Solar Photovoltaic System Engineering

The Theory, Technology and Practice of Solar Photovoltaic Systems for Electric Power Generation

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with Guest Lectures by
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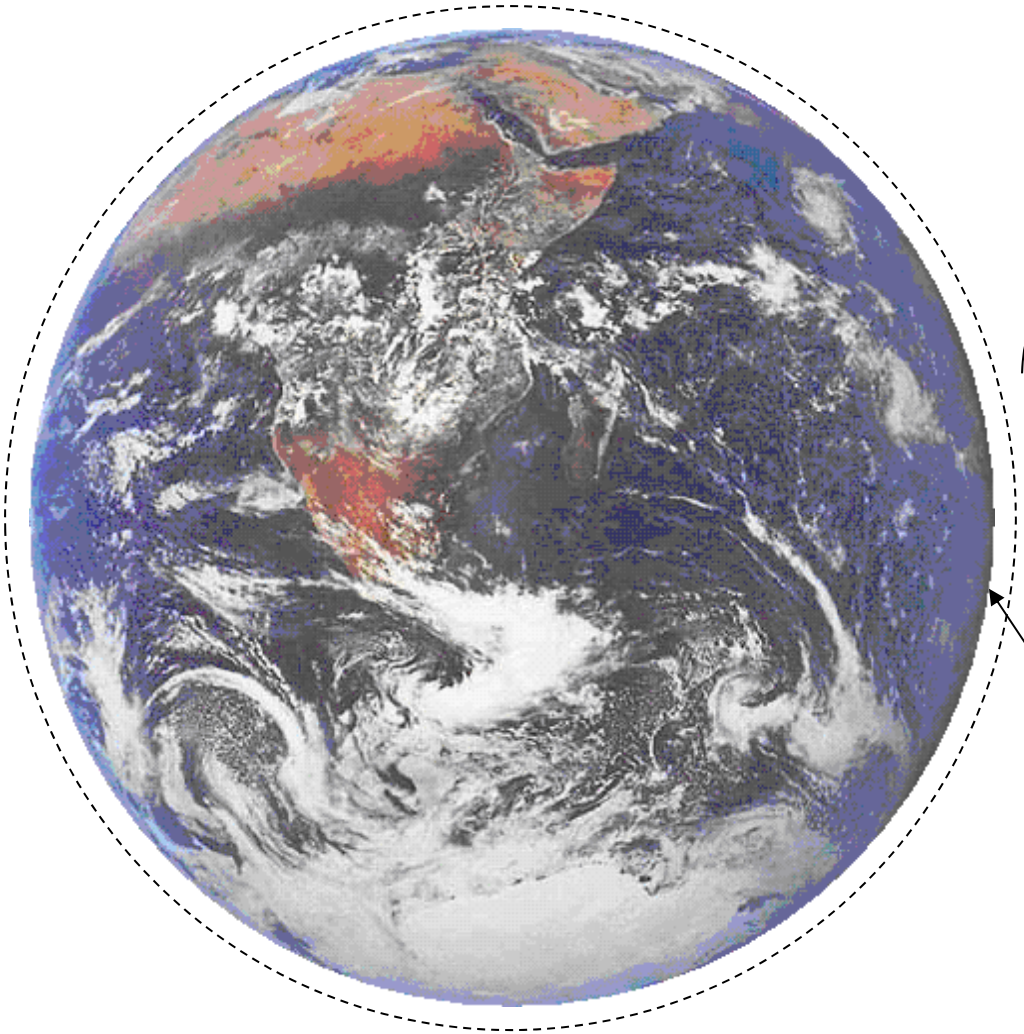
Lecture Material Credit:
Arno Smits, UT Delft NV
Dale Dolan, Cal Poly EE
Gabe Davis and others at REC Solar
Multiple Sources from Web, individually cited

Week 1:The Solar Thermal Balance of the Earth
And Causes of Global Warming

Earth: A System in Delicate Balance

The earth is a system in delicate climatic balance based on countless cycles and subsystems.



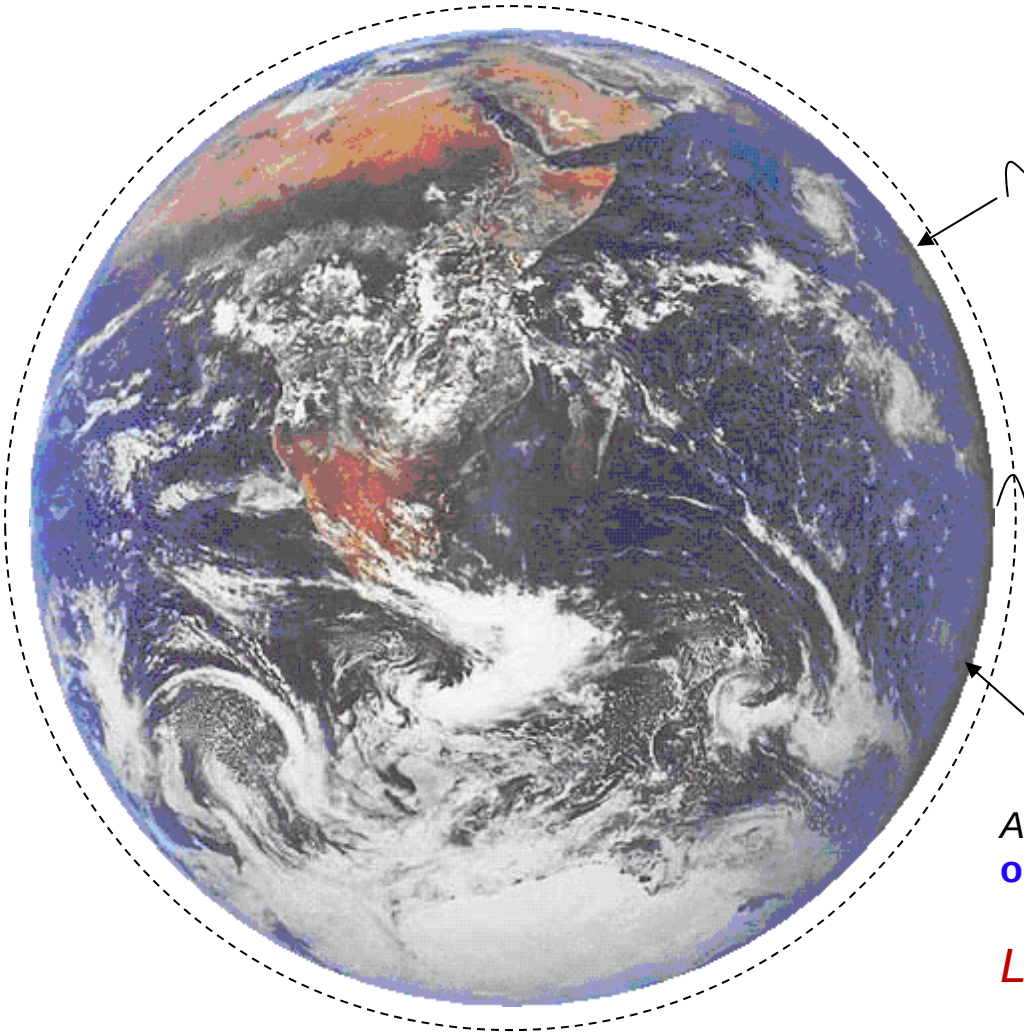
30% reflected by clouds and upper atmosphere

1372 W/m^2 from Sun 93 millions miles away

or 240 W/m^2 averaged over the entire surface of the earth

70% penetrates to the surface

If no Greehouse Gases….



Insolation reaching surface of earth, averaged over entire surface of earth: 240 watts/m^2

All 240 watts/m^2 re-radiated because no greenhouse gases.

Average surface temperature = **-18 degrees C or 0 degrees F**

Life as we know it would not exist.

The Greehouse Effect – Very Sensitive to Composition of Atmosphere

• Oxygen and nitrogen, the primary components of the atmosphere, are transparent to infrared energy, and do not block this re-radiation.

• But water vapor, methane, carbon dioxide, ozone, nitrous oxides, and synthesized gases such as chlorofluorocarbons absorb and re-radiate the reflected infrared energy both up into space, and *down* back to the earth.

• The retention of some of this heat near the surface is the *Greenhouse Effect*.

• This is a natural process critical to life on this planet. We rely on it to maintain an average surface temperature of about 58.3 degrees F.

• An increase in the Greenhouse effect leads to *Global Warming*.

Relative impacts on atmospheric heat retention by GHG

Based on concentrations (ppb) adjusted for heat retention characteristics	% of Greenhouse Effect	% Natural	% Man-made
Water vapor	95.000%	94.999%	**0.001%**
Carbon Dioxide (CO2)	3.618%	3.502%	**0.117%**
Methane (CH4)	0.360%	0.294%	**0.066%**
Nitrous Oxide (N2O)	0.950%	0.903%	**0.047%**
Misc. gases (CFC's, etc.)	0.072%	0.025%	**0.047%**
Total	100.00%	**99.72**	**0.28%**

Source: http://www.geocraft.com/WVFossils/greenhouse_data.html

Sample contradictory arguments:
http://www.skepticalscience.com/empirical-evidence-for-co2-enhanced-greenhouse-effect.htm

Anthropogenic (man-made) vs naturally-occurring GHGs

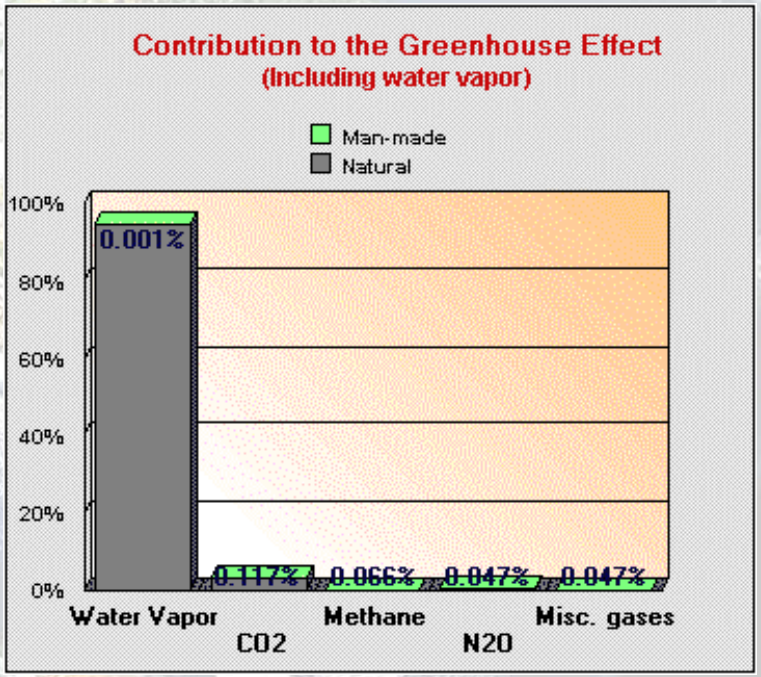
Naturally-occurring GHGs dominate the global temperature balance physics.

Water vapor is responsible for 95% of greenhouse effect, and is 99.9+% naturally-occurring.

Anthropogenic CO2 contributions cause only about 0.117% of greenhouse effect, And some argue that this means that we can ignore this contribution.

Including all GHGs total human contribution to the greenhouse effect is around 0.28%. Therefore, some argue that this means that we can ignore human contributions.

But the thermal balance of the planet is *very* delicate, and the ramifications of a few degrees F temperature change on all forms of life is huge (especially for human society).



The Dominant GHGs: Water vapor and Carbon Dioxide

- Both water vapor and Carbon dioxide are greenhouse gases. They both trap outgoing longwave infrared radiation in the troposphere.
- On a molar average basis, water vapor is about half as effective as a GHG compared with carbon dioxide. The exact effect varies highly with the form of the water vapor, e.g., humidity vs clouds.
- Water vapor in the atmosphere averages 2-3%, carbon dioxide averages 0.04%. (More than 60 times as much H_2O as CO_2.)
- Water vapor is removed from the atmosphere by precipitation. CO_2 is removed from the air by plant life, especially aquatic.
- The water vapor cycle is an unstable system: as global temperatures rise, more water is vaporized, leading to more heat entrapment and even higher temperatures. Water vapor feedback roughly doubles the amount of warming caused by CO_2. And when all feedback loops are considered, the total warming effect due to a 1°C change caused by CO_2 is nearly 3°C.

Ref: http://www.skepticalscience.com/water-vapor-greenhouse-gas.htm

What do we know vs what must we attempt to predict?

• The role of CO2 as a greenhouse gas was first published in 1896 by Swedish scientist Svante Arrhenius.

• Approximately 100 years ago, before large-scale use of fossil fuels, the atmosphere contained an average of 275 ppm CO_2. Greenhouse gases intercepted 88% of the re-radiated energy, which yielded an equilibrium average surface temperature of 57 °F in 1900.

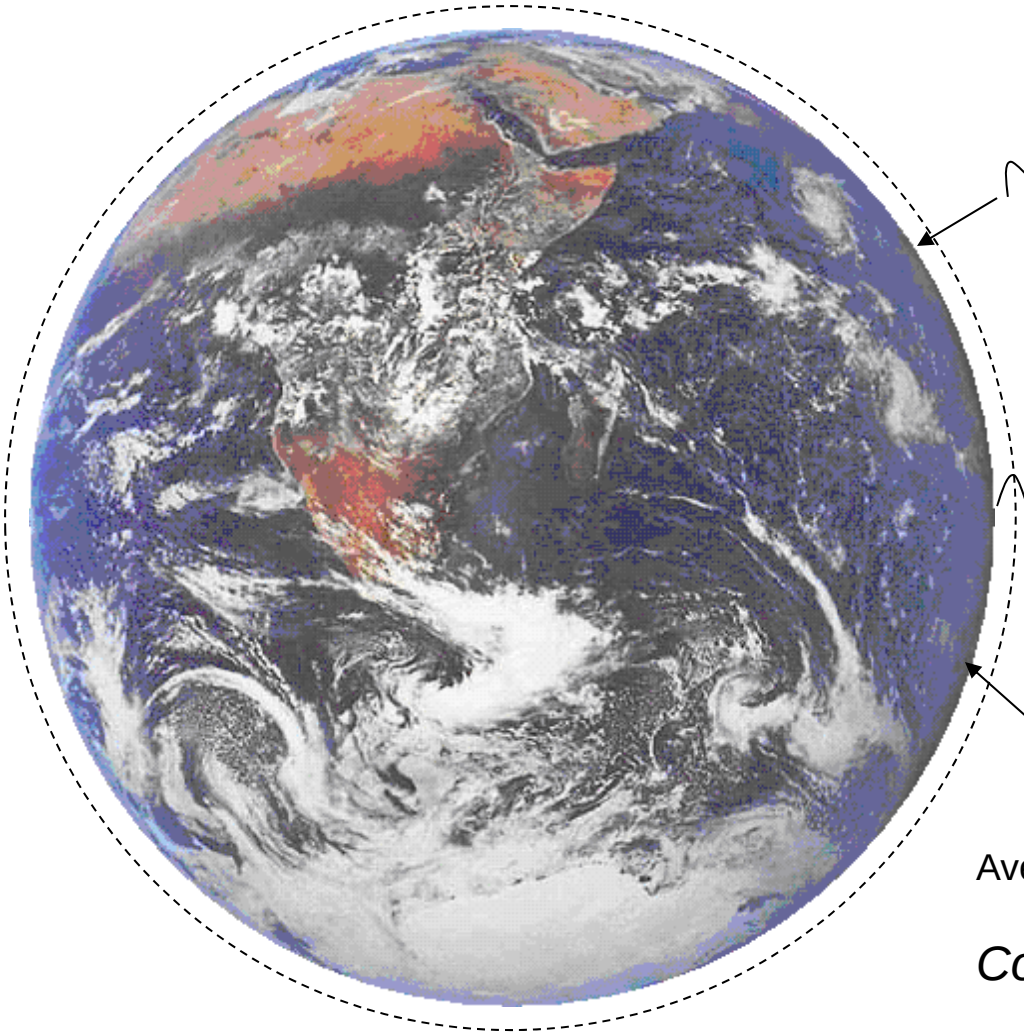
• Today, as a direct result of the combustion of fossil fuels, the atmosphere contains slightly about 400 ppm CO_2. There has also been an equivalent reduction in oxygen content.

• The natural CO_2 re-absorption and conversion processes of the earth cannot keep up with our man-made contributions.

• But we *know* that the average surface temperature rose 1.33 ± 0.32 °F to 58.3 °F between 1900 and in 2005 (when CO_2 was 320 ppm)

With Naturally-occurring Greehouse Gases….

275 ppm CO_2



Insolation reaching surface of earth, averaged over entire surface of earth: 240 watts/m^2

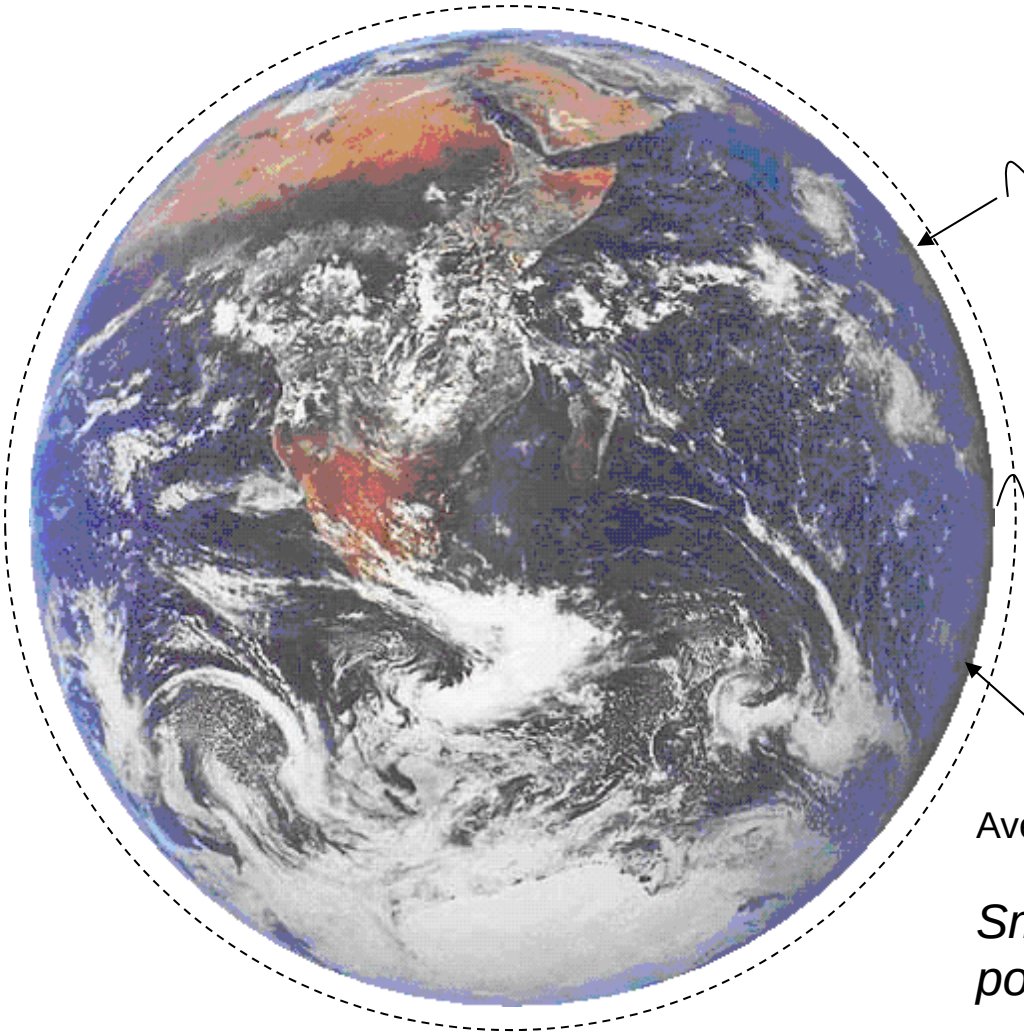
12% (29 watts/m^2) re-radiated while 88% (211 watts/m^2) absorbed by greenhouse gases.

Average surface temperature = **57 degrees F**

Comfortable for life, including humans

After 100 years of burning fossil fuels….

400 ppm CO_2



Insolation reaching surface of earth, averaged over entire surface of earth: 240 watts/m^2

10% (24 watts/m^2) re-radiated while >90% (216 watts/m^2) absorbed by greenhouse gases.

Average surface temperature = **58.3 degrees F**

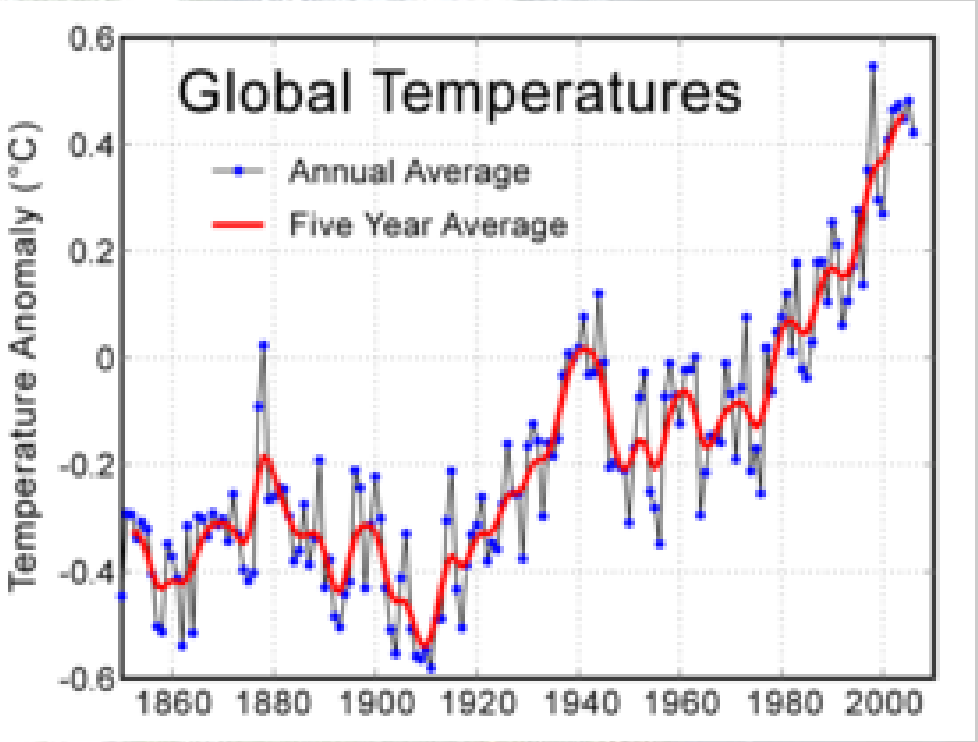
Small change in temperature, but potentially large difference in climate.

Climate – Very Sensitive to the Heat Balance of the Planet

- If we continue to burn fossil fuels until they start to become exhausted, the CO2 concentration is expected to increase to about 550 ppm.

- Climate model projections reported by the IPCC* suggest that the average surface temperature will likely rise another 1.1 to 6.4 °C (2.0 to 11.5 °F) during the 21st century

- Ramifications for global climate change *could* be huge, as speculated in many forums, such as film by Al Gore "An Inconvenient Truth". There is not a clear consensus on this.



Sources: **History:** Energy Information Administration (EIA), *International Energy Annual 2004* (May-July 2006), web site www.eia.doe.gov/iea. **Projections:** EIA, System for the Analysis of Global Energy Markets (2007).

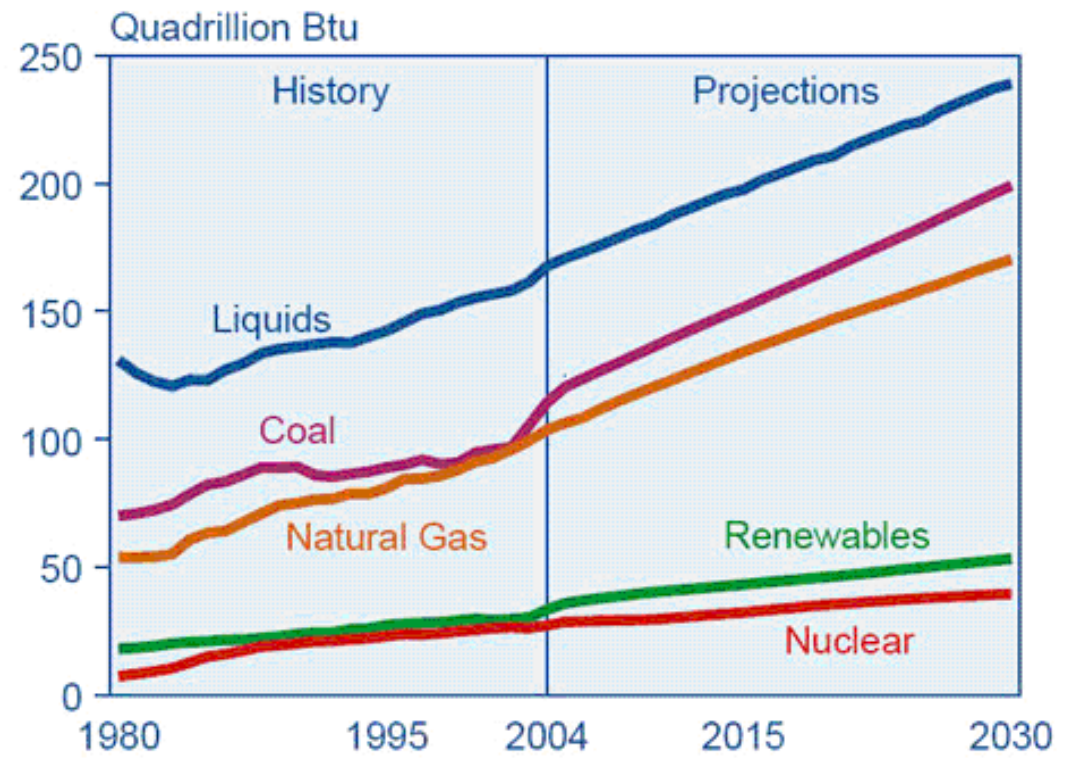
* Intergovernmental Panel on Climate Change http://www.ipcc.ch/

Unexpected Contribution of Humans: Combustion of Fossil Fuels

- Fossil fuels (hydrocarbons or coal) contain organic carbon stored and reduced to its present form over hundreds of millions of years

- Combustion of fossil fuels using this long-stored carbon into the atmosphere

- We currently derive at least 86% of our global energy from combustion of fossil fuels

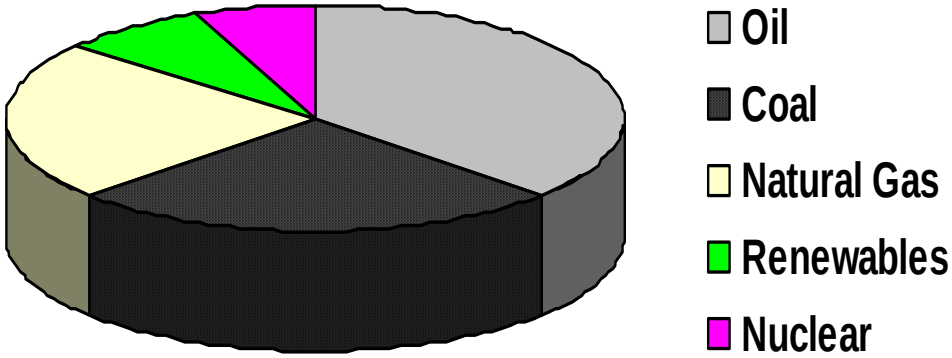


Sources: **History:** Energy Information Administration (EIA), *International Energy Annual 2004* (May-July 2006), web site www.eia.doe.gov/iea. **Projections:** EIA, System for the Analysis of Global Energy Markets (2007).

Fossil Fuel Combustion

WORLD ENERGY CONSUMPTION

86% Fossil Fuels



The International Energy Outlook 2007 (IEO2007)
Energy Information Administration (EIA) – U.S. Government

Relative CO_2 Contributions and O_2 Utilization of Some Fuels:

Remember, all HC's burn in air to create predominantly CO_2 and H_2O

Combustion of Coal (no sulfur)

$$C + O_2 \rightarrow CO_2 +$$ some CO, NO_x and C (particulates)

Combustion of Methane (majority component of natural gas)

$$CH_4 + O_2 \rightarrow CO_2 + 2H_2O + trace\ particulates\ and\ NO_x$$

Combustion of Gasoline (average composition represented by n-heptane C_7H_{16})

$$C_7H_{16} + 11O_2 \rightarrow 7CO_2 + 8H_2O +$$ small amounts of CO, various HC's, NO_x and C (particulates)

Sunlight to Energy: The Plant-based Carbon Cycle

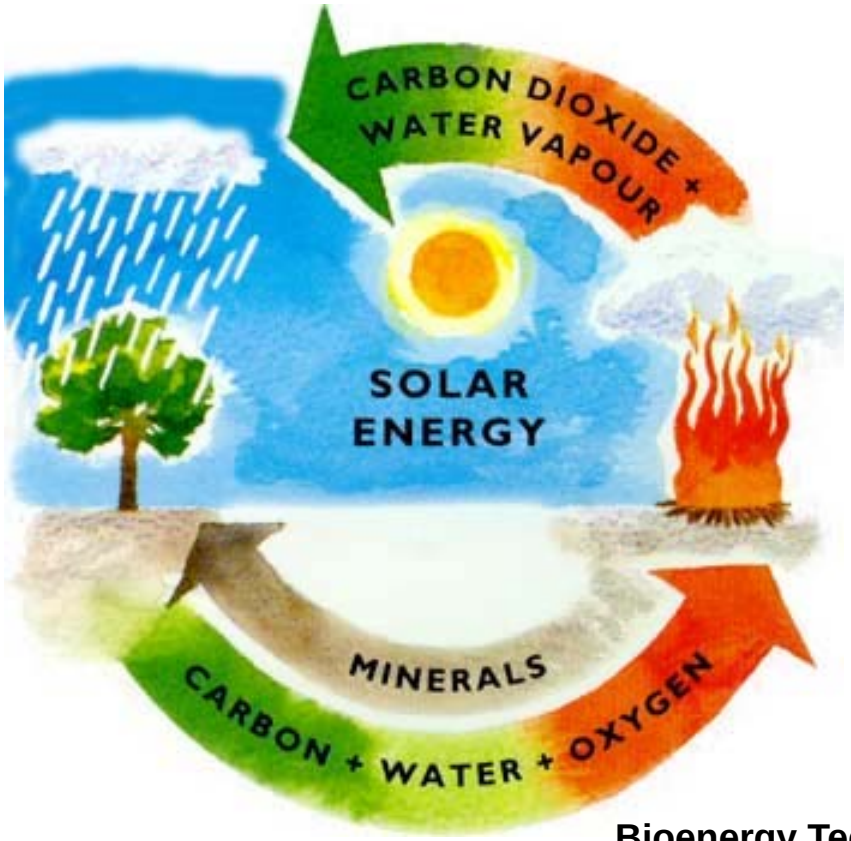
• Fossil fuels (hydrocarbons or coal) contain organic carbon stored from decayed plant life and reduced to its present form *over hundreds of millions of years*.

• Combustion of fossil fuels releases this stored carbon into the atmosphere, overloading the normal Biological *Carbon Cycle* of the planet, which has a time constant between *a year to a few decades*.

• The closed carbon cycle of agriculture and biomass-derived fuels returns the carbon back to the fuel feedstock in a matter of years, rather than the millions of years to took to make fossil fuels.

Renewable Fuels

- Closed-loop, carbon neutral with a *short time constant*



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Every potential solution has its costs

All “solutions” have consequences – some short term, and some long term.

Technology is only one component… every solution involves people, politics, and economics.

The profit base of much of an industrialized economy is predicated on transferring costs to the general public and the planet.

Examples:

- the complete environmental costs and energy balance for corn-derived ethanol
- the waste storage risk of nuclear power
- the environmental damage done by hydroelectric dams
- the size, noise and risks to avian life of wind generators
- the “true” life cycle costs of any manufactured product
- the energy and environmental consequences of replacing an inefficient machine with a more efficient one

The real problem is much greater than obvious – threaded throughout global society, politics and economics.

Fossil-Fuel Combustion

CO_2

Air Pollution

Extraction

Habitat Loss

More Pollution

Transport

Oil Spills

More Pollution

Refining

More Pollution

Water Pollution

Hazardous Waste