

HARVARD | BUSINESS | SCHOOL

HBS BUSINESS AND ENVIRONMENT INITIATIVE

MBA ELECTIVE

FIELD PROJECT: INNOVATION IN BUSINESS, ENERGY, AND ENVIRONMENT

Faculty Presentation:

“Some Basic Background on Energy and Environment”

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Some Basic Background on Energy & Environment

Prof. Woodward Yang

IBEE Spring 2012

Objective of this lecture

- Provide some scientific background and historical context about energy resources used by humans
- Try to answer these basic questions
 - How much energy do we use and for what?
 - How much does energy cost?
 - What is the impact on the environment?

Power and Energy

- Power = Energy/time
 - 1 Watt = 1 Joule / second
- Energy
 - 1 Joule = 1 Newton (force) x 1 meter (distance)
 - Calorie = 4.184 Joule (energy to raise 1g H₂O by 1C)
 - Food Calorie = 1kcal = 4184 Joules
 - 1 W-h = 3600 Joules
 - 1 kW-h = 3600 kJ = 3.6 MJ = 3.6×10^6 Joules
 - 1 BTU = 1055 Joules (energy to raise pound of H₂O by 1F)
 - 1 Quad = 1 Quadrillion BTUs = 1×10^{15} BTU
 - 1 Exajoule = 1×10^{18} Joules = 0.95 Quads = 278 TW-h
- Amount of Energy used per year = Power
 - Average and Continuous Power
 - 1 year = 31.54 million seconds
 - 1 Quad/yr = 33.45 GW (continuous)

Some Typical Values of Energy

- Energy to lift a regular apple by 1m = 1 J
- Energy to lift an iPad2 (Apple) by 1m = 6 J
- Energy in D-size alkaline battery = 20 W-h = 72,000 Joules
- Energy in 1g of fat = 9 calories (food) = 37,700 Joules
- Energy in 1g of gasoline = 46,800 Joules
- Energy in laptop battery = 100W-h = 0.36 MJ
- Energy in stick of dynamite (0.28 kg) = 2.1 MJ

Some Typical Values of Power

- 100W is power used by 100W incandescent light bulb
- 100W = power consumed by human body at rest
- 1kW = power consumed by active human body (running)
- 1kW = typical average electrical power usage of US household
- 1 horse power = 746W = 0.746kW
- V6 2liter engine (peak) = 130 hp = 97kW
- 400MW = typical large gas turbine generator
- 1GW = typical output power of nuclear power plant

Energy Density

- Batteries and Explosives
 - Li-ion battery = 460 kJ/kg
 - Gunpowder = 3.0 MJ/kg
 - Dynamite = 7.5 MJ/kg
- Combustible Fuels
 - Gasoline = 47.2 MJ/kg
 - Butter = 30 MJ/kg
 - Coal = 30 MJ/kg
 - Natural Gas = 49 MJ/Kg
 - Liquid H₂ Rocket Fuel = 140 MJ/kg

A Very Brief History of Energy Usage by Human Civilization Part 1 (pre-historic to 1800s)

- Wood was the first fuel used by humans (and Neanderthals)
- Fire was used for heat, cooking, protection, and illumination
- Wood was also used as a building material

- As population grew and civilizations expanded, many forests were decimated
 - To build cities in ancient Middle East
 - To make bronze weapons by Crete and Greece
 - To expand the Roman Empire and by China
 - To build sailing ships (for war) by Spain, England, France, and Holland
- Wood was an essential raw material for civilization and war until 1900
- Acute shortages of wood in 1800's lead to the increasing use of coal in Europe and especially England

A Very Brief History of Energy Usage by Human Civilization Part 2 (1800s to now)

- In 1800s, energy consumption exploded with increasing technology
- Coal was the energy source for the industrial revolution
 - Iron production was one of the largest users of wood and coal
 - Mechanical engines replace animals
- Oil was found to be the best fuel for automobiles in the early 1900's
 - Oil is still primarily used for transportation
- Oil replace wood as an essential raw material for civilization and war
- Since 1950s, coal, natural gas, hydro, and nuclear became the major fuels used for electricity generation

- Known supplies of oil, gas, and coal are limited
- Measurable changes in atmospheric gas composition
 - CO₂ from 270ppm to 390ppm over past 200 years
 - CO₂ from 310ppm to 390ppm over past 50 years

Impact of Technology on Energy Usage

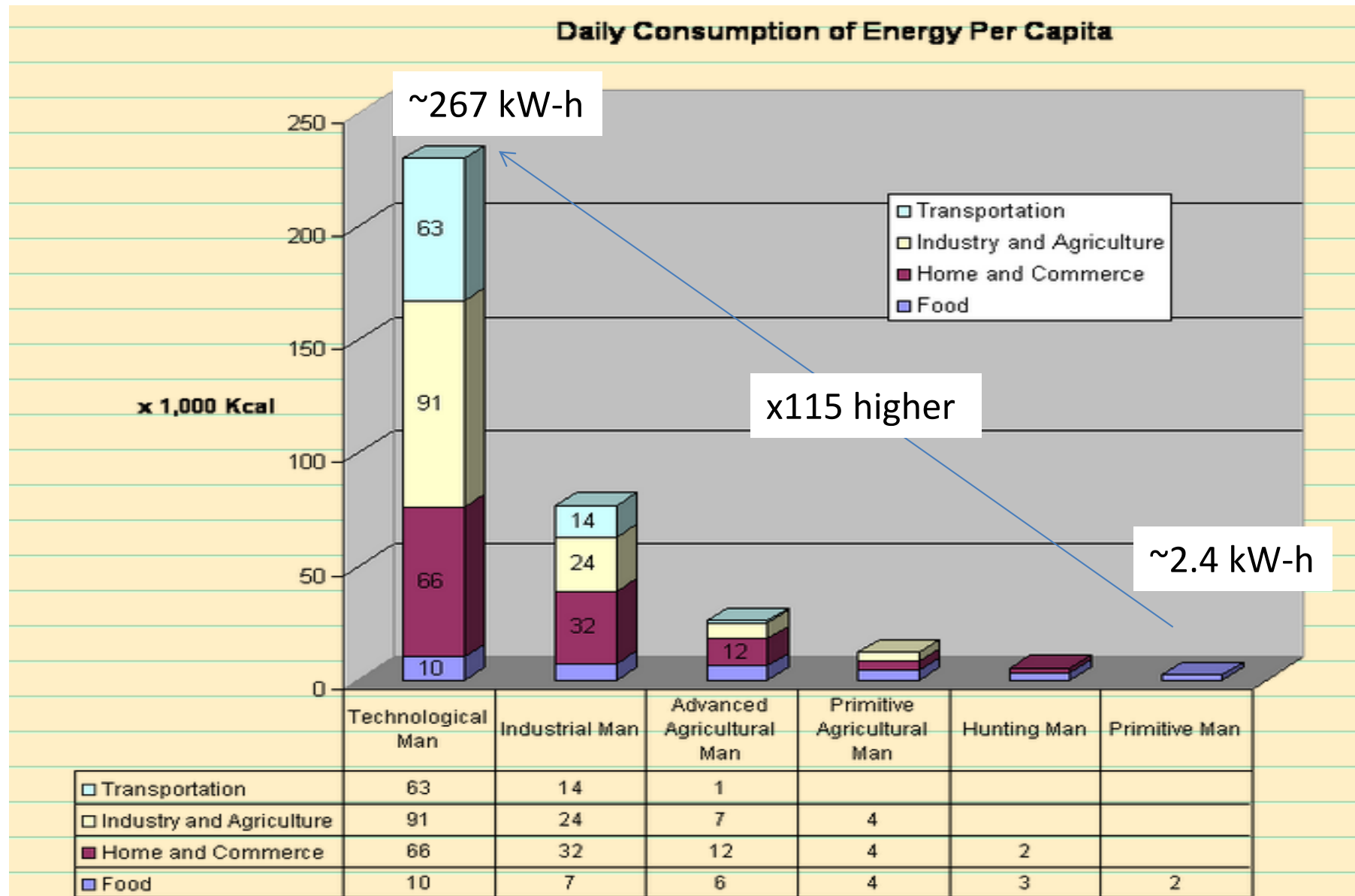


Figure 1. Estimated Daily Consumption of Energy per Capita at Different Historical Points

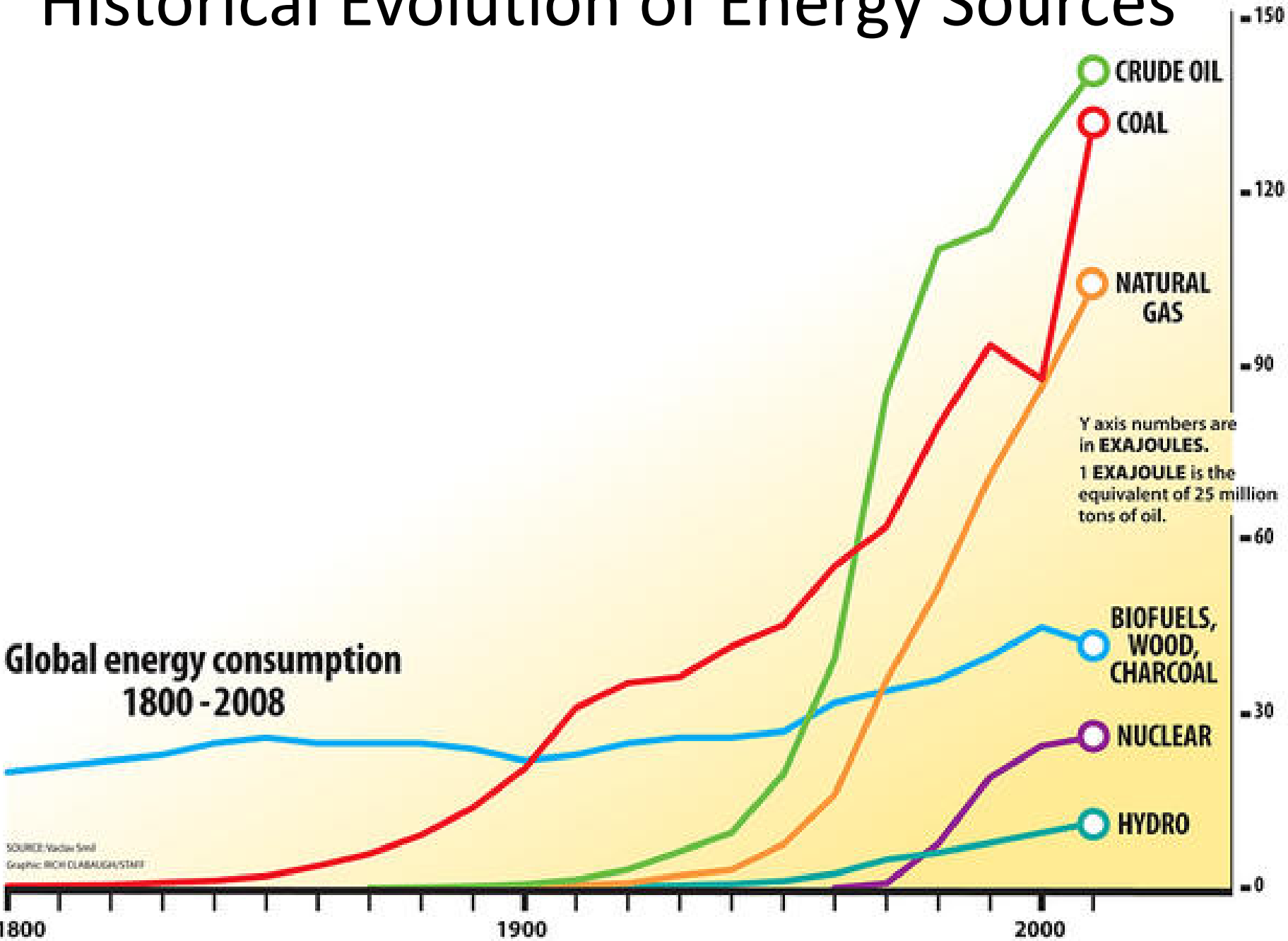
Adopted from: E. Cook, "The Flow of Energy in an Industrial Society" *Scientific American*, 1971 p. 135.

Total Human Energy Consumption

- Annual WW Energy Usage = 500 Quads/yr = 16.73 TW (continuous)
- Annual Energy Usage Per Person
 - United States 350 MMBTU/person-year = 11.7 kW/person
 - Avg Industrialized 200 MMBTU/person-year = 6.7 kW/person
 - Avg Developing 75 MMBTU/person-year = 2.5 kW/person
- Annual US Energy Usage = 100 Quads/yr = 3.34 TW
 - Electricity Usage = 11.9 Quads/yr = 397 GW (continuous)
 - US has about 1,100 GW installed electricity generating capacity

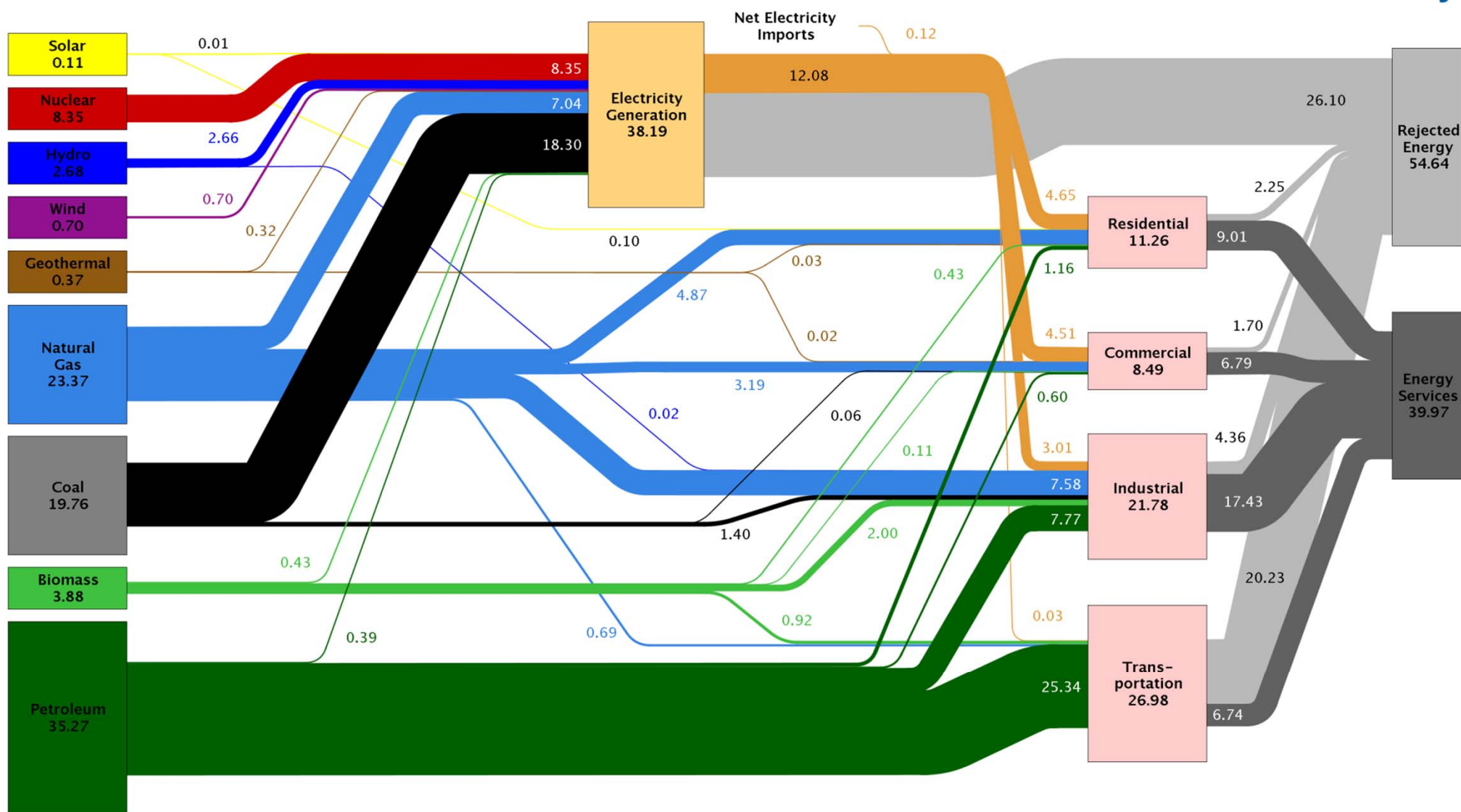
Approx figures for 2002-2008

Historical Evolution of Energy Sources



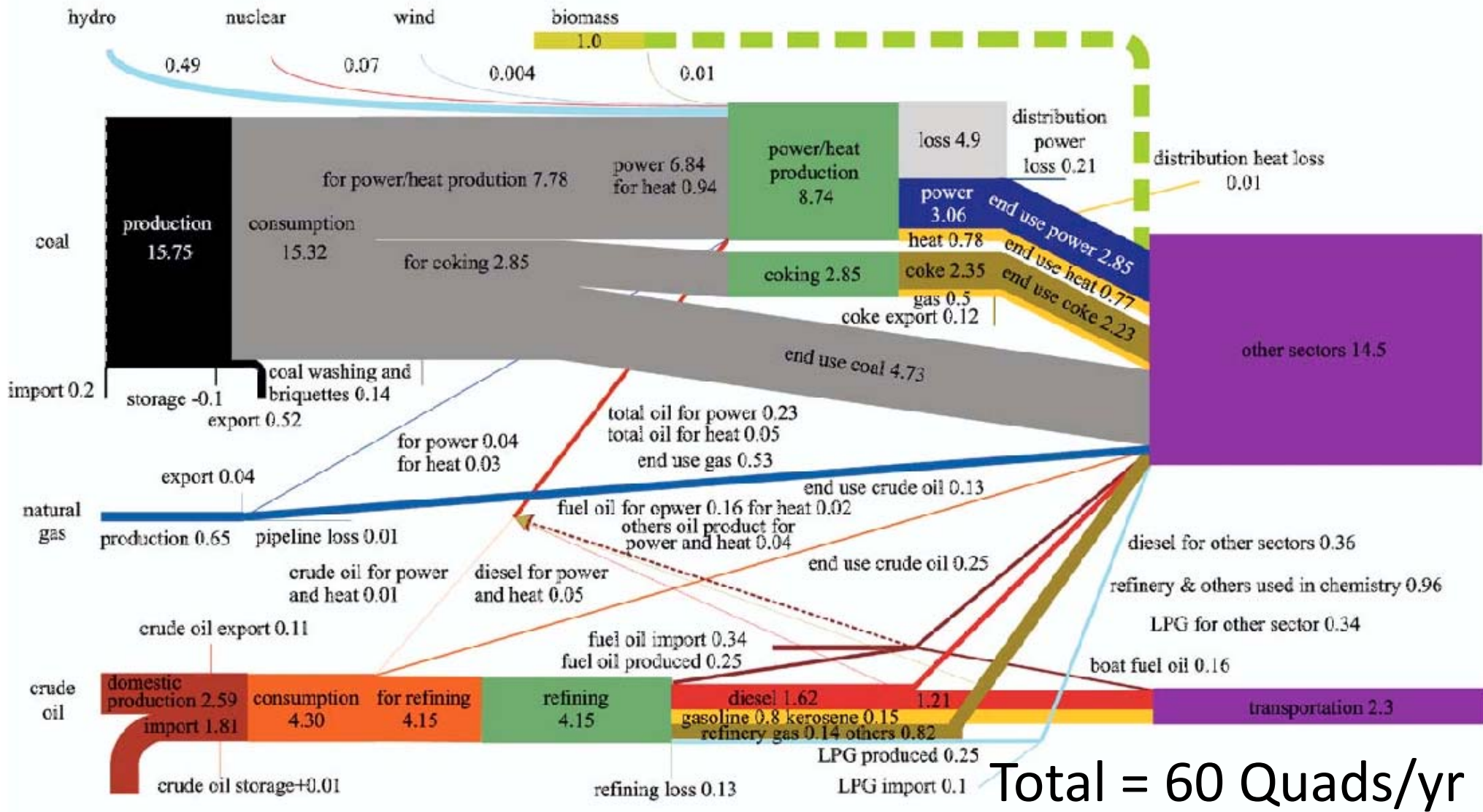
SOURCE: Yonke and
Graphic: RICH DLABAUGH/STAT

Estimated U.S. Energy Use in 2009: ~94.6 Quads



Source: LLNL 2010. Data is based on DOE/EIA-0384(2009), August 2010. If this information or a reproduction of it is used, credit must be given to the Lawrence Livermore National Laboratory and the Department of Energy, under whose auspices the work was performed. Distributed electricity represents only retail electricity sales and does not include self-generation. EIA reports flows for non-thermal resources (i.e., hydro, wind and solar) in BTU-equivalent values by assuming a typical fossil fuel plant "heat rate." The efficiency of electricity production is calculated as the total retail electricity delivered divided by the primary energy input into electricity generation. End use efficiency is estimated as 80% for the residential, commercial and industrial sectors, and as 25% for the transportation sector. Totals may not equal sum of components due to independent rounding. LLNL-MI-410527

China Energy Flow 2006



unit: 100 million tce
 data source: Statistics Yearbook of China Energy 2006

TCE = Ton Coal Equivalent = 29GJ

Cost of Fuels

- **Coal**

- 21-32 GJ/ton (depends on composition and quality)
- 1800kW-h/ton (assuming 30% efficiency)
- Burning causes 2.8-3.3 tons of CO₂/ton
- Market Price \$13-80/ton
- \$0.02/kW-h (fuel cost using \$40/ton coal in 30% electric power plant and 1.5kg CO₂/kW-h)

- **Natural Gas**

- 1000 BTU/scf = 1.1 MJ/scf (standard cubic foot of natural gas)
- Burning causes 55.6 Kg of CO₂/1000scf
- Market Price \$2-14/1000 scf or \$2-14/MMBTU
- \$0.03/kW-h (fuel cost using \$3/MMBTU gas in 30% electric power plant and 0.5kg CO₂/kW-h)

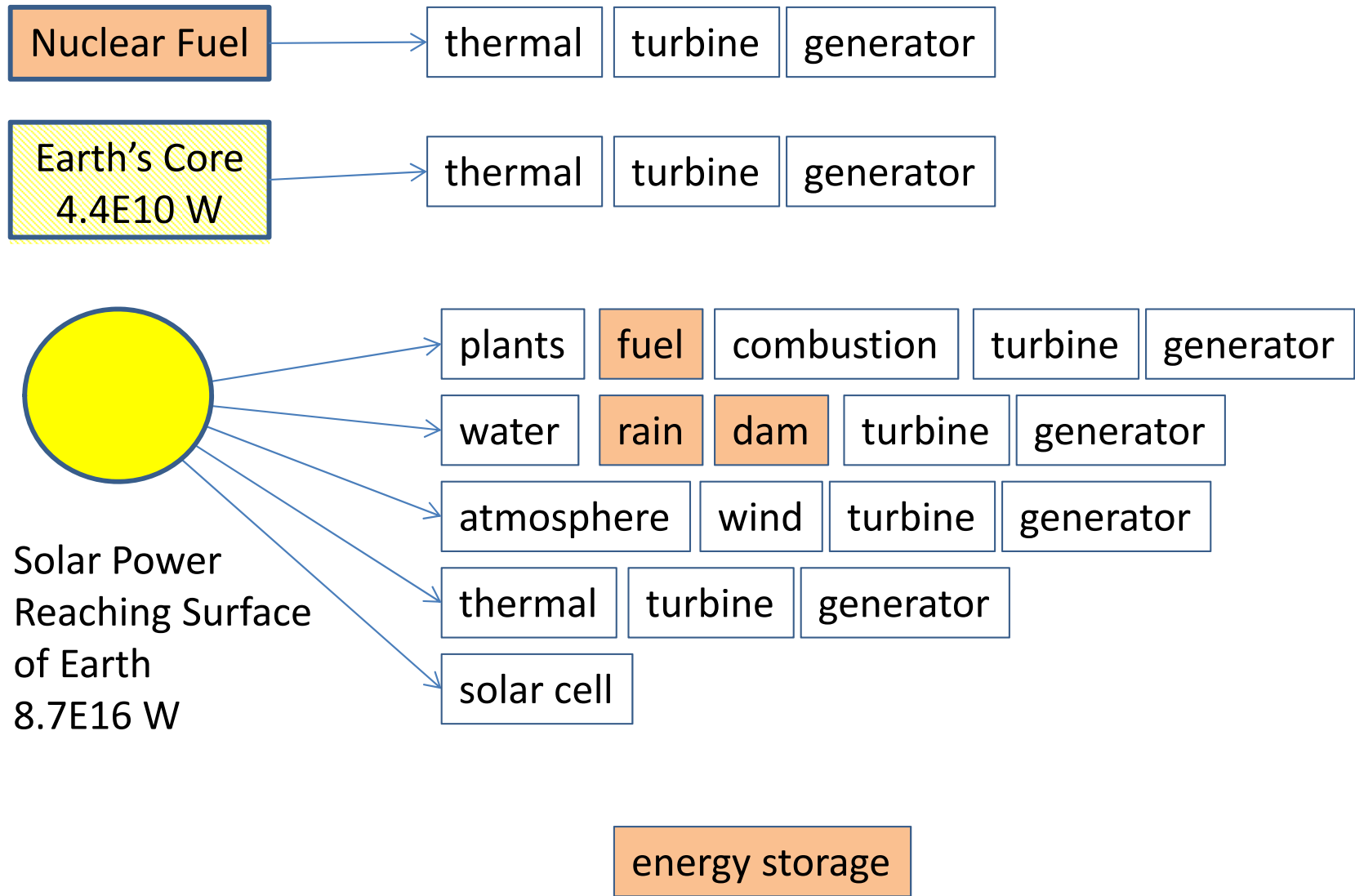
- **Oil**

- 6.1 GJ/barrel (42 gallons of crude oil) @ \$80-100/barrel
- Burning causes 300 Kg of CO₂/barrel (not all burned as fuel)
- \$0.157/kW-h (fuel cost using \$80/barrel oil in 30% electric power plant and 0.6kg CO₂/kW-h)
- 130 MJ/gallon (gasoline) @ \$3/gallon
- Burning causes 8.8 kg of CO₂/gallon

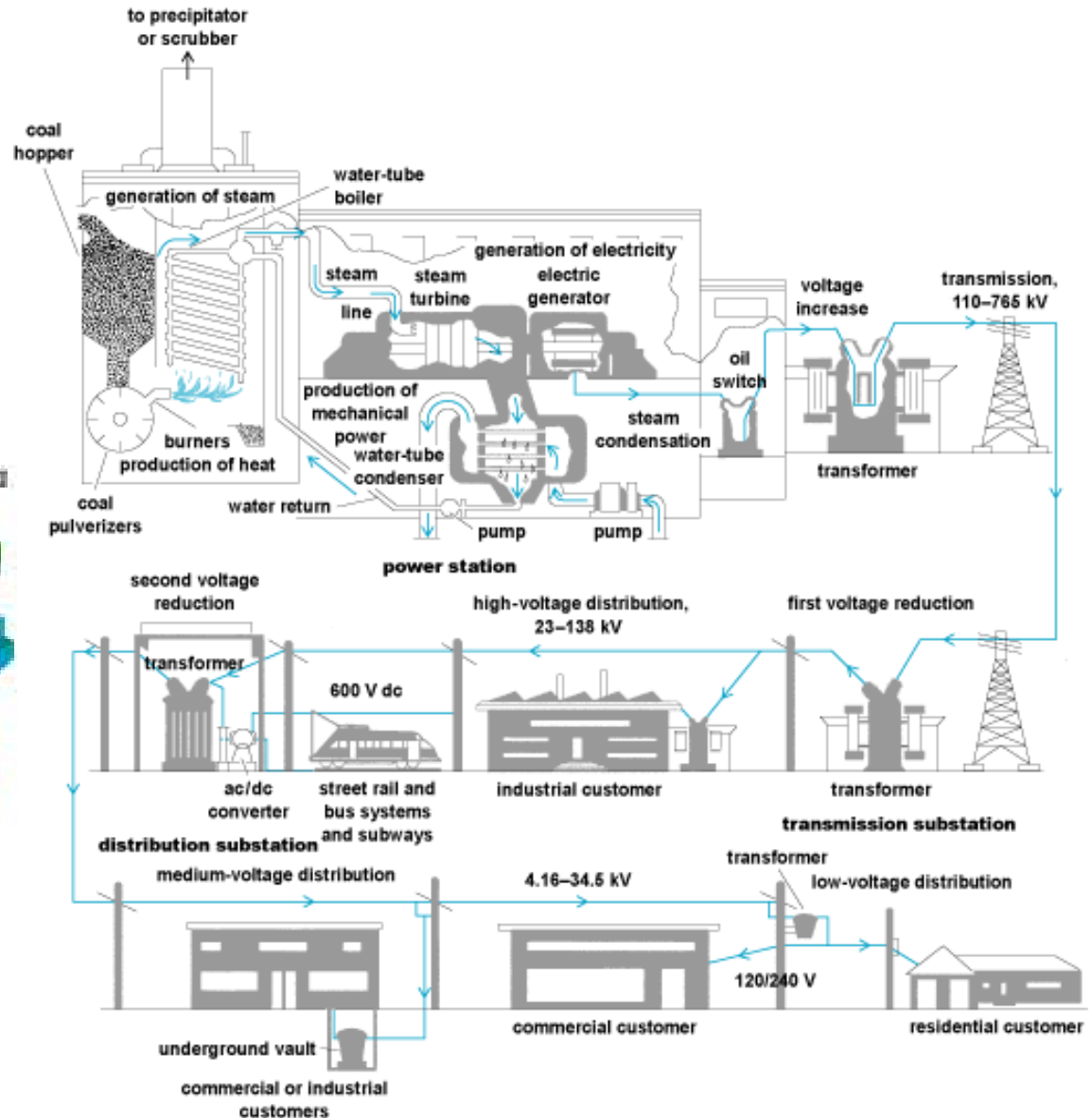
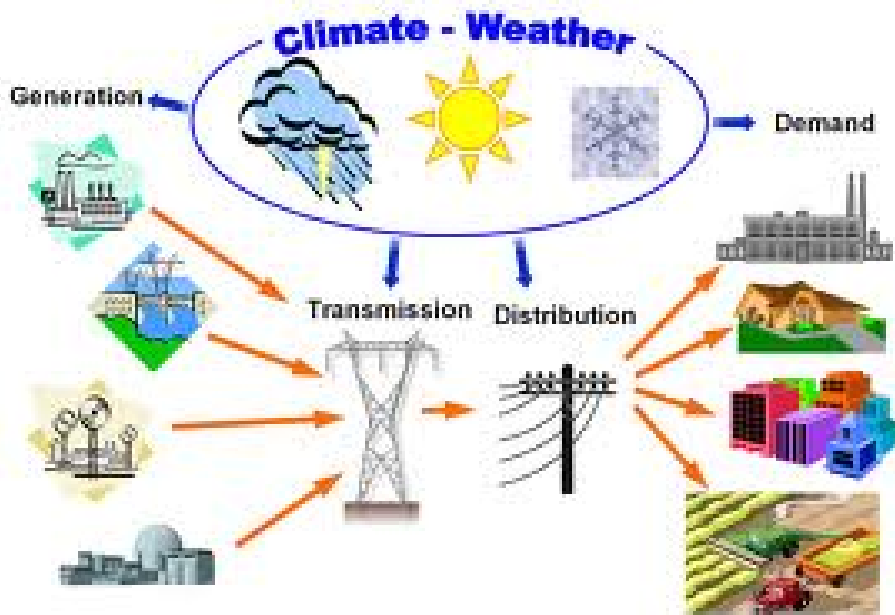
Important Takeaways

- Energy is very cost sensitive
- Oil is used primarily for transportation
 - Small volume and high energy density of oil
 - Energy efficiency of transportation is only 25%
- Electricity is produced with coal, natural gas, hydro, and nuclear
 - Electricity generation efficiency is only about 30%

Energy Sources

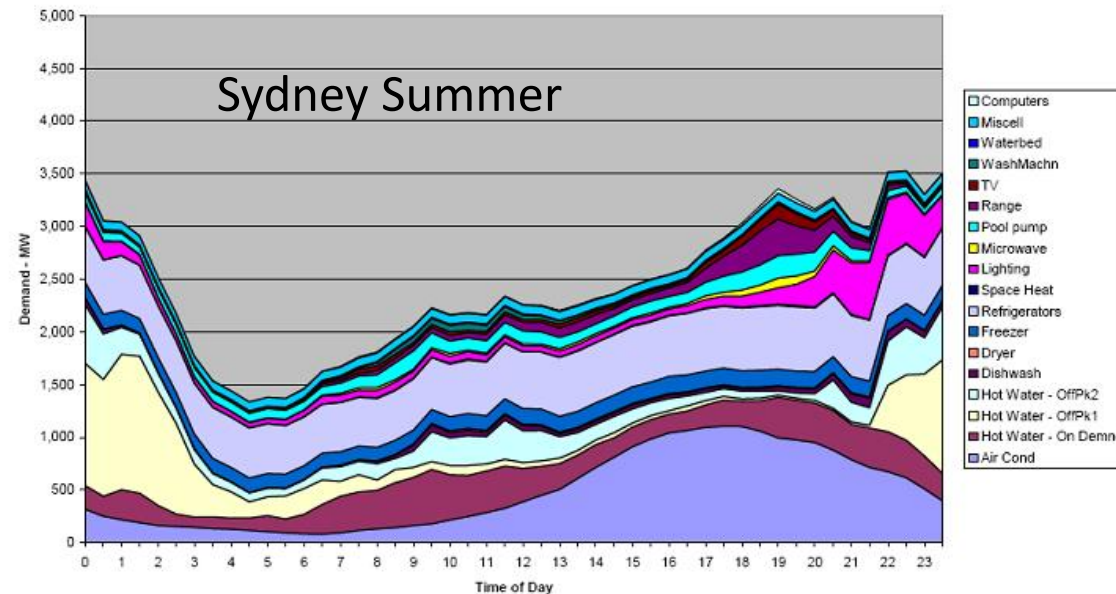
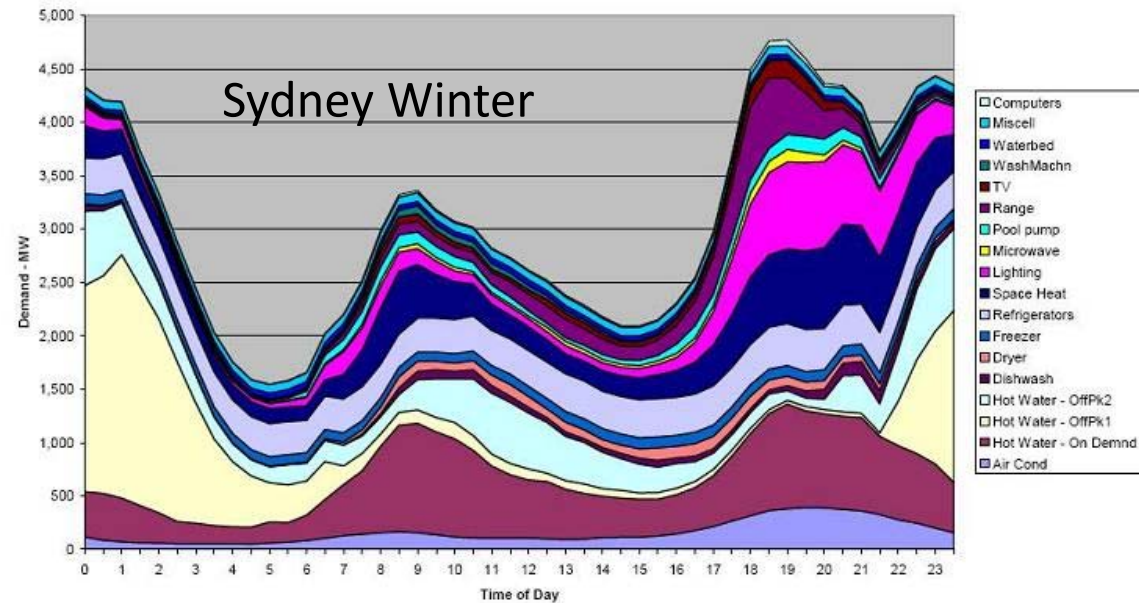
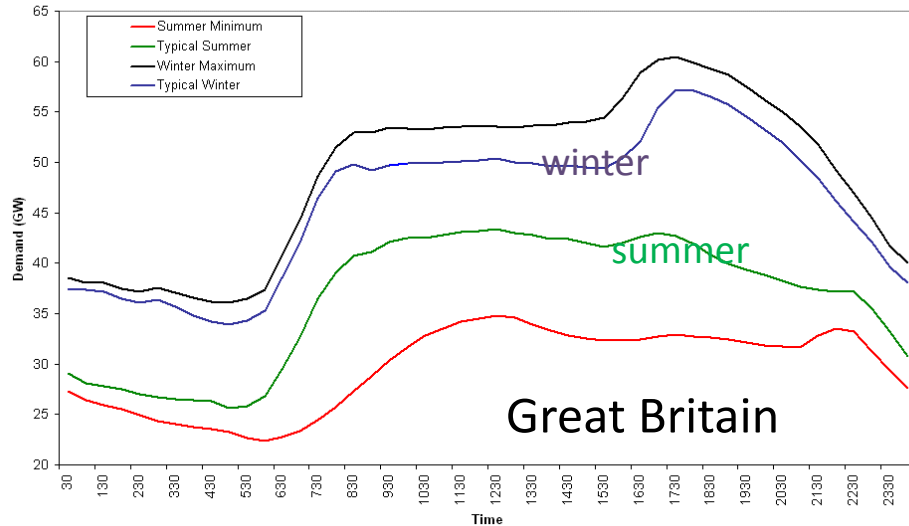


Electric Power System



Demand Variability for Electric Power

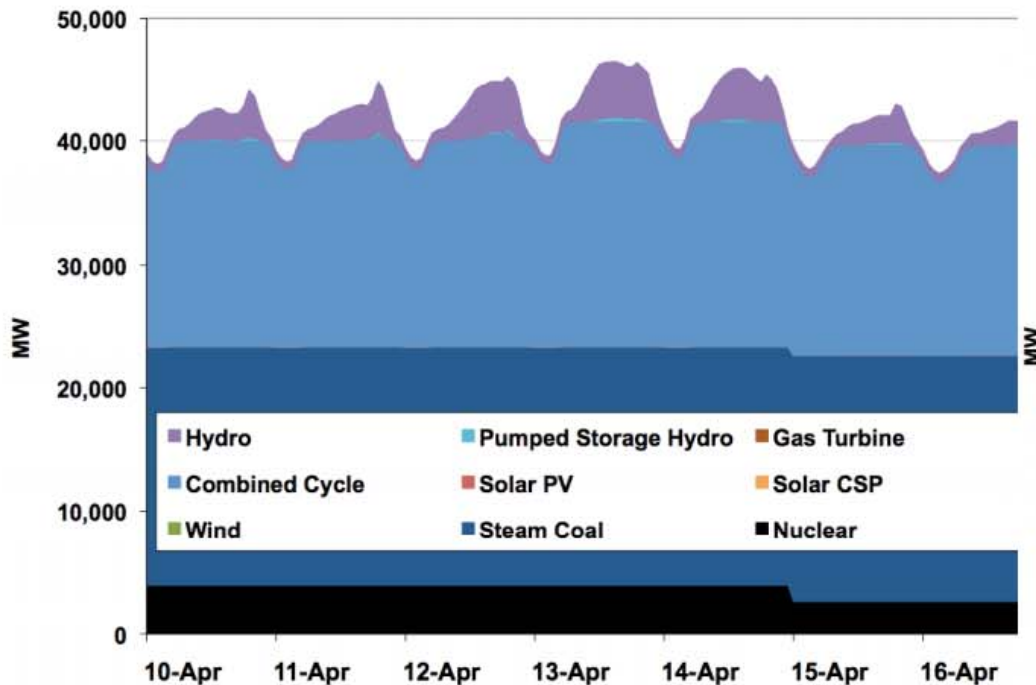
Figure 2.2 - GB Summer and Winter Daily Demand Profiles in 2007/08



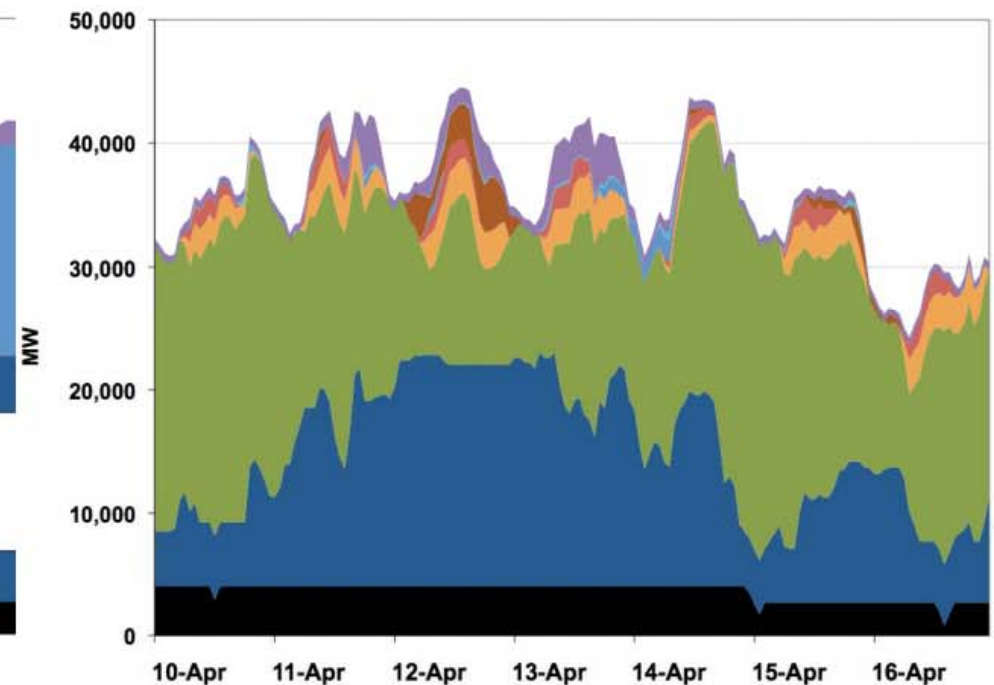
- Will depend on
 - Time of Day
 - Season
 - Weather
 - Location
 - Usage Types
 - Residential
 - Commercial
 - Industrial

Impact of Wind and Solar on Grid

No Wind/Solar



High renewables case



Variability of wind and solar electricity generation is a problem in managing other sources to match demand

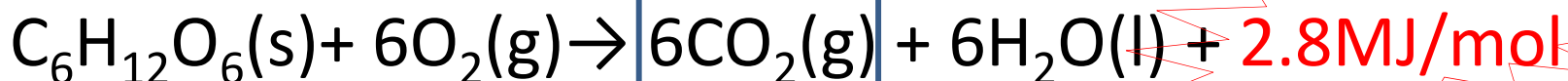
From NREL

Price of Electricity in Cambridge, MA

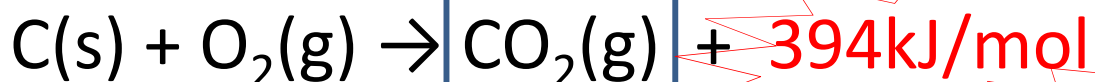
- Determined by local utility and government regulators
 - Some acceptable profit margin over cost
- Roughly \$0.20/kW-h here in Northeast
- 2 major cost components
 - Distribution (\$0.10/kW-h)
 - Build and Maintain Power Wires/Transmission
 - Power Transmission losses (<10%)
 - Generation (\$0.10/kW-h)
 - Fuel to burn in generators (depends on market prices)
 - Cost of capital for Generation Capacity
- Variations across US depending policy and infrastructure
- Does not depend on time, season, weather, etc.

Energy from Combustion

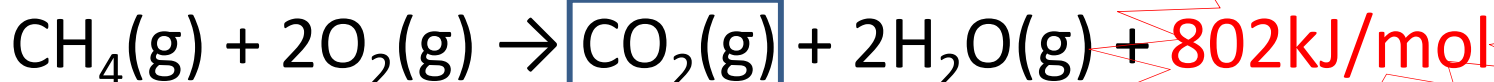
- Food (mostly glucose)



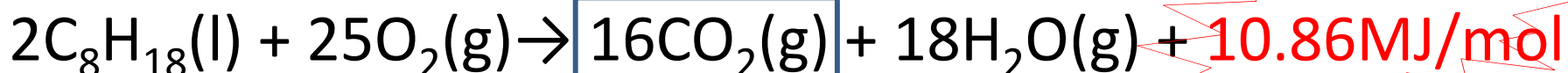
- Wood (about 50% C) and Coal (about 80% C)



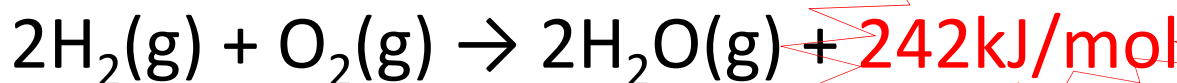
- Natural Gas (mostly methane)



- Gasoline (mostly octane)



- Hydrogen

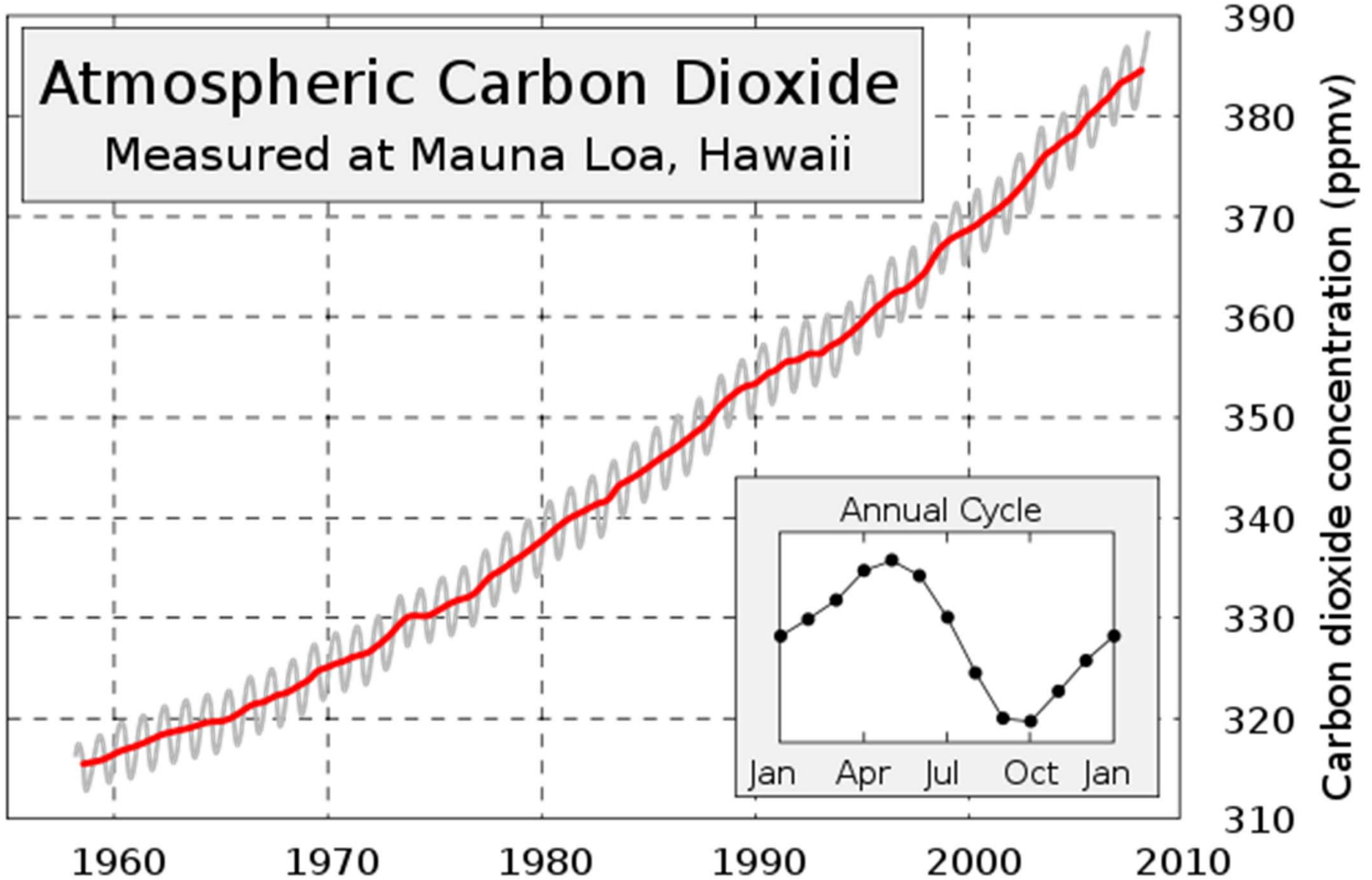


That's a lot of fire... how much CO₂ is that?

Amount of CO₂

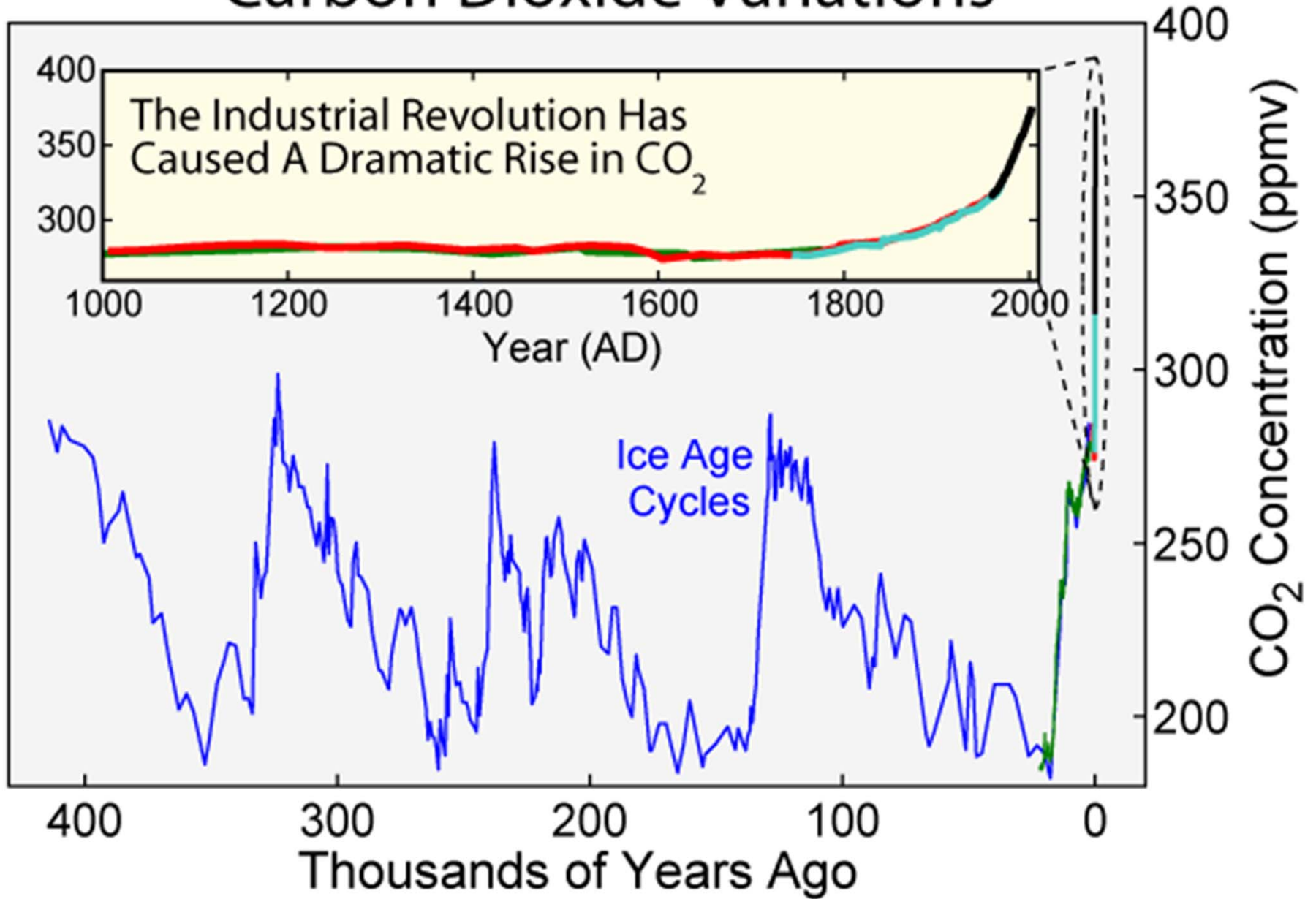
- Coal
 - WW consumption ~135 Exajoules/yr
 - Avg Energy Content of Coal ~25 GJ/ton
 - Annual Coal Consumption ~5.4 billion ton/yr
 - Annual CO₂ released by Coal ~16.2 E9 tons/yr
- Natural Gas
 - WW consumption ~105 Exajoules/yr
 - Avg Energy Content of NG ~1.1MJ/scf
 - Annual NG Consumption ~95 trillion scf/yr
 - Annual CO₂ released by NG ~5.3 E9 tons/yr
- Oil
 - WW consumption ~140 Exajoules/yr
 - Avg Energy Content of Oil ~6.1GJ/barrel
 - Annual Oil Consumption ~23 billion barrels/yr
 - Annual CO₂ released by Oil ~6.9 E9 tons/yr

Human Activity Releases
~28 billion tons/yr of CO₂
Is this a lot?



From wikipedia

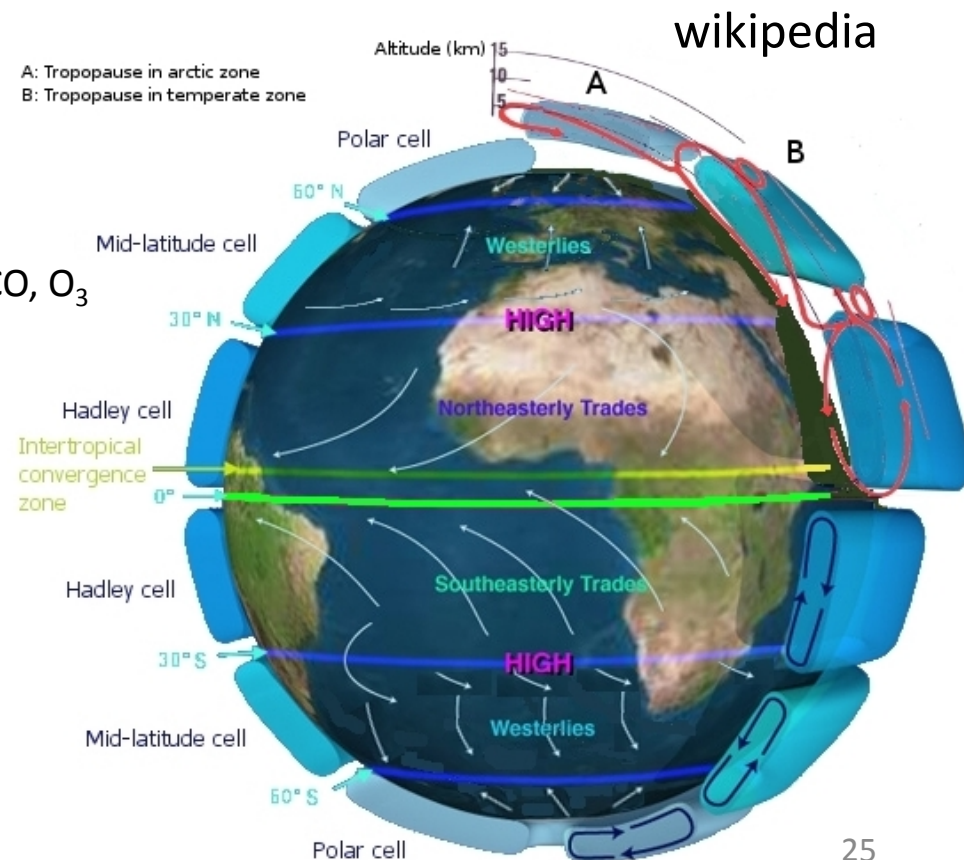
Carbon Dioxide Variations



From wikipedia

Some facts about the Atmosphere

- 75% of Atmosphere is between 0-11km in altitude
- Mass of Atmosphere is about 5,000,000 billion tons
 - Major Gases
 - 77% of N_2
 - 21% of O_2
 - 0.9% of Ar
 - Trace Gases
 - variable amounts of H_2O (~1%)
 - 0.038% of CO_2
 - tiny amounts of Ne, He, CH_4 , Kr, H_2 , N_2O , CO, O_3
- Atmospheric Circulation (wind)
 - Mixing of gases
 - Movement of thermal energy
 - Coupled to Ocean currents
 - Drives global weather and climate



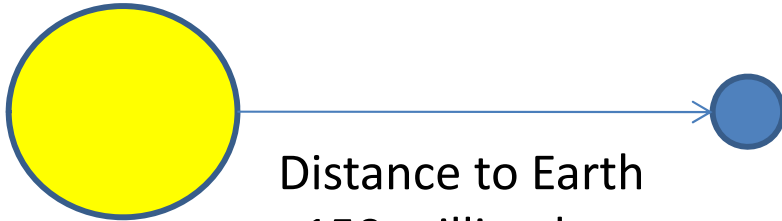
CO₂ and Climate

- 2600 billion ton of CO₂ in atmosphere
 - 400 billion tons/yr CO₂ natural exchange air-vegetation
 - 300 billion tons/yr CO₂ natural exchange air-ocean
 - 28 billion tons/yr of CO₂ into atmosphere by human activity
 - Observed CO₂ levels rising are clearly rising due to human activity
- Carbon Cycle
- But, climate is really complicated and depends on
 - Solar Radiation
 - Clouds
 - Wind
 - Ocean Currents
 - Land Masses
 - Vegetation
 - Volcanic Activity
- specific consequences are difficult to predict or quantify

Energy of the Sun

Power Output of Sun

$$3.86 \times 10^{26} \text{ J/s}$$



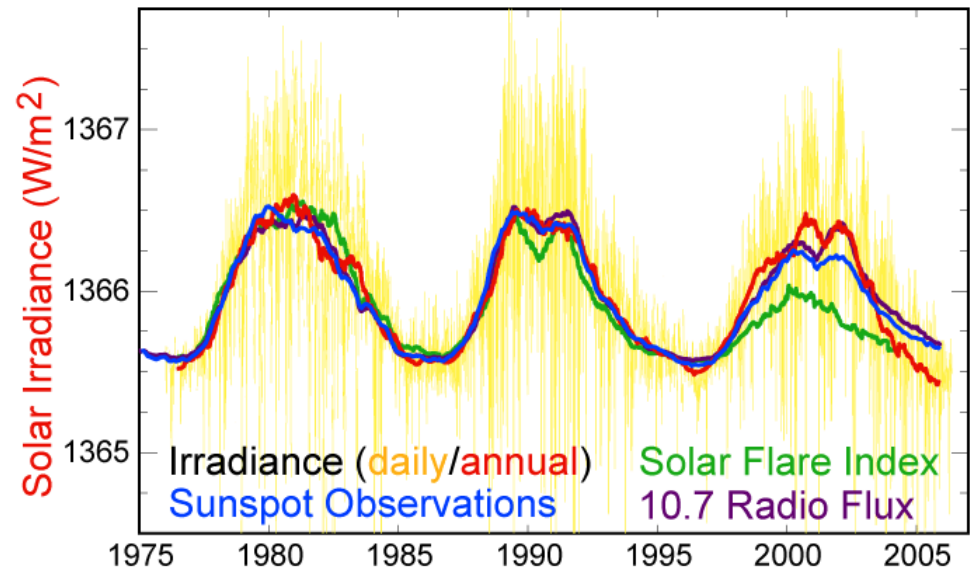
Distance to Earth
150 million km

Power Arriving at Earth

$$3.86 \times 10^{26}$$

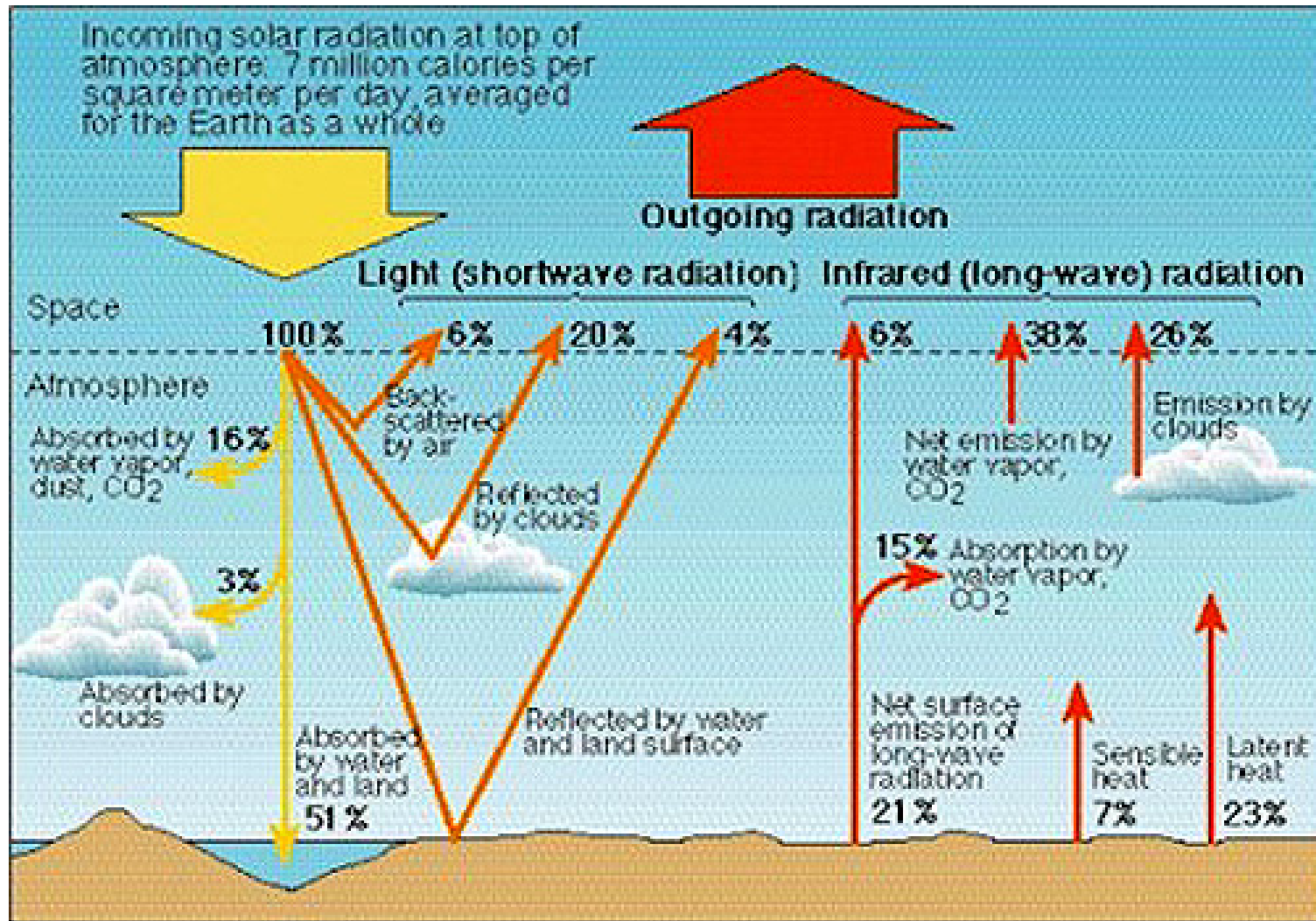
$$P = \frac{3.86 \times 10^{26}}{4\pi \times (1.5 \times 10^{11})^2} = 1365 \text{ W/m}^2$$

Solar Cycle Variations



Data from W.M. Connolley

Solar Radiation to Earth's Surface



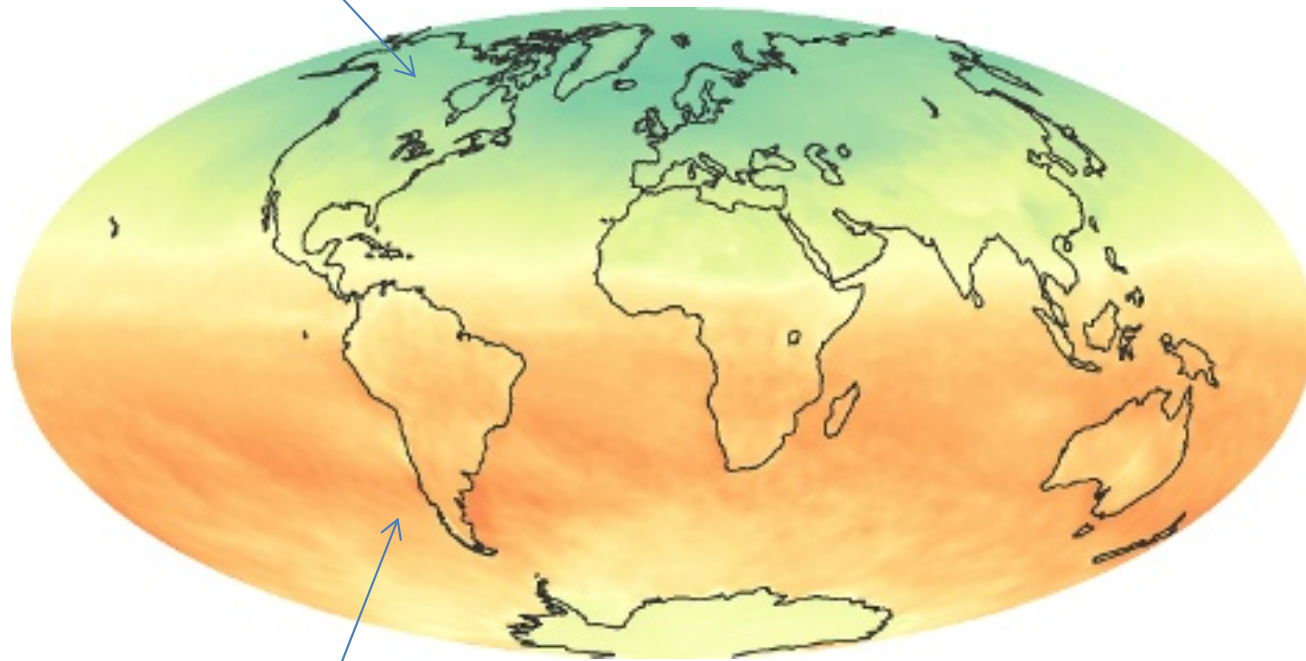
Total Power from Sun reaching the Earth = 5.2 million Quads/yr = 1.74×10^{17} W.
 Actual Power from Sun at one location depends on time of day, latitude, season, weather, and geography.

Net Radiation

Net Energy Lost to space



season
wind
ocean currents
snow cover
cloud cover

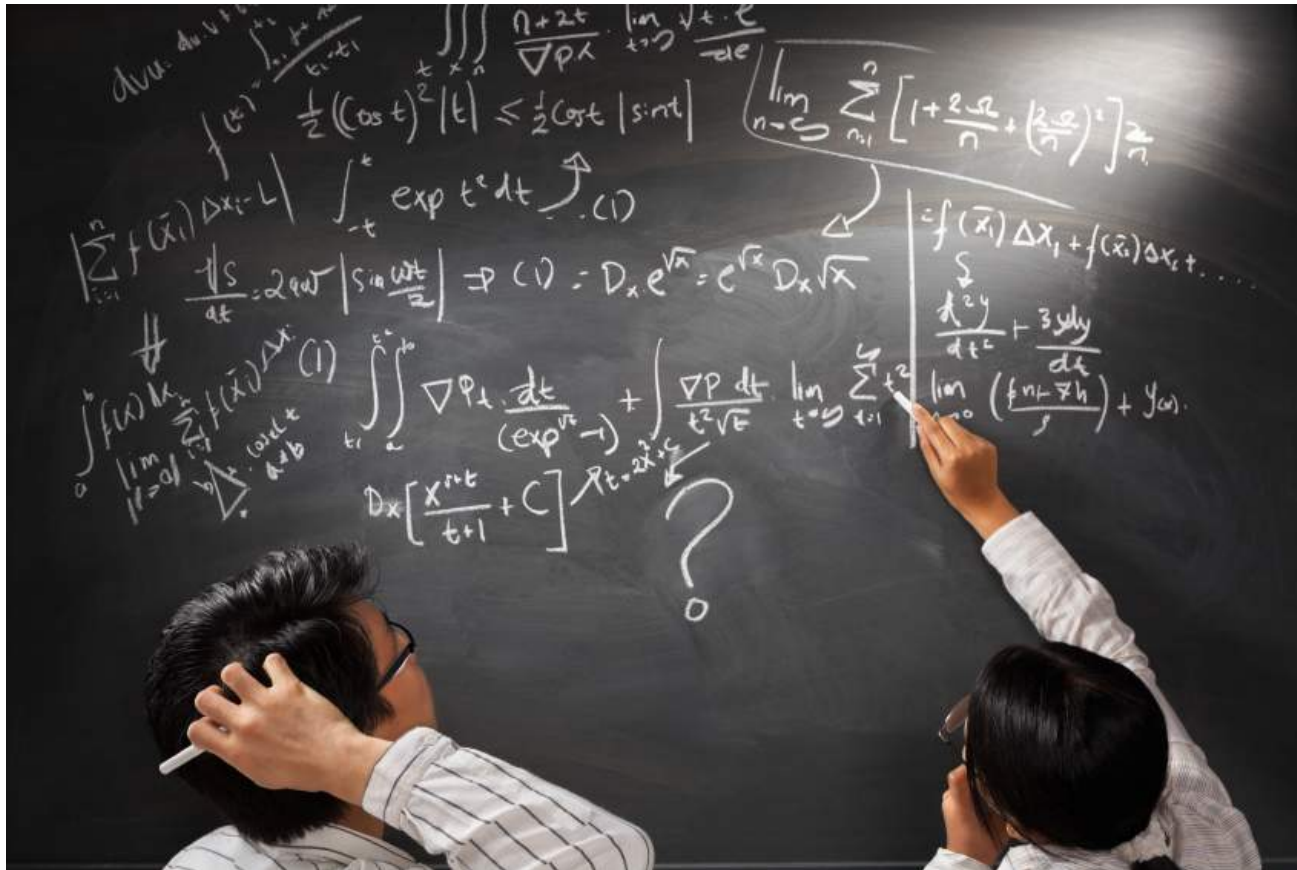


February 2009

NASA Earth Observatory

Net Energy Gained from Sun

CO₂ is certainly rising but consequences on climate are complicated...



If consequences are not clear, it is hard to figure out what to do...

Some Sources of Information

- US Energy Information Administration
 - www.eia.gov (lots of good statistics)
- US Department of Energy
 - www.doe.gov (mostly fluff)
- British Petroleum
 - www.bp.com (Statistical Review of World Energy)
 - Production, Demand, & Proven Reserves
- Intergovernmental Panel on Climate Change
 - www.ipcc.ch