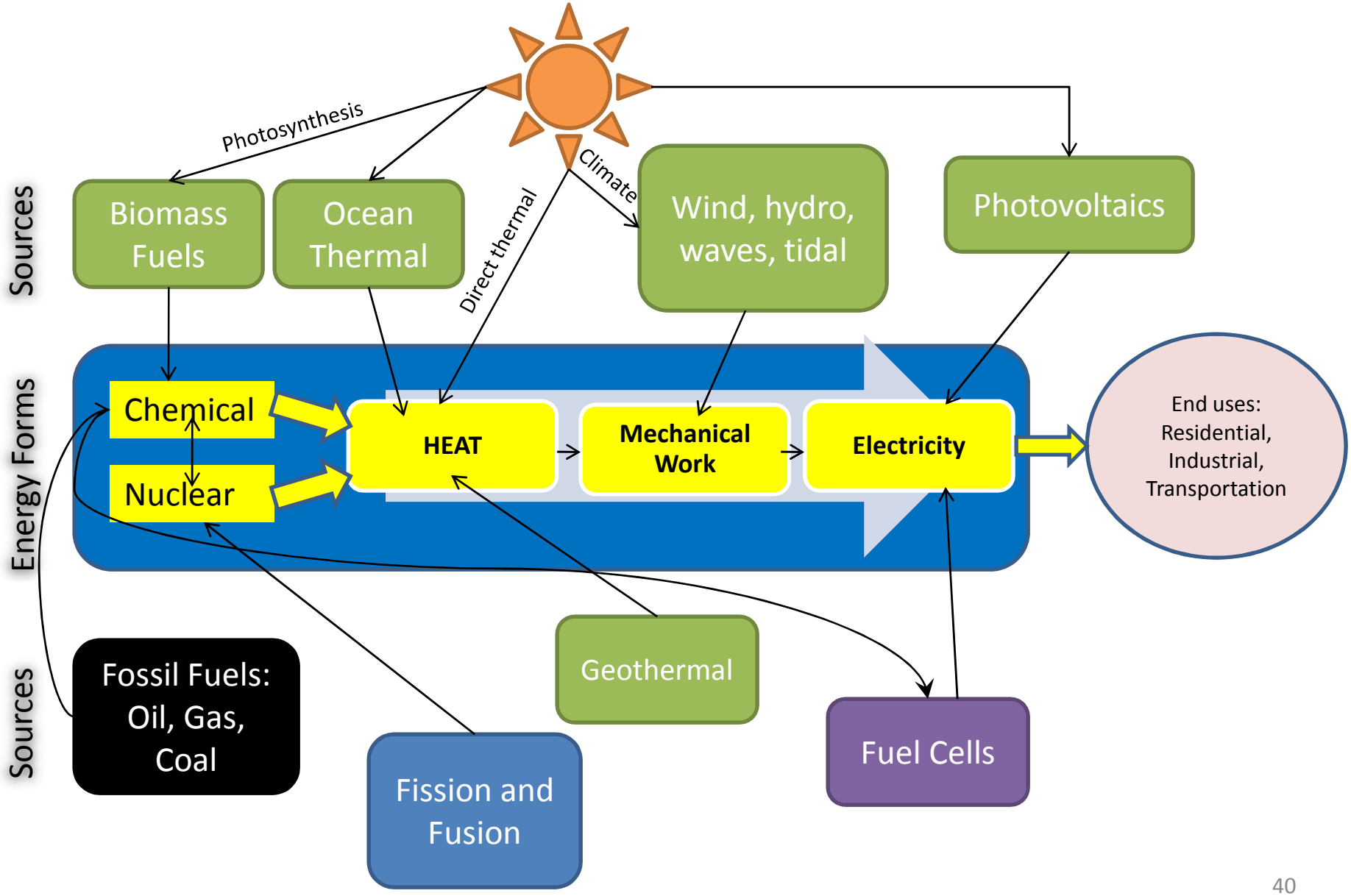
China

- Solar collectors in Fuyang City
- Provide hot water for about 10% of Chinese residents.
- Chinese government predicts at least 150 million m^2 heat-absorbing glass vacuum tubes will be atop rooftops by end of 2009.

Source: Fairley, Peter, *Technology Review*, Vol. 113, No. 3, pp. 36-43, May/June 2010.

1.1.4 Alternative and Renewable Energy Statistics

Energy Sources and Conversion Processes



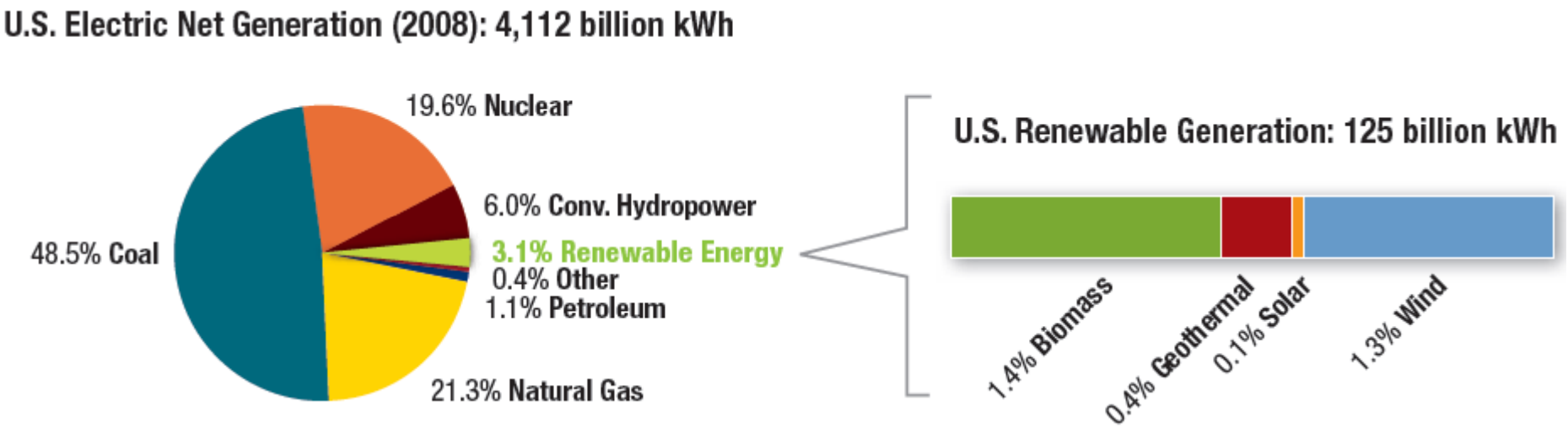
Source: Sustainable Energy: Choosing Among Options, J.W. Tester, et. al, MIT Press, 2005, adapted

Alternative and Renewable

	Non renewable	Renewable
Conventional	Coal Oil Gas	Wood Hydropower Human/Animal
Alternative	Oil Shale Tar Sands Nuclear Fission Geothermal	Wind Solar Biomass Wave/Tide Ocean Thermal

Source: FIT, Renewable Energy course, spring 2010

Renewable Energy's Share of Electricity Generation

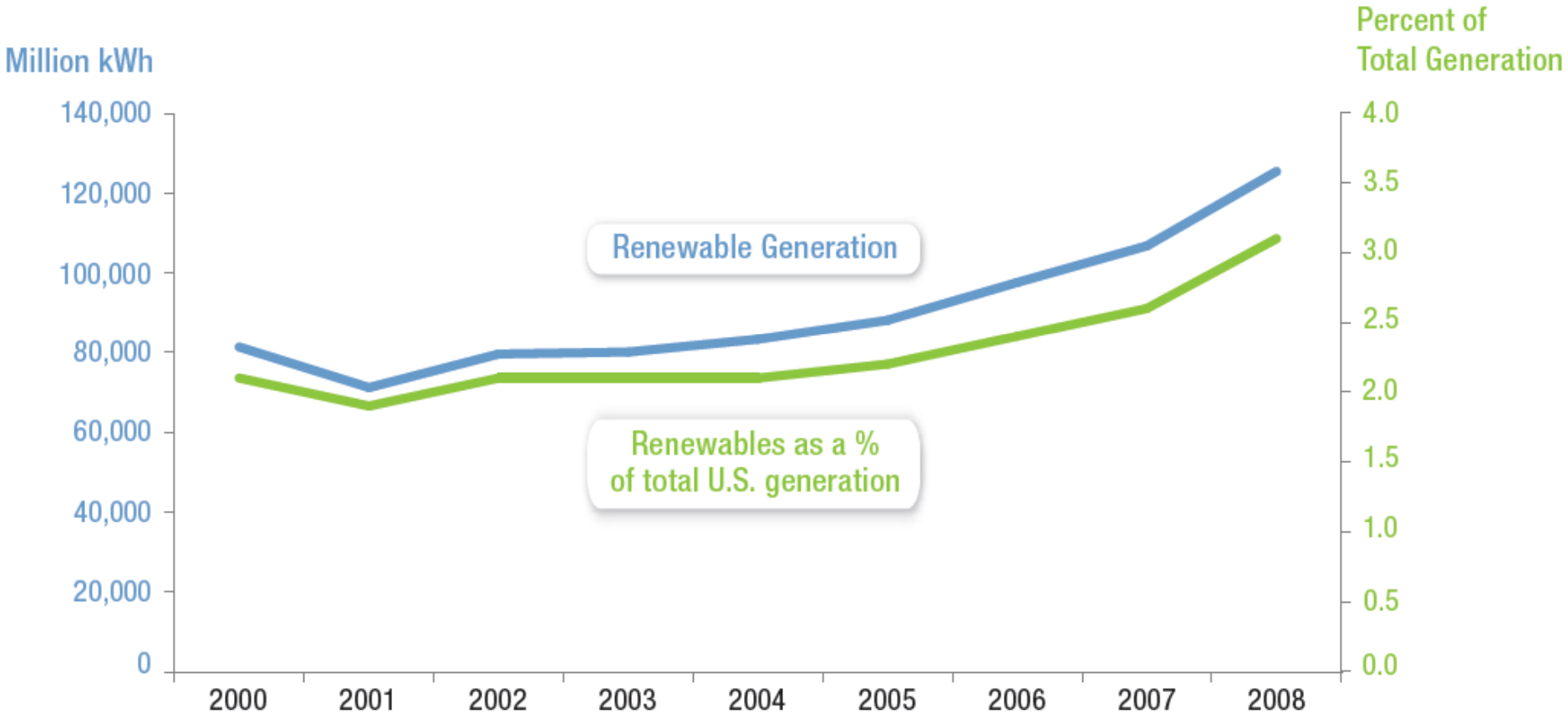


For all the hype, solar made up only 0.1% of US electricity generation and wind 1.3% in 2008.

Source: EERE, 2008 Renewable Energy Data Book, July 2009.

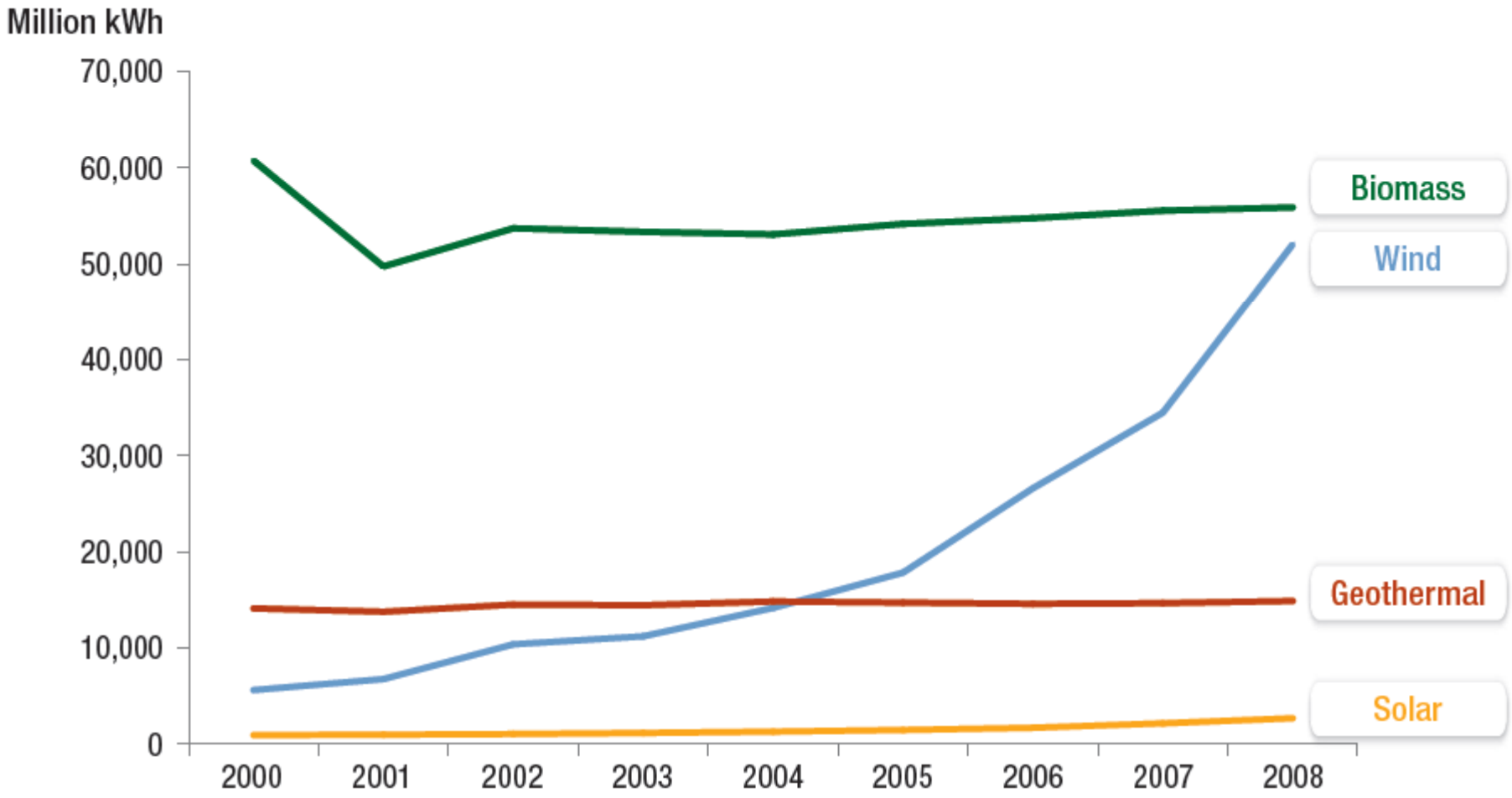
US Renewable Electricity Generation

(Excluding hydropower)



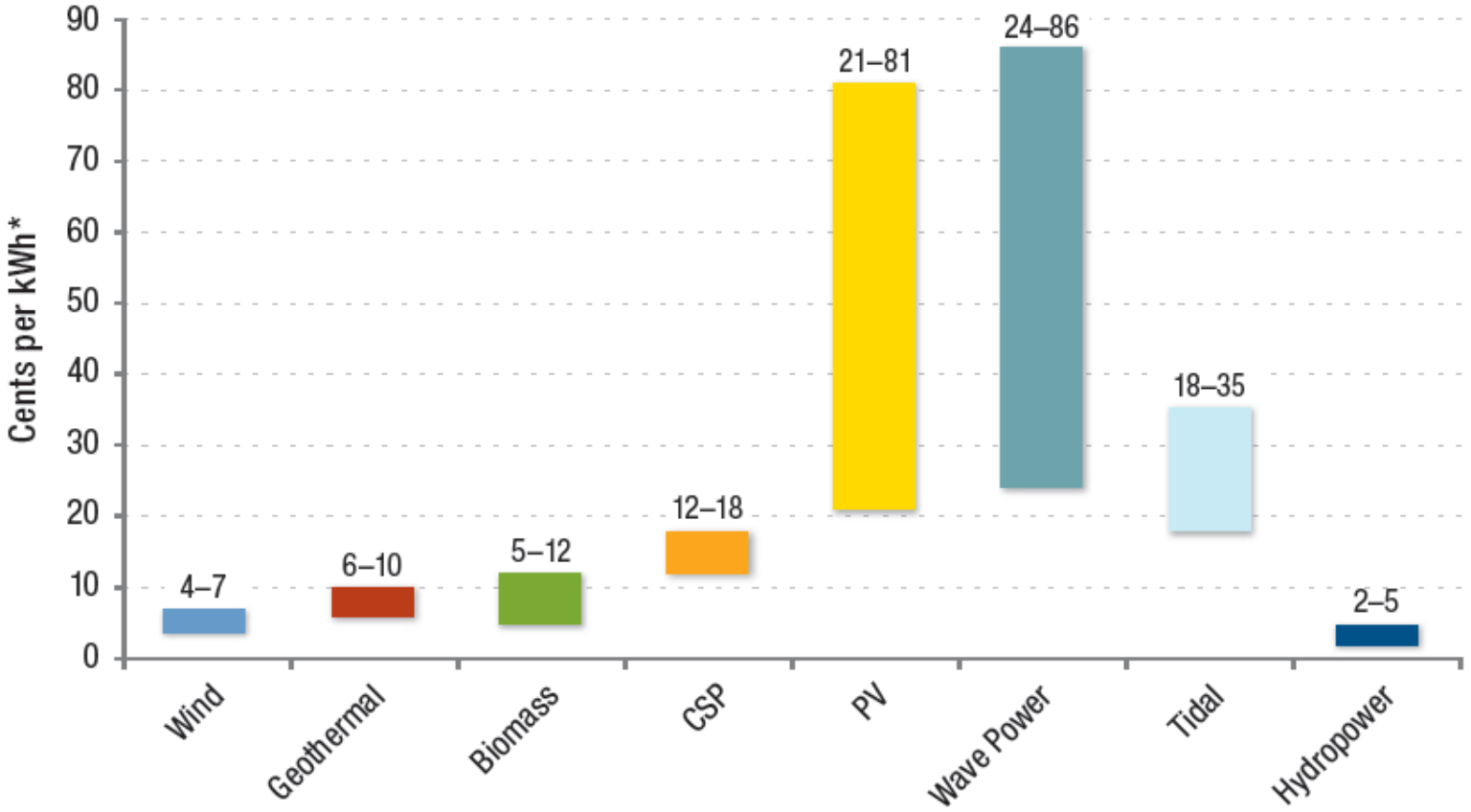
Source: EERE, 2008 Renewable Energy Data Book, July 2009.

US Renewable Generation by Technology (Excluding hydropower)



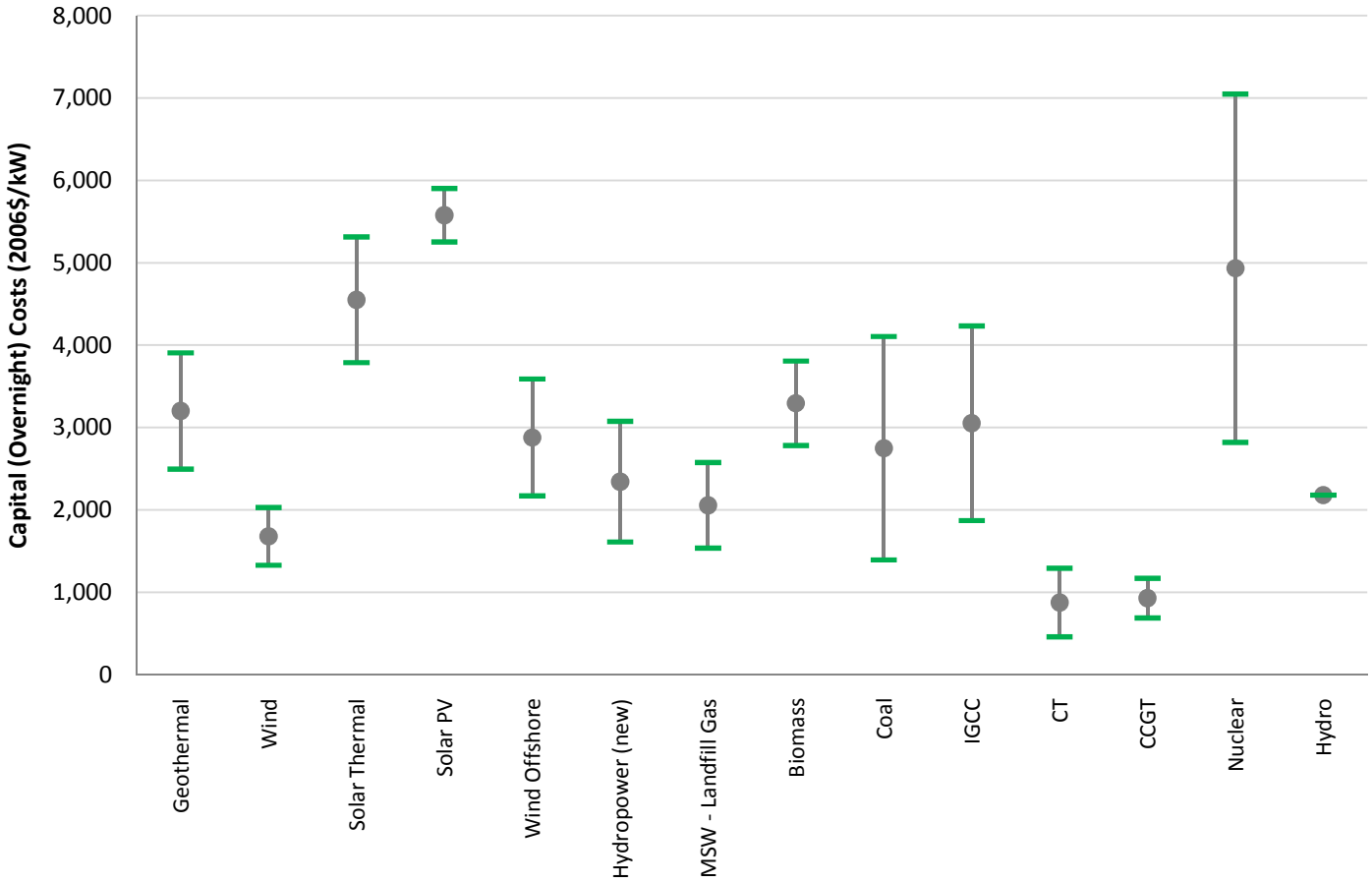
Source: EERE, 2008 Renewable Energy Data Book, July 2009.

Price range of renewable electricity by technology



Source: EERE, 2008 Renewable Energy Data Book, July 2009.

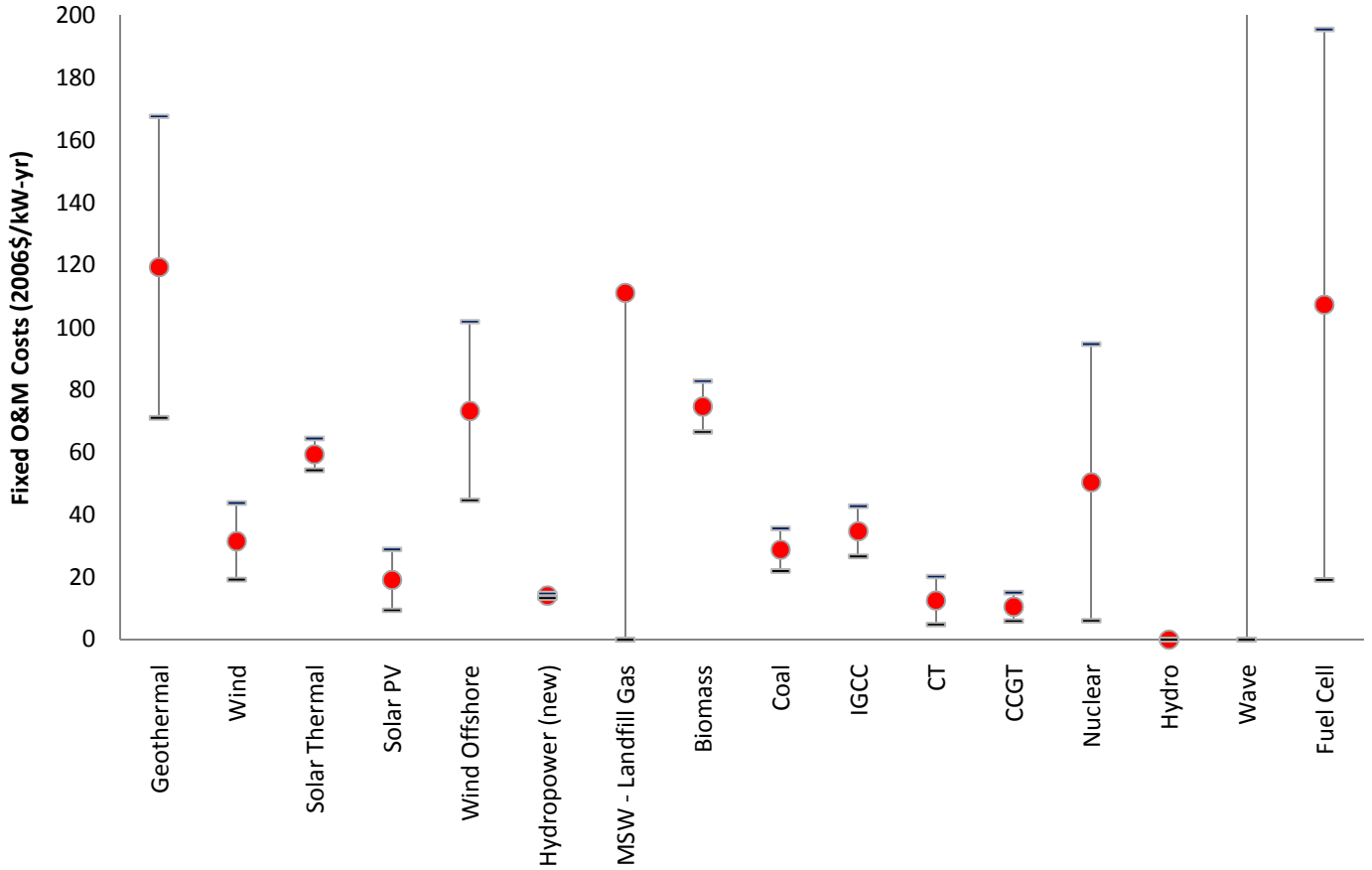
Total “Overnight” Costs in 2007-2008



Overnight cost is the cost of a construction project if no interest was incurred during construction, as if the project was completed "overnight."

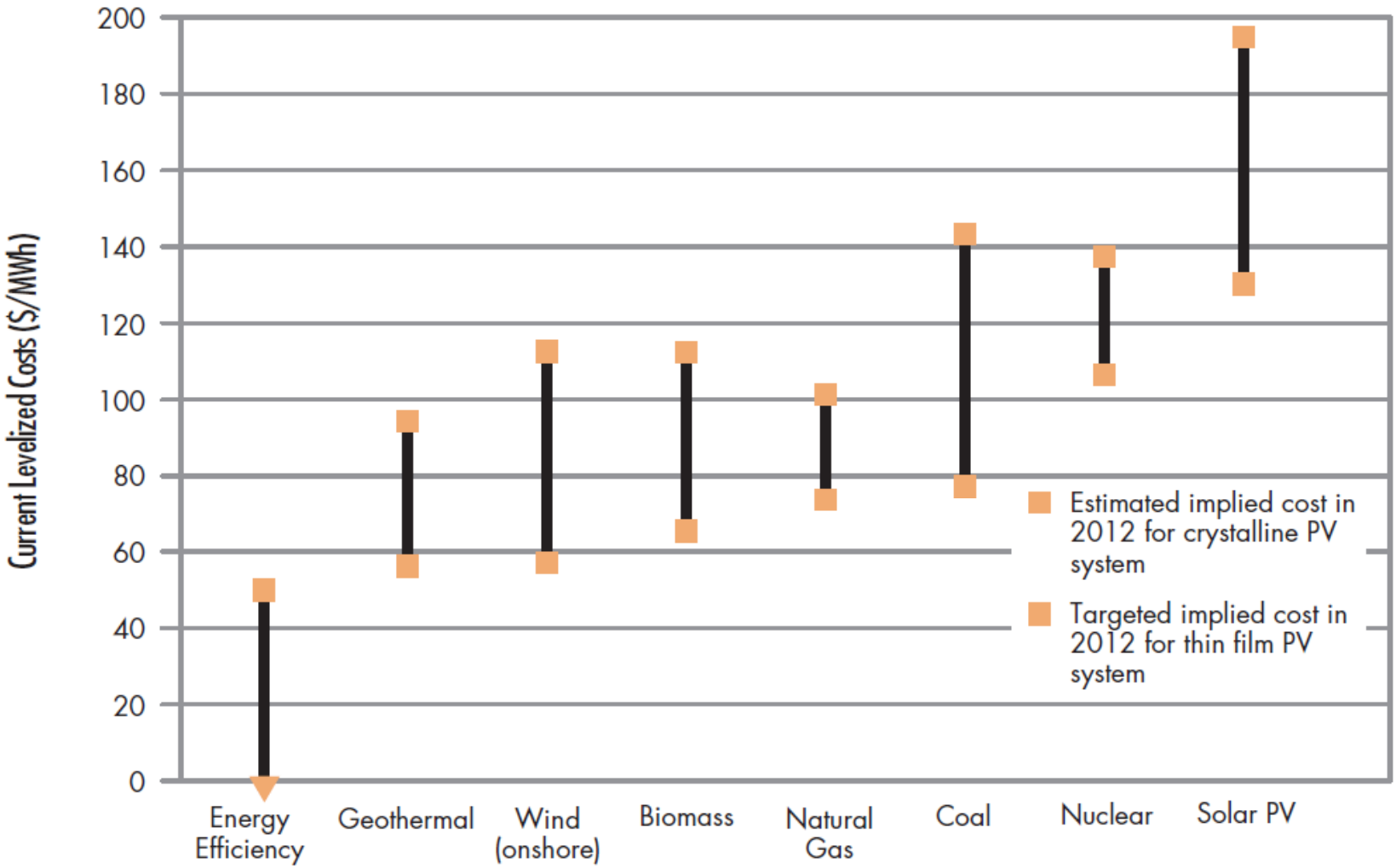
http://vibe.nrel.gov/files/datasets/1692/re_costs_20090806.xls

Fixed Operating & Maintenance Costs in 2007-2008



http://vibe.nrel.gov/files/datasets/1692/re_costs_20090806.xls

Figure 2. Levelized cost of new power generation technologies in 2008

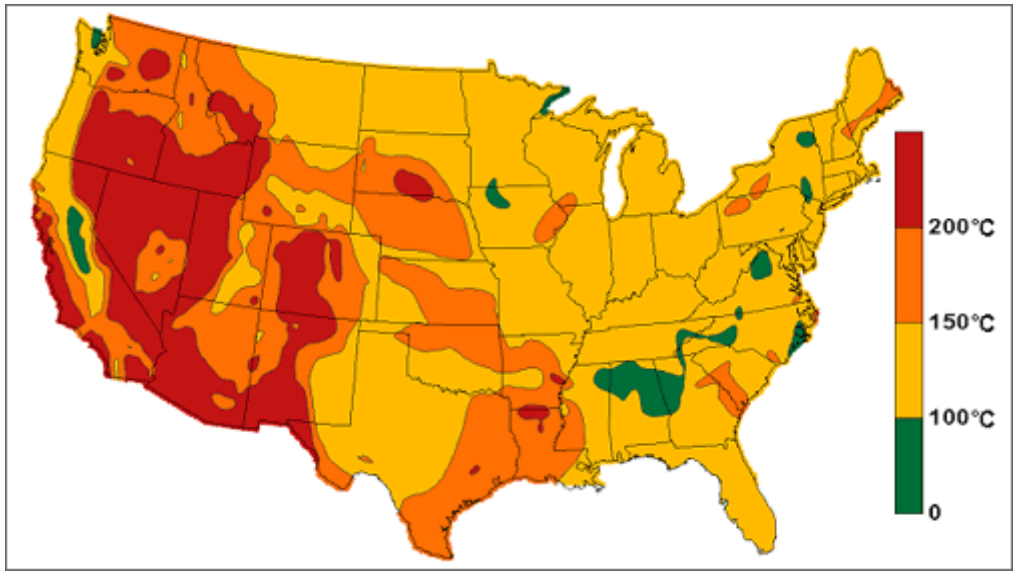


Note: Costs have been levelized over the lifetime of the technology and include construction, fuel, and operation and maintenance costs. The bars represent typical cost ranges at average capacity factors for each technology.

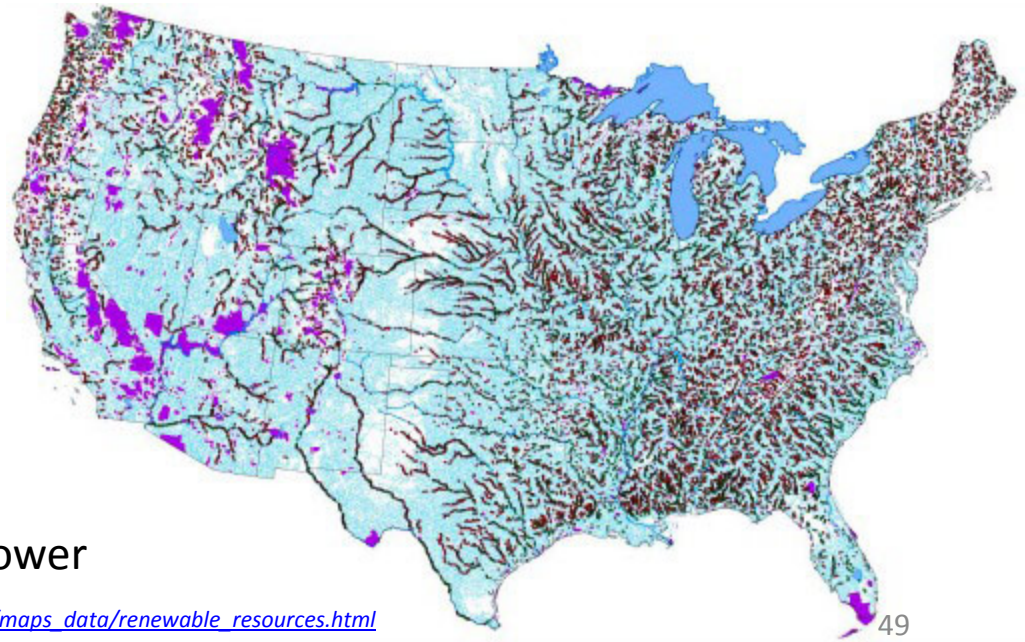
Source: Lazard. February 2009. Levelized Cost of Energy Analysis, Version 3.0.

<blog.cleanenergy.org/files/2009/04/lazard2009_levelizedcostofenergy.pdf> .

Renewable Energy Resources: Geothermal and Hydropower



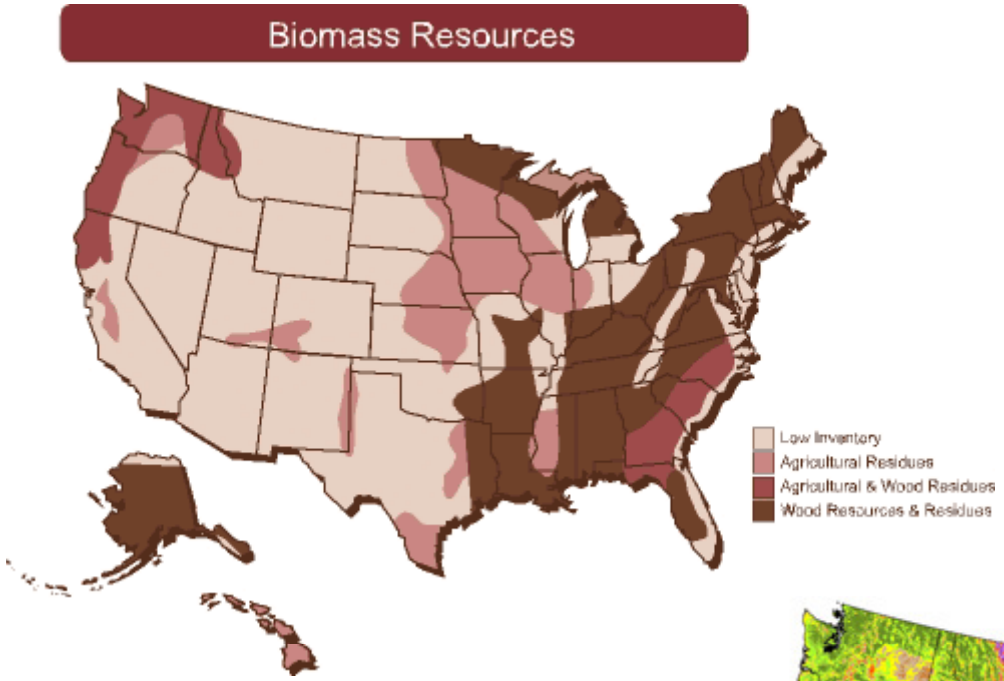
Geothermal

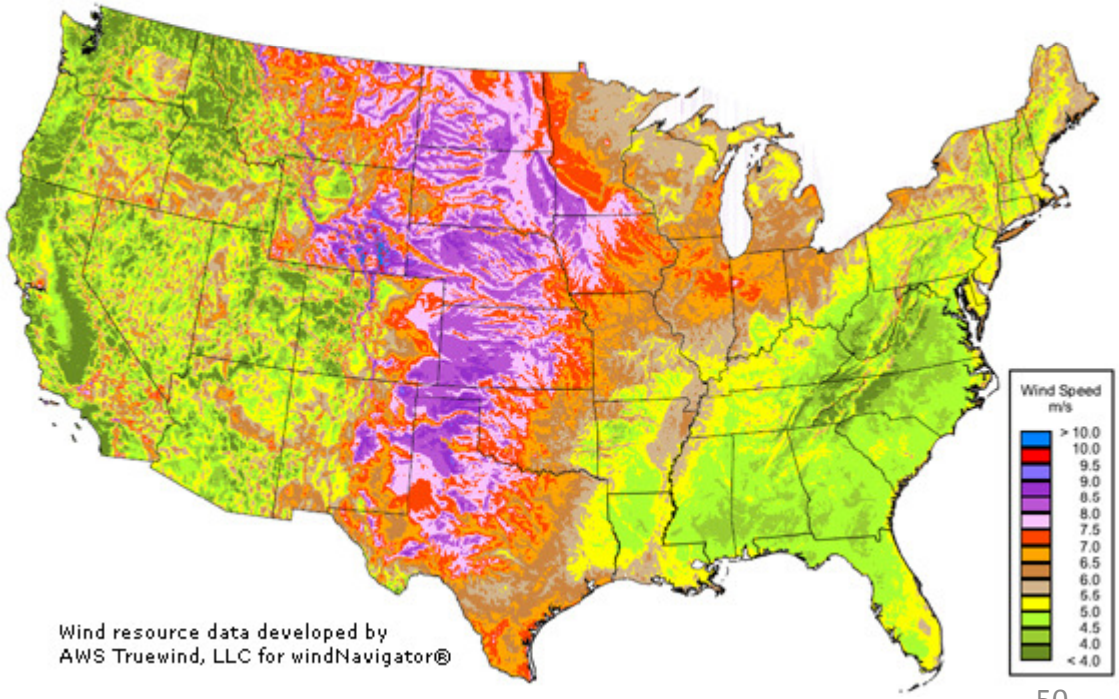


Hydropower

Source: http://www1.eere.energy.gov/maps_data/renewable_resources.html

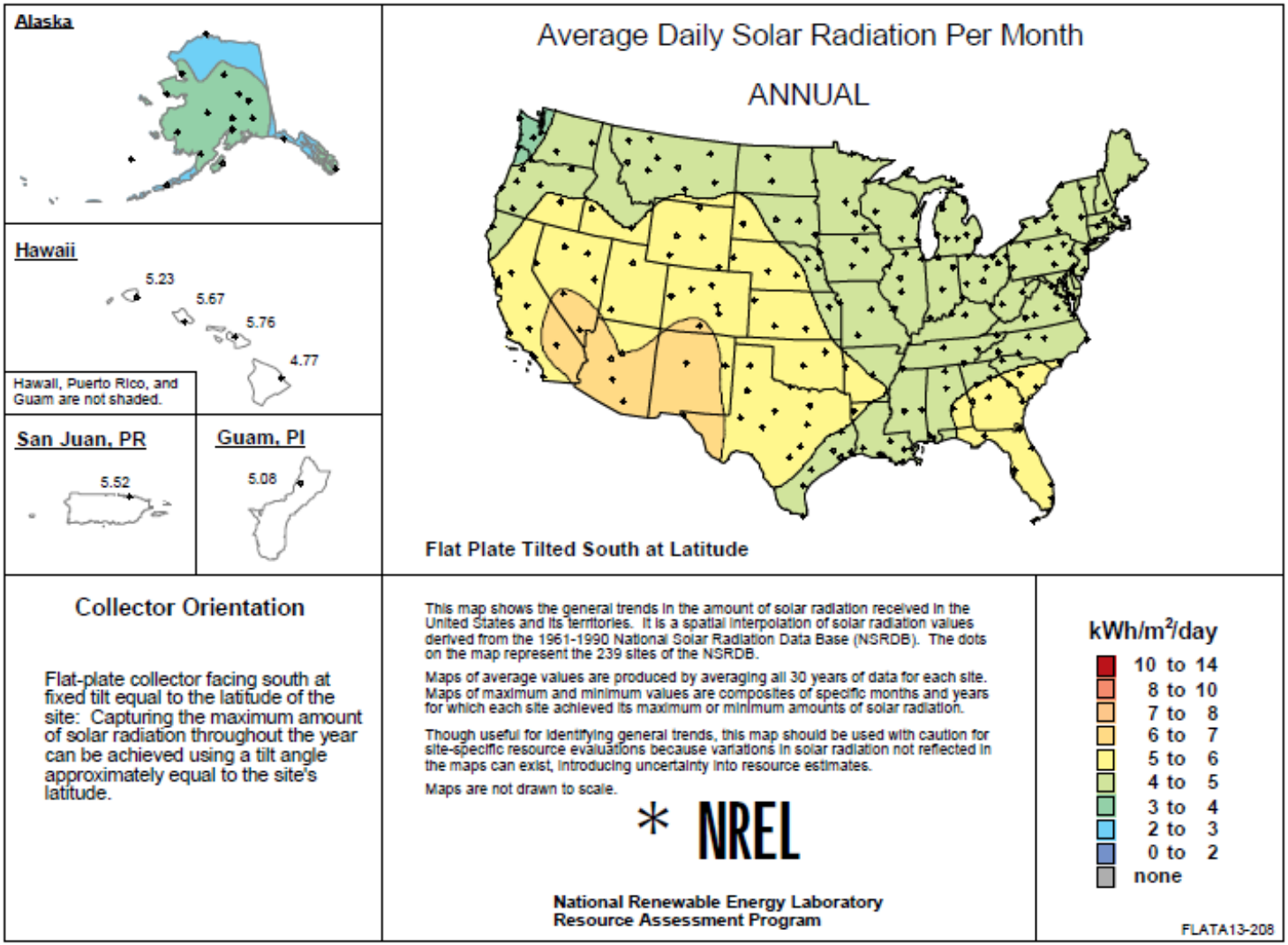
Renewable Energy Resources: Biomass and Wind





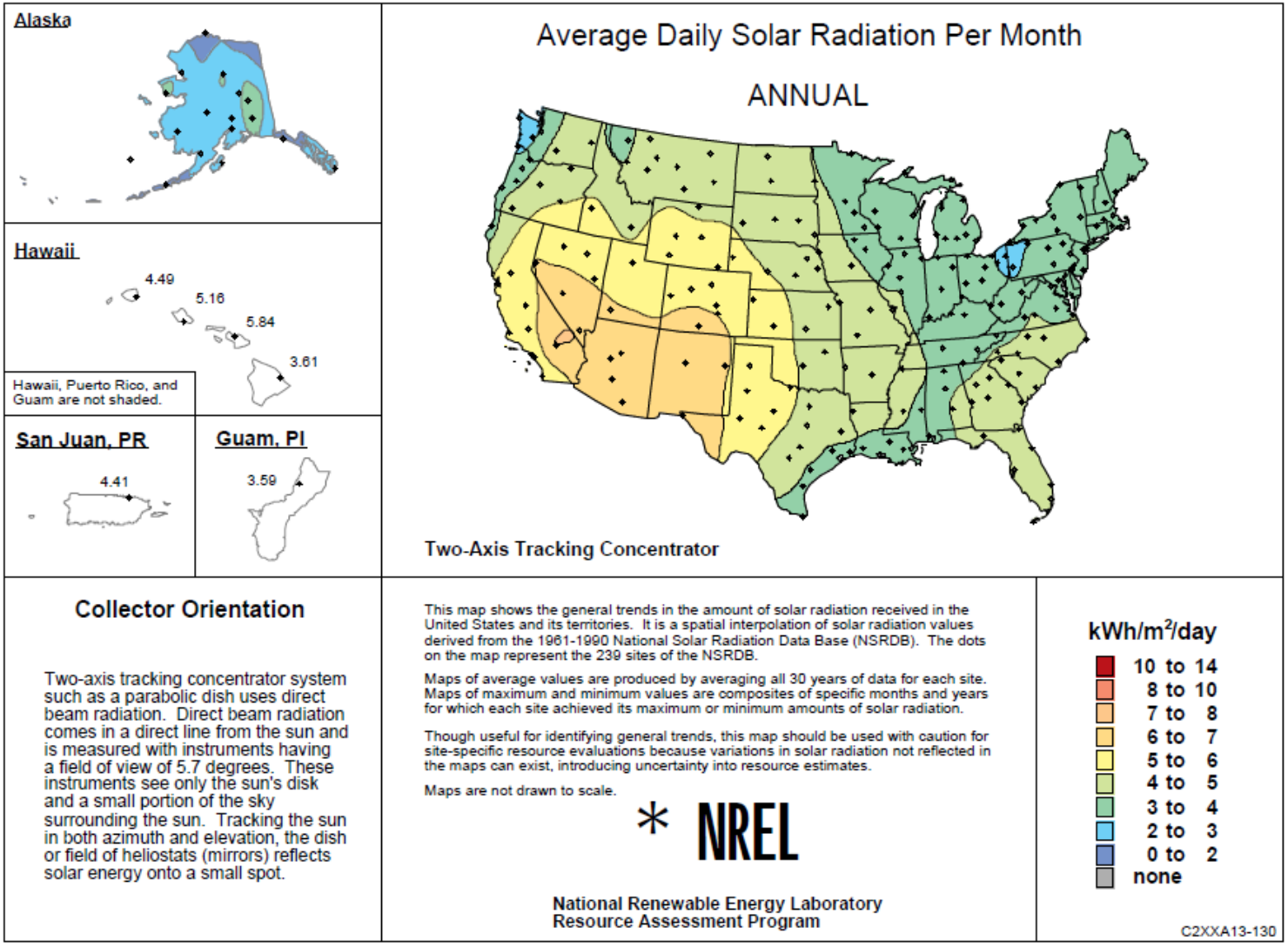
Source: http://www1.eere.energy.gov/maps_data/renewable_resources.html

Renewable Energy Resources: Solar Photovoltaic



Source: http://www1.eere.energy.gov/maps_data/renewable_resources.html

Renewable Energy Resources: Solar Thermal



Source: http://www1.eere.energy.gov/maps_data/renewable_resources.html