Energy and Sustainability in Europe

Distribution / Storage / Efficiency

Ed Gatzke

Department of Chemical Engineering

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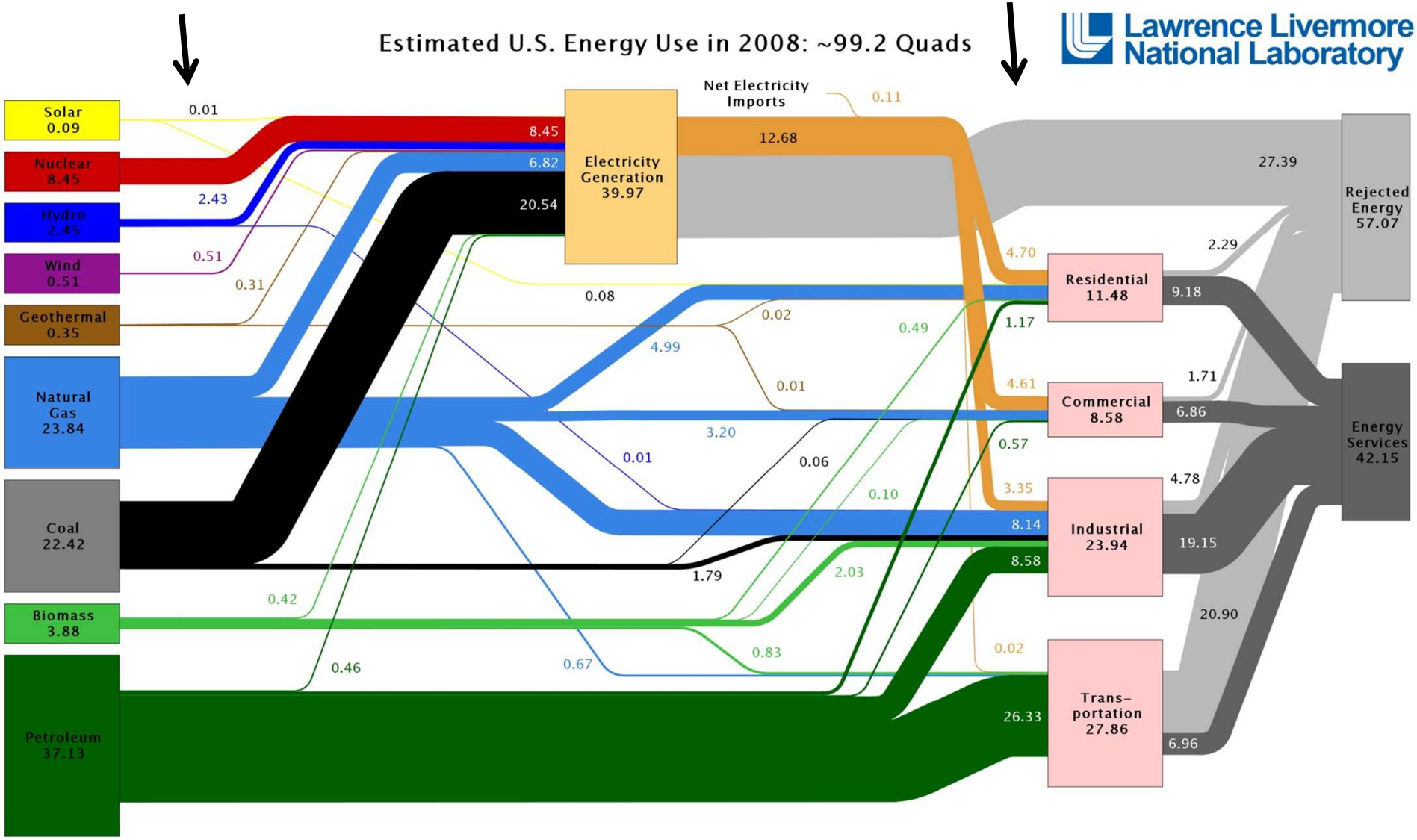
Background Concepts

- Energy production
  - Convert energy into useful form
  - Burn coal to make electricity, convert wind to power
- Energy transportation
  - Power grids, gasoline / coal / CNG distribution
- Energy consumption
  - HVAC, automobiles, lighting
- Efficiency
  - Always have losses
  - Must minimize losses
  - Must balance various costs (capital, production, maint.)

Energy Sources
(scaled lines)

Lost Energy
(light gray)



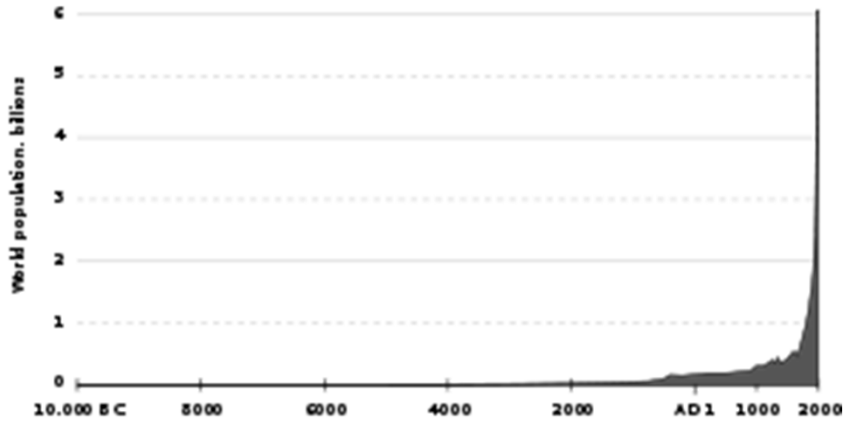
Source: LLNL 2009. Data is based on DOE/EIA-0384(2008), June 2009. If this information or a reproduction of it is used, credit must be given to the Lawrence Livermore National Laboratory and the Department of Energy, under whose auspices the work was performed. Distributed electricity represents only 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

Example Code of Conduct

- Be on time for meetings and activities
  - For safety and security
- Let us know if your roommate is missing or unaccounted for
- Recognize your own limits if/when you consume alcohol
  - Do not let alcohol consumption interfere with your ability to function
- Common sense suggests you travel in groups of 2 or more
- You should learn and observe German customs and laws
- Violation of rules will be dealt with in a three-step process
  - Verbal warning
  - Written warning
  - Suspension (return home)

Sustainability

- Definition: to maintain
- Interface of Society – Economy – Environment
- Carrying capacity (steady state population)
  - Population growth in developing countries
  - Consumption related to population
  - Energy relates to consumption



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Life Cycle Analysis

- Must consider full life of a product
  - Creation / use / disposal
  - Components, maintenance, transportation
- Energy and material inputs / releases
- Potential impacts during life

Overview

- Energy Distribution and Storage
  - Efficient production
  - Power grid
  - Storage
- Home and Building Efficiency
- Transportation

Catalyst Design

Jennifer Fadimba

- Speeds up reactions/kinetics
- Supported catalysts = higher thermal stability
- Should only be an intermediate

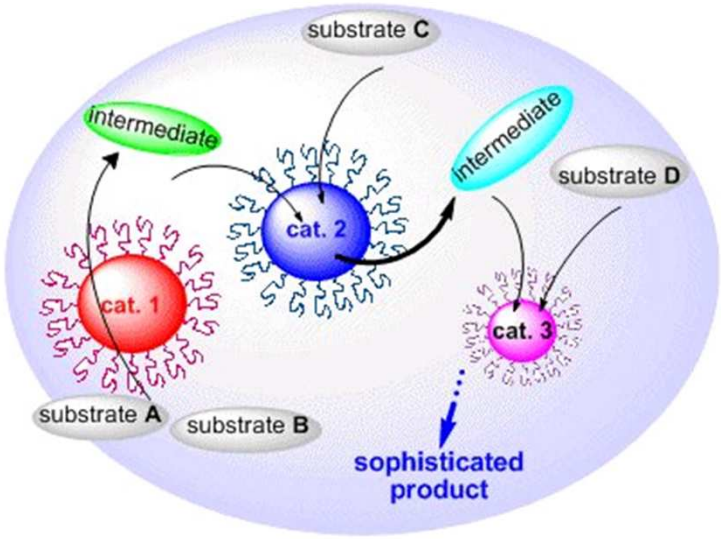
  - Not be part of the end products

Advantages

- Used for Green Chemistry
- Results achieved faster

Disadvantages

- Use expensive rare metals (Pt)



http://bravenewclimate.com/2010/04/05/pumped-hydro-system-cost/

Pumped Hydro Storage

Ed Gatzke

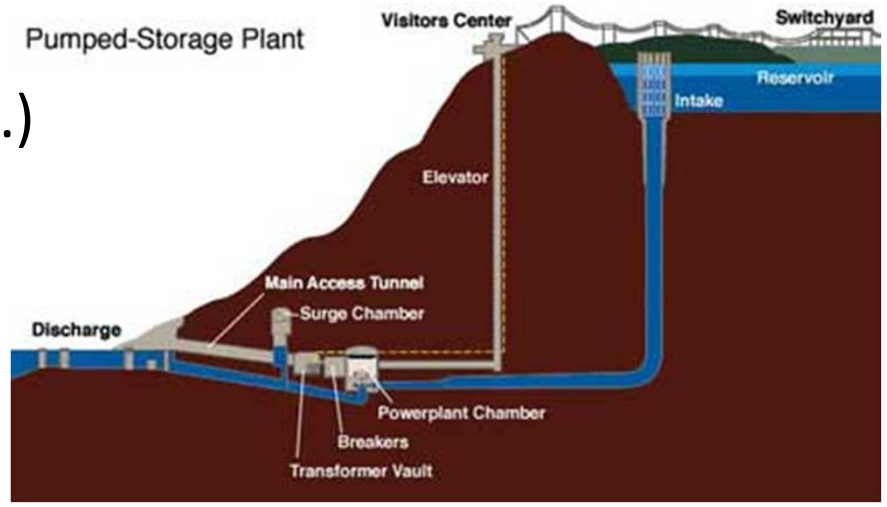
- Use electricity to pump water uphill to reservoir
- Water runs down hill to turn turbine
  - 99% of all world storage
  - 20 GW in US (~20% world tot.)

Advantages

  - Simple design
  - 70-87% Efficient

Disadvantages

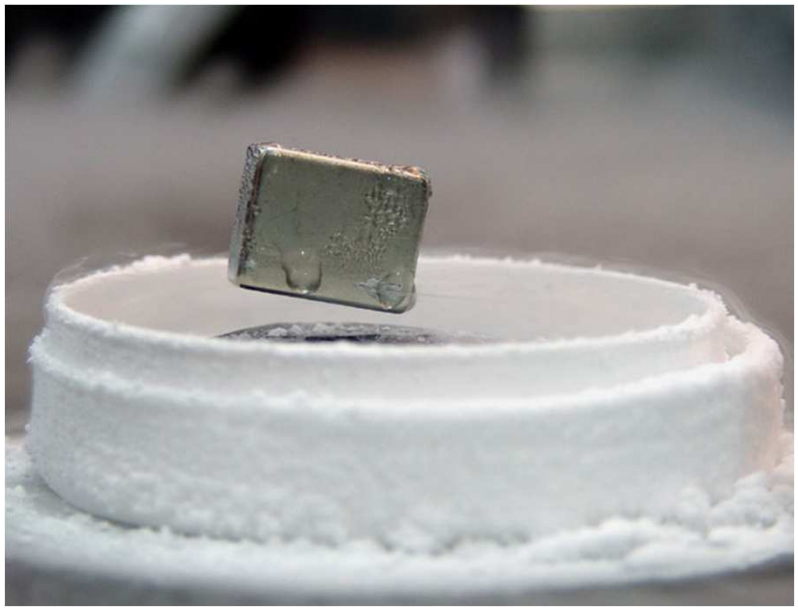
  - Not available in all locations



http://bravenewclimate.com/2010/04/05/pumped-hydro-system-cost/

Superconducting Electricity Distribution

Superconductivity is the phenomenon in which a material loses its resistance to the conduction of electricity and loses internal magnetic fields. This will usually only occur at some critical temperature.



The Meissner Effect

Superconducting Electricity Distribution

Advantages:

- Transmits 100-150 more energy than traditional copper wires
- Allows for conduction of electricity without energy losses.
- Allows for energy generation far from where the energy will be utilized (Solar plant out in the sunny desert supplying energy to far away cities)

Disadvantages:

- Requires very low temperatures (originally around 30 Kelvin but new technology raises that to around 90 Kelvin)
- Requires a lot of energy to maintain such low temperatures

Cost:

- About 4 times as expensive as traditional wiring.

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Storage Technology: Flywheels

- A flywheel is defined as a rotating mechanical device that is used to store rotational energy
- Flywheel energy storage works by accelerating a rotor (flywheel) to a very high speed and maintaining the energy in the system as rotational energy
- This type of system runs off the principle of conservation of energy
  - Adding energy to the system increases the rotational speed and subtracting energy decreases the rotational speed
- Typically flywheels are contained inside a vacuum chamber to reduce friction and they are connected to a combination electric motor and electric generator

Advantages

- Not Adversely affected by temp changes, so it is not subject to the common failures of rechargeable batteries
- It is easy to calculate the exact amount of energy stored by measuring the rotational speed of the flywheel
- Unlike Lithium Ion Batteries which operate for roughly 36 months, flywheels have the potential to operate for an infinite amount of time

Disadvantages

- Limited to the tensile strength of the material of the flywheel, if the tensile strength is exceeded the flywheel will explode in to dangerous bullet like fragments.
- Energy storage time is greatly affected by friction of the bearings. Flywheels using mechanical bearings can lose 20%-50% of their energy in 2 hours.
  - Most of this friction results from flywheel changing orientation due to the rotation of the earth. This change in orientation is resisted by the gyroscopic forces exerted by the flywheels angular momentum. This force on the bearings increase friction.
- Current advanced flywheel systems completely levitate the spinning mass using maintenance free magnetic bearings, thus eliminating mechanical bearing maintenance and failure.
- Flywheels with magnetic bearings and high vacuum can maintain 97% mechanical efficiency.

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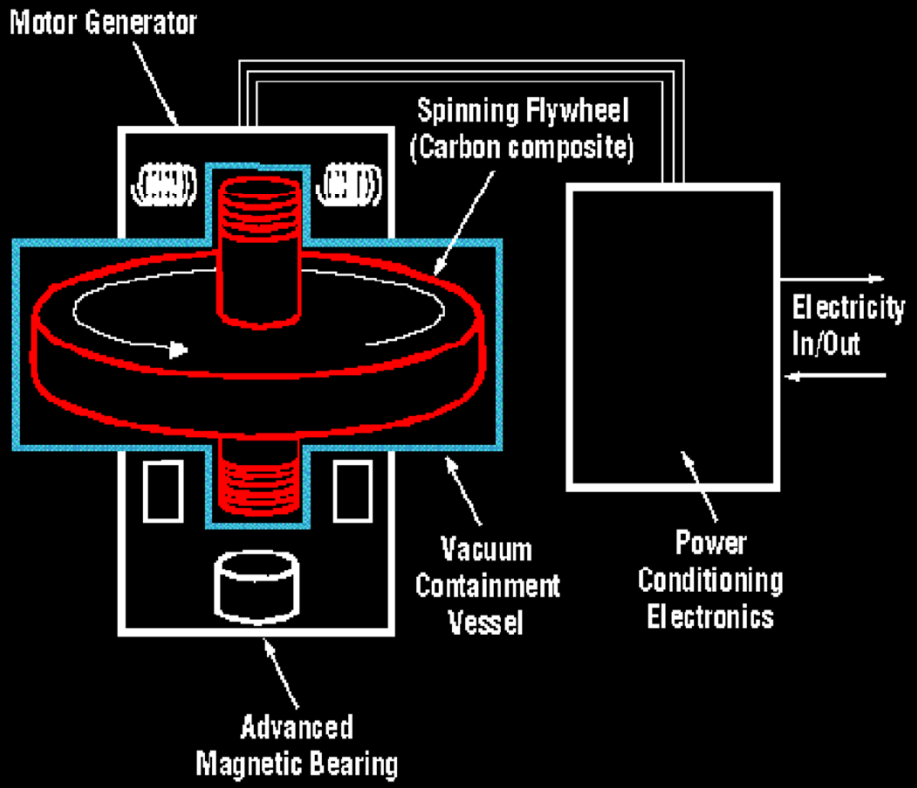
http://en.wikipedia.org/wiki/Flywheel_energy_storage
http://www.dg.history.vt.edu/images/image2_41.gif

FLYWHEEL STORES ENERGY



ADVANTAGES

- **High power output**
- Long life
- Unaffected by ambient temperature extremes

CHALLENGES

- Reduce cost of flywheel rotor and advanced magnetic bearing
- Mass produce with quality
- Develop lightweight vacuum containment vessel
- Reduce overall system weight

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Batteries

John Clegg

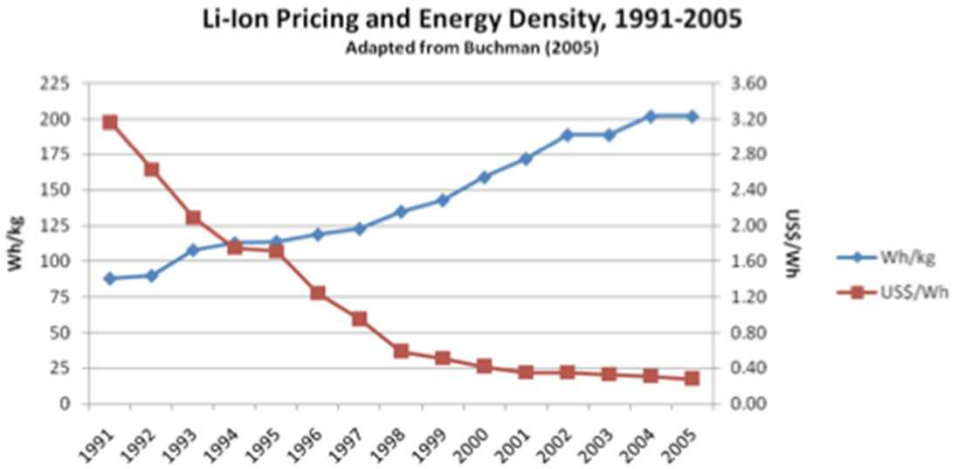
- Energy storage
  - Converts stored chemical energy into electrical energy
  - Primary batteries: cannot be recharged
  - Secondary batteries: can be recharged, and through recharging are restored to original condition (or close to it)
- Advantages:
  - Portable
  - Frequently Rechargeable
  - Available in many shapes/sizes

http://stuffyoudontwant.com

Batteries Continued

John Clegg

- Disadvantages
  - Environmental Concerns
    - Electronic waste
    - Mercury, Lead
  - Leakage of corrosive or poisonous ions/chemicals
- Economics
  - $68-406 per kWh
  - Depends on type of battery
  - Rechargeable more economically favorable, estimated at $1.20 kWh
  - Over time, energy density is increasing, and cost is decreasing



http://energyselfreliantstates.org

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Flow Cell Storage

- Rechargeable fuel cells that converts chemical energy to electricity
- Process: electrolytes dissolved into an electroactive species flow through an electrochemical cell
- Recharge occurs when electrolyte liquid is replaced
  - recovered material can be re-energized
- Primary cells: can be discharged only (irreversible reactions)
- Secondary cells: rechargeable cells (reversible reactions)
  - Ex. Redox flow battery – regenerative fuel cell

Is it worth it?

- Advantages
  - Flexible layout
  - Long cycle life
  - Quick response
  - No harmful emissions
- Disadvantages
  - More complicated than standard batteries
    - Pumps, sensors, control units, extra containment vessels

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Efficiency/Cost

- The zinc-bromine battery (flow cell battery)
  - Charge/discharge efficiency of 70%
  - Energy price as $400 kW/h
  - Has greater than 2000 potential cycles

Also has no shelf life limitations

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Overview

- Energy Distribution and Storage
- Home and Building Efficiency
  - Recycling
  - Home and Building
- Transportation

Recycling: Metal

Mac Rogers

- **Most commonly recycled metals:**
  - Aluminum
  - Steel
  - Iron
  - Copper
  - Tin
- **General process flow (varies depending on the metal):**
  - Collection
  - Sorting
  - Melting / Refining
  - Production

http://www.personal.psu.edu/lat5088/edsgn100/lifecycle.jpg

Example: Aluminum

Recycling: Metal

Mac Rogers

Advantages

- For some metals, more efficient than raw production
  - Aluminum recycling 96% more efficient than bauxite refining.
- Can be recycled indefinitely, in theory
- Reliable supply: waste

Disadvantages

- Each cycle degrades quality
- Not always efficient
  - Can take more energy to recycle than mine
- Sorting can be expensive, time consuming

Recycling Paper

Sultan Al Masroori

- turning waste paper into new paper products
- over 1/2 of the material used to make paper is recovered waste

http://goo.gl/wdQji

Advantages

–40% reduction in energy

–35% less water pollution,74% less air pollution

–Recycling 1 ton of paper saves 2 tons of wood

Disadvantages

–Recycling doesn't stop the destruction of forests.

–Downcycling-”mixed”-lowers the overall quality of the recycled product

–Collection Costs

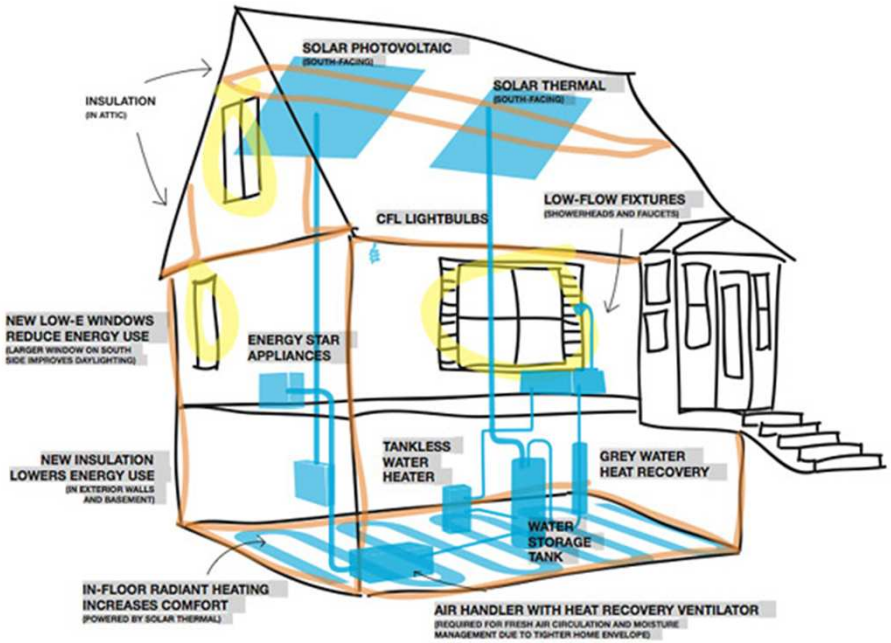
Economic / efficiency information

- ton of newspaper saves about 4,000 kWh

Efficient Building Design

Allison Tipton

- Use Energy Efficient Equipment
  - High Efficiency Heat Pumps, Gas Boilers, Coolers, etc.
  - Low Flow Faucets and Toilets
- Use Renewable Energy Sources
  - Solar or Wind Energy
  - Biomass
  - Minimize Use of Fossil Fuels
- Benefits
  - Saves Money/Costs Less over a Long Time Period
  - Great Indoor Climate
- Disadvantages
  - Initial Cost is more
- Cost Varies depending upon which energy efficient approach taken

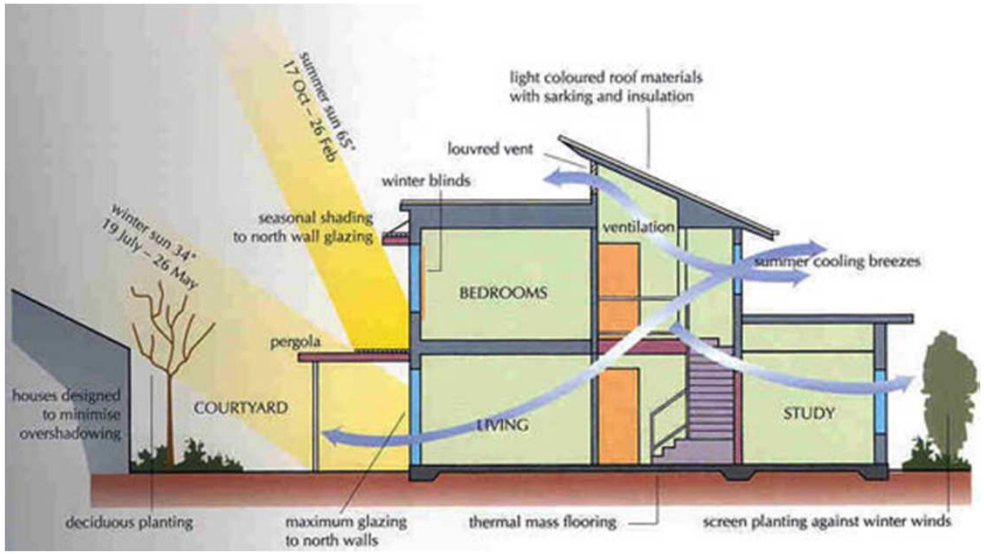


http://www.andymtran.com/

Efficient Building Design

Allison Tipton

- Optimize the positives of the building location
- Bioclimatic Building
  - Shape and Orientation
  - Shading and Wind Protection
- Improved Insulation
  - Floors
  - Walls
  - Roofs
  - Piping
  - Windows and Doors
- Make the building air tight (reduce leaks)
- Controlled Ventilation
  - Allows air to circulate in an air tight building
  - Reduces mold and fungi



http://www.energyfool.com/site/?q=home-efficiency/building-%26-design-subcat

Overview

- Energy Distribution and Storage
- Home and Building Efficiency
- Transportation
  - Automotive
  - Infrastructure

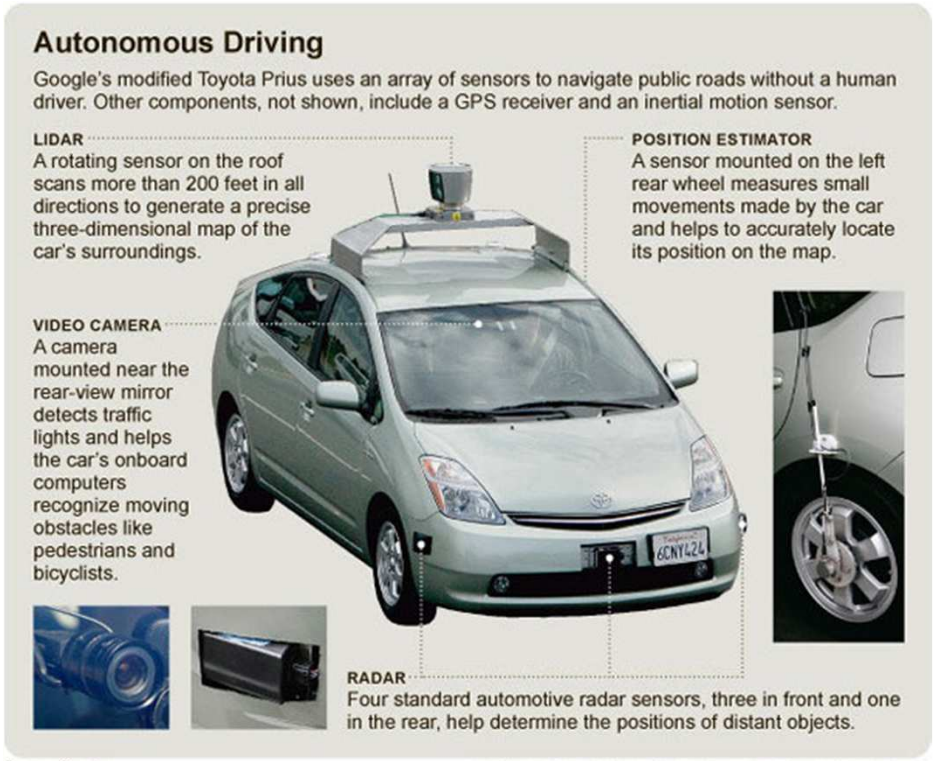
Automatic Drive

Alexander Barr

- Robotic self-driving vehicle
- Robotic drive determines surroundings using radar, lidar, and GPS

Advantages

  - Fewer accidents
  - Reduced parking scarcity
  - Ability to drive with no occupants
  - Cheaper public transit



http://www.botjunkie.com/2010/10/12/googles-autonomous-car-takes-to-the-streets/

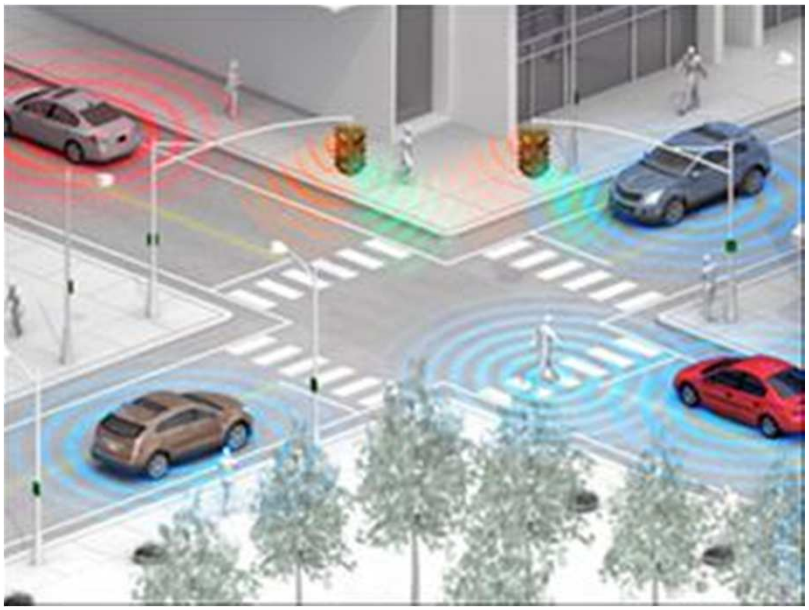
Automatic Drive

Alexander Barr

Disadvantages

- Cost of technology
- Tension between cars and pedestrians

- Economics
  - Hardware is expensive
  - Lidar sensor alone $80,000
  - Equipment total $250,000+

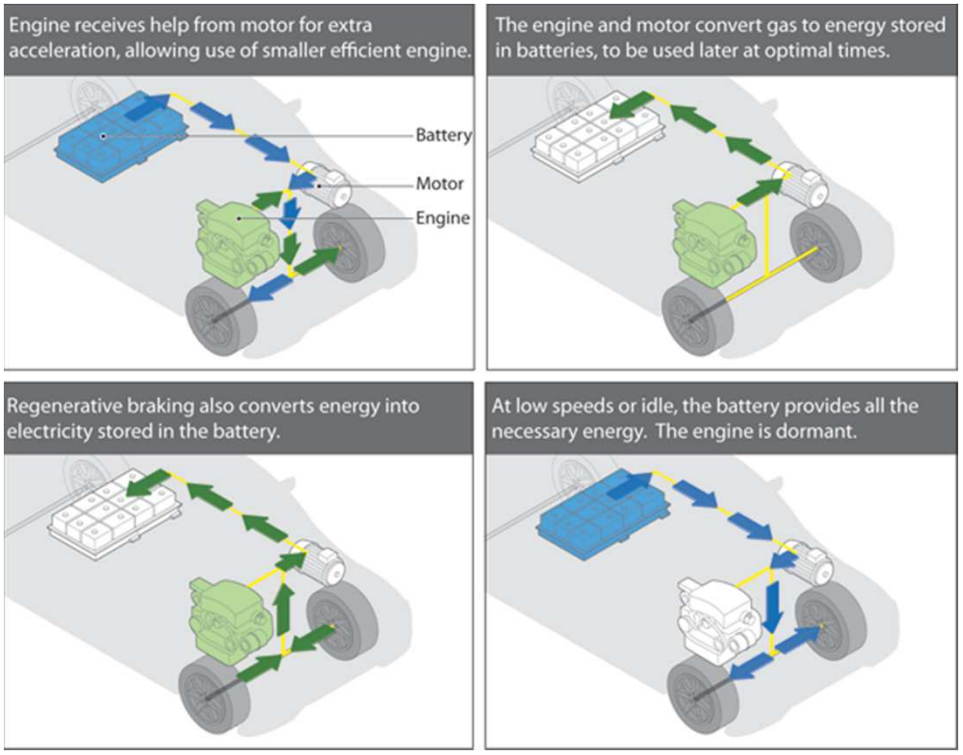


http://www.kbb.com/car-news/all-the-latest/gm-says-autonomous-vehicle-technology-could-be-here-by-2020//

Hybrids

Meredith Nix

- Vehicle that uses 2+ energy sources to power it
  - Usually electricity (HEVs)
  - Internal combustion engine and electric motors



http://www.hybridcars.com/files/Hybrid_FINALRevisedMar2009b.gif

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Hybrids

Meredith Nix

Advantages

- "Fuel efficient"—varies with the model, but about average of 10 mpg city better than gasoline cars
- Less greenhouse gas emissions
- Tax breaks

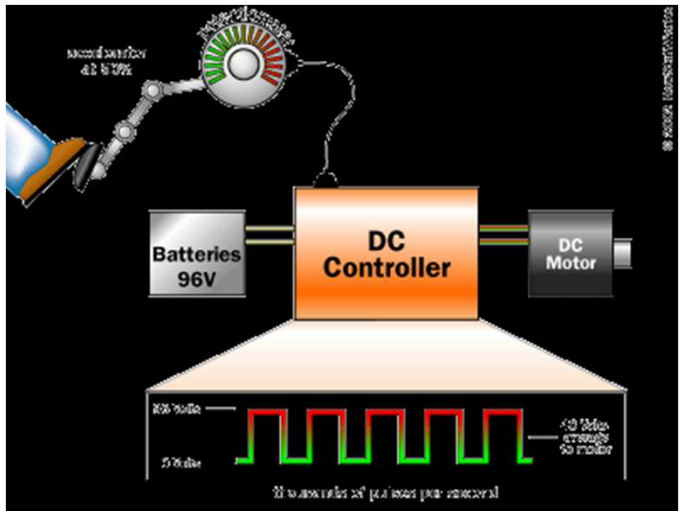
Disadvantages

- Cost—can be up to $10,000 more than gasoline car
- Increased maintenance

Electric Vehicles

Trent Weaver

- Basic Idea
  - A battery powers an electric motor
  - A controller controls the motor
- Technology
  - Old idea but still effective
  - AC and DC motors can be used
  - Weight directly affects performance and range
  - Expensive lithium ion batteries give a longer range
  - Light materials like carbon fiber can reduce weight



http://auto.howstuffworks.com/electric-car2.htm

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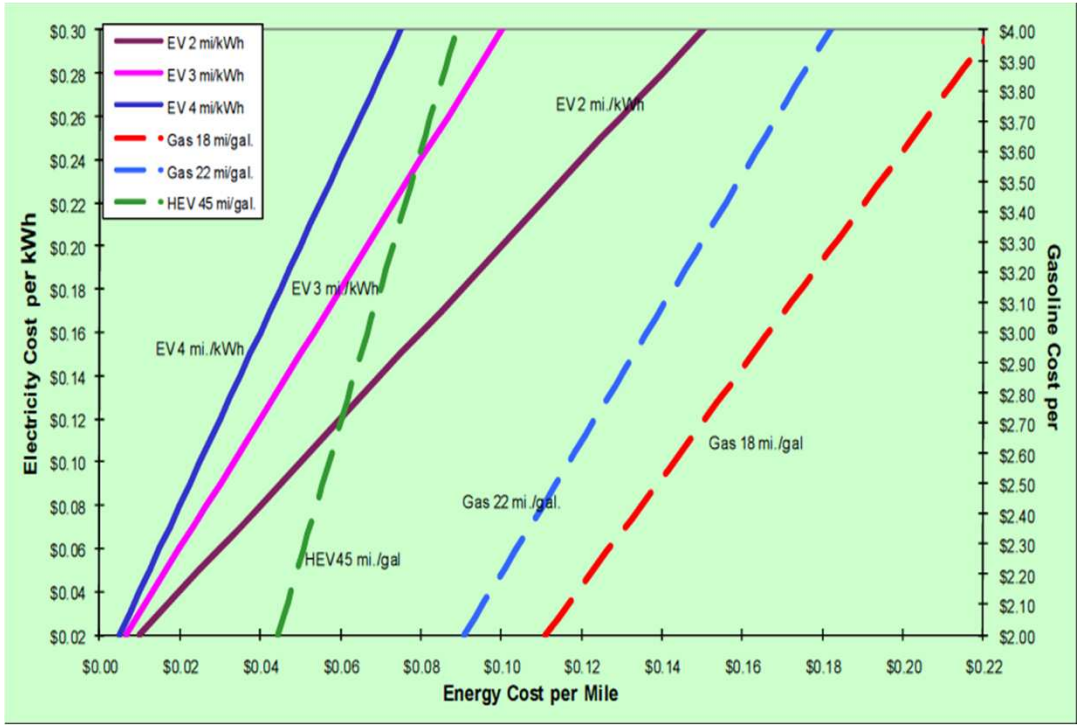
Electric Vehicles

Trent Weaver

- Economic information
  - 3 to 6 cent per mile
  - Depends on the price of electricity
- Advantages
  - Simple concept
  - No emissions from the car
  - Good acceleration
  - Government incentives
- Disadvantages
  - High initial cost
  - Battery replacement Cost
  - Low range
  - Producing electricity causes emissions



http://avt.inel.gov/pdf/fsev/costs.pdf

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Gaseous Generation

- Compress natural gas
- Stored and distributed at high pressures
- Energy efficiency about equal to gasoline engines
- Advantages:
  - Cleaner than coal and gasoline
  - Widely available
- Disadvantages:
  - Less mileage
  - Still releases CO_2

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CNG/LPG

Tim Barnhill

- Compressed Natural Gas
  - Methane compressed to <1% standard volume
  - Fuels traditional internal combustion engine
- Advantages
  - Costs 30% less than gasoline
  - Less auto-ignition on hot surfaces
  - Less pollution and greater efficiency
- Disadvantages
  - Vehicle tanks require more space
  - Engine conversion expensive

http://upload.wikimedia.org/wikipedia/commons/e/e0/Carroagas.jpg

CNG/LPG

Tim Barnhill

- Liquefied Petroleum Gas (Liquid Propane)
  - Also referred to as “autogas”
  - Made by refining “wet” natural gas
  - Evaporates quickly, stored in pressurized gas cylinders

Advantages

- 35% less CO_2 emissions than gasoline
- Less expensive than gasoline

Disadvantages

- Limited availability
- Fewer miles on tank of fuel

http://upload.wikimedia.org/wikipedia/commons/5/52/Autogas_station.jpg

Bike Friendly Development

Andrea Eggleston

- Infrastructure for bicycles
  - Cycle tracks
  - Traffic lights for bikes
  - Involves city reconstruction
    - Muenster after WWII
      - 43% bike travel today
- Bicycle types
  - 5 speed
    - Not designed for speed or off road use
  - Wheel fenders to cover rain spray
  - Built-in locks on rear wheel

http://www.geo.sunysb.edu/bicycle-muenster/index.html#transportation

Bike Friendly Development

Andrea Eggleston

Advantages

- Reduce CO_2 production
- Reduce brown smog
- Reduce traffic
  - Biking: 72 people/90 m^2
  - Car: 72 people/1000 m^2
- Health benefits

Disadvantages

- Change infrastructure
- Change driver mentality
- Short range excursions
- Less protection in accidents

High Speed Trains

Mazin Al Masrouri

- Operate significantly faster than normal speed trains.
  - Usually used for passenger travel.

http://goo.gl/eQW6E

- Advantages
  - Cleaner air and less sprawl
  - Convenience and mobility
  - Travel time
  - New jobs and economic growth
  - Cost effective

High Speed Trains

Mazin Al Masrouri

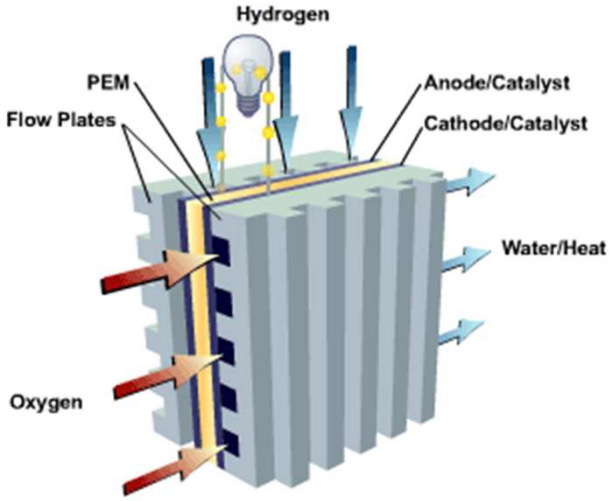
- Disadvantages
  - High construction and maintenance cost
  - Tickets are expensive
  - Geographical terrain
  - Safety

- Economics
  - Every dollar of cost yields between $1.70 and $2.50 of benefits

Hydrogen Fuel Cells

Keith Michaud

- Concept
  - Catalyst oxidizes Anode producing ion+e^-
  - Electrons flow through load
  - Ions pass through Electrolyte to Cathode and join e^-
- Advantages
  - Hydrocarbon Free
  - Fuel abundance
  - Direct fuel-to-power conversion
  - Cheap fuel

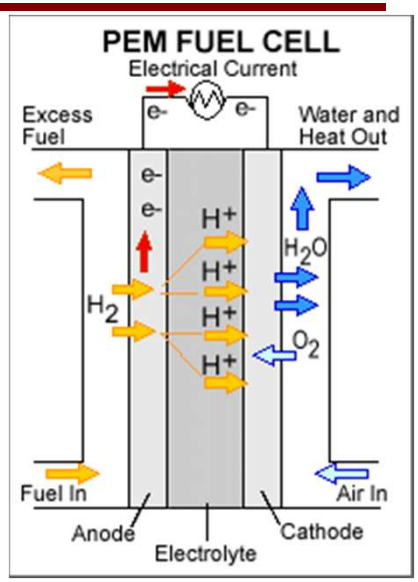


http://goo.gl/JD2RZ

Hydrogen Fuel Cells

Keith Michaud

- Disadvantages
  - Lack of infrastructure
  - System complexity
  - High initial cost (materials)
- Economics
  - 22-45% efficient tank-to-wheel
  - Nearly self heating at steady state operating conditions (efficiency increases with temperature)
  - $30-35/W in commercial systems



http://goo.gl/lLfF7

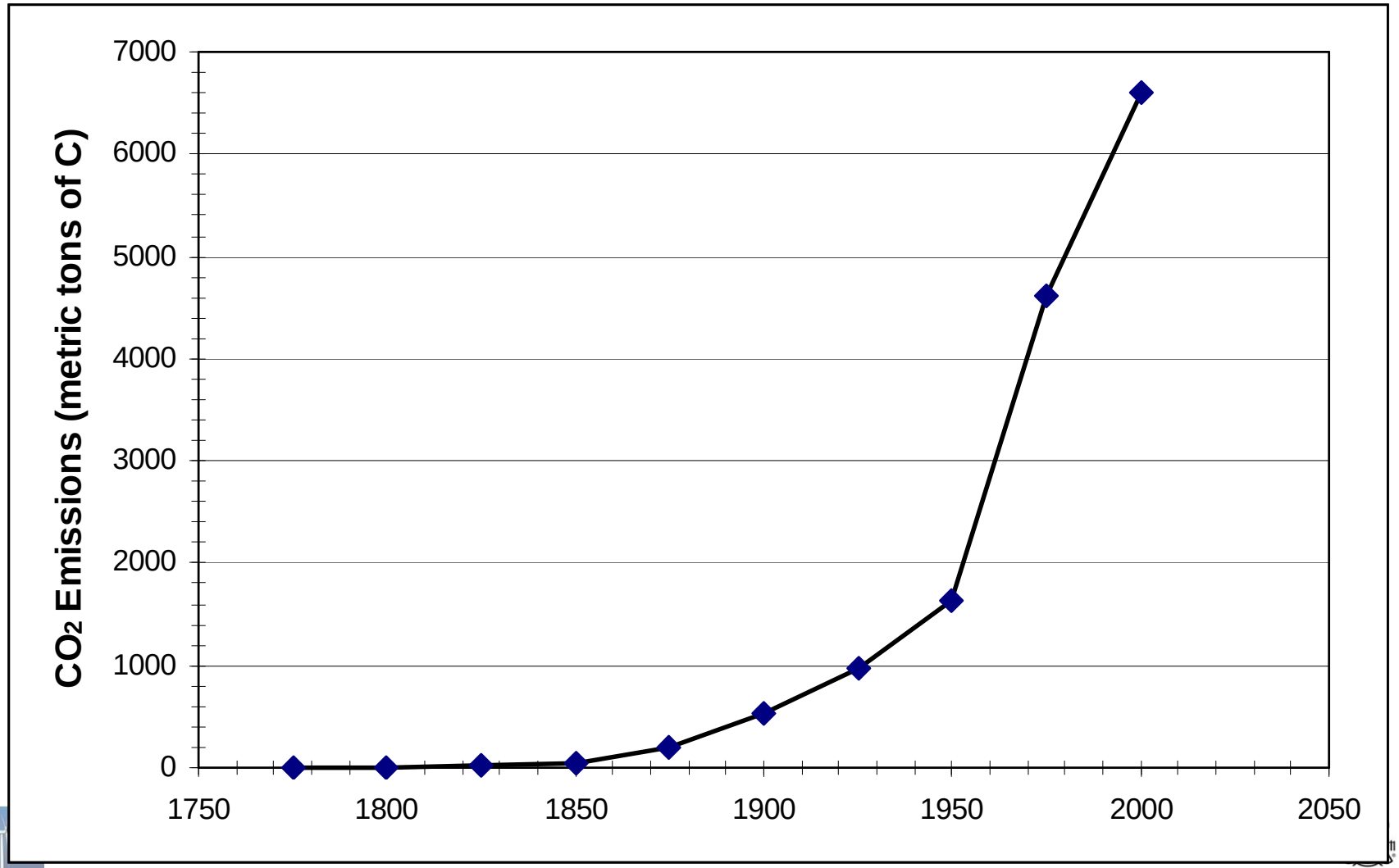
Motivation: Why the need for different forms of energy?

- Growing Demand
- Limited Resources
- Energy Independence
- Global Warming
- Regional Environmental Problems
- Communities where energy is used.
- Regions where energy is obtained.
- (e.g., Arctic National Wildlife Refuge)
- Economics

Questions Around Global Warming

- Does CO_2 and other gases trap heat, much like a green house?
- Are levels of CO_2 and other "greenhouse gases" rising in the atmosphere?
- Is the Earth warming?
- Are oceans becoming warmer and more acidic?
- Are sea levels rising? Snow cover falling?
- Are humans causing any of these changes?
- How will climate change over the 21st century?
- Is the threat real enough to warrant an immediate response?

Global CO_2 Emissions



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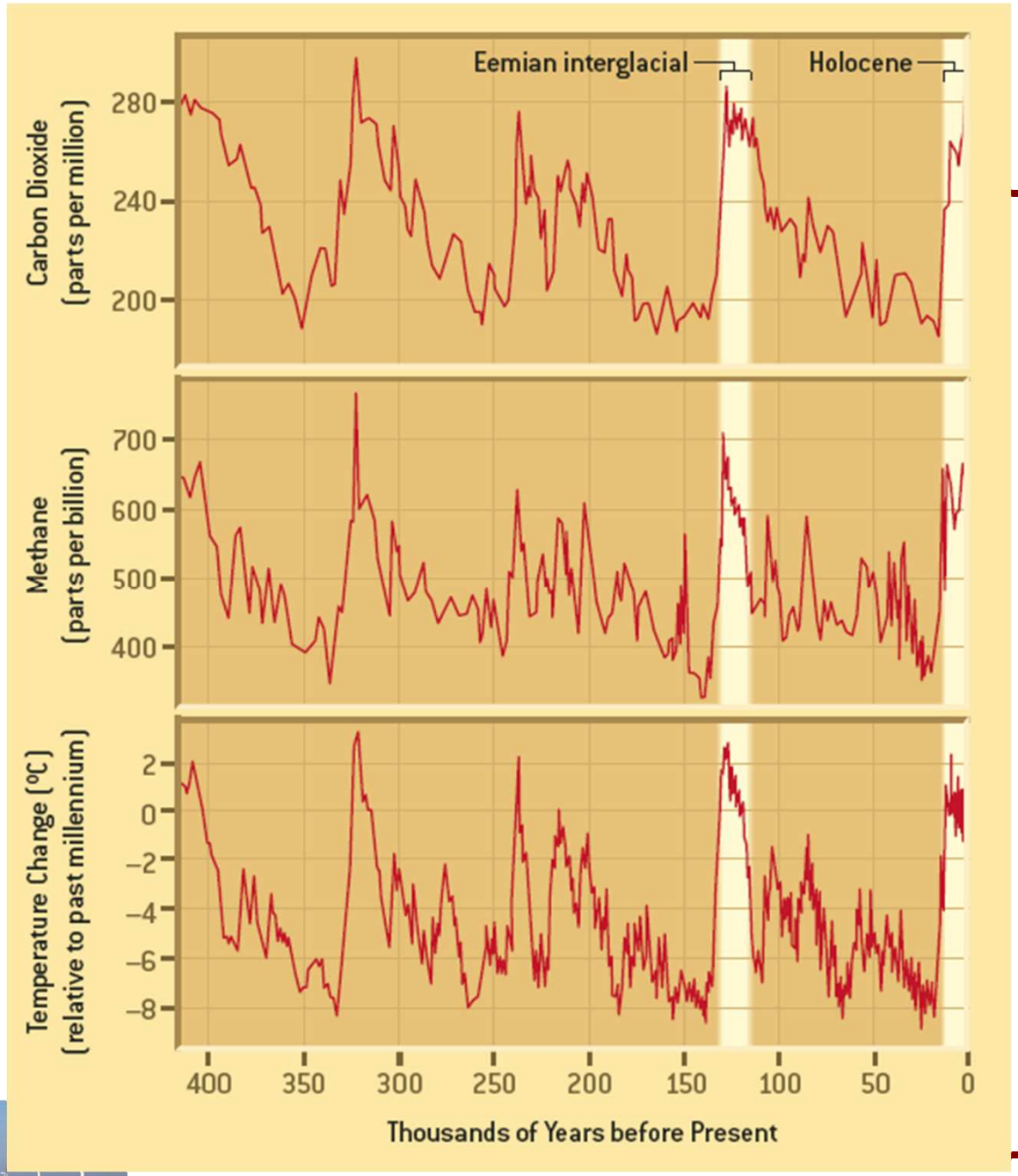
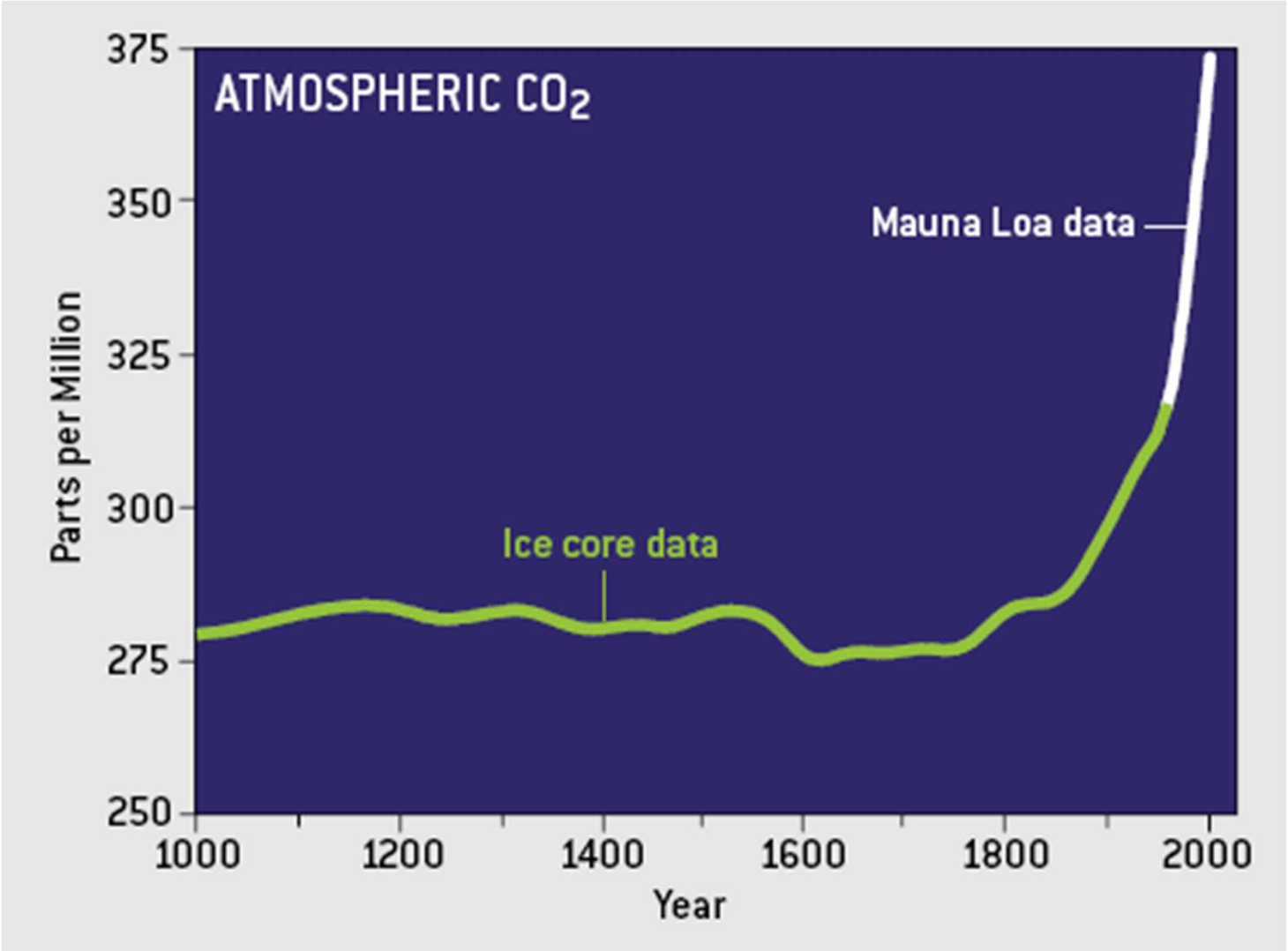


40,000 Years of Climate Change

"*A Plan to Keep Cargon in Check,*" R. Socolow and S. Pacala, Scientific American, 2004.

Atmospheric CO_2 Levels



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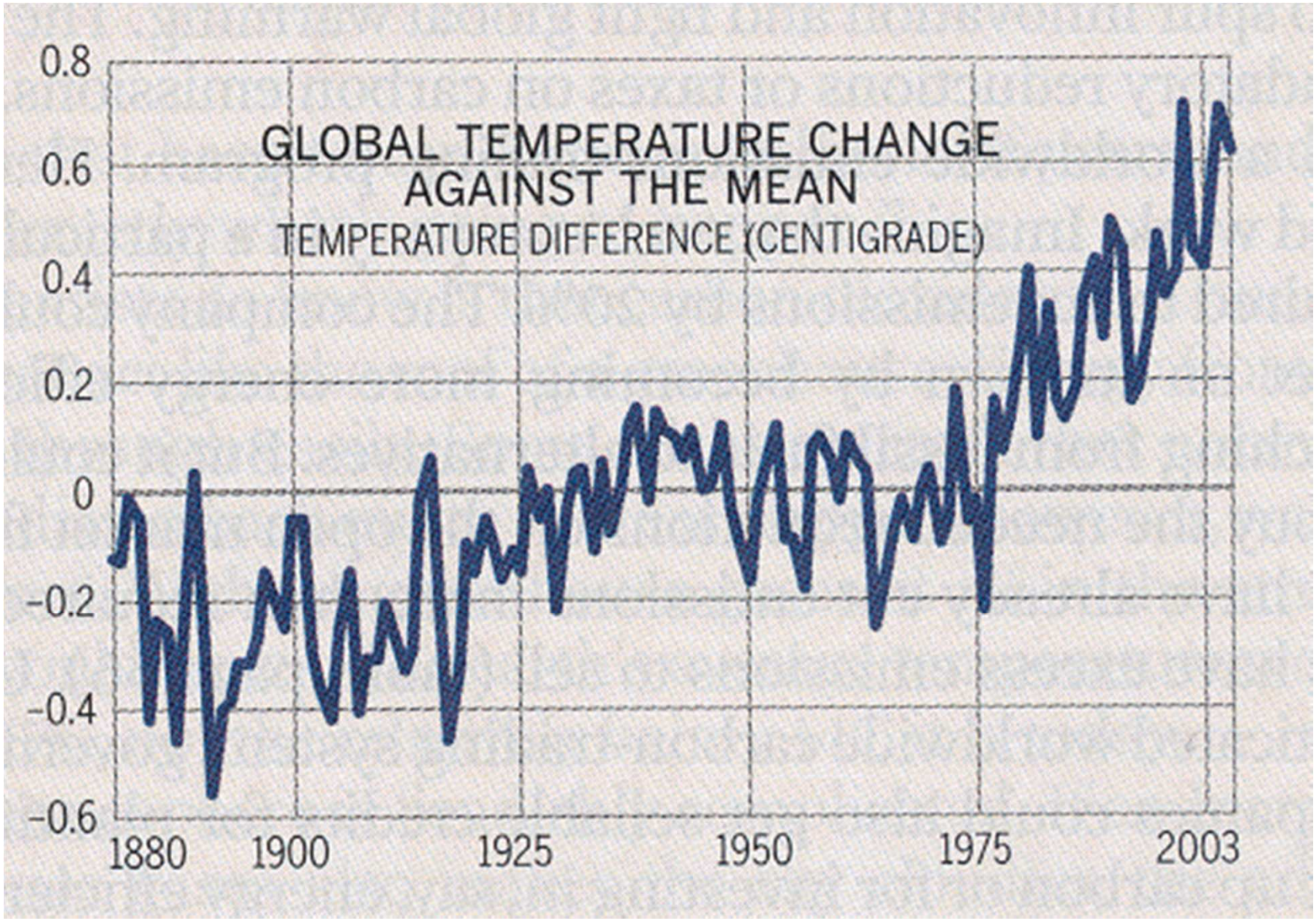

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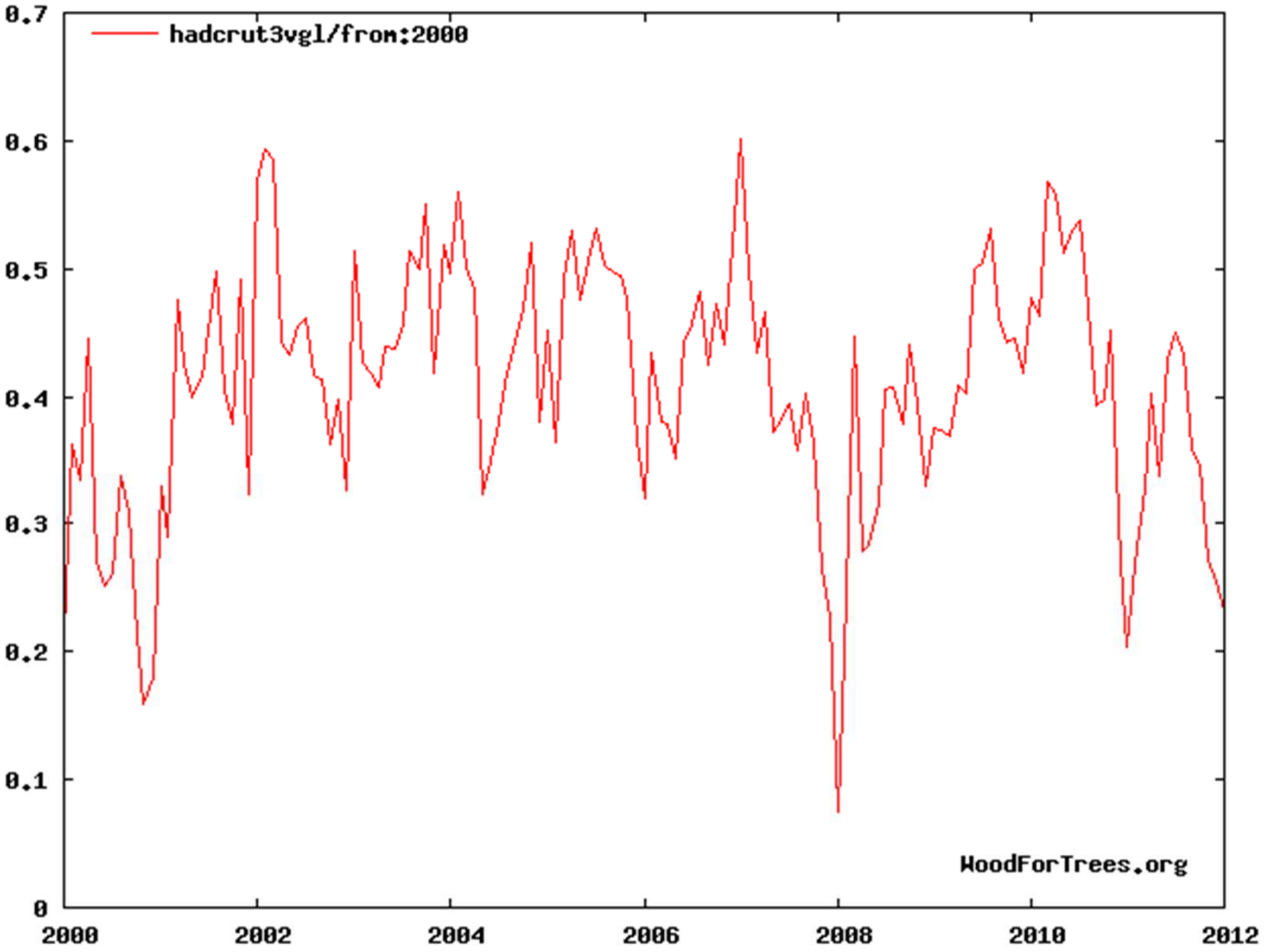
Global Temps from 2000



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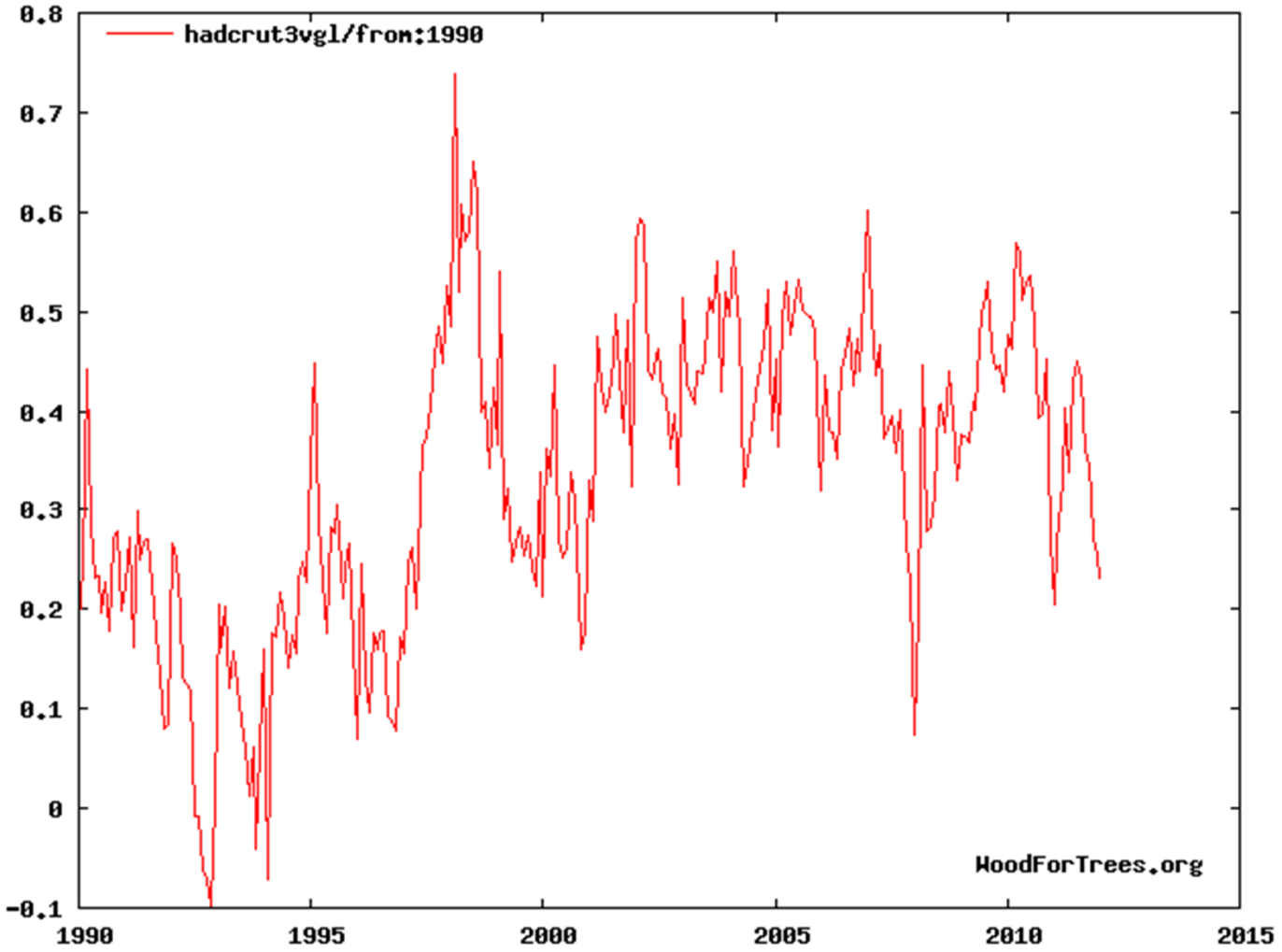
Global Temps from 1990



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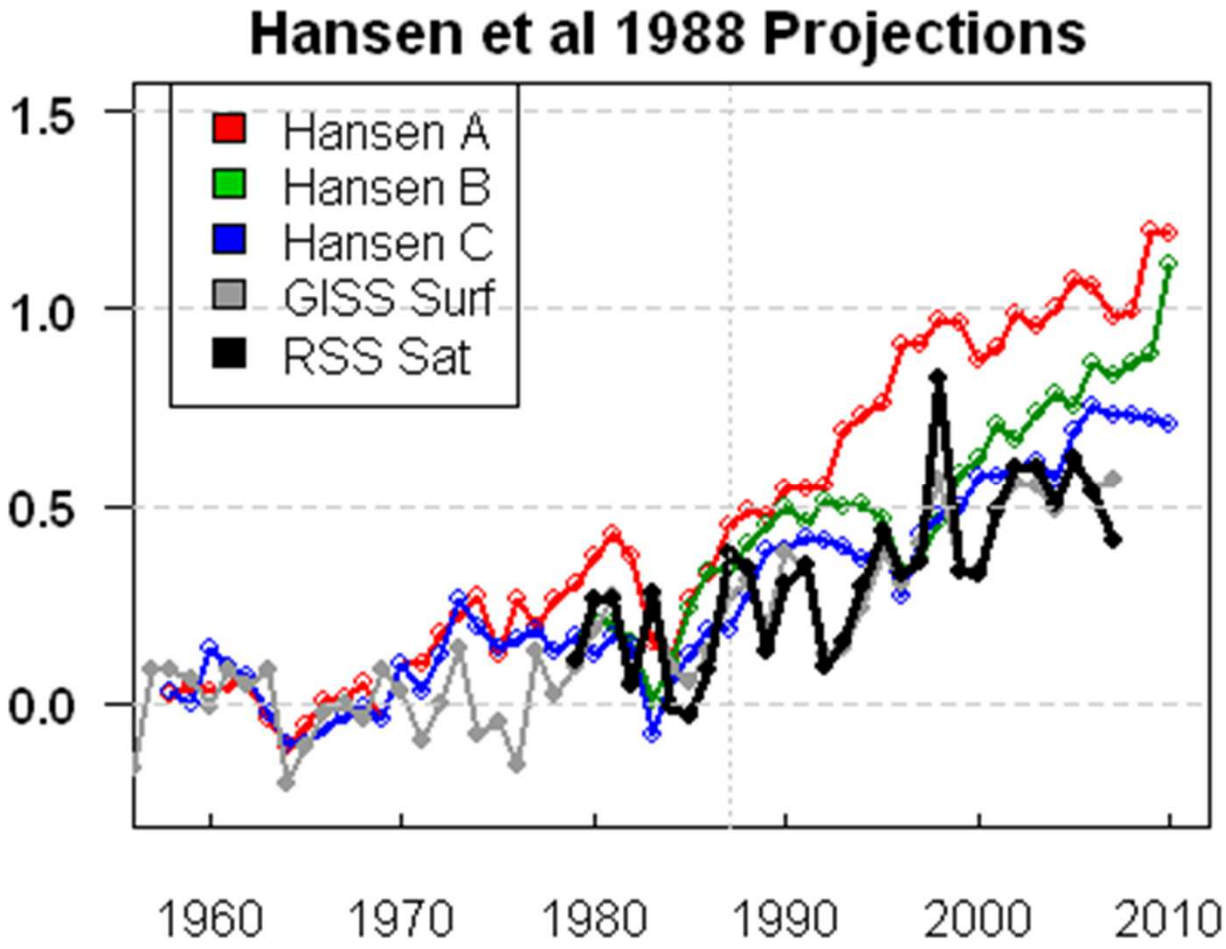
Models?



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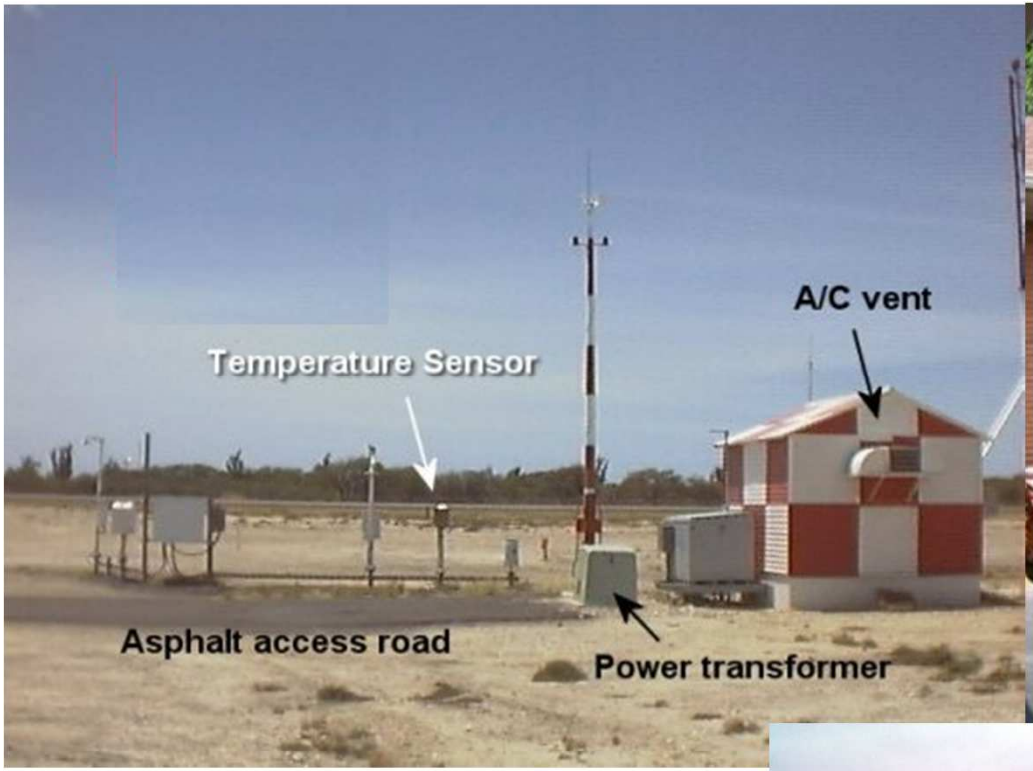
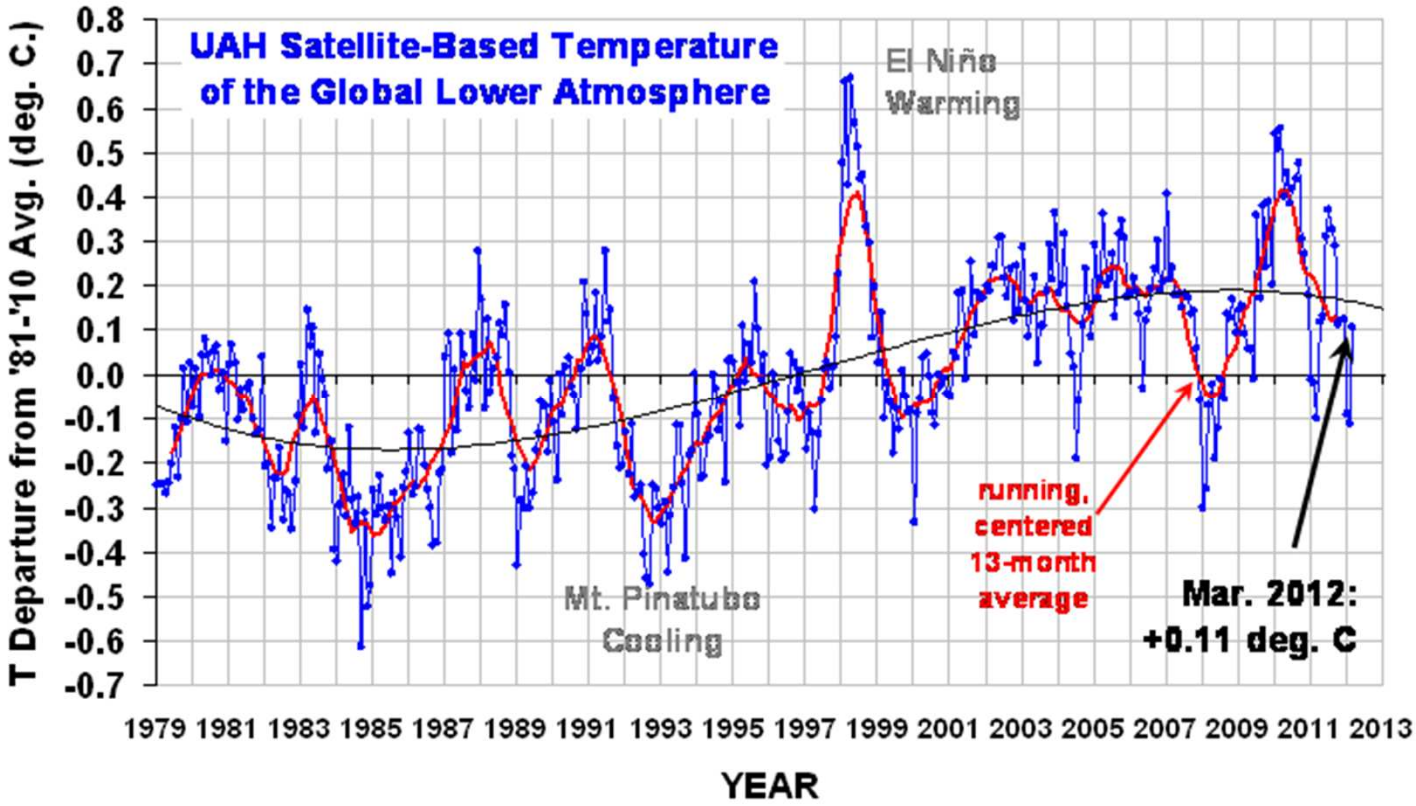
Sensor Network



Satellite Temperature Records



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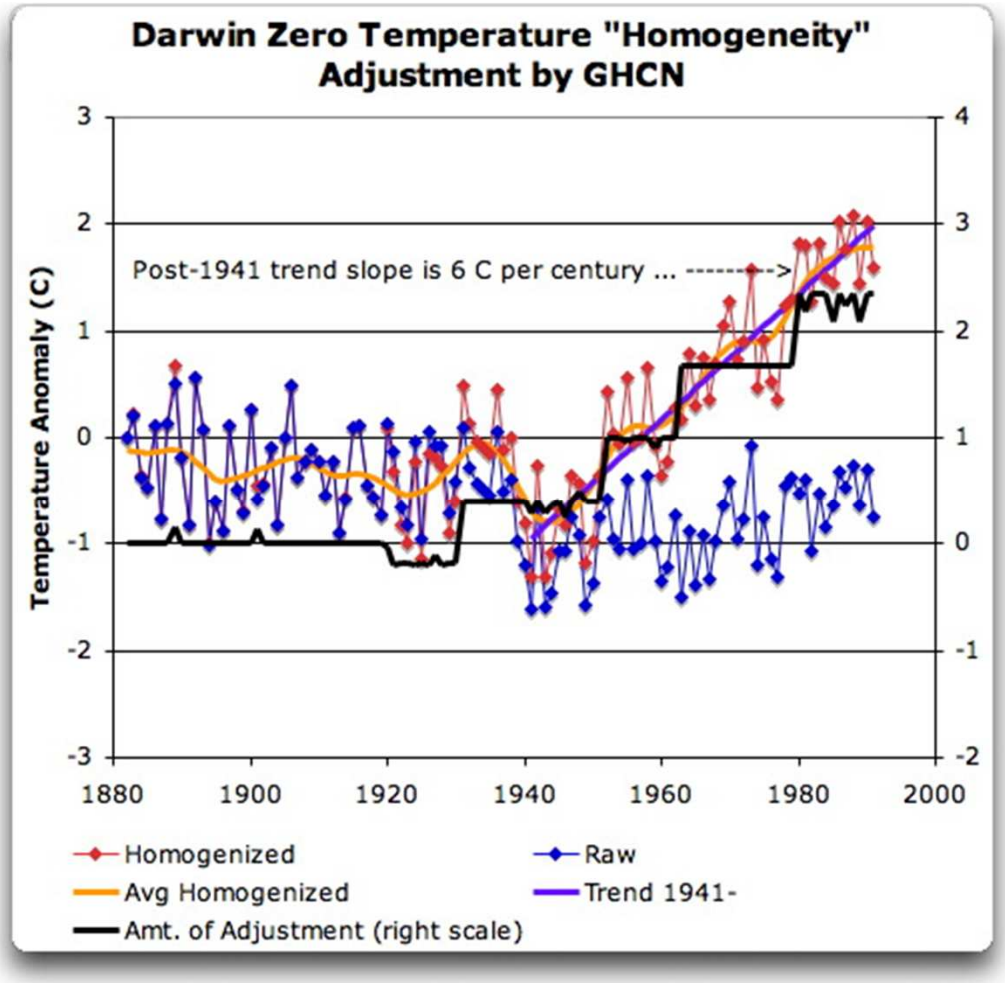
Homogenization of Data



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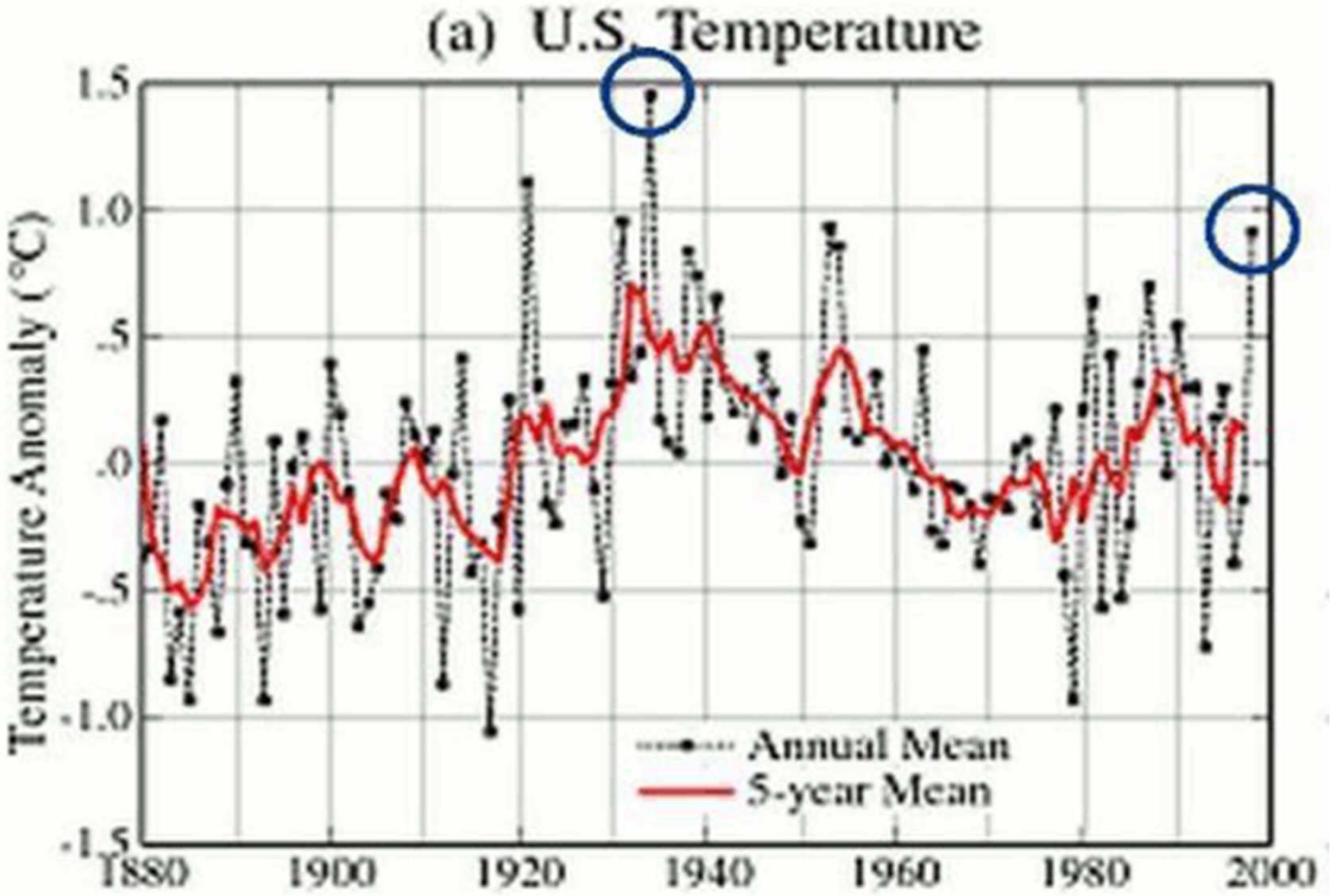
Homogenization in 2000



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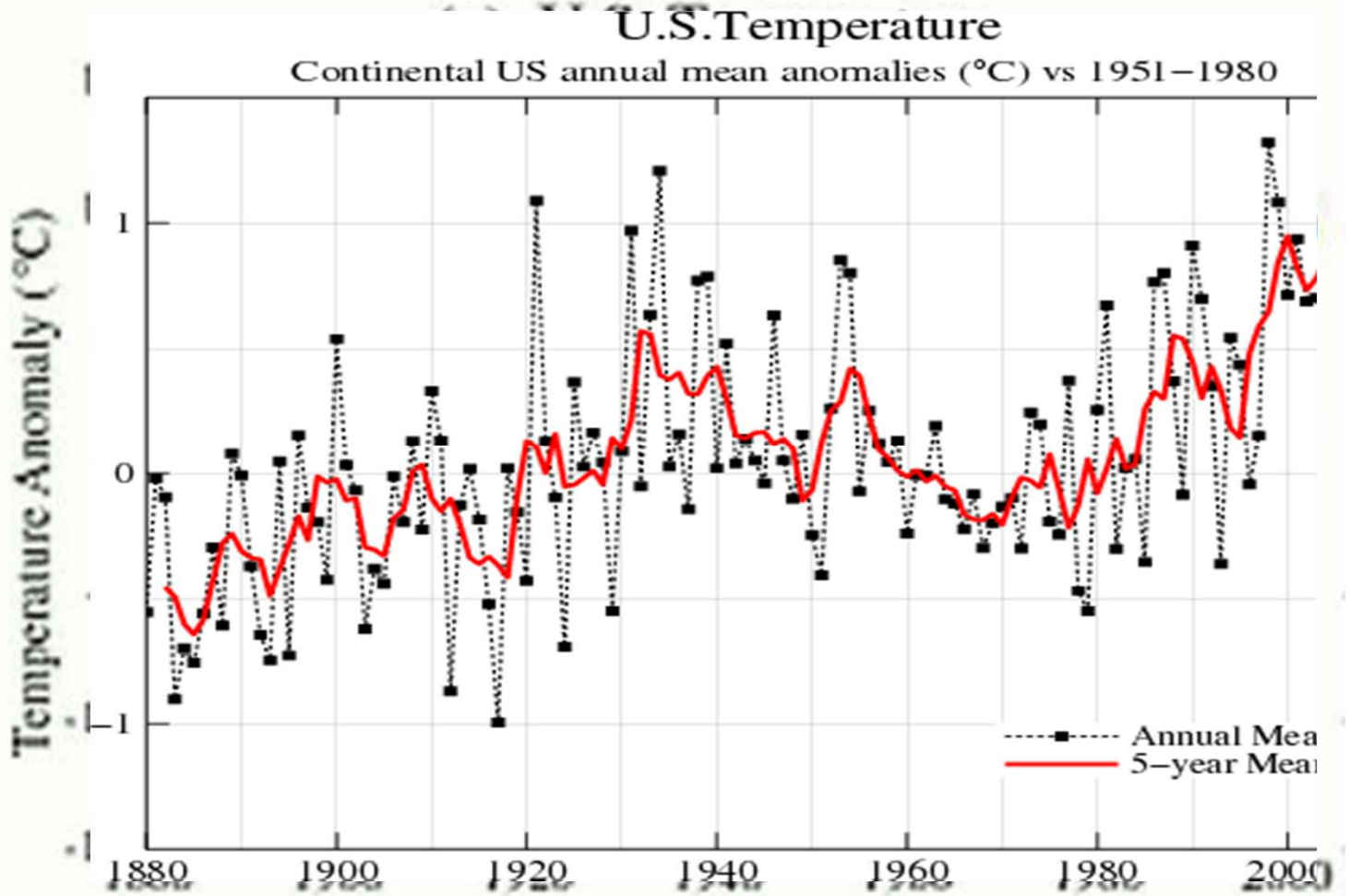
Homogenization in 2000



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"Last winter was so cold! I don't notice any global warming!"

Global warming is ubiquitous, but its magnitude so far is only about one degree Fahrenheit. Day-to-day weather fluctuations are roughly 10 degrees F. Even averaged over a season this natural year-to-year variability is about two degrees F, so global warming does not make every season warmer than a few decades ago. But global warming already makes the probability of a warmer than "normal" season about 60 percent, rather than the 30 percent that prevailed from 1950 to 1980.

"The warming of the past century is just a natural rebound from the little ice age."

Any rebound from the European little ice age, which peaked in 1650–1750, would have been largely complete by the 20th century. Indeed, the natural long-term climate trend today would be toward a colder climate were it not for human activities.

"Isn't human-made global warming saving us from the next ice age?"

Yes, but the gases that we have added to the atmosphere are already far more than needed for that purpose.

"*A Plan to Keep Cargon in Check,*" R. Socolow and S. Pacala, Scientific American, 2004.

"The surface warming is mainly urban 'heat island' effects near weather stations."

Not so. As predicted, the greatest warming is found in remote regions such as central Asia and Alaska. The largest areas of surface warming are over the ocean, far from urban locations [see maps at www.giss.nasa.gov/data/update/gistemp]. Temperature profiles in the solid earth, at hundreds of boreholes around the world, imply a warming of the continental surfaces between 0.5 and one degree C in the past century.

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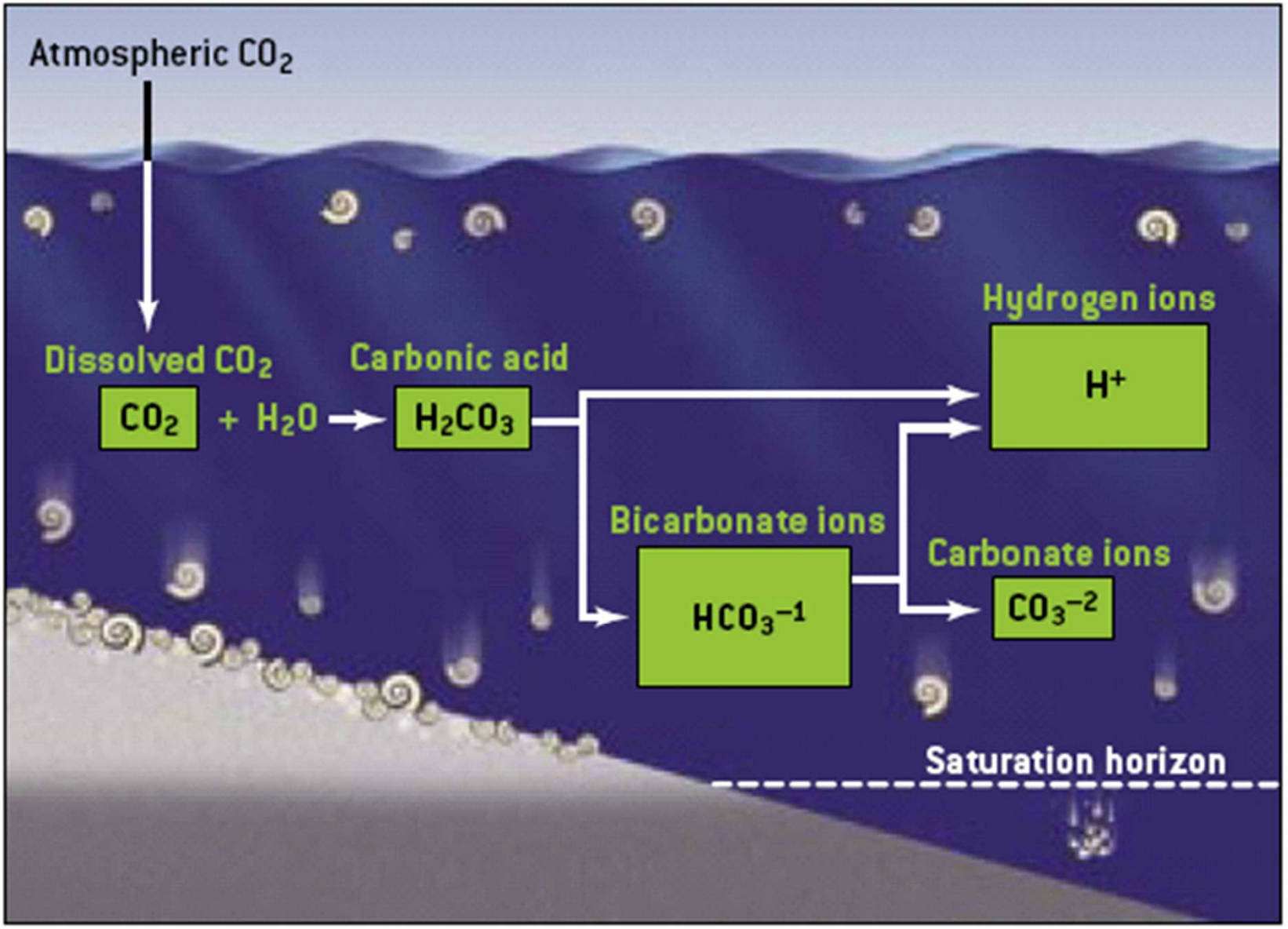
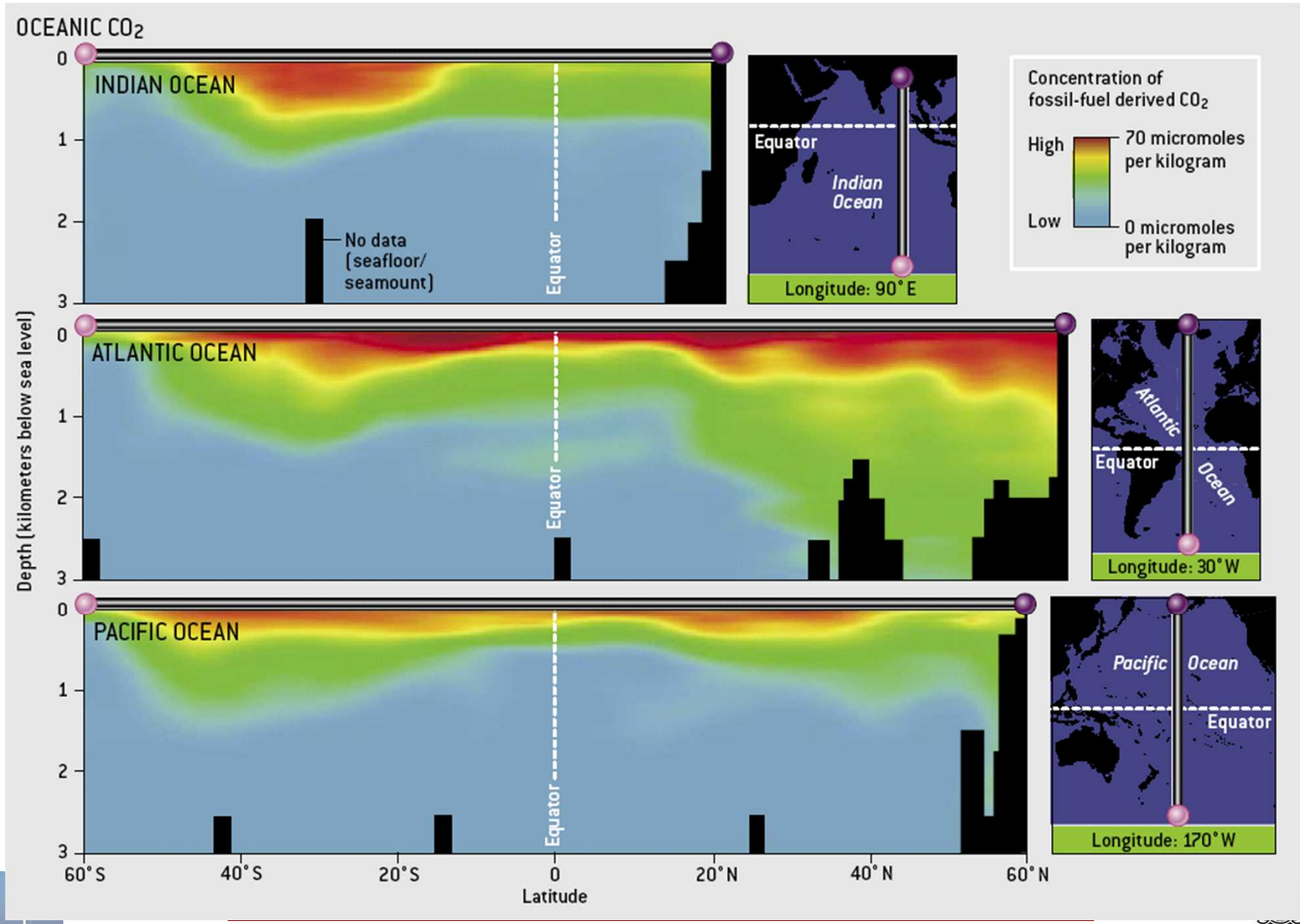
Ocean Chemistry



Ocean CO_2 Concentrations



"*The Dangers of Ocean Acidification*," S. Doney, Scientific American, 2007.

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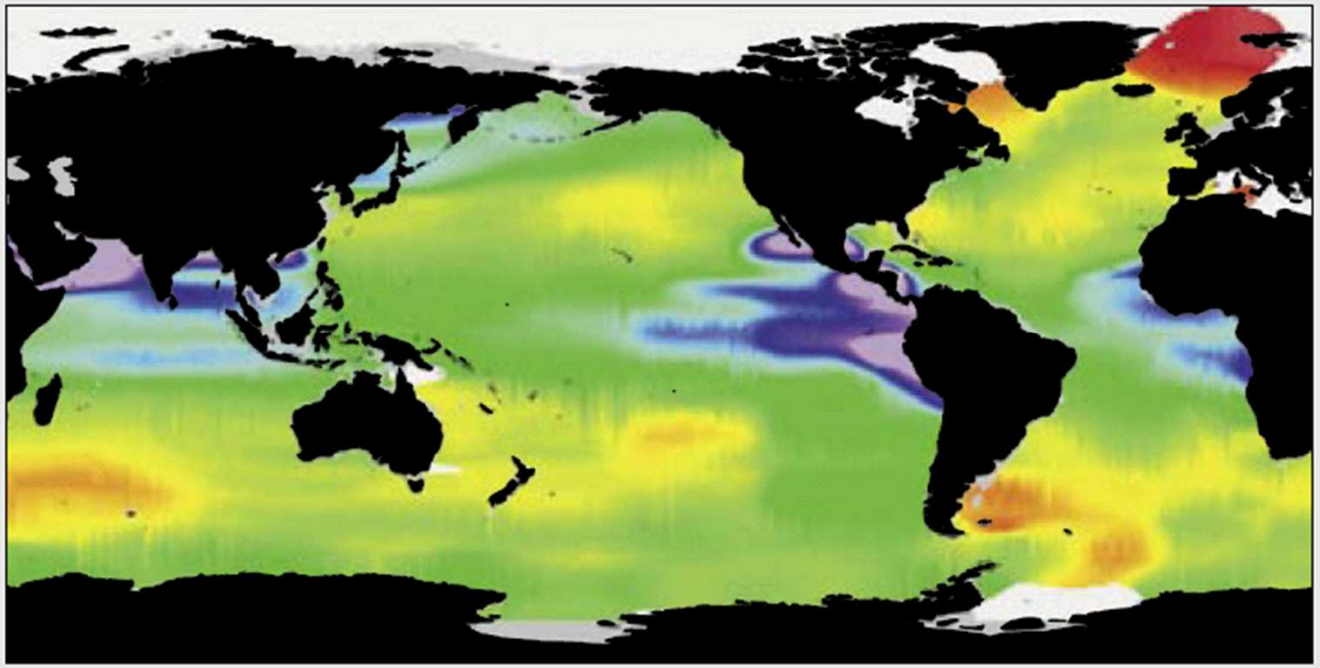
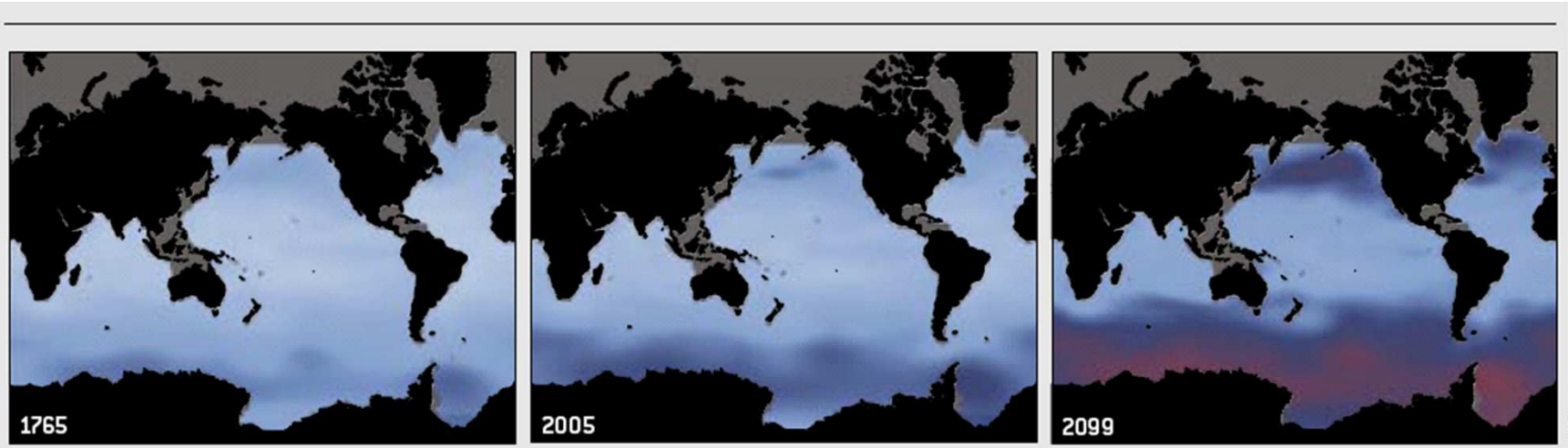
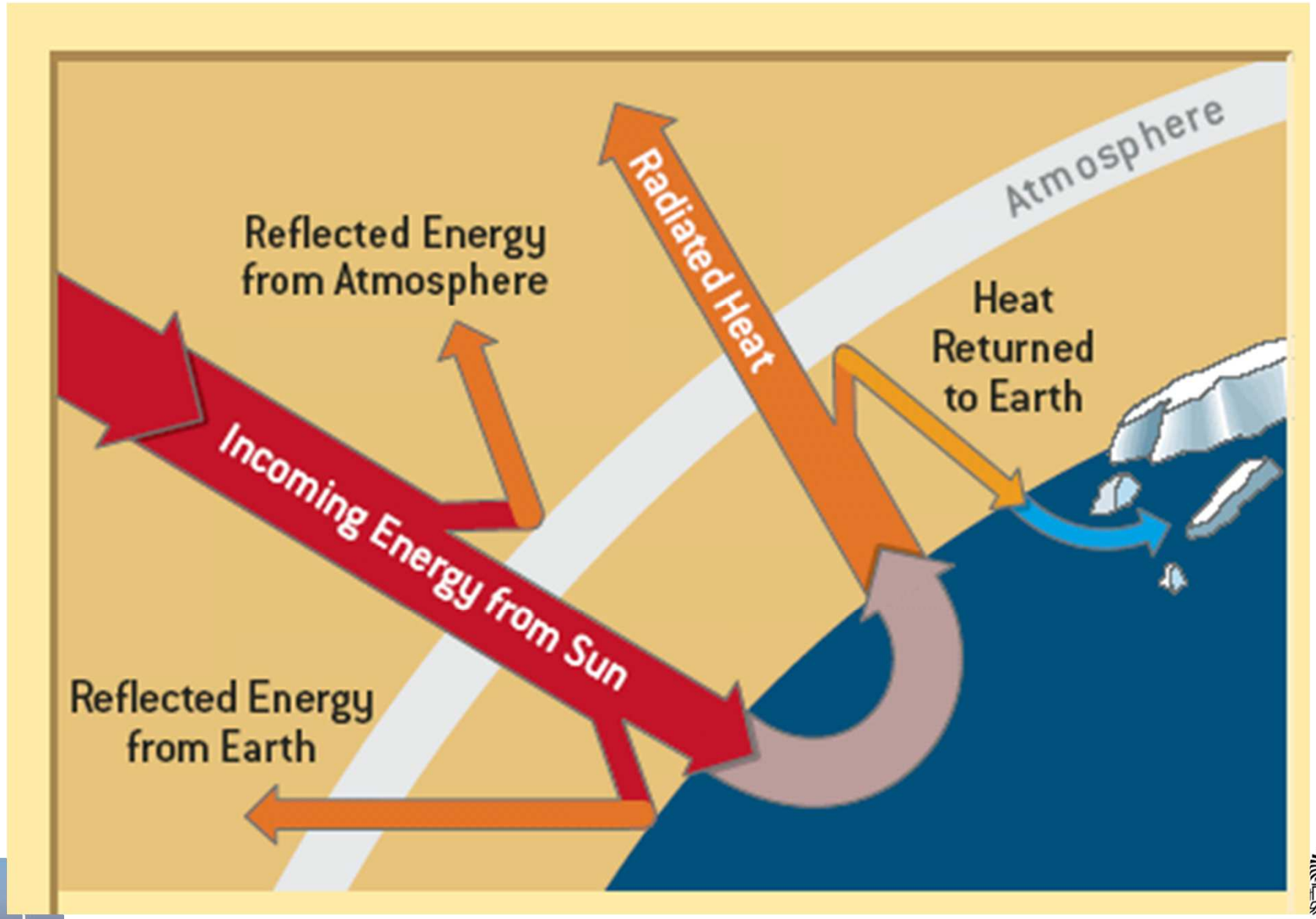
pH Levels



Aragonite Levels



Solar Energy Balance



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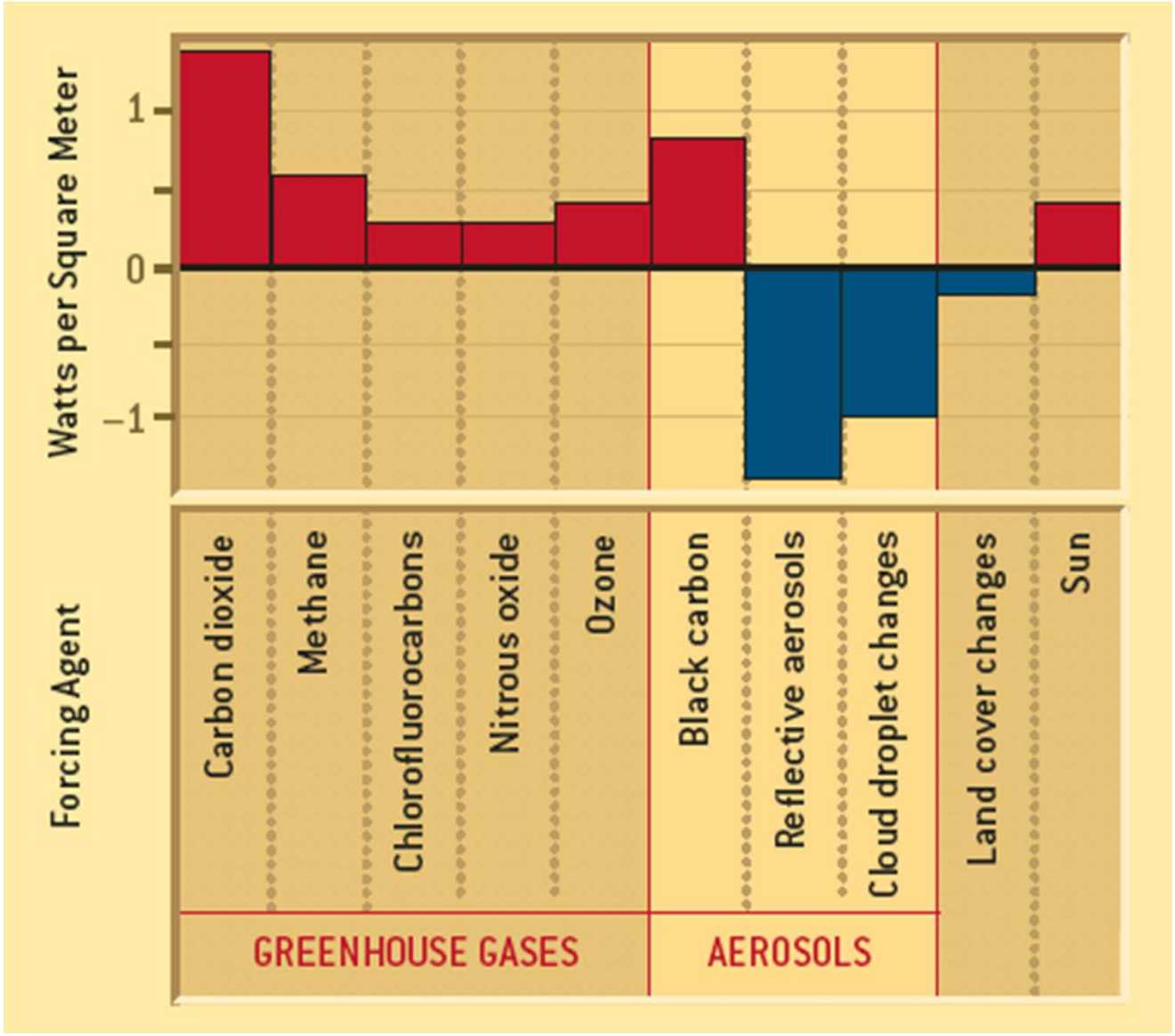
Climate Forcing



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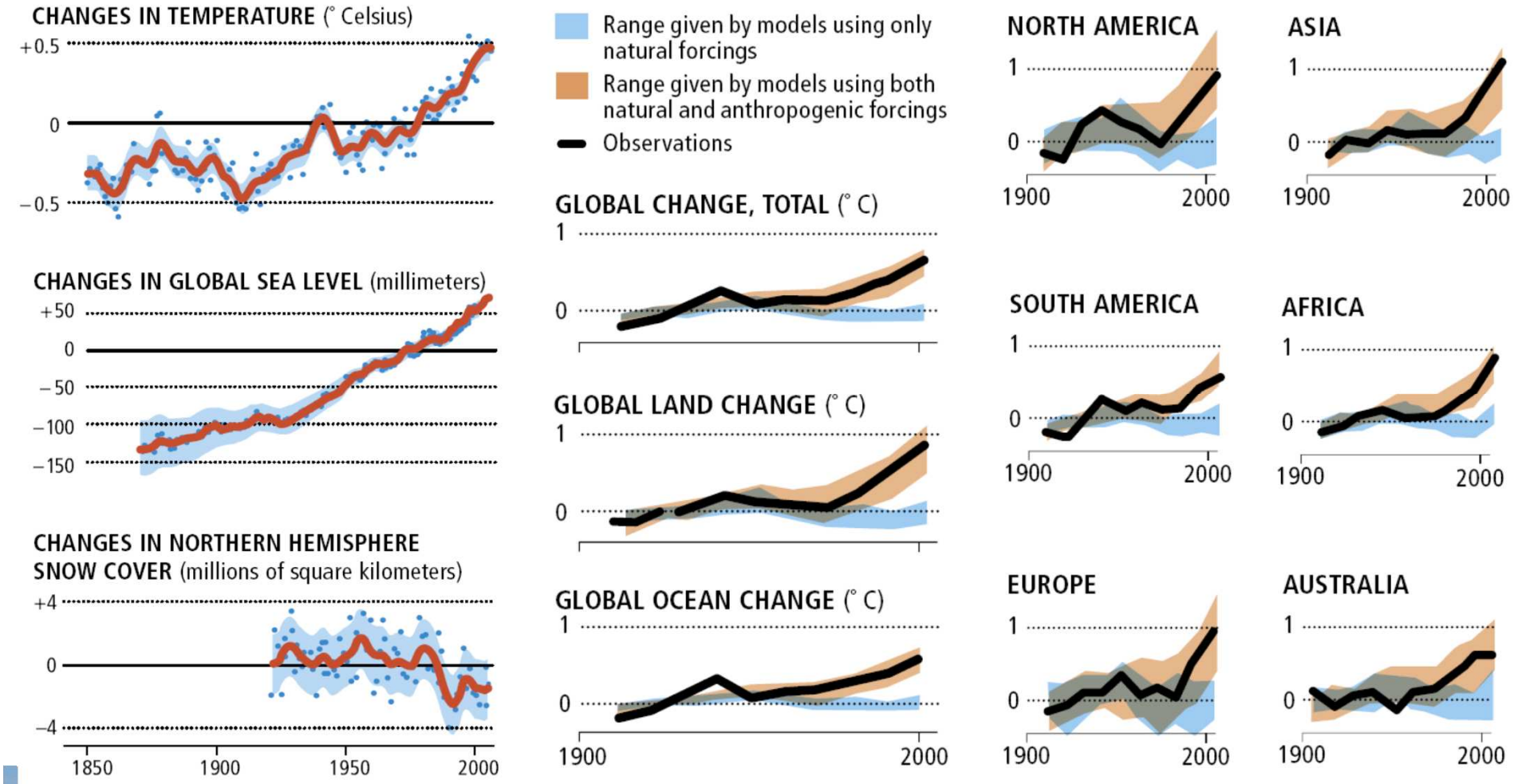
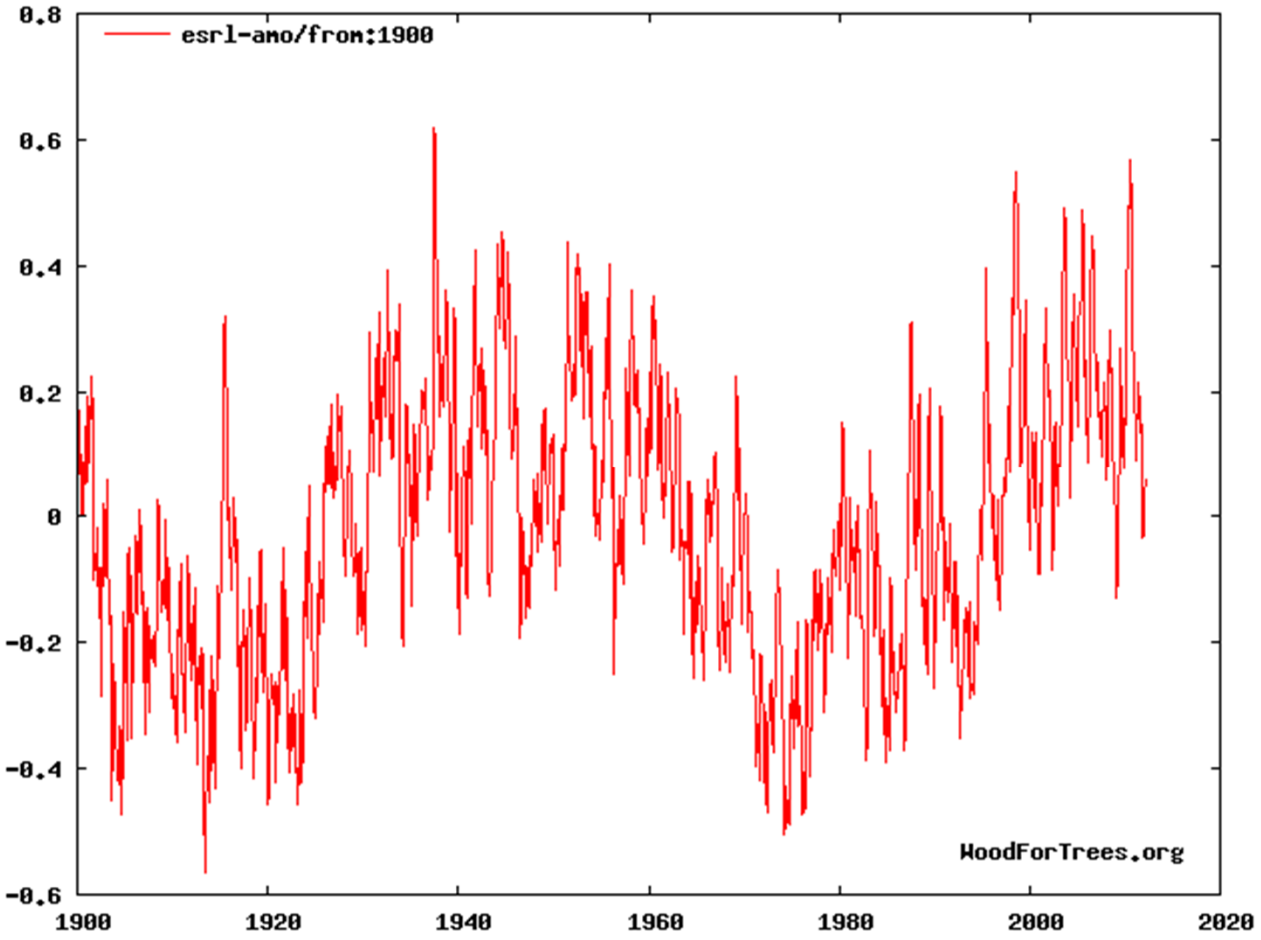
Global Changes

Oceans absorb 80% of the heat added to the climate



"The Physical Science Behind Climate Change" W. Collins, et al., Scientific American 2007

Global Ocean Temperature Index



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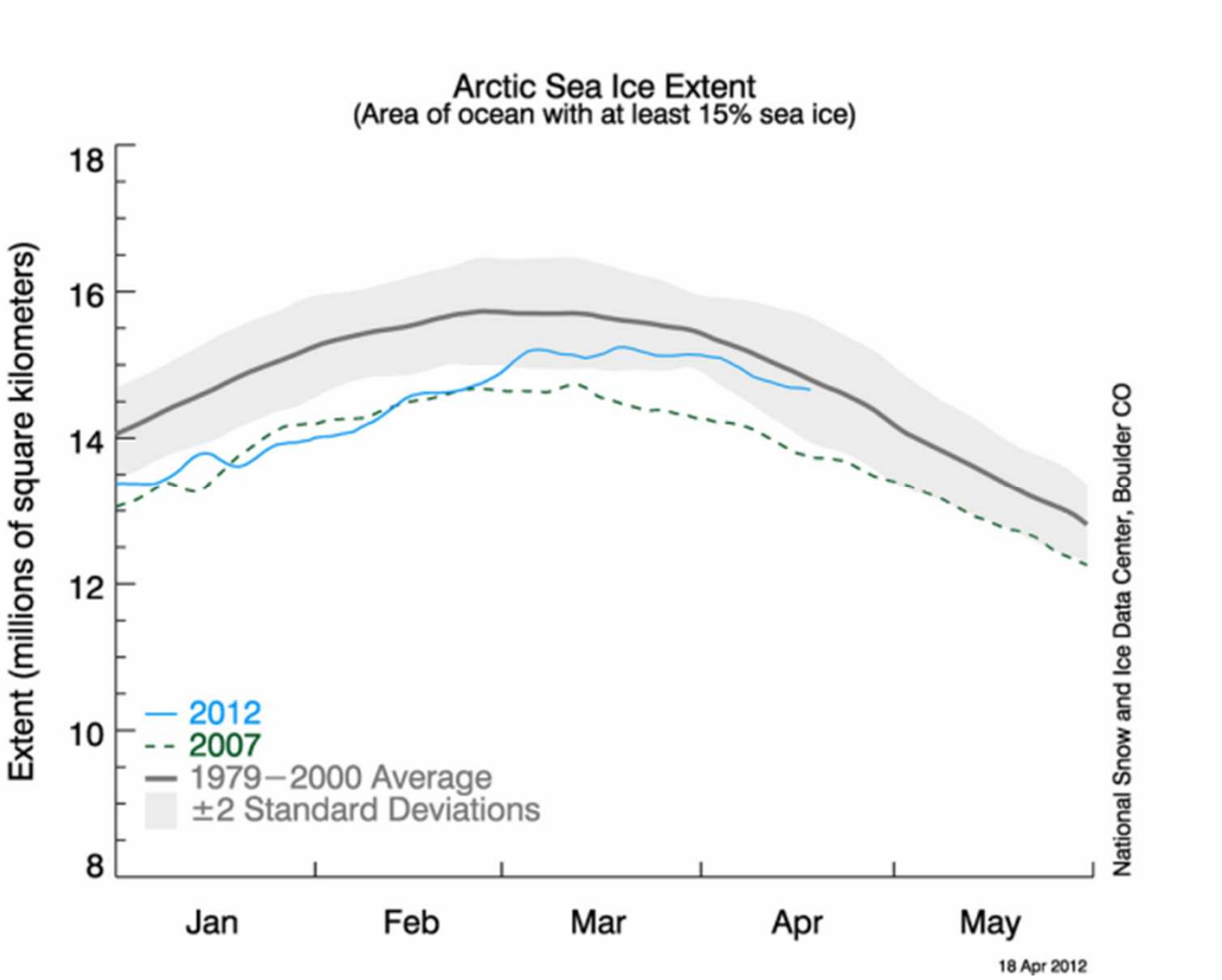
Arctic Sea Ice



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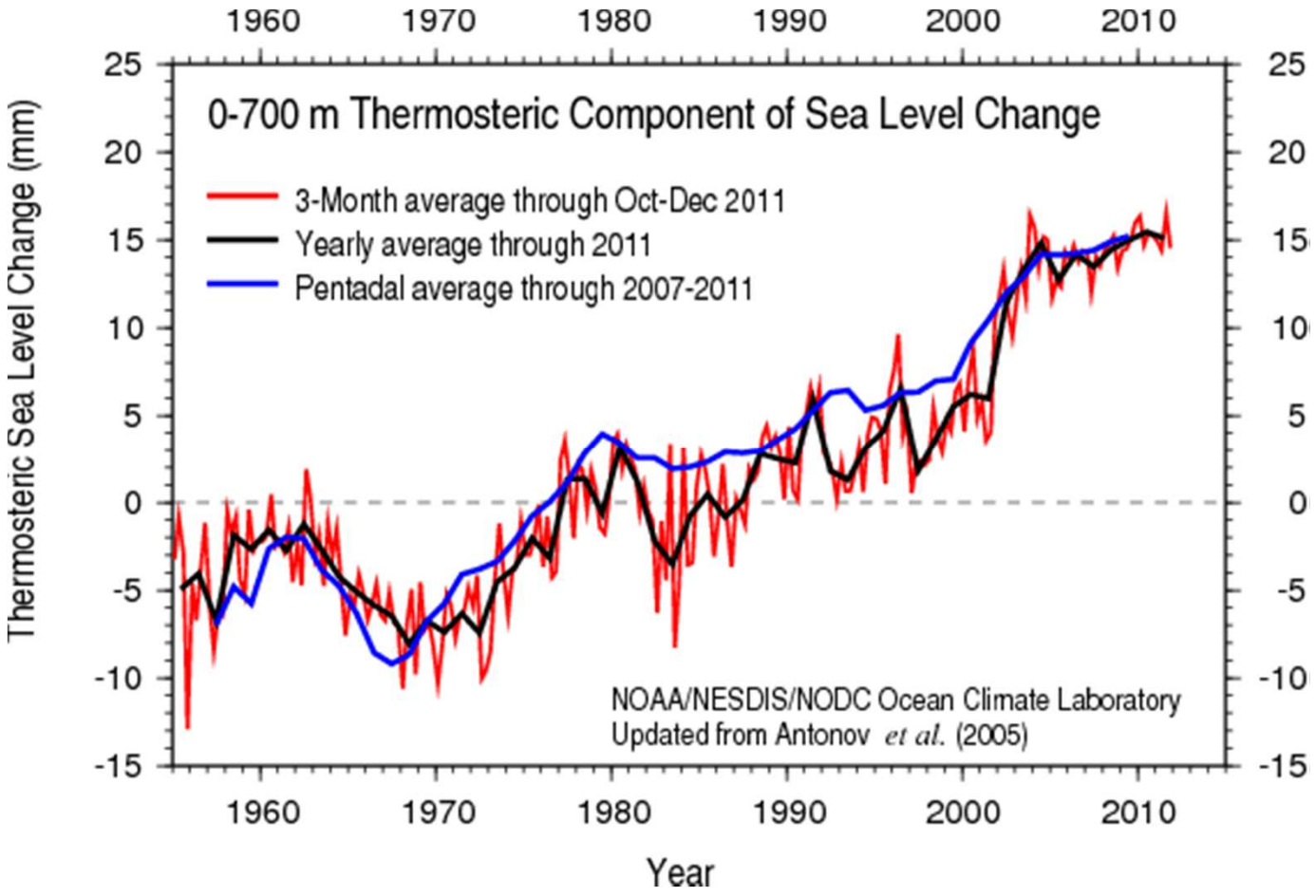
Sea Level



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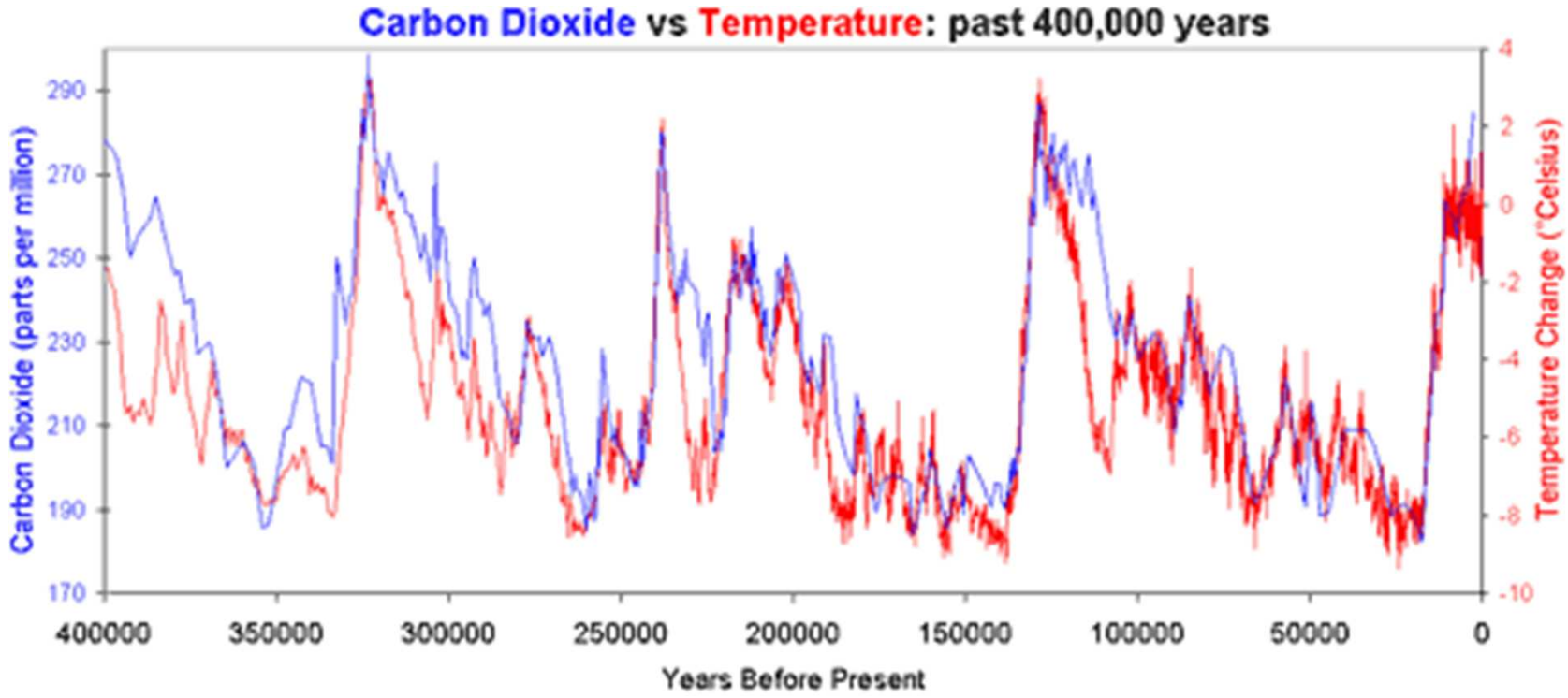
CO_2 Follows Temperature



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What is IPCC?
Intergovernmental Panel on Climate Change

- Established by governments in 1988 to provide assessment of available scientific and technical information on climate change.
- Comprehensive assessments done in 1990, 1995, 2001, and 2007.
- Three separate working groups
- Physical science of climate change.
- The effects on nature and society
- Methods for mitigation.
- Each working group issues a “Summary for Policy Makers”.
- Lead authors are active participants in the relative research, nominated by governments.
- A review process tests the authors assessment against views in the broader expert community.
- 600 experts provided 30,000 comments on the first working group alone.

Are Human Activities Primarily Responsible for Observed Climate Change?

- The 2001 IPCC report concluded it was *likely* (more than 66% probable)
- The 2007 IPCC report concluded it was *very likely* (more than 90% probable)

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Remaining Uncertainties

- How will clouds respond to temperature increases?
- How will ecosystems respond to climate change?
- How will ocean circulation patterns be affected by gradual or sudden changes?
- What other effects are a result of global warming?
- Will hurricanes be stronger and more numerous?

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Facts to Keep in Mind

- CO_2 contains 27.3% carbon by mass

  (MW_C = 12 g/mol; MW_{CO2} = 44 g/mol)
- Metric ton = 1,000 kg = 2,200 lb

  Ton = 2,000 lb
- 1000 million tons = 1 gigaton
- Annual worldwide emissions:

  ~6.5 gigatons of carbon or

  ~25 gigatons of CO_2.

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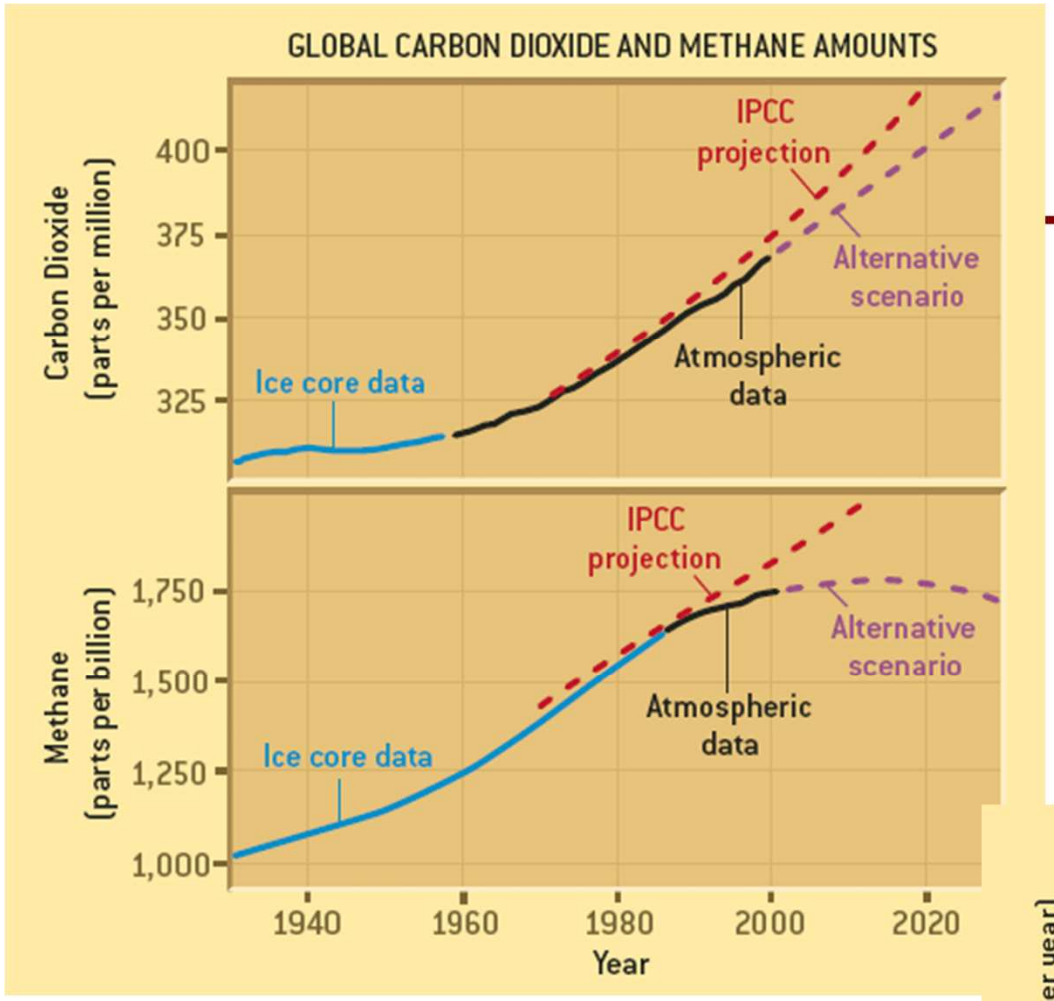
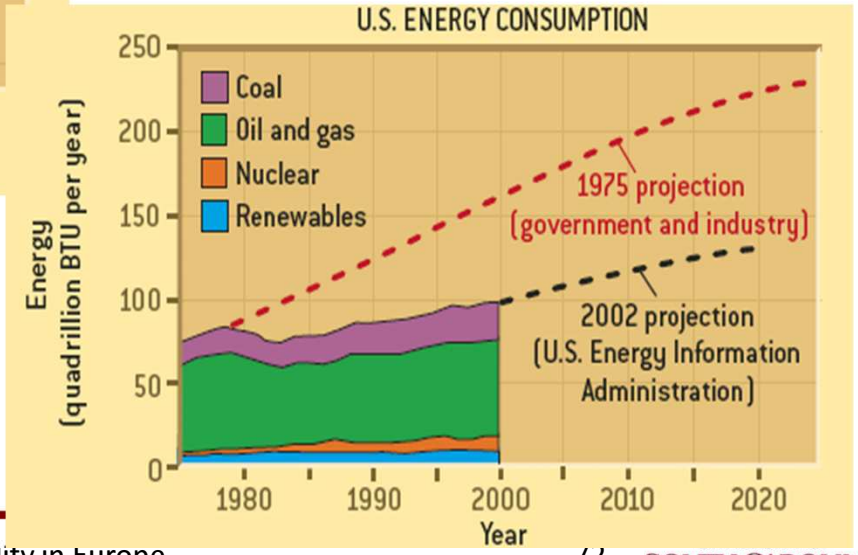
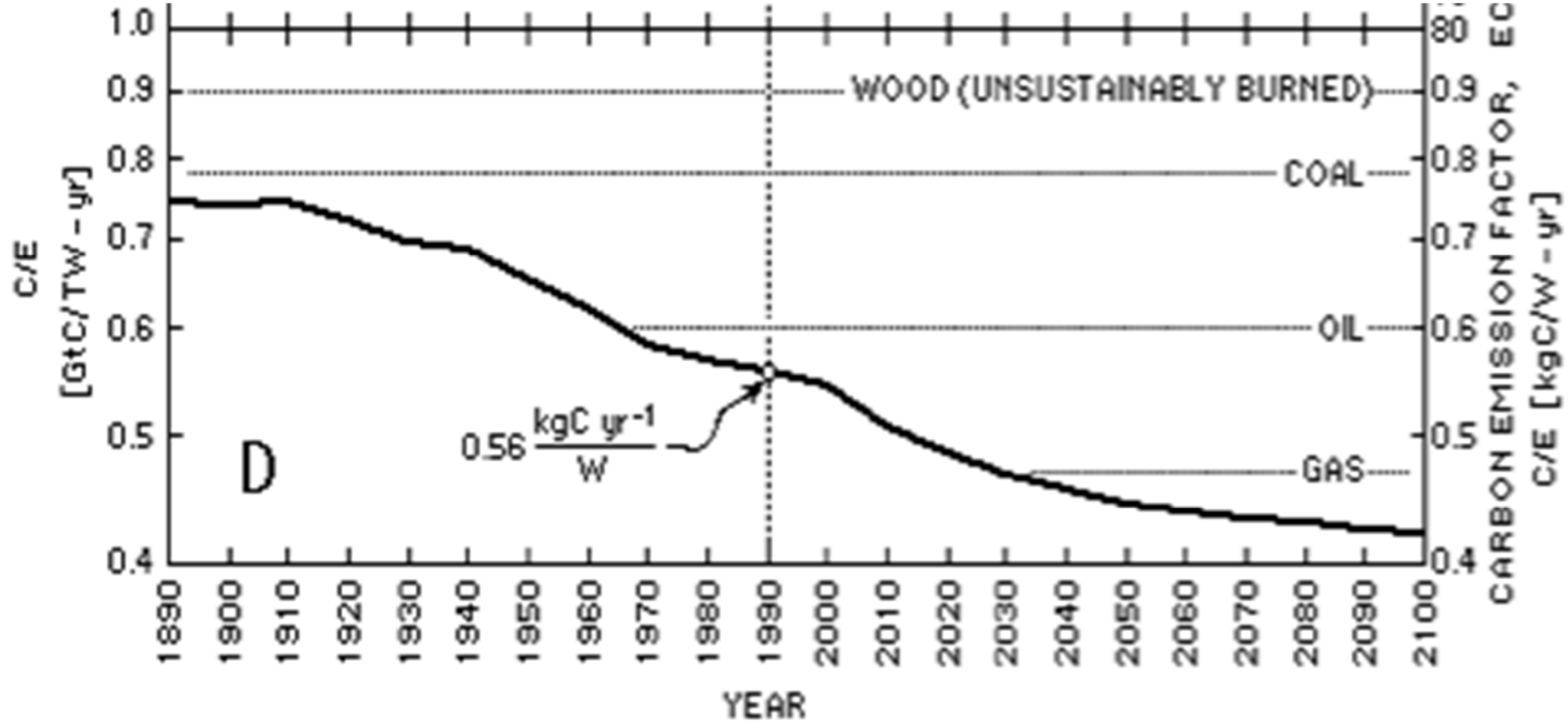
Greenhouse Gases



Energy Consumption



Carbon Intensity of Energy Mix



*M. I. Hoffert et. al., Nature, **1998**, 395, 881*

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2000 Carbon Emissions by Sector and Fuel

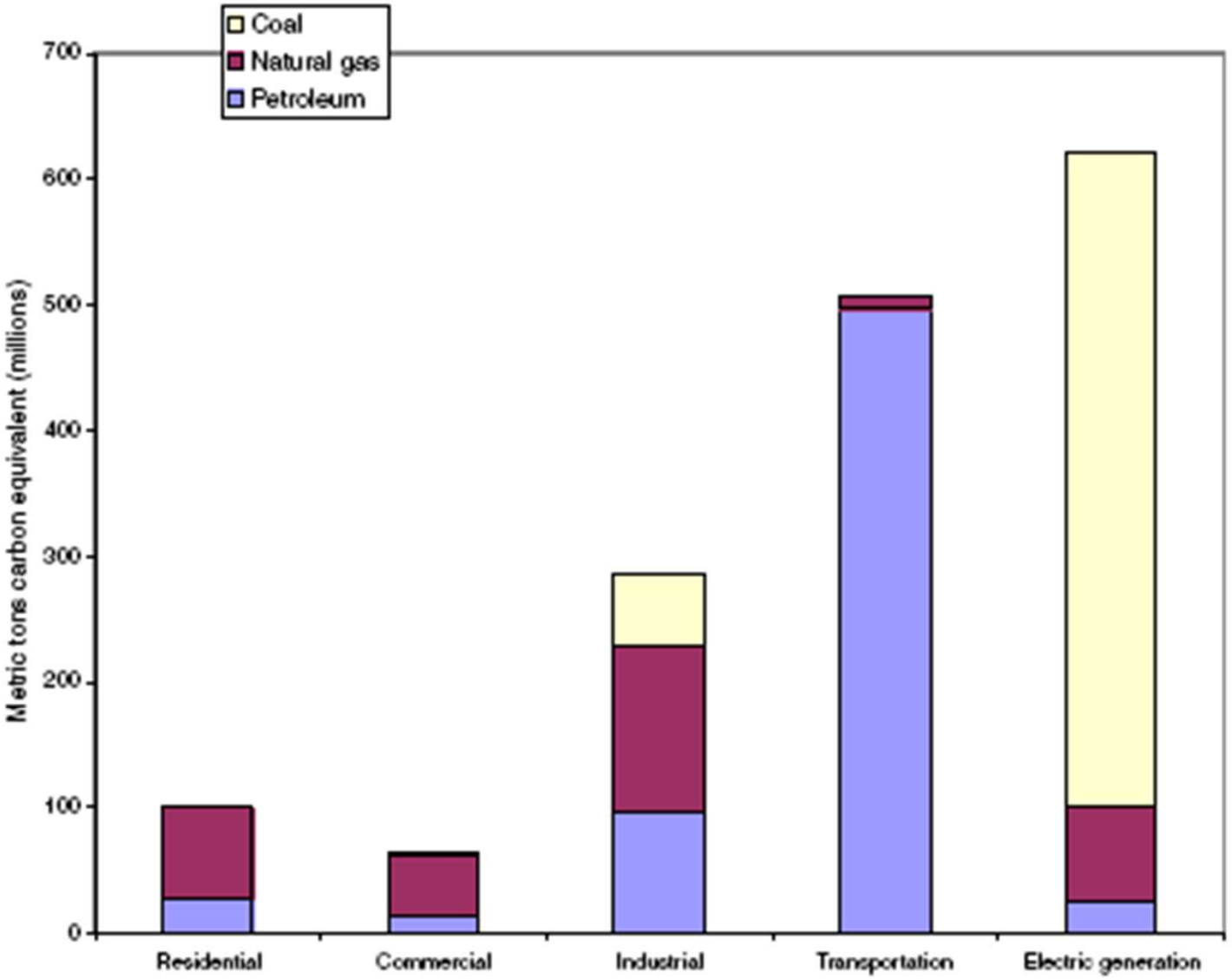
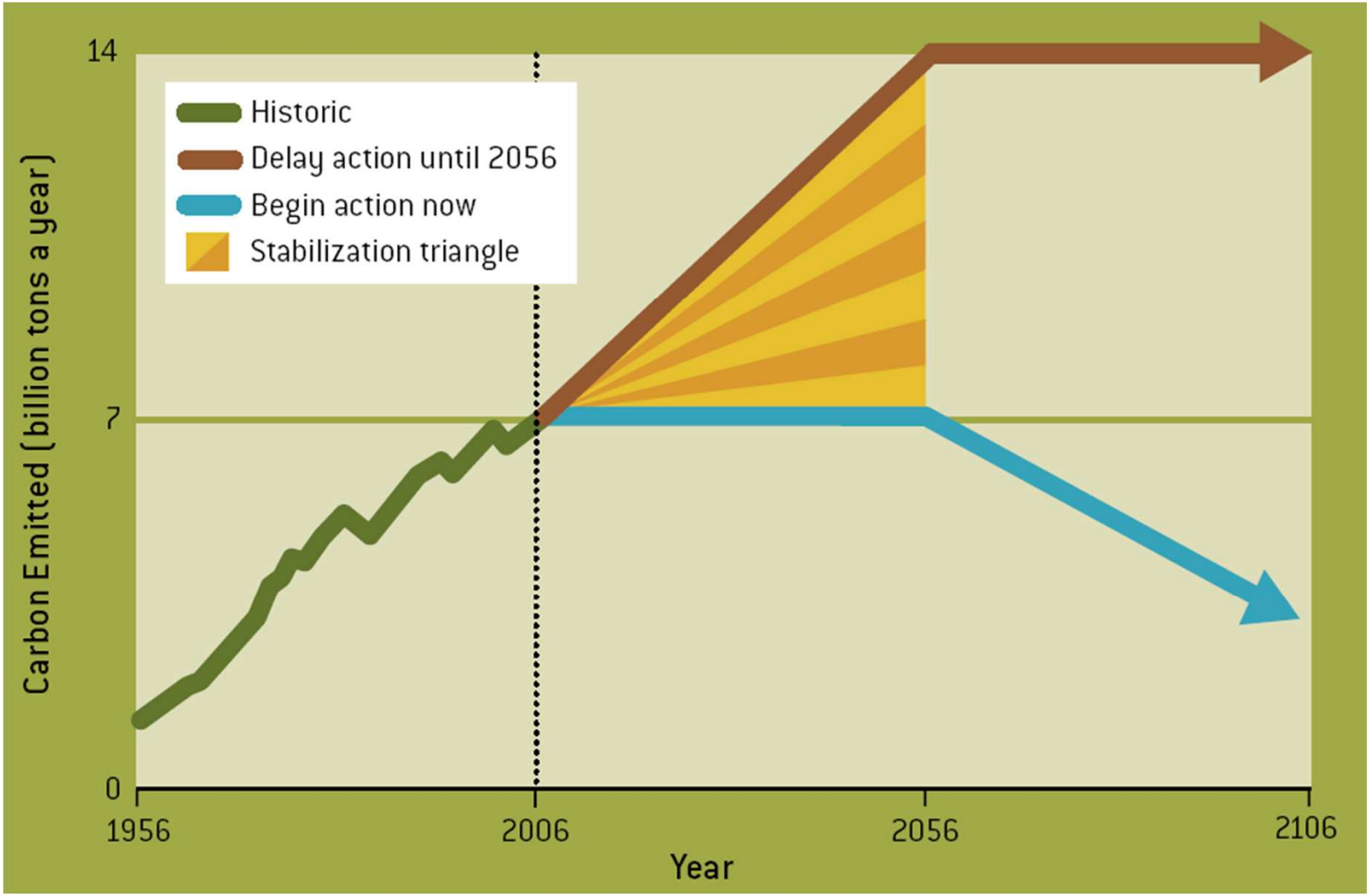


FIGURE 2-7 U.S. emissions of carbon dioxide, by sector and fuels, 2000. SOURCE: EIA (2002).

CO_2 Emissions



"*A Plan to Keep Cargon in Check,*" R. Socolow and S. Pacala, Scientific American, 2006

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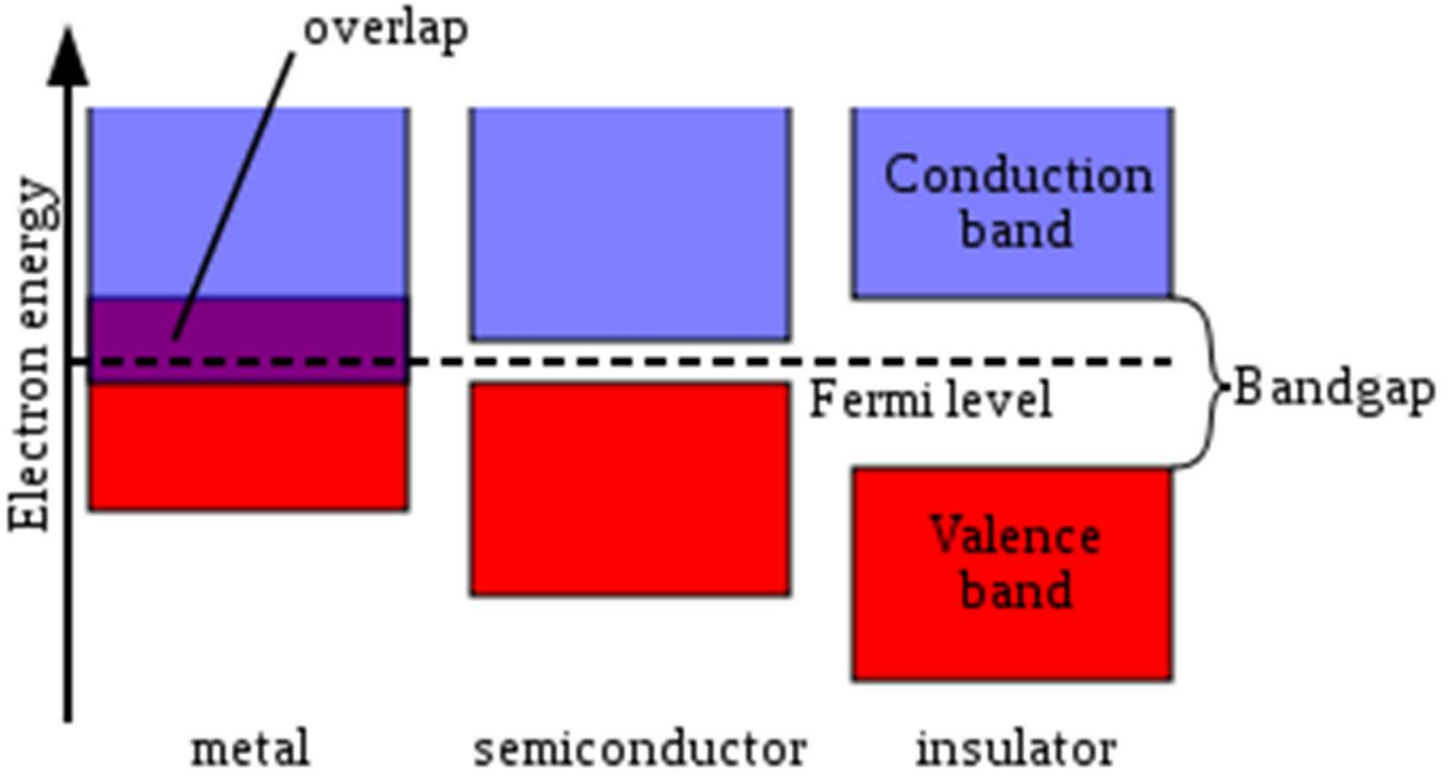
Photovoltaic Solar



Photon Energy

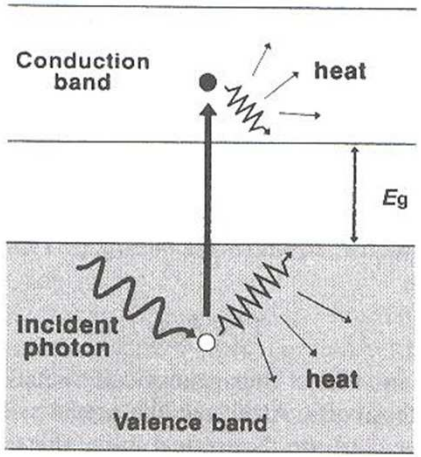


Fig. 3.8 The generation of electron–hole pairs by light

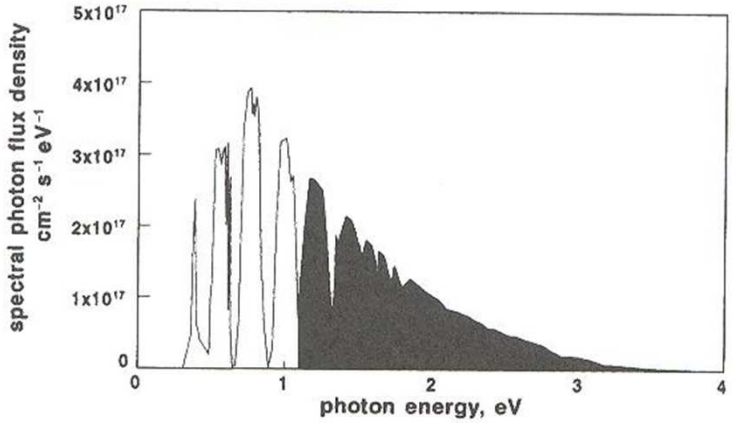


Fig. 3.9 Photon flux utilised by a silicon solar cell

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PV Cost Projections

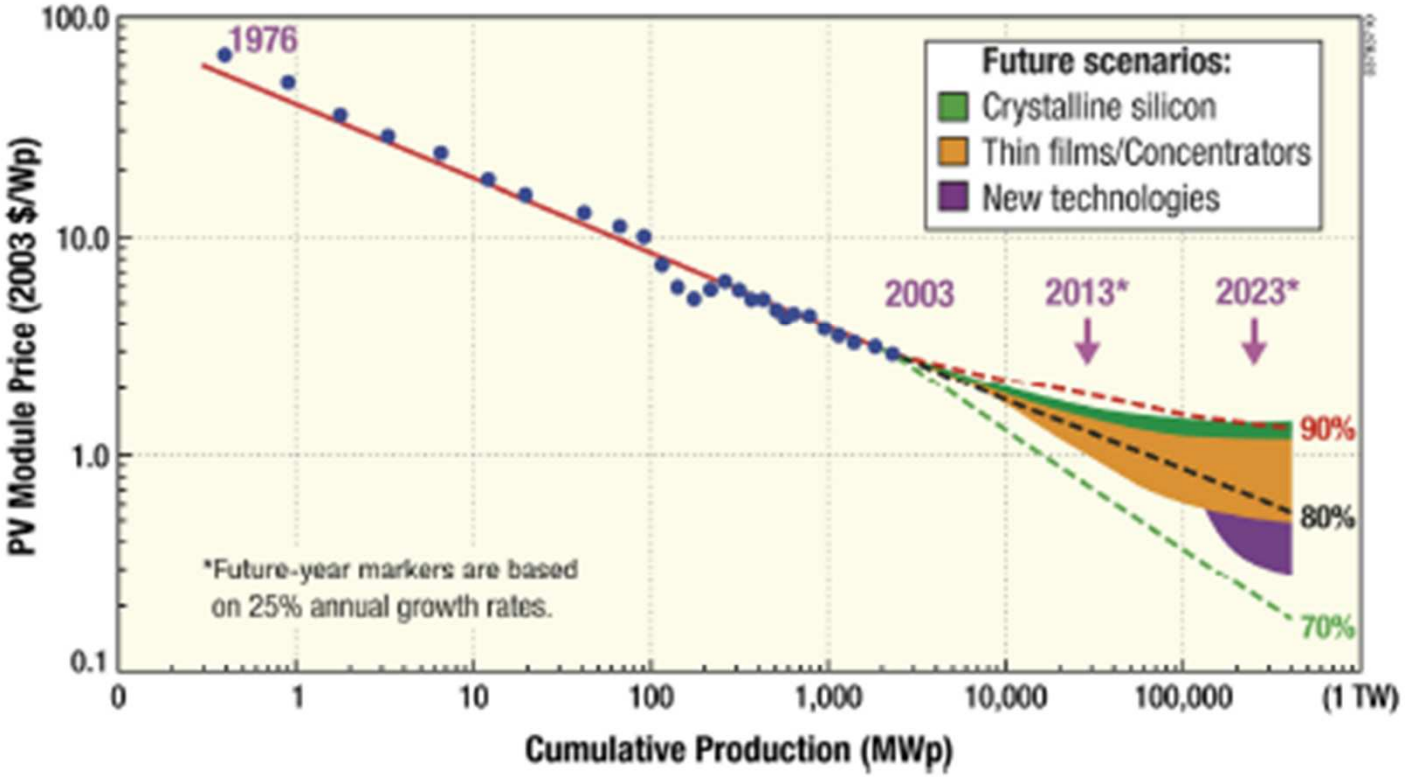

Figure 4 Learning curve for PV production. The present learning curve rate is 80% (20% cost reduction for every doubling of cumulative production); projected rates of 90% and 70% are shown for years beyond 2003. (Source: Surek 2005)

PV Cell Types

- Crystalline Silicon
- Amorphous Silicon
- Cadmium Telluride
- Cu(In,Ga)Se2
- Super-high Efficiency III-V Compound Cells
- Organic Photovoltaics
- Multi-junction
- Quantum Well
- Thermophotovoltaics
- Photoelectrochemical Cells

Multi-Junction Cells

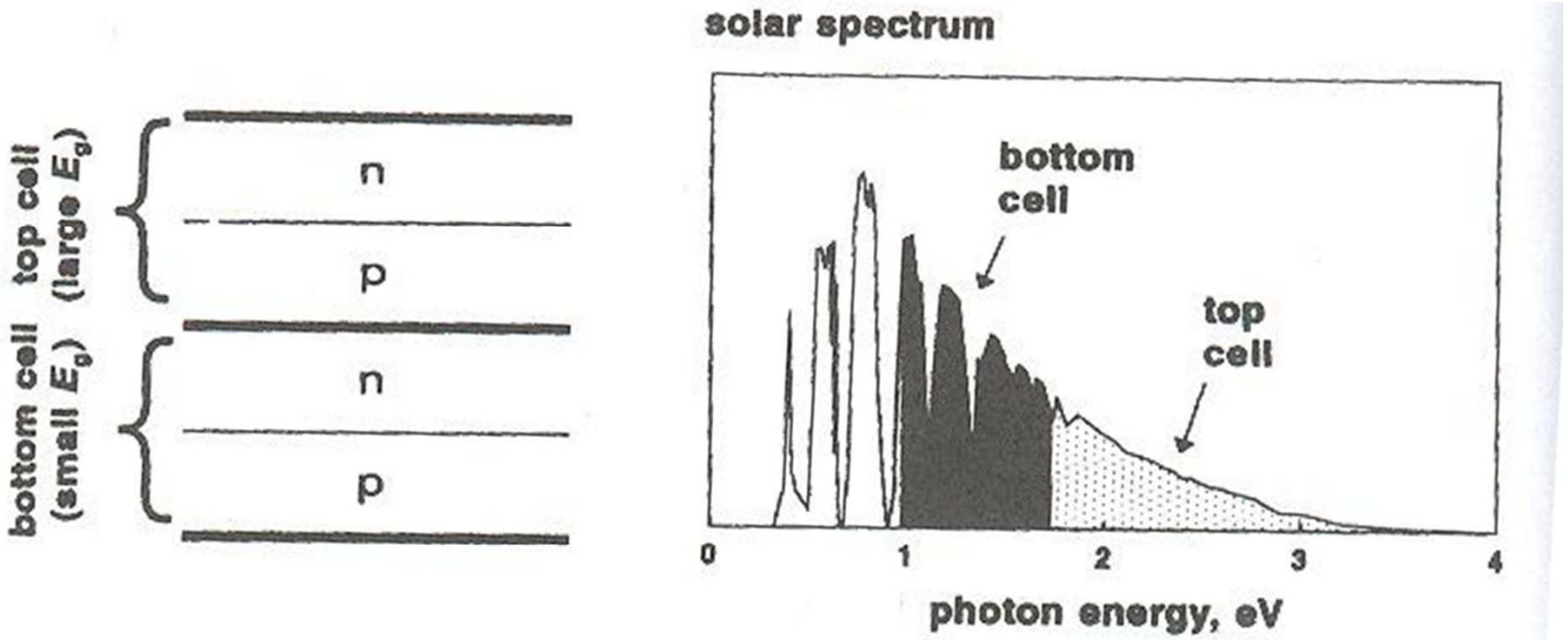

Fig. 3.17 The structure and spectral contributions of the tandem cell

Solar Cell Efficiency

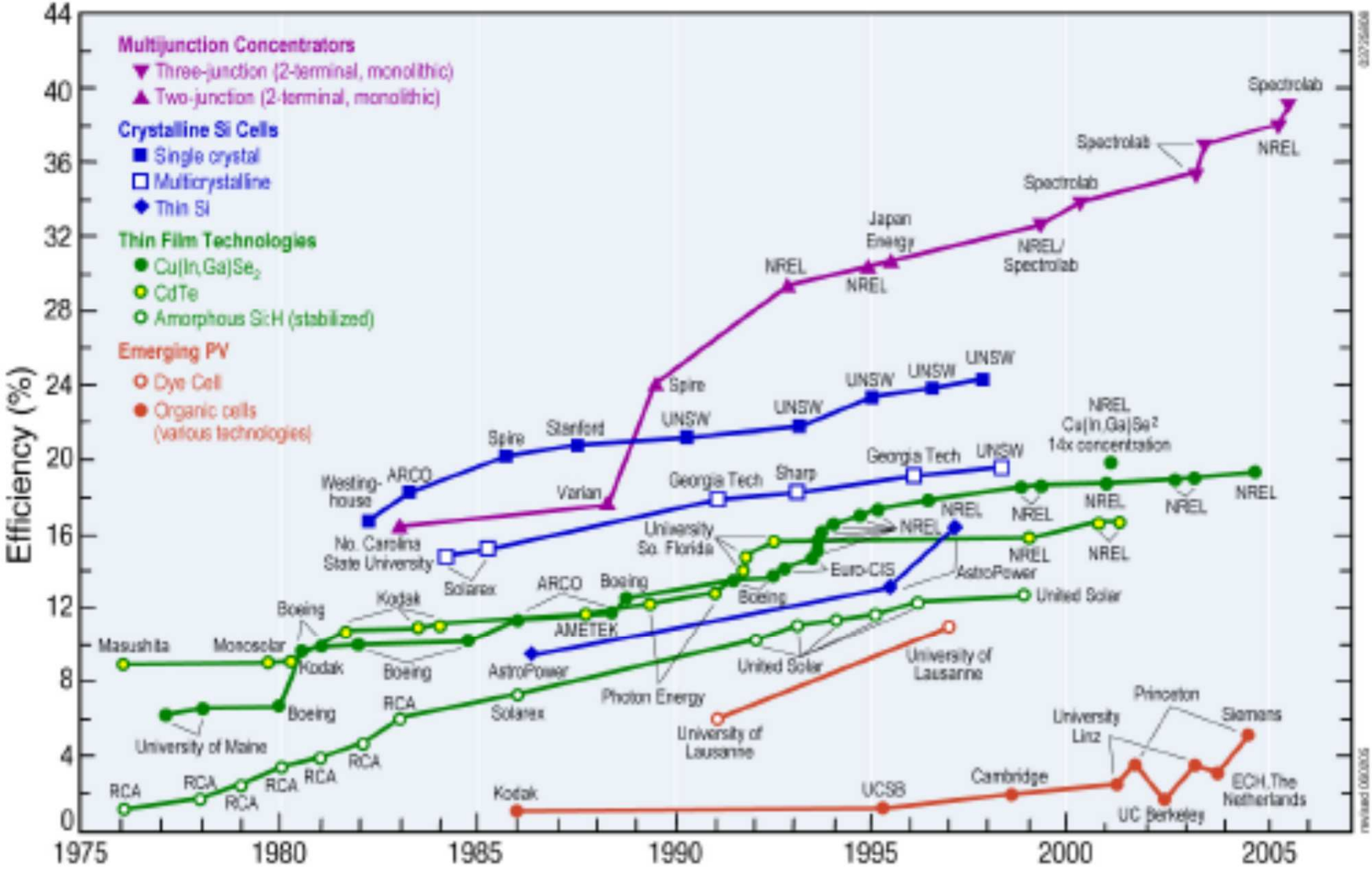

Figure 3 Improvements in solar cell efficiency, by system, from 1976 to 2004