ENCORE Lecture - April 20, 2011

Human Responses to Climate Change

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Background of Lecturer:

NCSU Physics: BS (62), MS (64), PhD (66)

1966-1987 - AF Cambridge Research Lab, Hanscom AFB, MA

1988-2009 - Penn State University, Electrical Engineering Dept.

2009-present - NCSU

Recommended Readings:

Jared Diamond, Collapse, How Societies Choose to Fail or Succeed, Penguin Books 2005

Thomas Friedman, Hot, Flat and Crowded, Farrar, Straus and Giroux, NY 2008

IPCC Plenary XXVII (Valencia, Spain, 12-17 November 2007) 4th Assessment

Robert Socolow and Stephen Pacla, *“A Plan to Keep Carbon in Check”* Sci. American, Sept. 2006

Life on Planet Earth – Supporting and Sustaining Conditions

Long-lifetime star (late development of our galaxy)

Close enough to galaxy center to have heavy isotopic masses

Far enough from galaxy center to have low energetic radiation levels

Distance from Sun in life sustaining region (temperature)

Atmosphere that supports life forms – water, oxygen

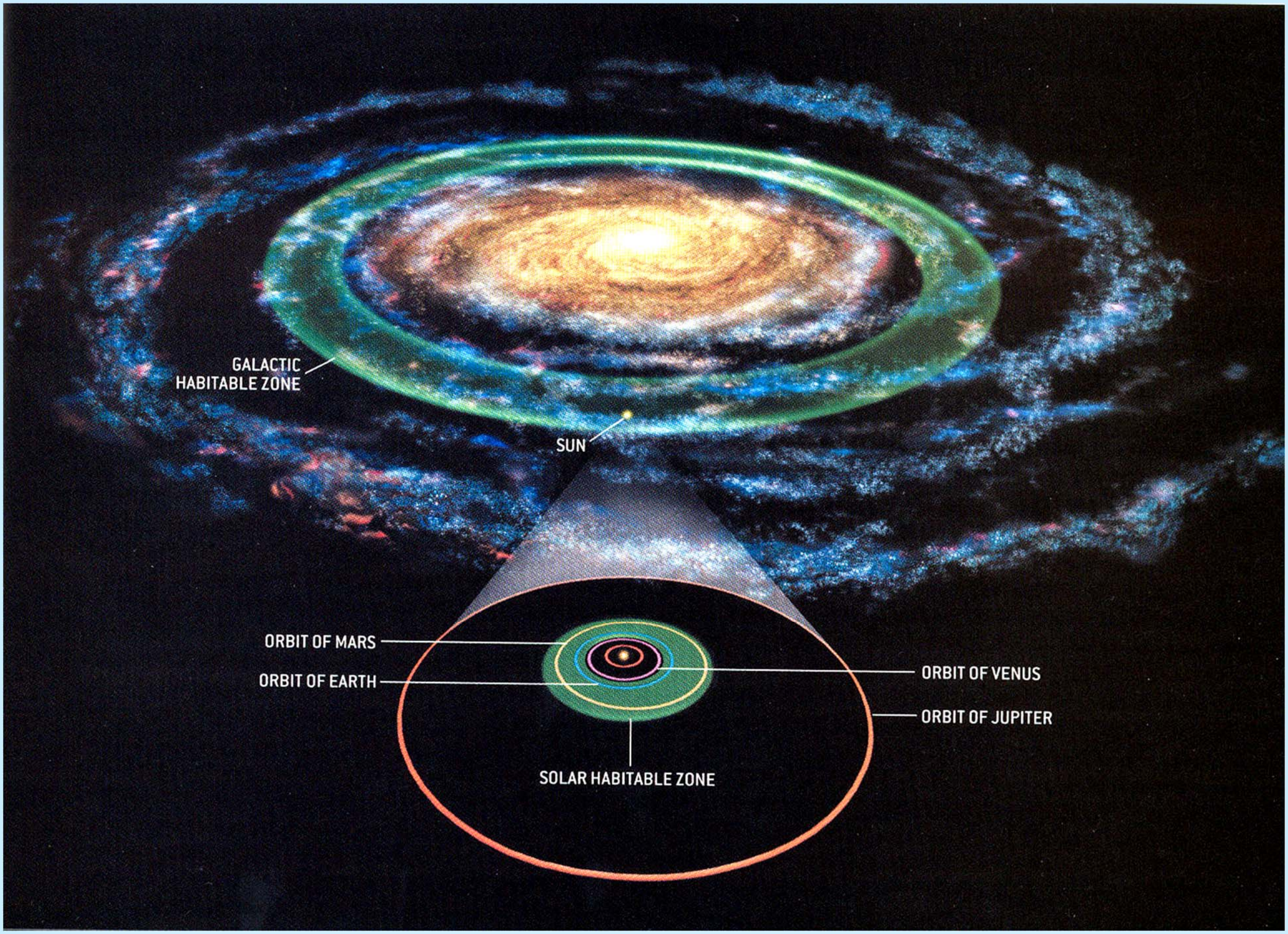
Atmosphere removes (cosmic rays, particles, γ-radiation, x-ray, UV)

Atmosphere protects against interplanetary dust and meteors

Magnetic field rigidity protects against high energy ionized particles

Water vapor transports latent heat, distributes energy to polar regions

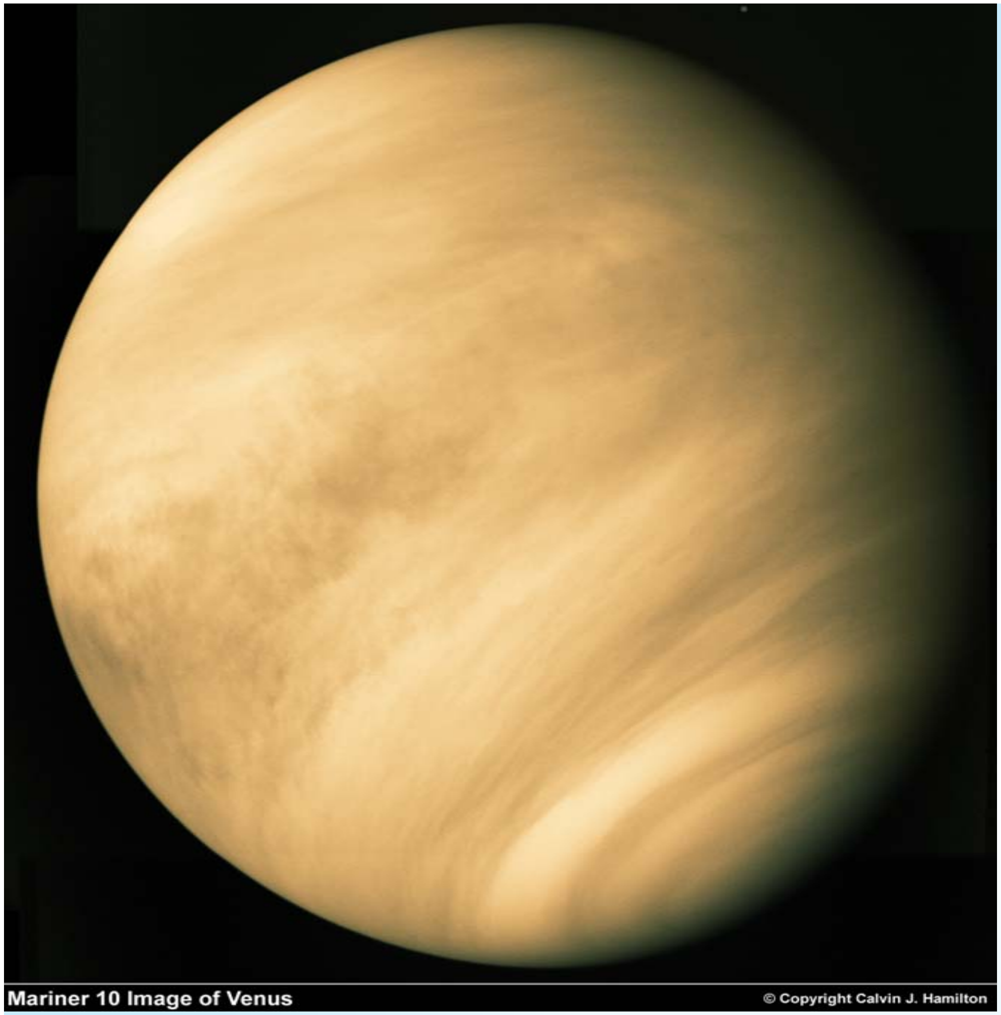
Global radiation balance is controlled primarily by the “greenhouse” gasses and the planetary albedo (and radiation from Sun)



Habitable regions of our Milkyway galaxy are very limited

Scientific American, pg 63, October 2001.

The Blue Planet



Venus

Earth's sister planet.

(similar size, gravity, and bulk composition)

Venus has a run-away greenhouse atmosphere.

<u>Atmosphere at Surface</u>*

Temperature 460^{o}C
Pressure 93 bars
~96.5% Carbon dioxide
~3.5% Nitrogen
0.015% Sulfur dioxide

***Wikipedia**

Venus is believed to have had water oceans, but these evaporated as the temperature rose. The water probably dissociated, and hydrogen was swept into interplanetary space by the solar wind.

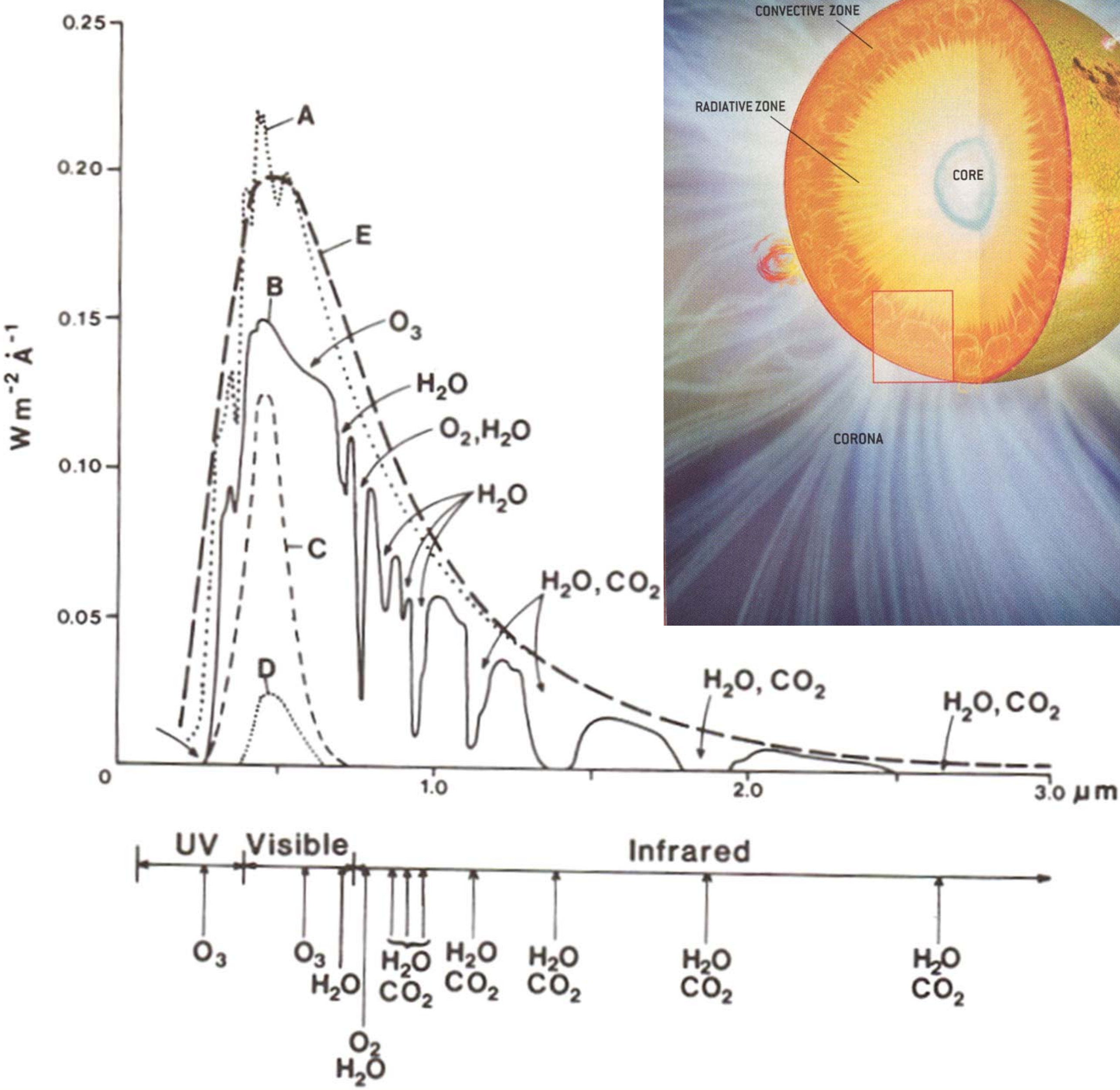
Our atmosphere is subject to non-linear processes, which we do not know how model to determine the tipping point.

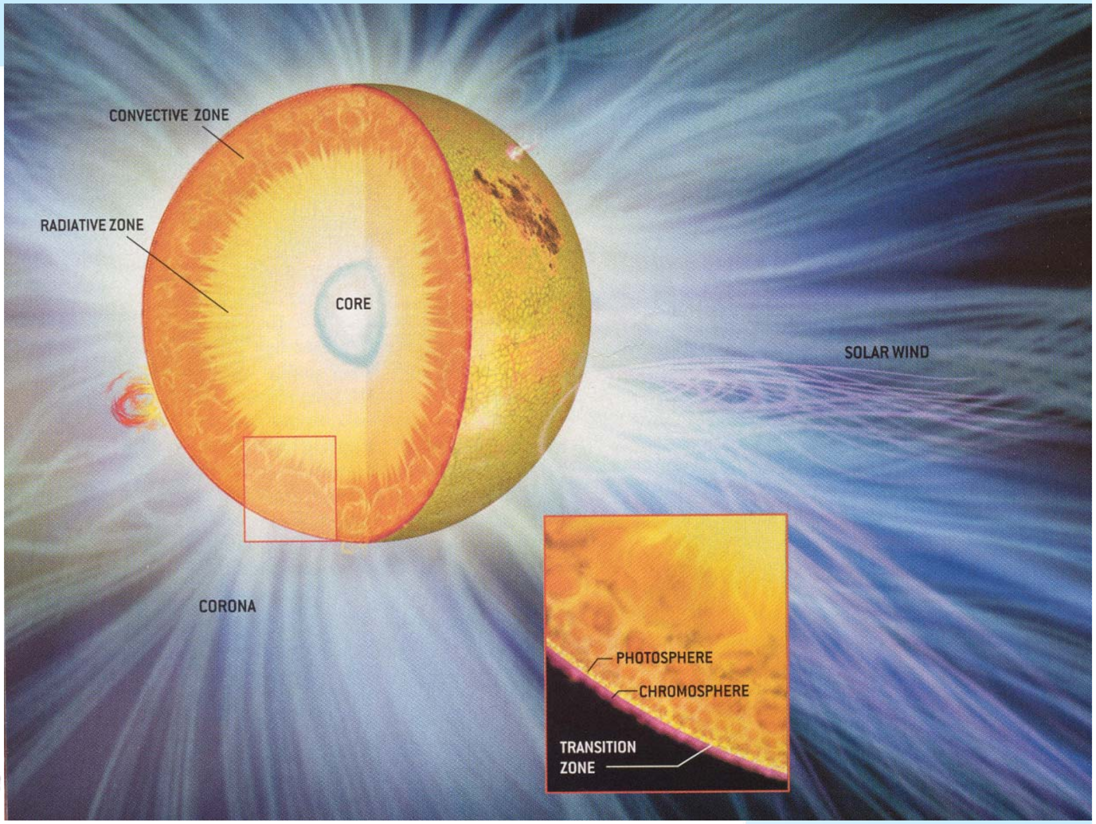
The basic question **– Can scientific, political, corporate and public interests come together to provide solutions for societal issues?**

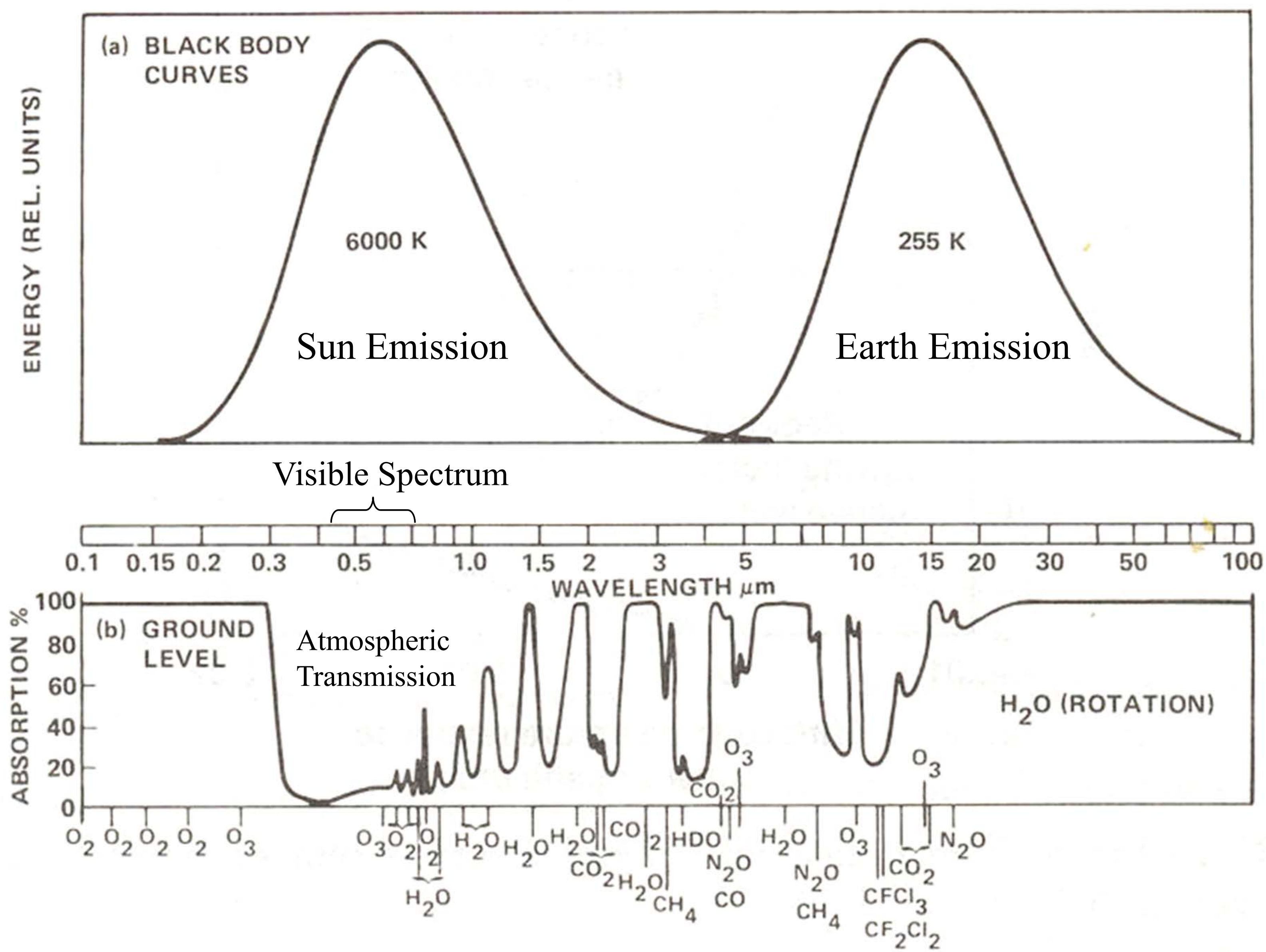
This is not an acceptable alternative!

IBM Advertisement Websphere for Mankind – Back cover Discover Magazine September 2001.

Our Primary Energy Source

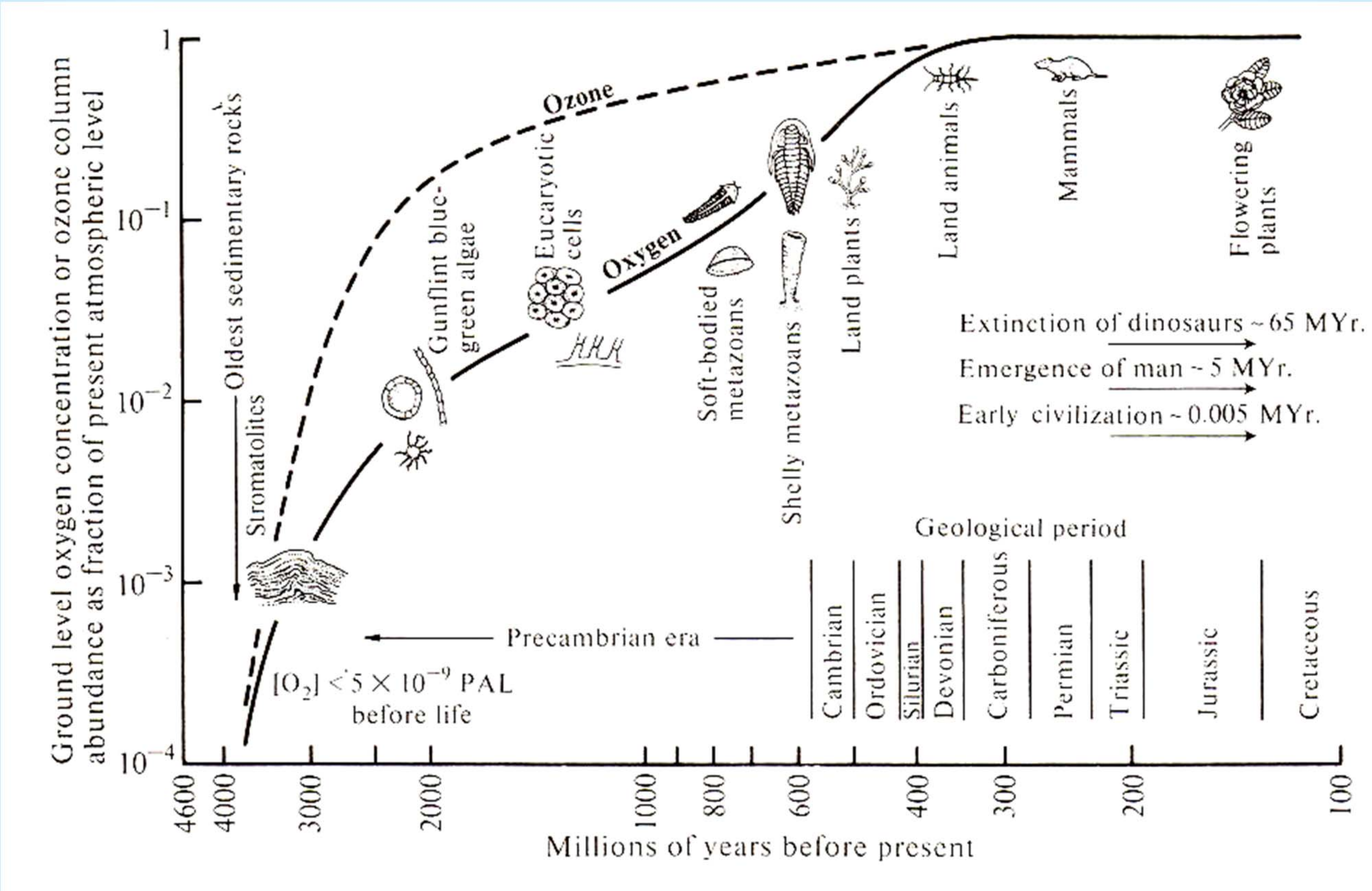




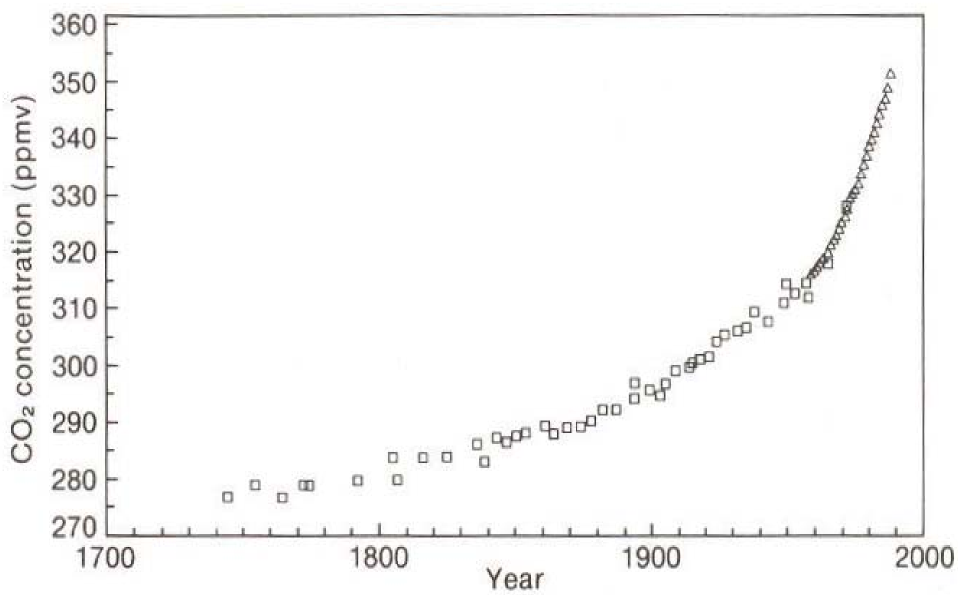


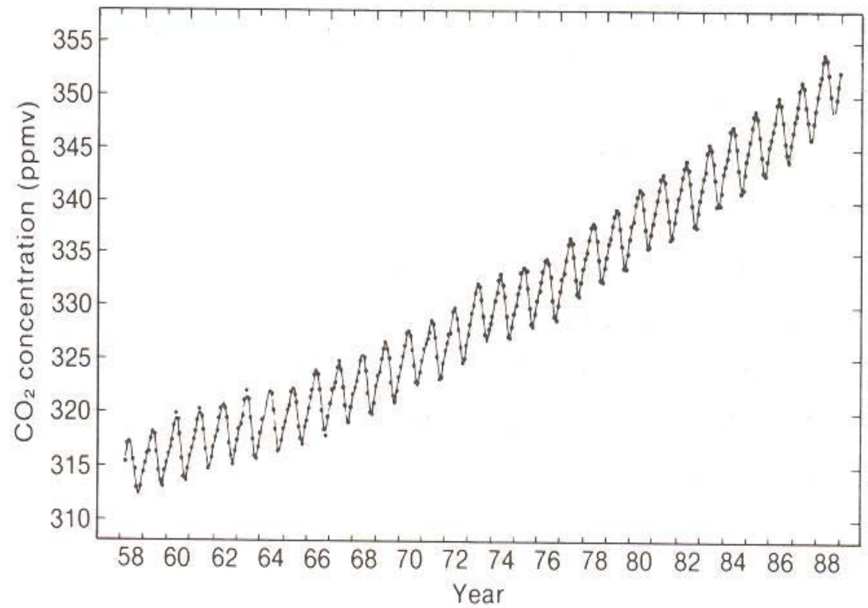
(a) BLACK BODY CURVES
ENERGY (REL. UNITS)
6000 K
255 K
Sun Emission
Earth Emission
Visible Spectrum
0.1 0.15 0.2 0.3 0.5 1.0 1.5 2 3 5 10 15 20 30 50 100
WAVELENGTH μm
(b) GROUND LEVEL
ABSORPTION %
100 80 60 40 20 0
Atmospheric Transmission
H2O (ROTATION)
O2 O2 O2 O2 O3 O3 O2 O2 H2O H2O H2O H2O CO2 CO2 H2O CH4 HDO CO2 O3 N2O CO H2O N2O CH4 O3 CO2 CFCl3 CF2Cl2 O3 N2O

The primordial atmosphere of Earth had no oxygen. The present 21% of O_2 is due to the plant production by photosynthesis which produced oil and coal deposits.



Chemistry of Atmospheres, R.P. Wayne, Oxford Science Publication, 1991.

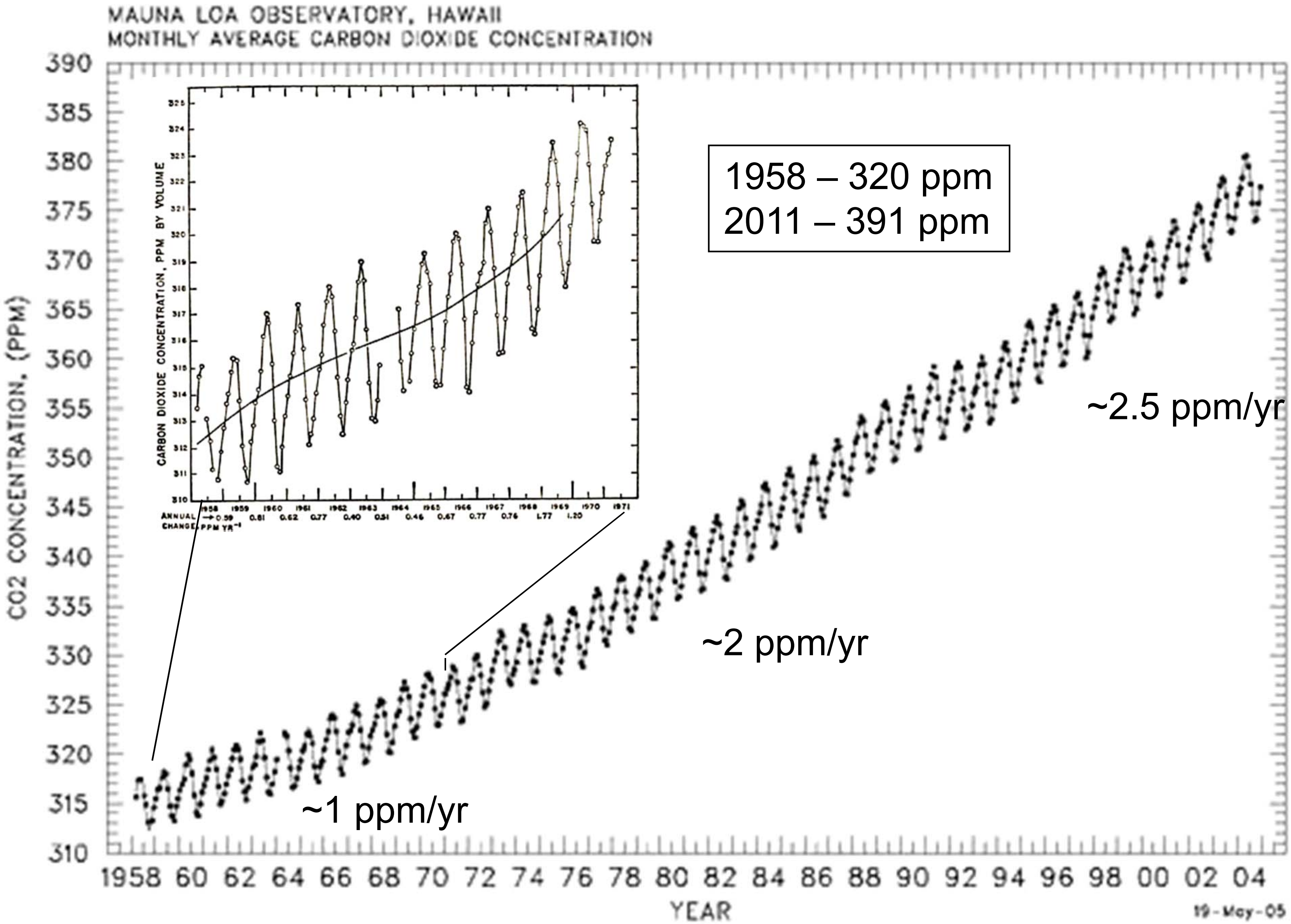




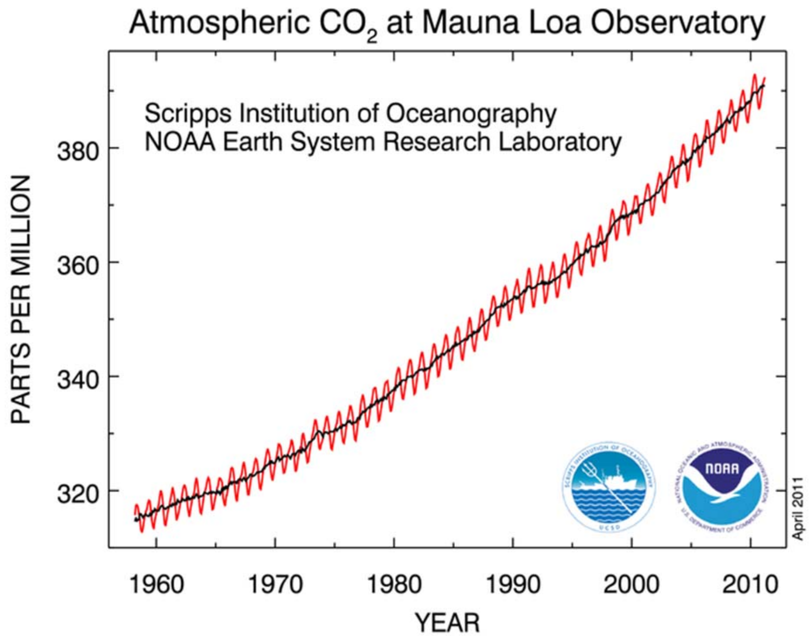
CO_2 Increase

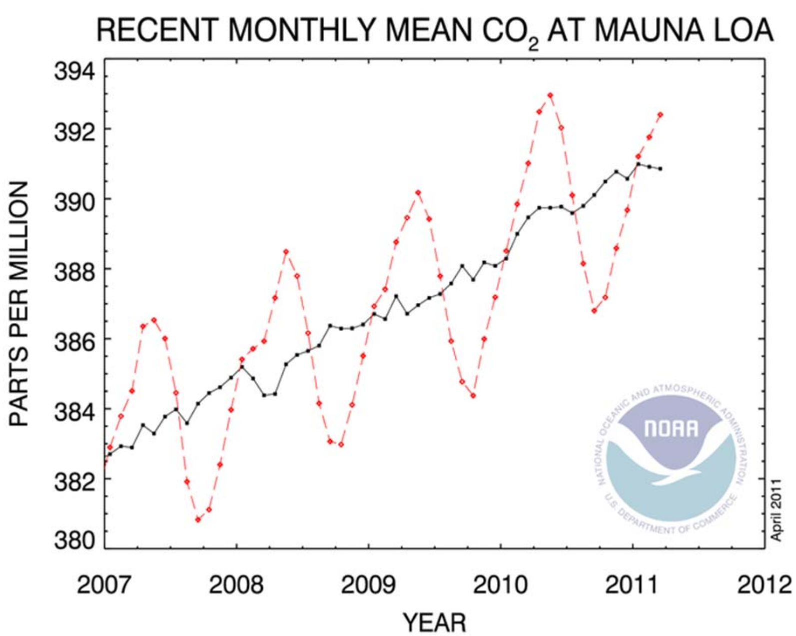
CO_2 is combustion by product of all anthropogenic fuels –
it is used by plants in the cycle of photosynthesis to produce oxygen.
The increase follows the increase burning of anthropogenic fuels and the oscillation follows the summer/winter conversion of CO_2.

Climate Change: The IPCC Scientific Assessment – World Meteorological Organization, Cambridge University Press, 1990.



CO_2 → Chlorophyll → O_2





NOAA: Earth System Research Laboratory

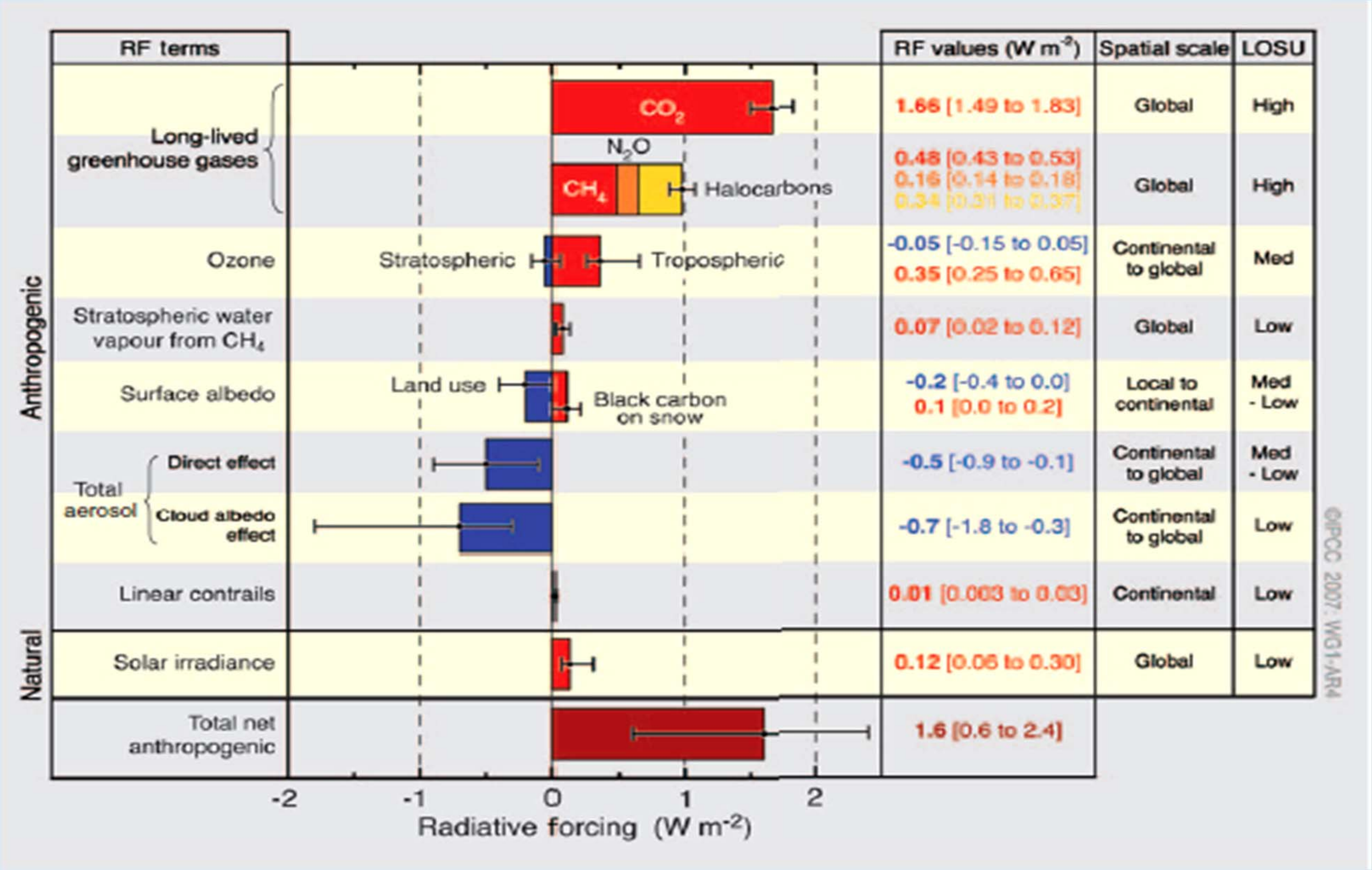
Red line is the CO_2 data measured as the mole fraction of dry air

Black curve is the seasonally corrected data

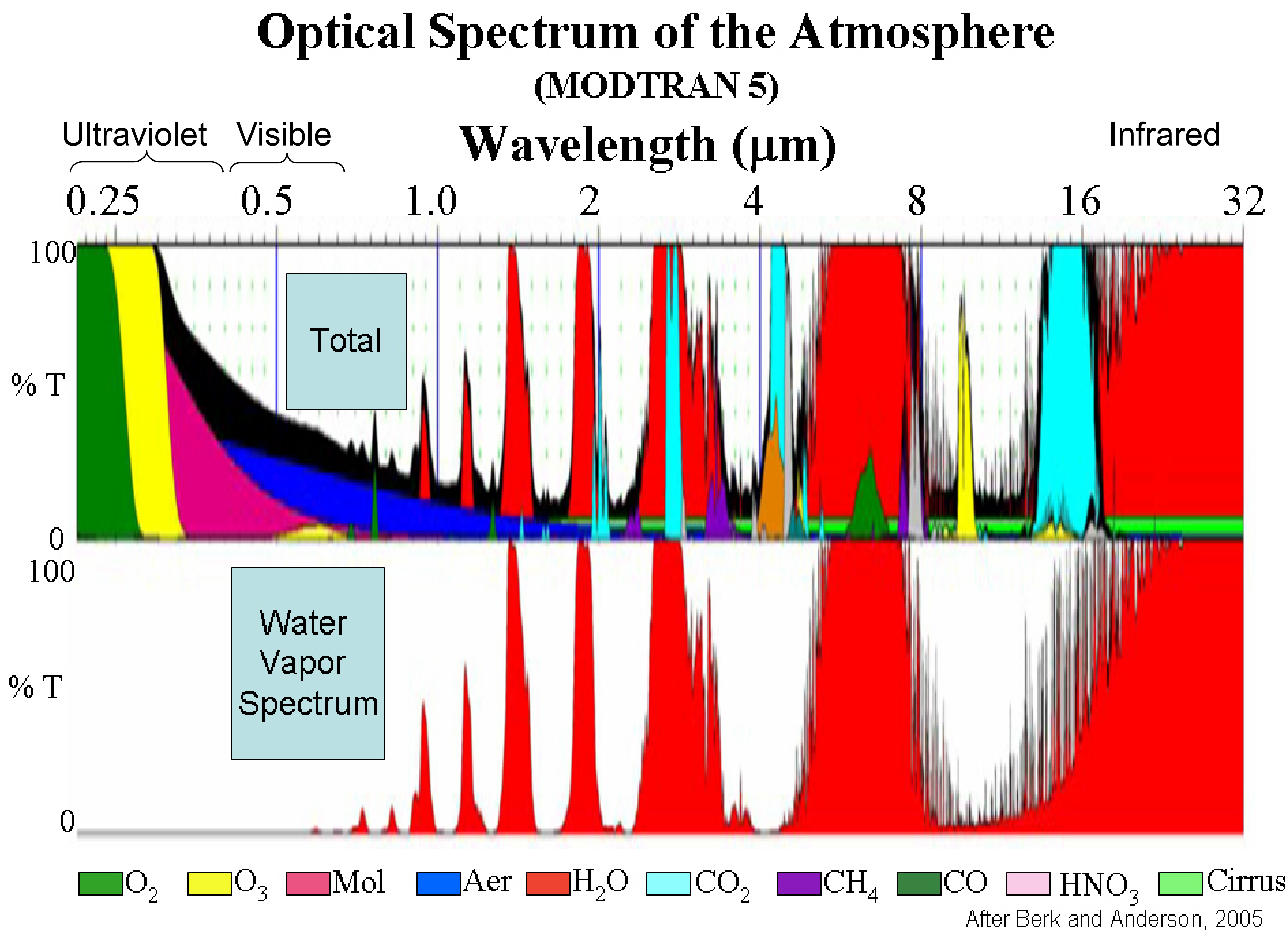
1998, 2002, 2005, 2010 experienced the greatest annual increase

March 2011: 392.40 ppm

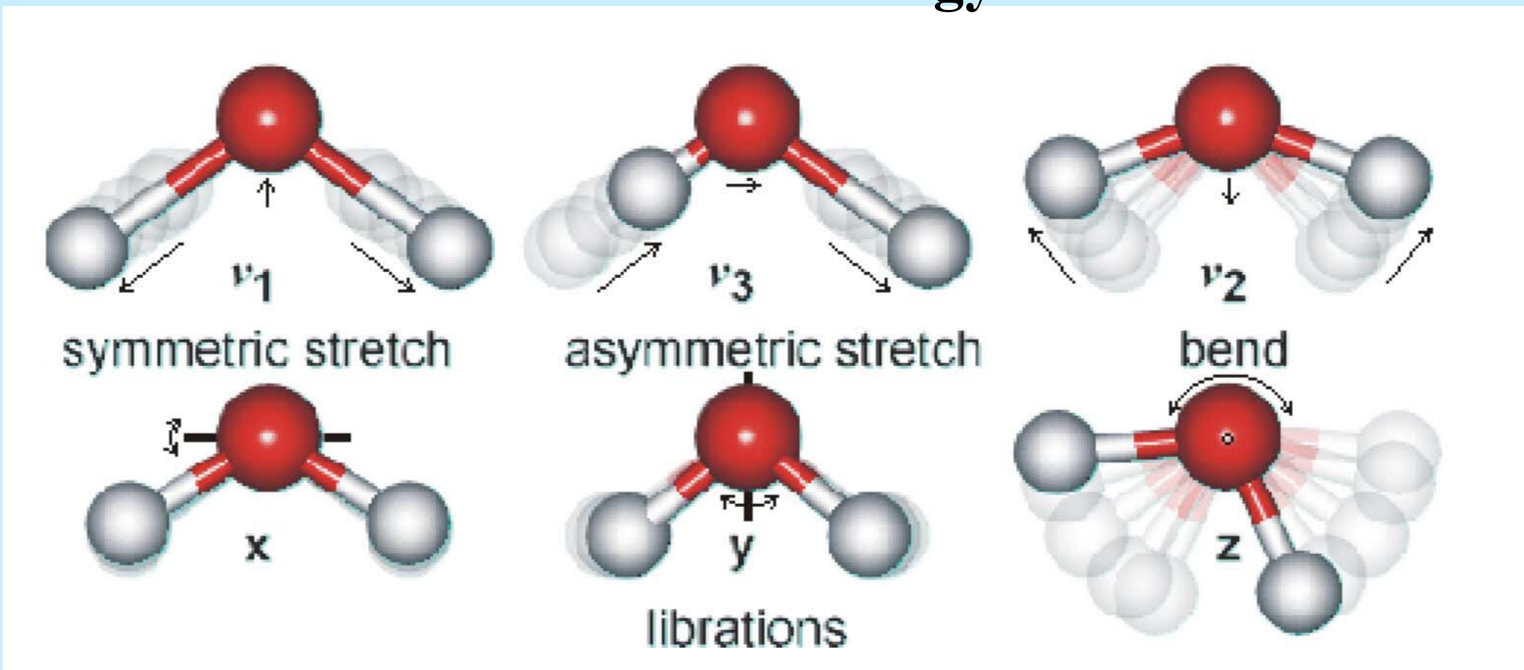
Radiative Forcing Components



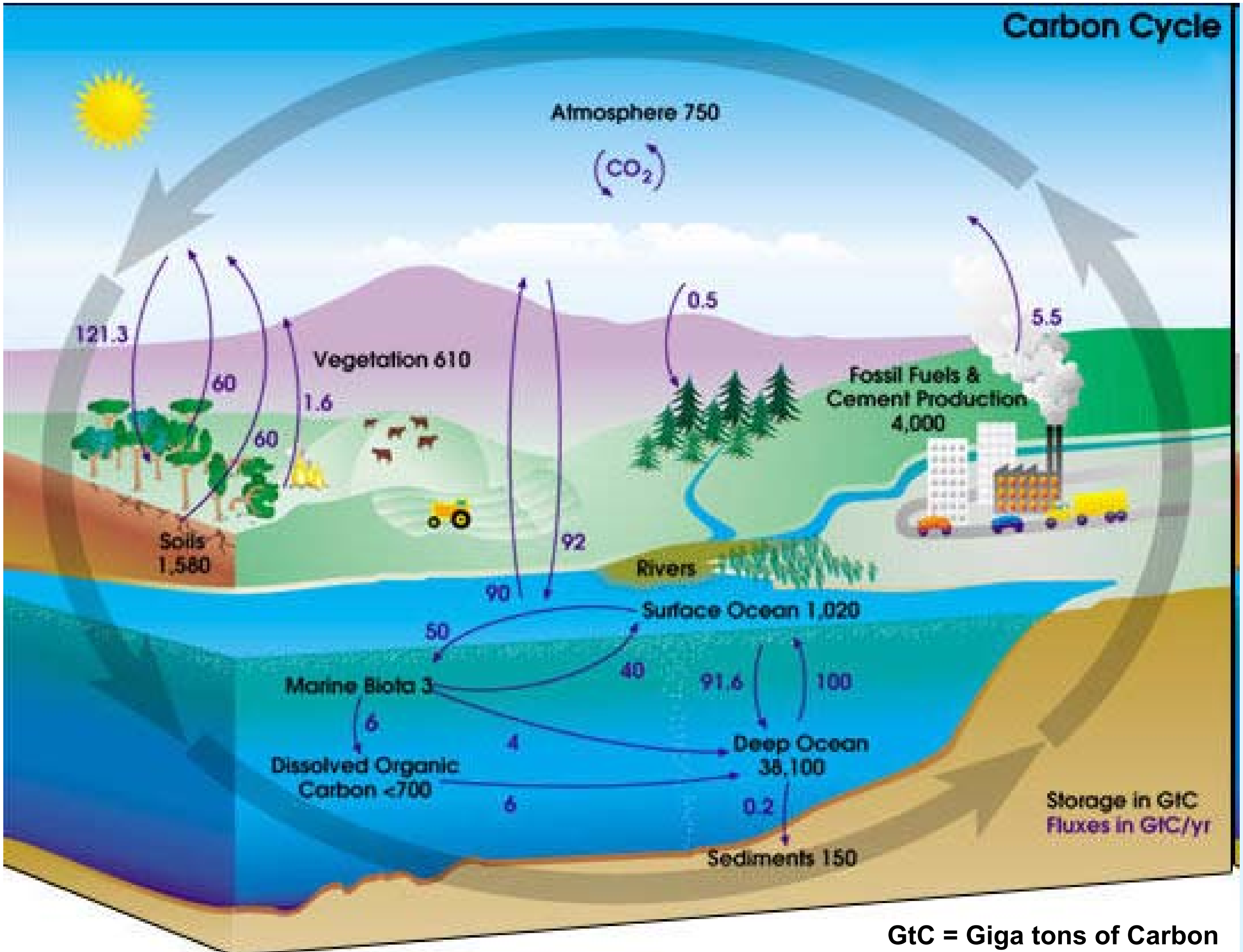
Intergovernmental Panel on Climate Change (IPCC), Climate Change 2007


Optical Spectrum of the Atmosphere
(MODTRAN 5)
Ultraviolet
Visible
Wavelength (µm)
Infrared
0.25
0.5
1.0
2
4
8
16
32
100
% T
0
Total
100
% T
0
Water Vapor Spectrum
O_2
O_3
Mol
Aer
H_2O
CO_2
CH_4
CO
HNO_3
Cirrus
After Berk and Anderson, 2005

Water Molecule - Energy States



http://www.lsbu.ac.uk/water/images/v1.gif



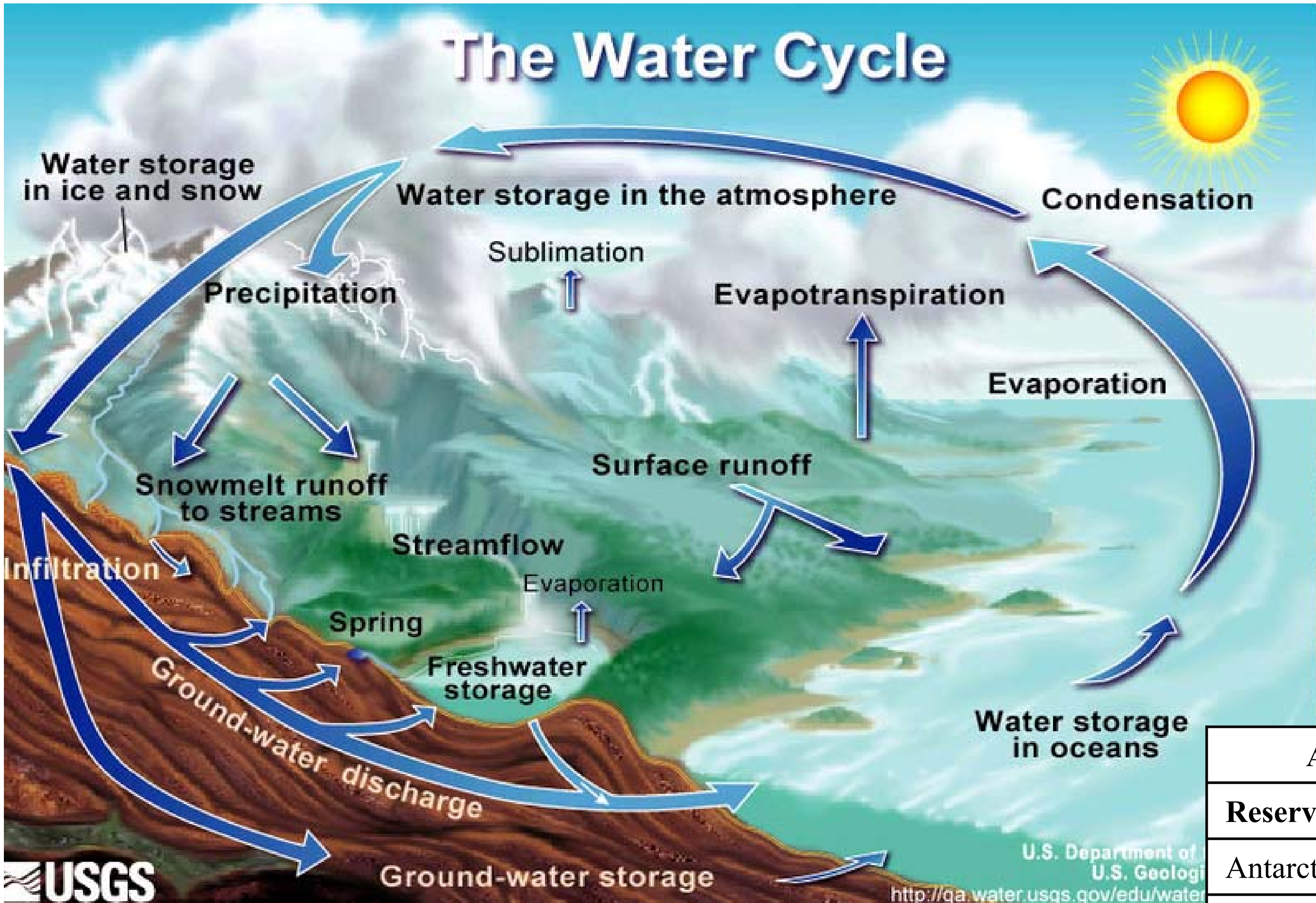
GtC = Giga tons of Carbon

http://earthobservatory.nasa.gov/Library/CarbonCycle/carbon_cycle4.html

We release 5.5 x 10^9 (billion) tons of carbon by burning fossil fuels each year. From this, 3.3 x 10^9 tons goes into the atmosphere and the rest into the ocean.

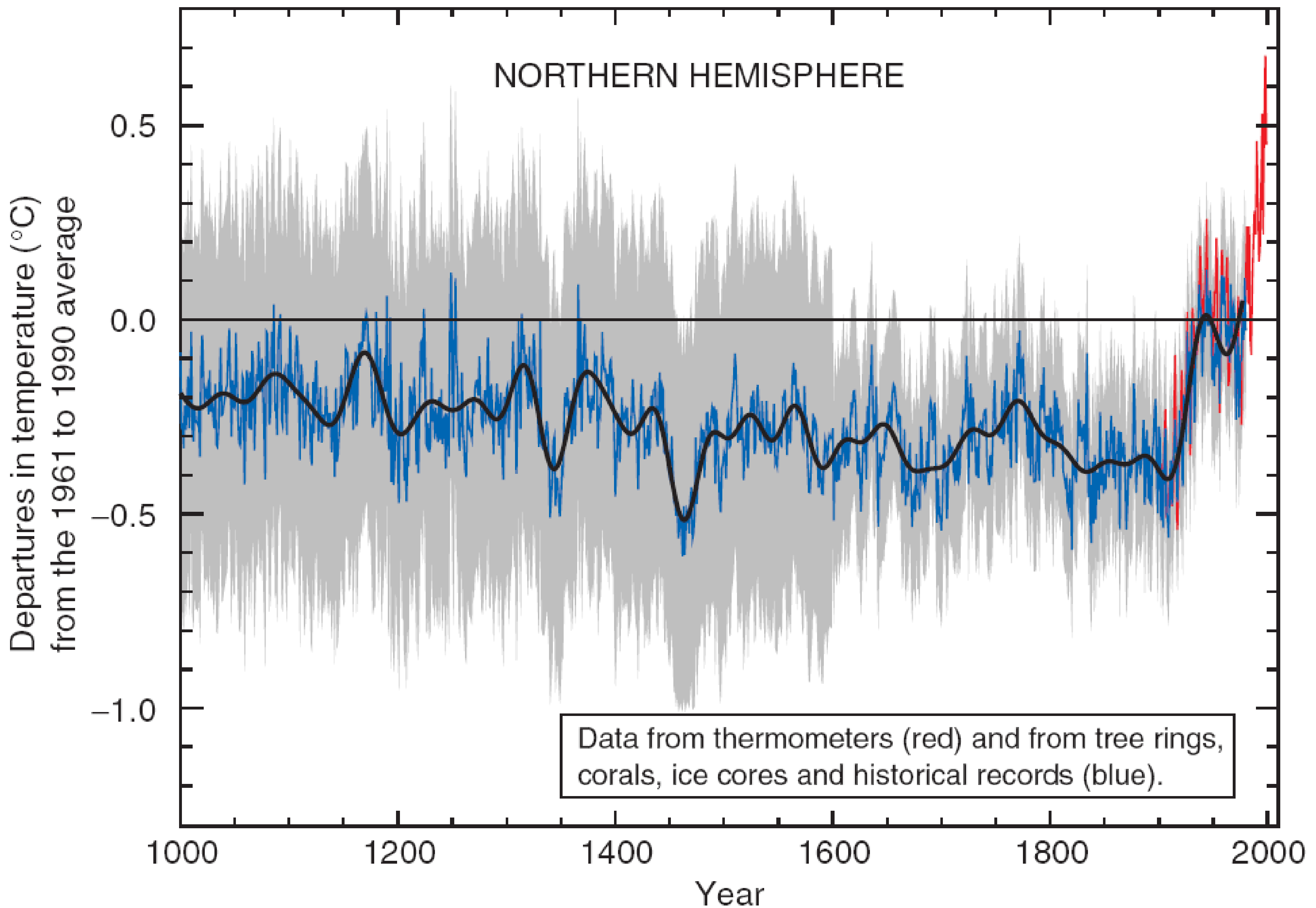
Photosynthesis reaction $6CO_2 + 6H_2O \rightarrow C_6H_{12}O_6 + 6O_2$

National Earth Science Teachers Association

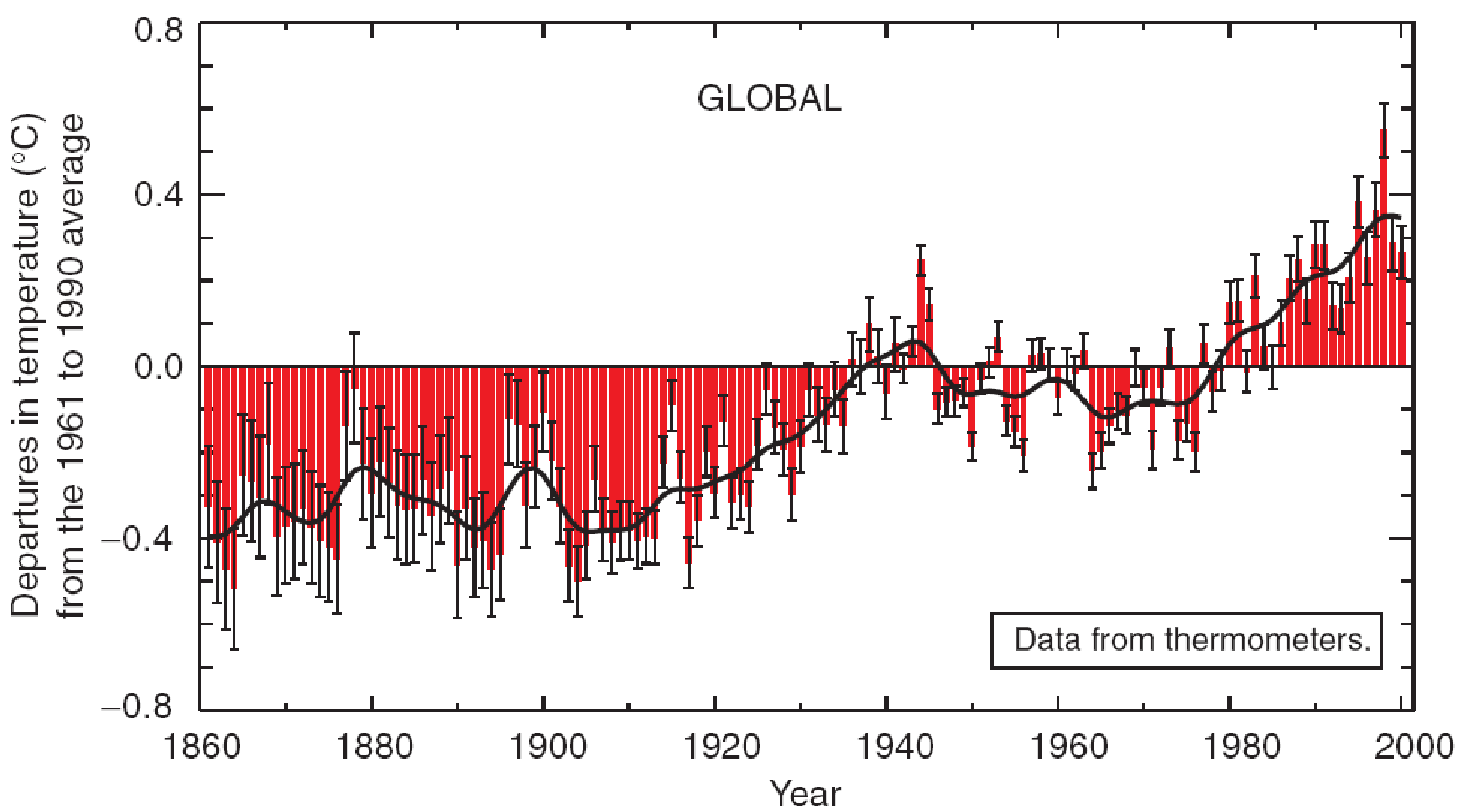


Average reservoir residence times*	
Reservoir	**Average residence time**
Antarctica	20,000 years
Oceans	3,200 years
Glaciers	20 to 100 years
Seasonal snow cover	2 to 6 months
Soil moisture	1 to 2 months
Groundwater: near	100 to 200 years
Groundwater: deep	10,000 years
Lakes	50 to 100 years
Rivers	2 to 6 months
Atmosphere	9 days

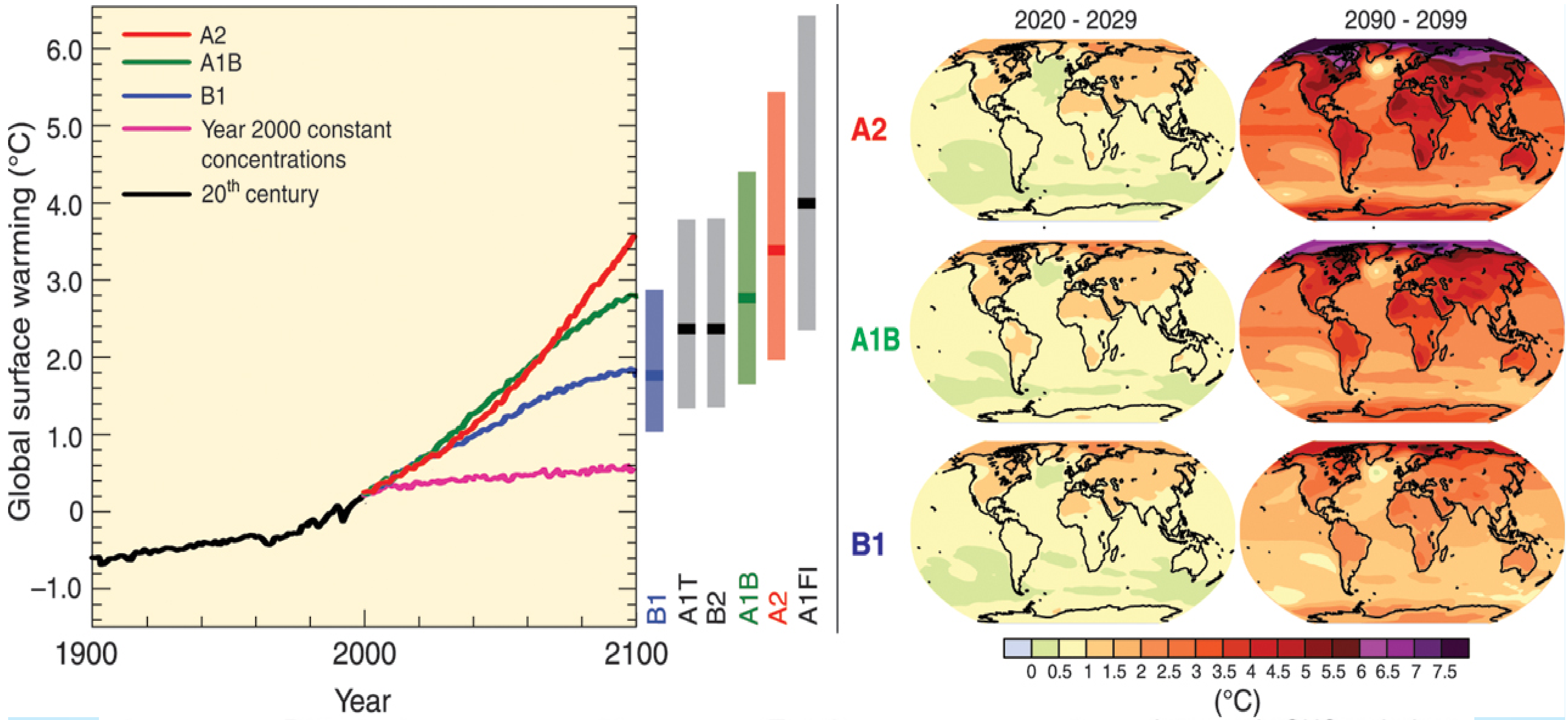
*** PhysicalGeography.net. CHAPTER 8: Introduction to the Hydrosphere**

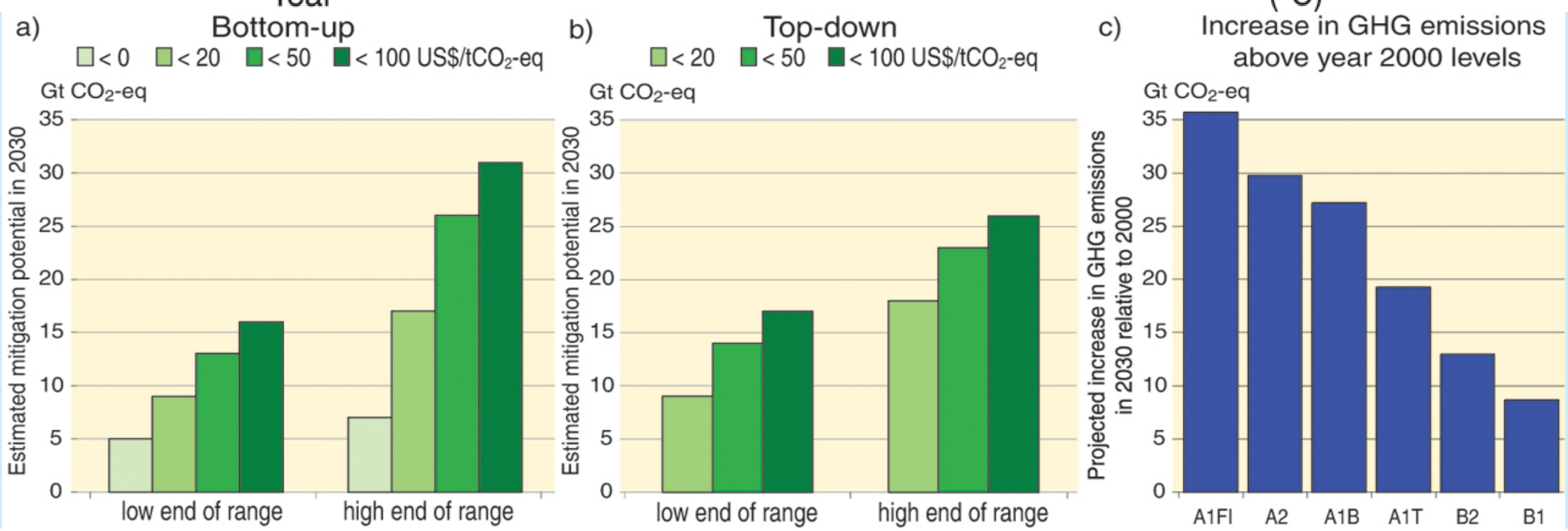


Intergovernmental Panel on Climate Change (IPCC), Climate Change 2007

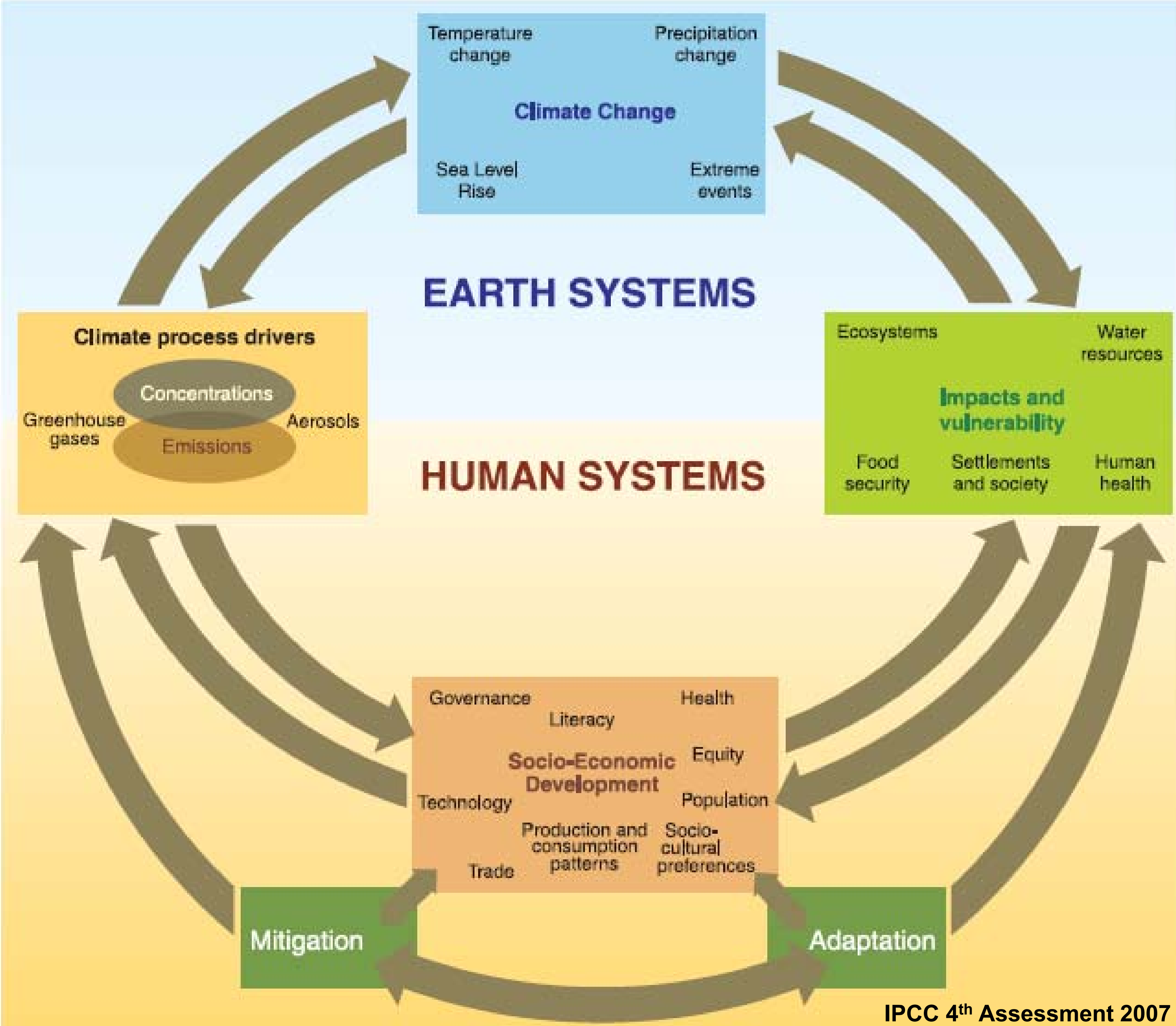


Intergovernmental Panel on Climate Change (IPCC), Climate Change 2007


A2
A1B
B1
Year 2000 constant concentrations
20th century
Global surface warming (°C)
6.0
5.0
4.0
3.0
2.0
1.0
0
−1.0
1900
2000
2100
Year
B1
A1T
B2
A1B
A2
A1FI
2020 - 2029
2090 - 2099
A2
A1B
B1
0 0.5 1 1.5 2 2.5 3 3.5 4 4.5 5 5.5 6 6.5 7 7.5
(°C)


a)
Bottom-up
< 0
< 20
< 50
< 100 US$/tCO2-eq
Gt CO2-eq
Estimated mitigation potential in 2030
35
30
25
20
15
10
5
0
low end of range
high end of range
b)
Top-down
< 20
< 50
< 100 US$/tCO2-eq
Gt CO2-eq
Estimated mitigation potential in 2030
low end of range
high end of range
c)
Increase in GHG emissions above year 2000 levels
Gt CO2-eq
Projected increase in GHG emissions in 2030 relative to 2000
A1FI
A2
A1B
A1T
B2
B1

IPCC



IPCC 4th Assessment 2007

Unmitigated climate change would, in the long term, be *likely* to exceed the capacity of natural, managed and human systems to adapt. *{WGII 20.7, SPM}*

If we don't do anything about it, mankind is in deep trouble.

Some planned adaptation (of human activities) is occurring now; more extensive adaptation is required to reduce vulnerability to climate change. *{WGII 17.ES, 20.5, Table 20.6, SPM}*

Some efforts to adapt are being tried.

A wide range of mitigation options is currently available or projected to be available by 2030 in all sectors. The economic mitigation potential, at costs that range from net negative up to US$100/tCO2-equivalent, is sufficient to offset the projected growth of global emissions or to reduce emissions to below current levels in 2030. *{WGIII 11.3, SPM}*

Ideas for mitigation are available - $

IPCC 4th Assessment 2007

Many impacts can be reduced, delayed or avoided by mitigation. Mitigation efforts and investments over the next two to three decades will have a large impact on opportunities to achieve lower stabilization levels. Delayed emissions reductions significantly constrain the opportunities to achieve lower stabilization levels and increase the risk of more severe climate change impacts. *{WGII SPM, WGIII SPM}*

Must invest $ now to have a chance to mitigate future events.

Making development more sustainable by changing development paths can make a major contribution to climate change mitigation and adaptation and to reducing vulnerability. *{WGII 18.7, 20.3, SPM; WGIII 13.2, SPM}*

The choices we make now for future development are important.

IPCC 4th Assessment 2007

The Issues:

(1) Present CO_2 levels are approaching 400 ppm (>500 ppm by 2050)

(2) Most scientists that have studied the problem agree that unacceptable climate changes will have occurred by the time CO_2 reaches 450 ppm

(3) Fossil fuels account for 80% of the world's energy use

(4) A definite temperature increase is measured during the past 50 years
(20 of the hottest years on record occurred since 1980)

(5) US did not sign the Kyoto Protocol
(reduce emission to 7% below 1990 level)

(6) US produces 25% of carbon emission with 5% of population

(7) Today the global input is ~ $7x10^9$ tons per year and at present rate of growth that will be 14 billion tons per year by 2056

(8) Residential and commercial buildings account for > 60% of electric use

(9) Coal based synfuels add as much or more CO_2 as a gasoline car

(10) Corn based biofuels add as much CO_2 and may do more ecological damage because of fertilizers

(11) Today energy relies on digging or pumping 7 billion tons of carbon each year that is mostly input to the atmosphere

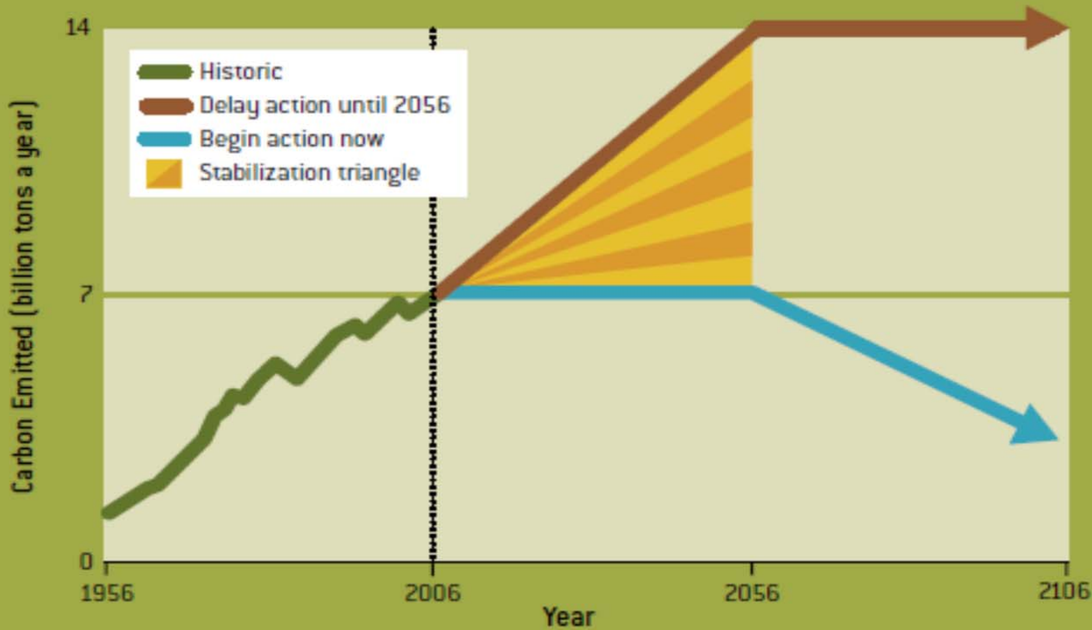
(12) No simple single fix will help to avert the eventual possibility of a "run-away greenhouse"

MANAGING THE CLIMATE PROBLEM

At the present rate of growth, emissions of carbon dioxide will double by 2056 (*below left*). Even if the world then takes action to level them off, the atmospheric concentration of the gas will be headed above 560 parts per million, double the preindustrial value (*below right*)—a level widely regarded as capable of triggering severe climate changes. But if the world flattens out emissions beginning now and later ramps them down, it should be able to keep concentration substantially below 560 ppm.

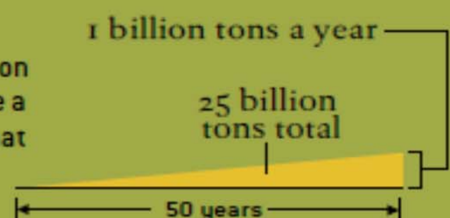
ANNUAL EMISSIONS

In between the two emissions paths is the "stabilization triangle." It represents the total emissions cut that climate-friendly technologies must achieve in the coming 50 years.



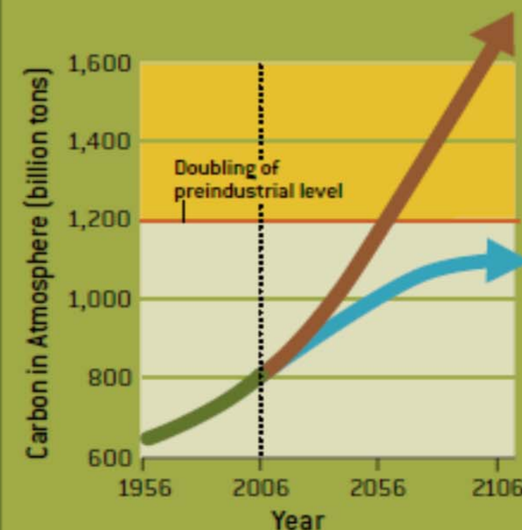
THE WEDGE CONCEPT

The stabilization triangle can be divided into seven "wedges," each a reduction of 25 billion tons of carbon emissions over 50 years. The wedge has proved to be a useful unit because its size and time frame match what specific technologies can achieve. Many combinations of technologies can fill the seven wedges.

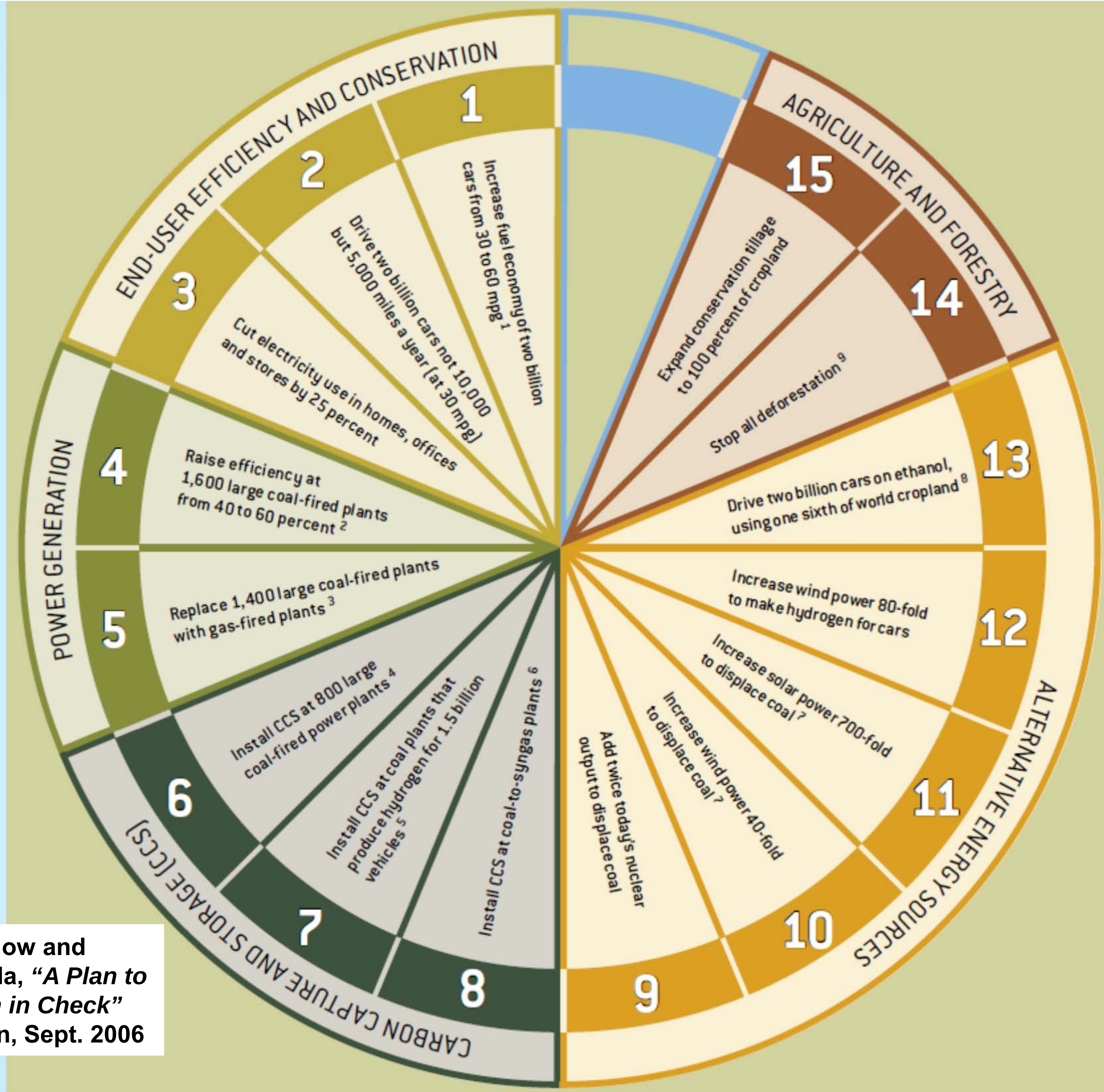


CUMULATIVE AMOUNT

Each part per million of CO_2 corresponds to a total of 2.1 billion tons of atmospheric carbon. Therefore, the 560-ppm level would mean about 1,200 billion tons, up from the current 800 billion tons. The difference of 400 billion tons actually allows for roughly 800 billion tons of emissions, because half the CO_2 emitted into the atmosphere enters the planet's oceans and forests. The two concentration trajectories shown here match the two emissions paths at the left.



Sci. American, Sept. 2006



Robert Socolow and Stephen Pacla, *"A Plan to Keep Carbon in Check"* **Sci. American, Sept. 2006**

Require a minimum of seven wedges to limit the CO_2 at a survival level
(wedges only count if added use of technologies that have already been demonstrated)

1 Wedge – Lower birth rate to hold global population below 8 billion people in 2056
1 Wedge – Curtail the emissions of methane (CH_4)
2 Wedges – Eliminate deforestation
1 Wedge – Wide spread use of synfuels with capture and storage of CO_2
2 Wedges – Expand the number of nuclear power plants by factor of five to displace conventional coal power plants
2 Wedges – Cut electricity use in building by half through use of super-efficient lighting and appliances
1 Wedge – Industrial use of electricity more efficiently
1 Wedge – Increased efficiency of automobiles
1 Wedge – Efficiency in transportation (other than automobile)
1 Wedge – Capture and store the carbon emissions from the present coal power plants
1 Wedge – capture and store carbon from large natural gas power plants
-1 to -3 Wedges – 700 coal power plants (1000 MW) emit one wedge (a few thousand such plants are presently expected to be built – natural gas plants burn half as much carbon per unit of electricity)

Robert Socolow and Stephen Pacla, *"A Plan to Keep Carbon in Check"* Sci. American, Sept. 2006

What is the level that we will experience irreversible changes?

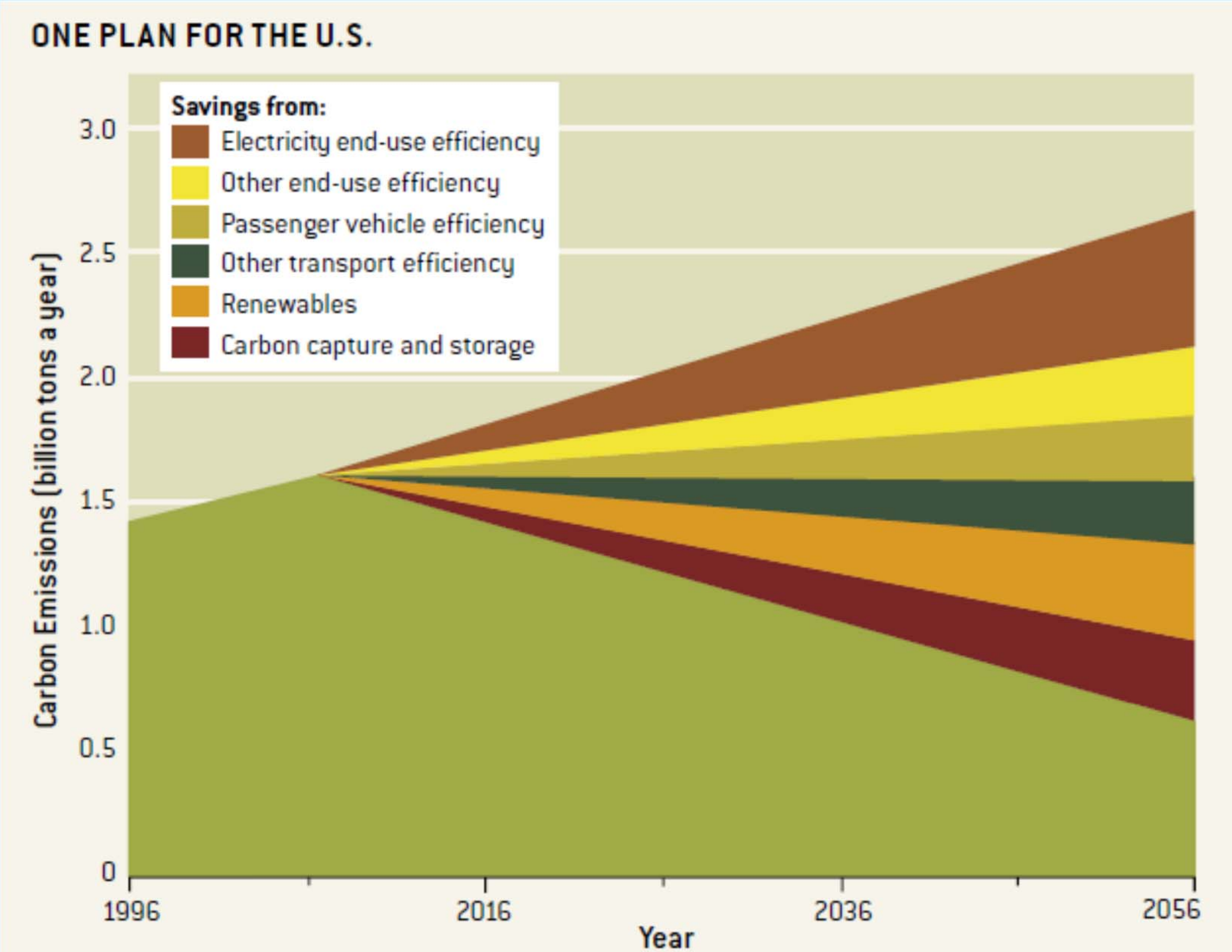
Concept of several wedges to arrive at a solution.
Hold CO_2 constant without choking economic growth.

2056 Goals

- 60 mpg car
- cut electricity use in homes and buildings by half
- carbon sequestering (capture and storage)
- increased nuclear power (but hostage to the world's least well-run plant)
- increased alternative sources (solar cells, wind, waves)

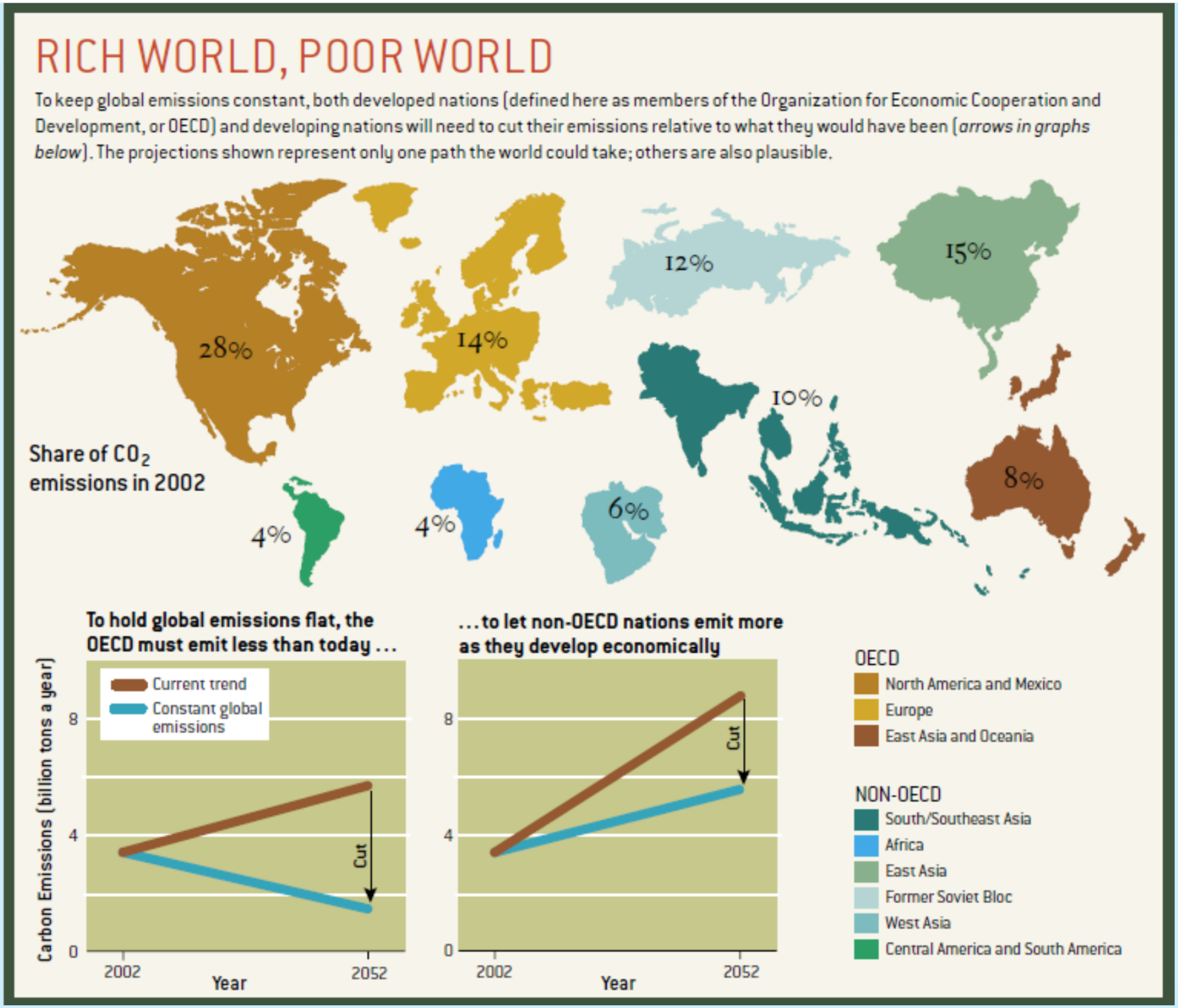
What set of polices will result in saving seven wedges?

(a wedge represents 1 billion tons of carbon per year)



▲ U.S. share of emissions reductions could, in this Natural Resources Defense Council scenario, be achieved by efficiency gains, renewable energy and clean coal.

Robert Socolow and Stephen Pacla, ***"A Plan to Keep Carbon in Check"*** **Sci. American, Sept. 2006**



US share of global CO_2 was 39% in 1952 and 23 % in 2002

OECD = Organization for Economic Cooperation and Development

Sci. American, Sept. 2006

Perspective –

Our universe has been here about 14 billion years,

our solar system formed about 4 billion years ago,

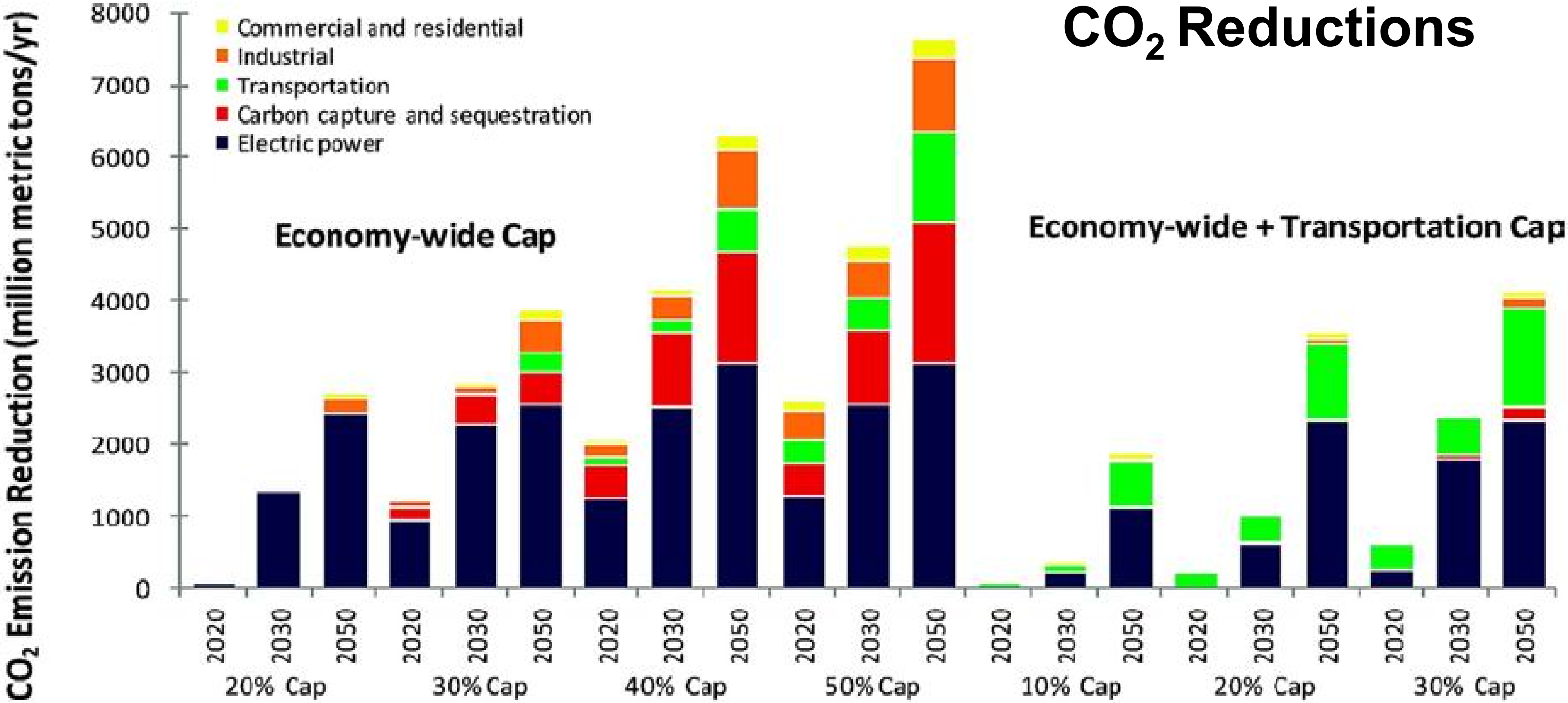
man has been walking this planet about 4 million years,

civilization's roots for modern society are about 2500 years old,

the industrial revolution to produce our goods and services began about 100 years ago.

Olympus Photo Deluxe, 2000

CO_2 Reductions



↑ We compared energy-related CO_2 emission reductions in 2020, 2030, and 2050 by sector for seven of our scenarios (the 20%E to 50%E scenarios and the 10%E&T to 30%E&T scenarios). Electric power and carbon capture and sequestration (CCS) account for most of the reduction in the economy-wide scenarios. The transportation sector starts to make more substantial reduction contributions at the 40-percent reduction target and above.

Yeh, Sonia and David McCollum. "Optimizing Climate Mitigation Wedges for the Transportation Sector." In STEPS Book: Institute of Transportation Studies, University of California, Davis.

Table 1

World per-capita energy use in 2003 and projections of future energy use based on current consumption of various countries.

Country	*Energy use (TW) per person*	*Population in 2003*	*Energy use by country (TW) for 2003*	*Projected energy need (TW) for entire global population (9 billion) in year 2050 based on individual country's energy use in 2003*
United States	1.1361×10^{-8}	290,342,554	3.3	102.2
China	0.1166×10^{-8}	1,286,975,468	1.5	10.5
India	0.0440×10^{-8}	1,049,700,118	0.46	4.0
Africa	0.0524×10^{-8}	856,082,181	0.45	4.7
Malaysia	0.3167×10^{-8}	23,092,940	0.073	28.5
Poland	0.3159×10^{-8}	38,622,660	0.12	28.4
Equatorial Guinea	0.3375×10^{-8}	510,473	0.00172	30.4
Samoa	0.3971×10^{-8}	70,260	0.000279	35.7
Western Europe	0.5049×10^{-8}	483,912,045	2.44	45.4
North America	0.9349×10^{-8}	427,585,501	4.00	84.1

Note: Data taken from the U.S. Department of Energy website: www.eia.doe.gov/iea/.

Daniel G. Nocera, *on the future of global energy, Dædalus Fall 2006*

Wind Power

Goal: 20% of US Power by 2030

Figure 1-2. Cumulative U.S. wind capacity, by year (in megawatts [MW])

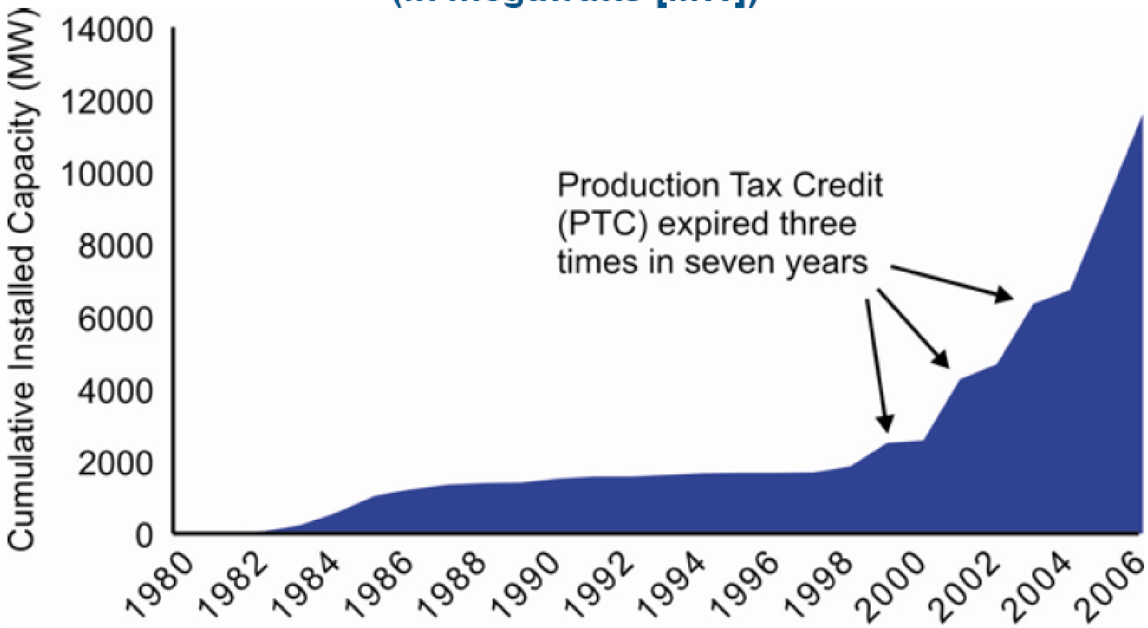
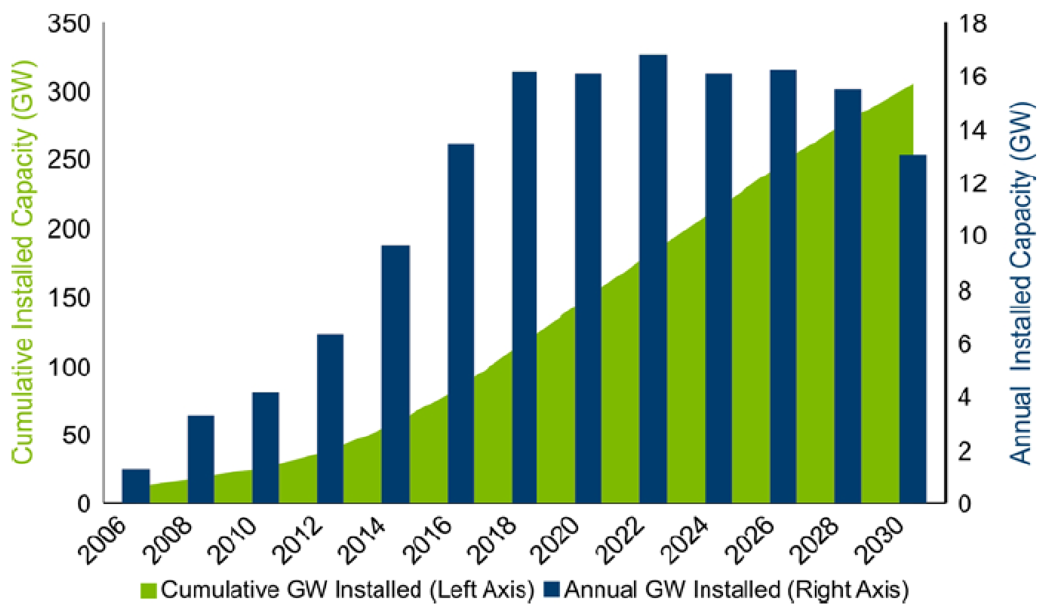
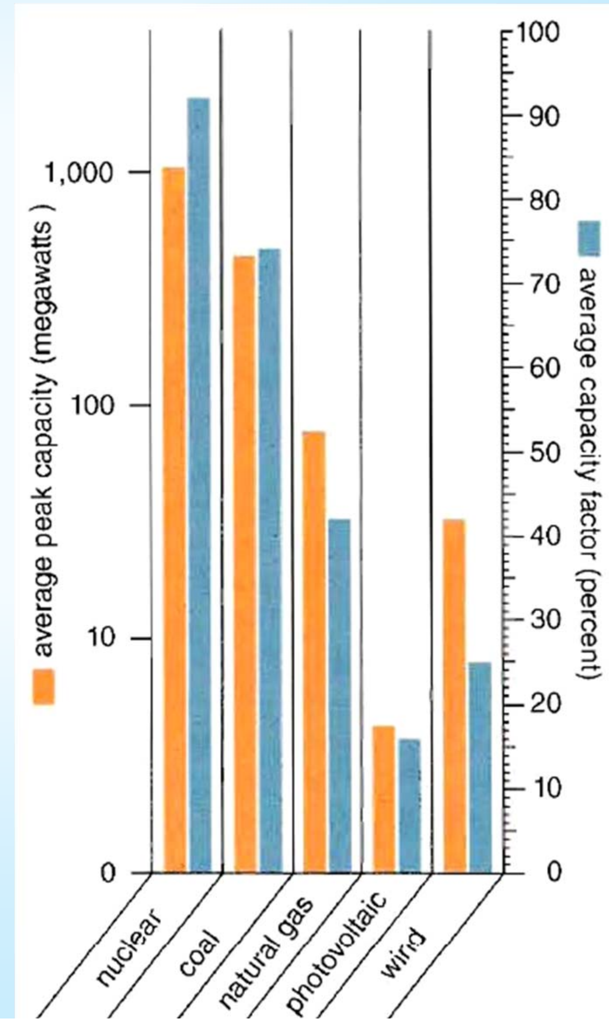


Figure 1-4. Annual and cumulative wind installations by 2030

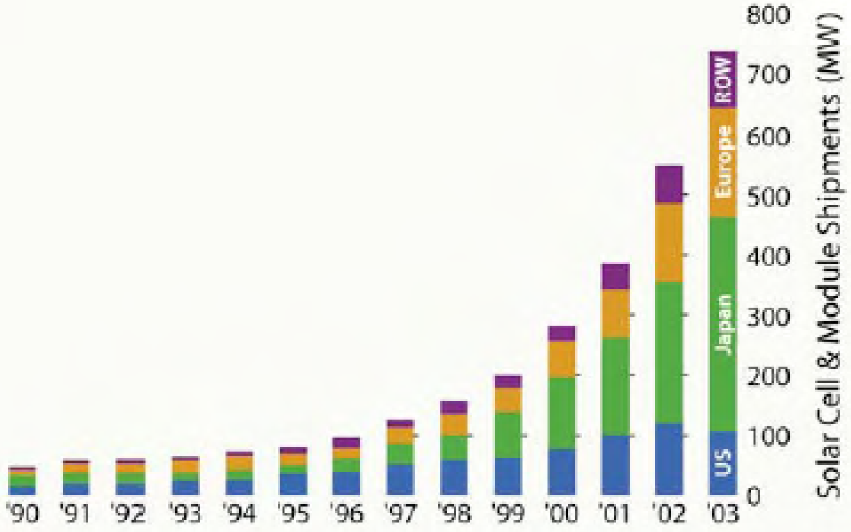


Energy Sources

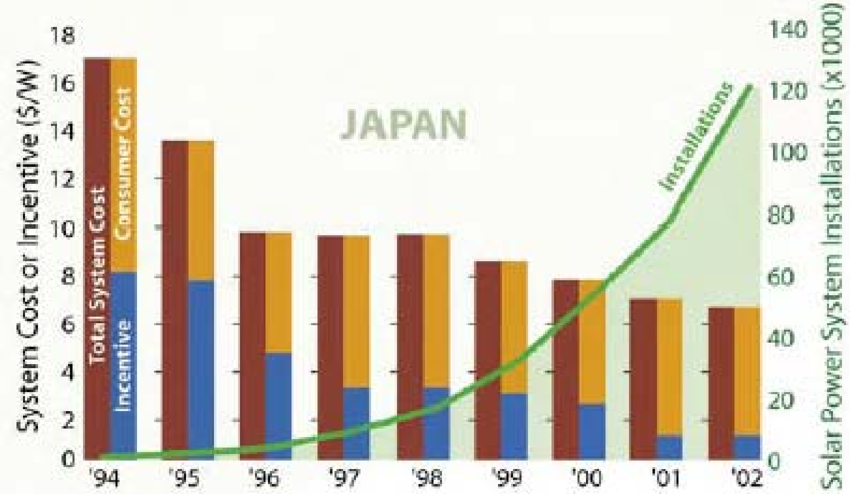


Smil, Global Energy, Am. Scientist, 99, p212, 2011

Solar Cell Market Growth



Worldwide solar power shipments in 2003 totaled 744 MW, with the U.S. share at only 14%.



Wind and Geothermal

http://www.solar.udel.edu/pdf/SEIA%20Roadmap.pdf

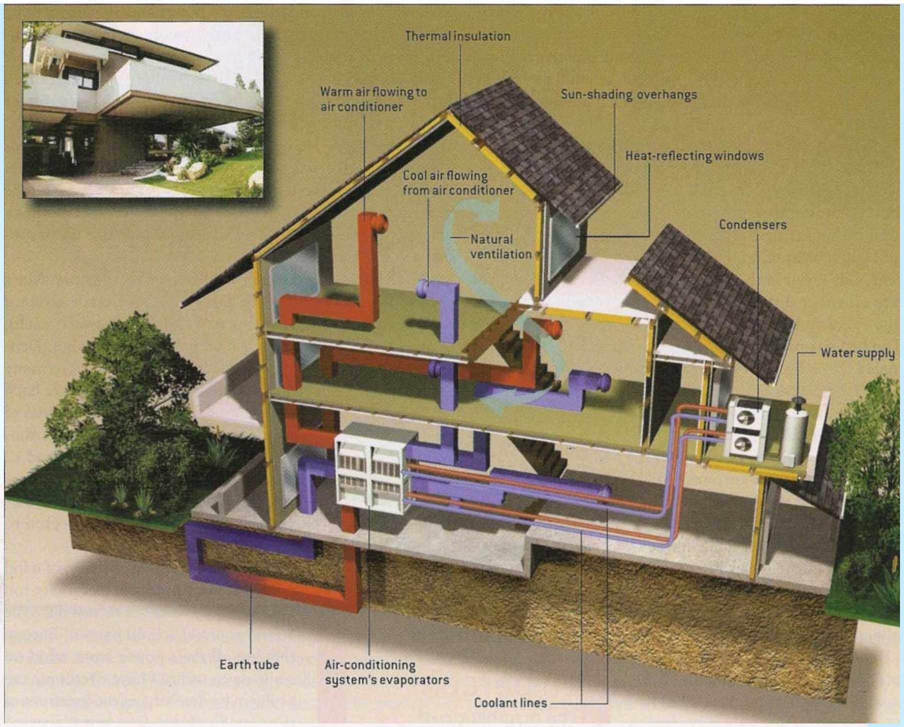
Table of Targets and Projections for Solar Power for 2004 to 2050

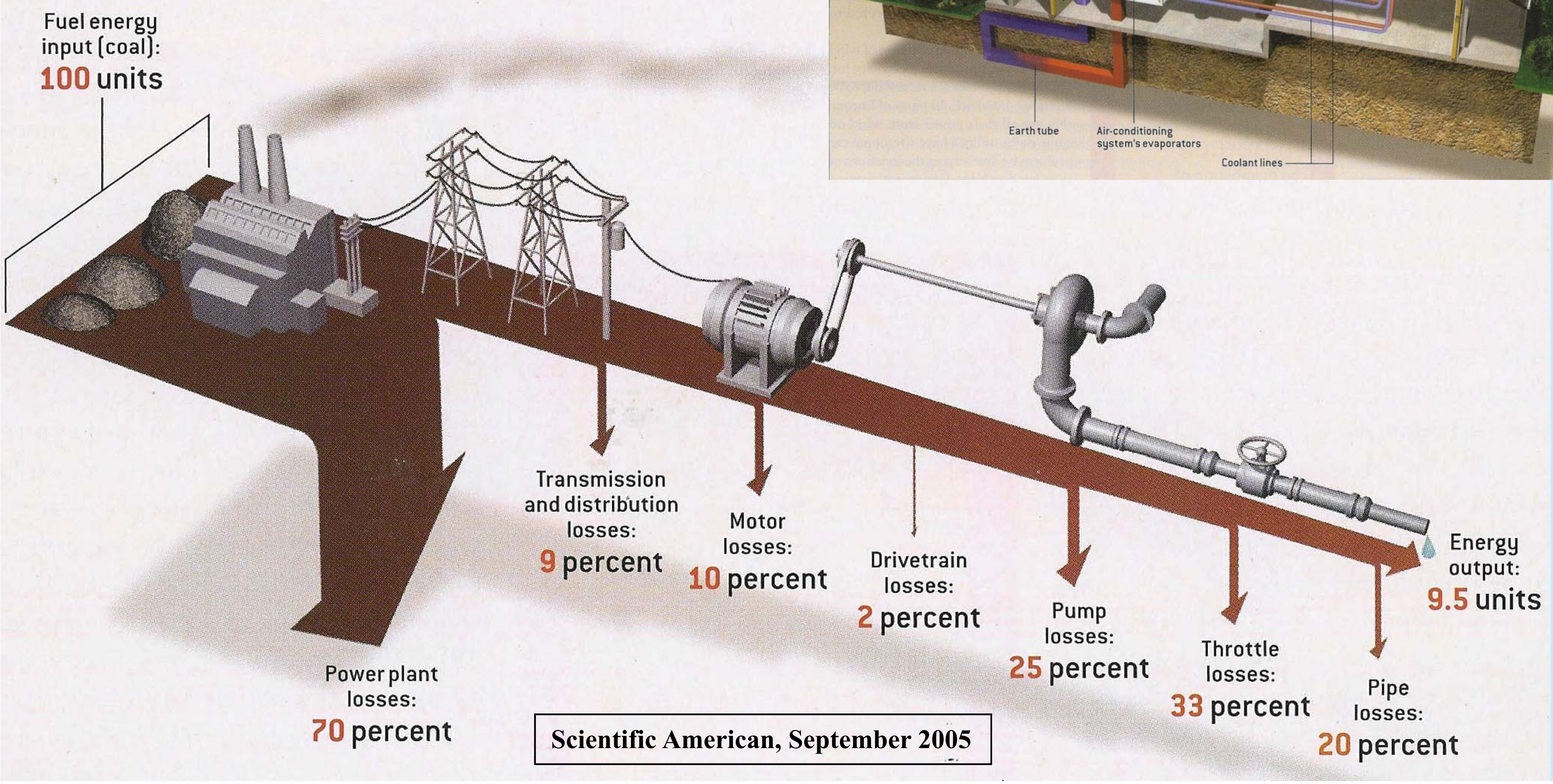
System Price and Electricity Cost, Commercial Systems		2004	2010	2015	2020	2030	2050
Best System Selling Price [a] ($/W)	Baseline	6.10	4.87	4.24	3.76	3.12	2.56
	Roadmap	6.10	4.65	3.68	3.01	2.33	1.93
Electricity Cost [b] (¢/kWh)	Baseline	18.2	13.4	11.5	10.0	8.2	6.8
	Roadmap	10.5	7.4	5.7	4.6	3.8	3.7
U.S. Solar Power Shipments, Installations, and Employment							
Annual U.S. Shipments (MW peak)	Baseline	120	240	480	950	2,400	5,500
	Roadmap	120	510	2,300	7,200	19,000	31,000
Cumulative U.S. Installations (MW peak)	Baseline	340	1,500	3,800	8,200	28,000	100,000
	Roadmap	340	2,100	9,600	36,000	200,000	670,000
Employment [c]	Baseline	20,000	23,000	28,000	37,000	59,000	95,000
	Roadmap	20,000	29,000	62,000	130,000	260,000	350,000
Performance Advances [d]							
Conversion Efficiency (%)	Cell	10–20	15–25	19–28	20–35	22–40+	Ultra-High Efficiency > 40
	Module	8–15	12–17	16–20	18–24	20–30	Ultra-Low Cost > 15
	System	6–12	9–14	13–18	14–20	18–25	

http://www.solar.udel.edu/pdf/SEIA%20Roadmap.pdf

Improve efficiency in design, construction, heating/cooling systems, appliances, industrial methods, and electrical transmission.

Particularly, cleaner transportation and generation of electrical energy.

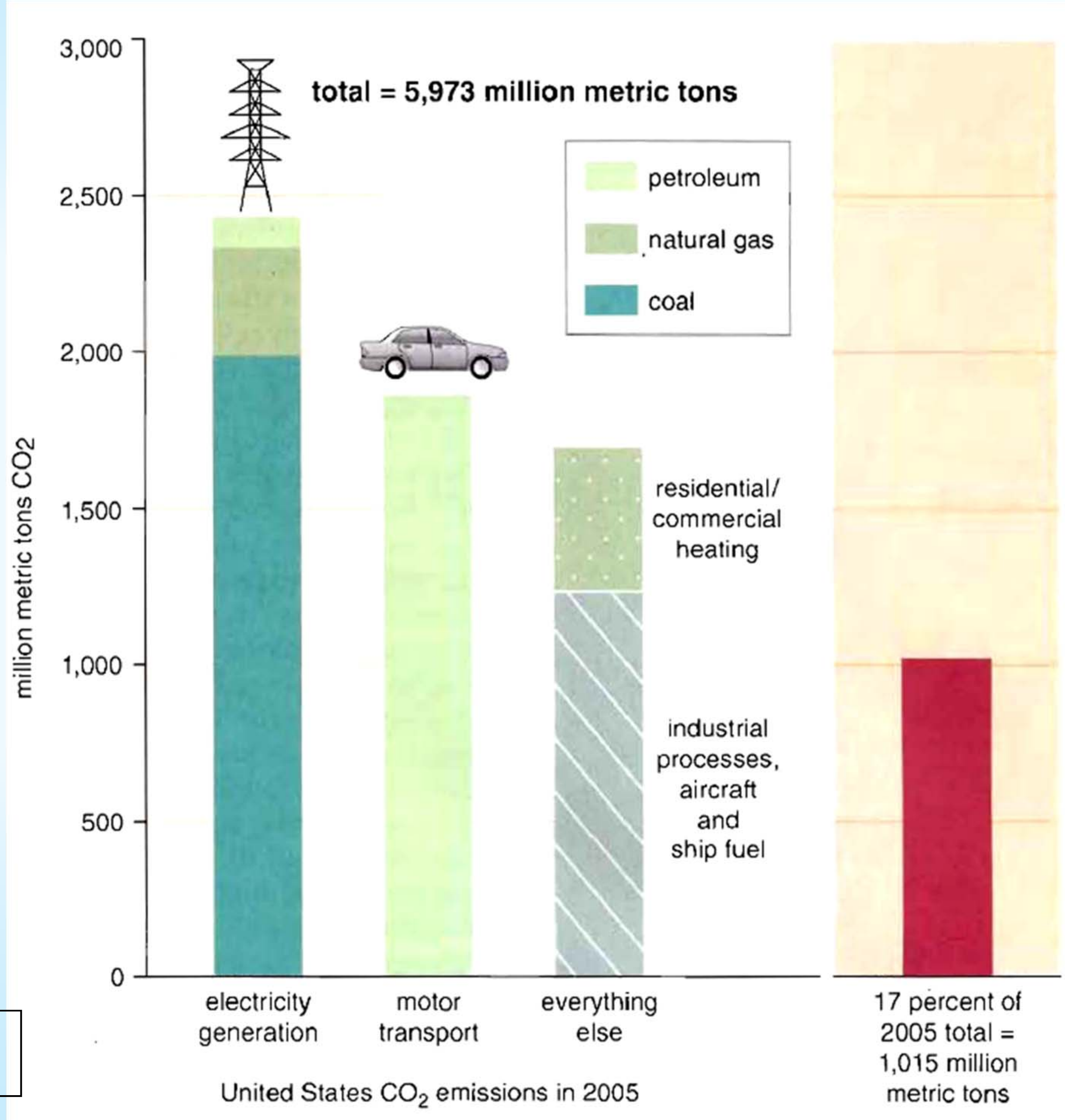




Scientific American, September 2005

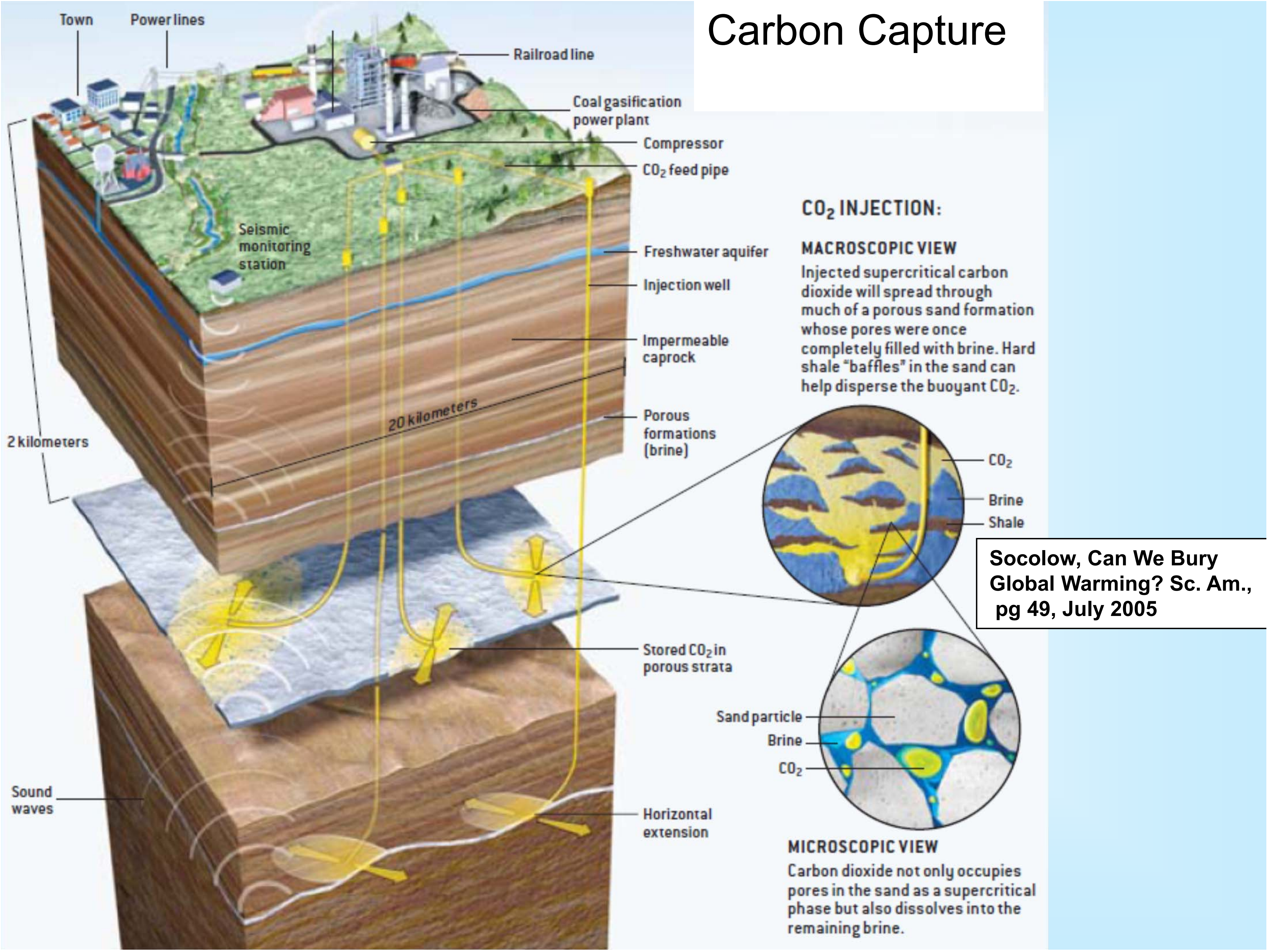
President Obama's total emissions goal for 2050.

Requires ~zero emission from transport and electric generation.



Pavlak, Strategy Versus Evolution, Am. Scientist, 98, p 448, 2010

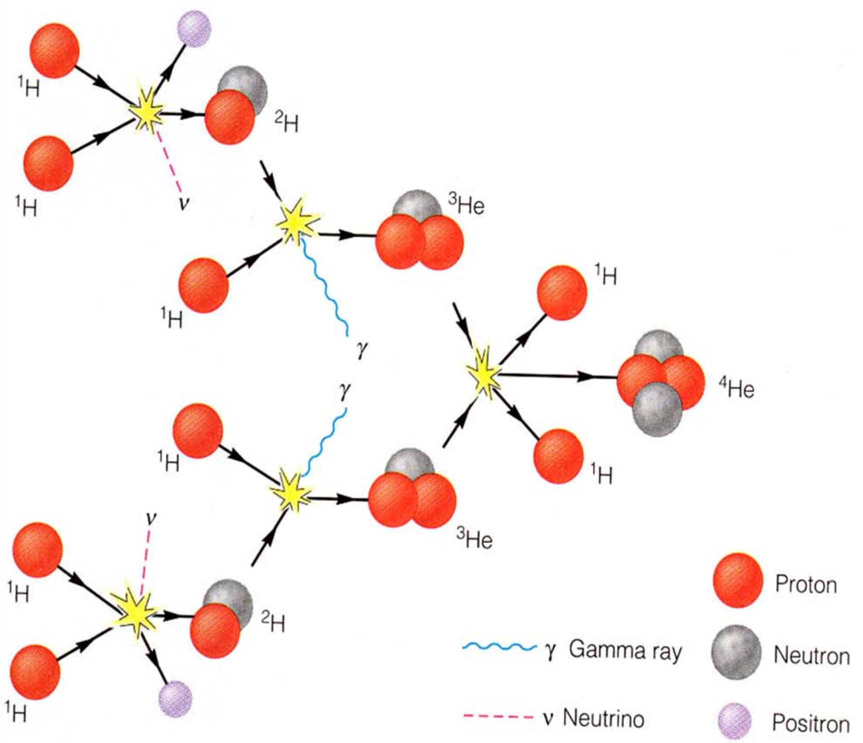
Carbon Capture



Socolow, Can We Bury Global Warming? Sc. Am., pg 49, July 2005

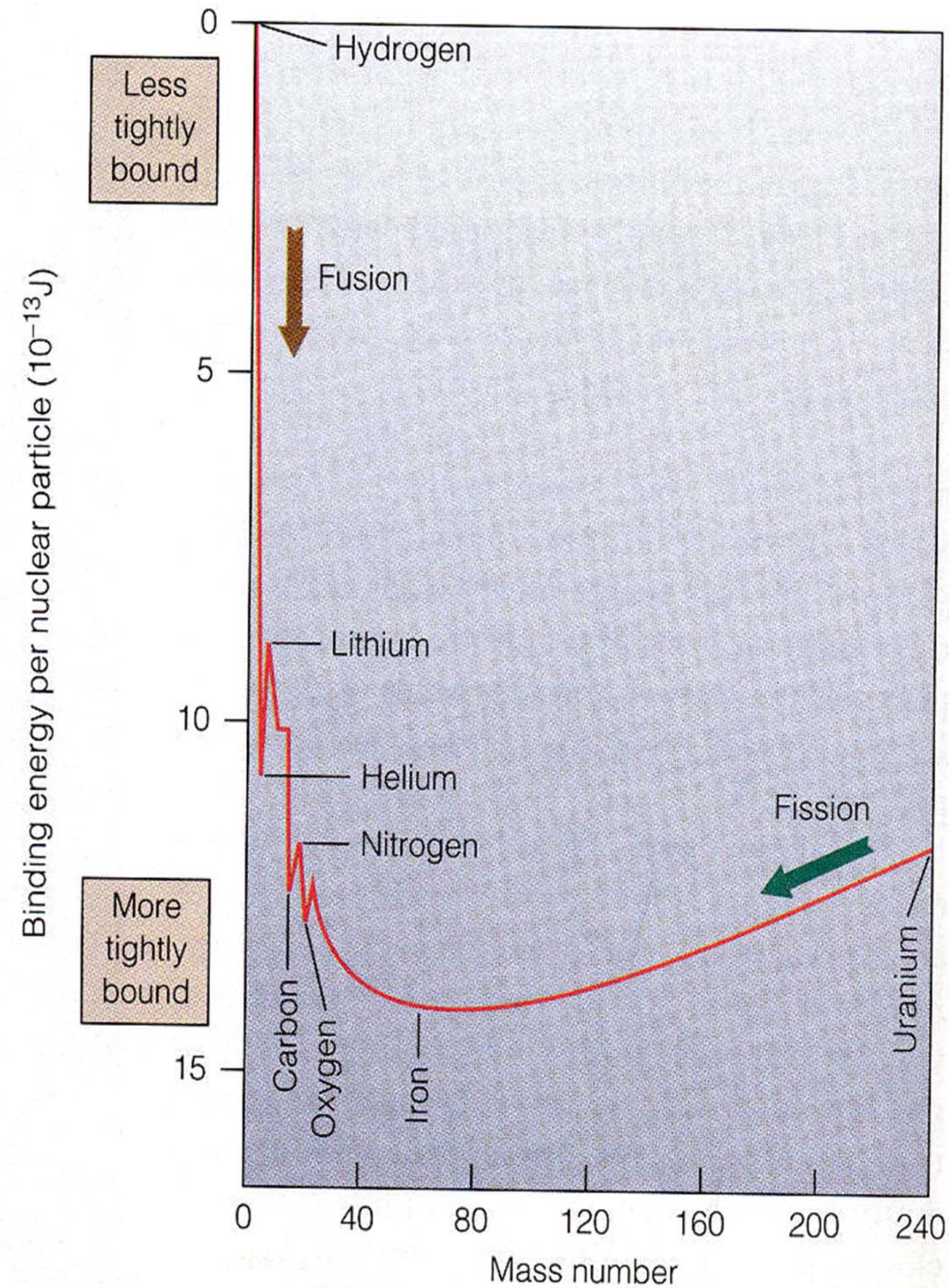
CO_2 is captured at Salah gas project in Algerian desert. Compressed gas is injected into a brine deposit at 2 km depth – the rate is 1/6 of that required for a 1,000 MW coal gasification plant fitted for capture and storage.

Socolow, Can We Bury Global Warming? Sc. Am., pg 49, July 2005



Nuclear Energy

Fission and **Fusion**

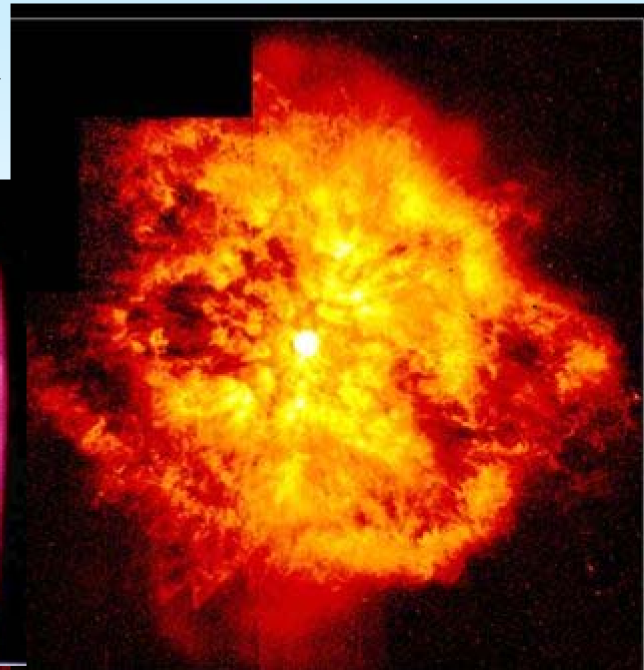


Plasma Fusion

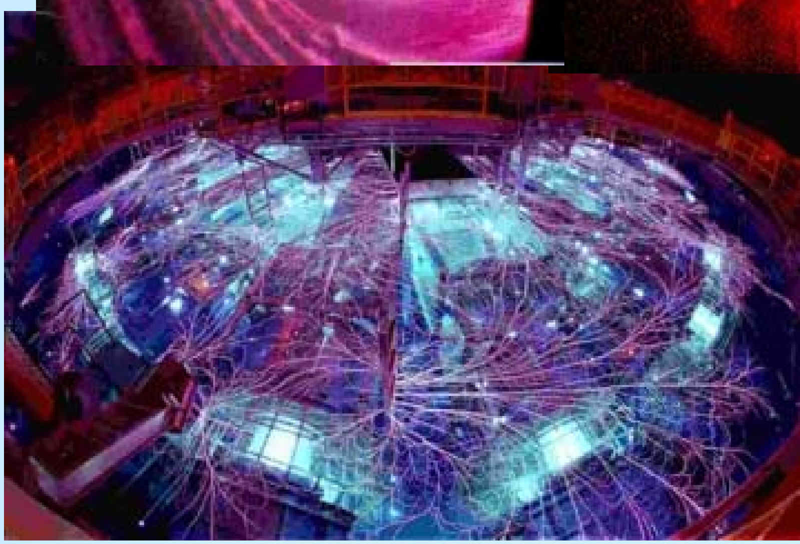
Plasma fusion reactors hold the promise for a long term, relatively clean energy source.

Tokamak Plasma - Princeton

Nebula M1-67



Inertial Confinement – Univ Rochester



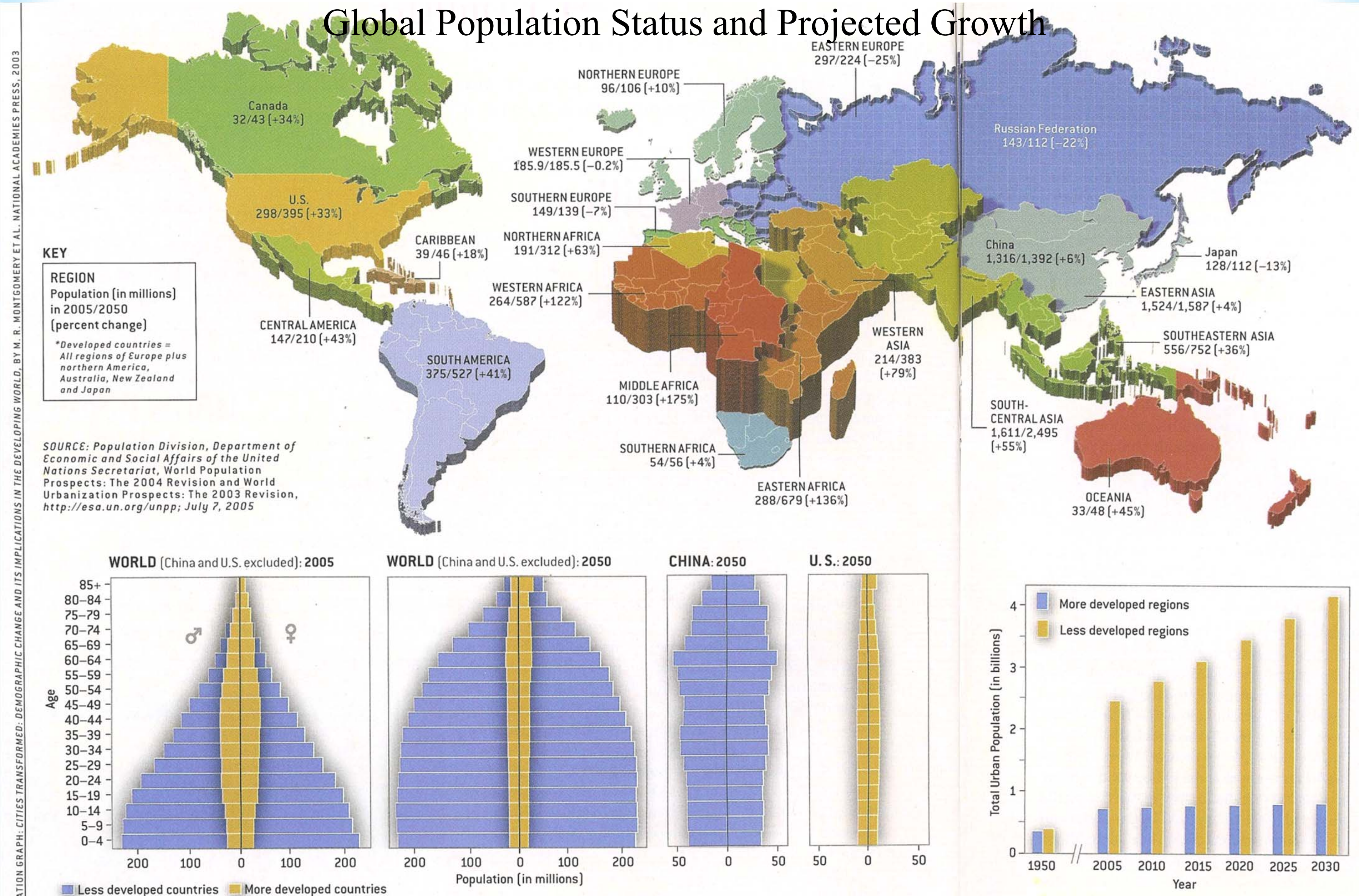
Z-Machine
Sandia

JET-Tokamak
UK Physics

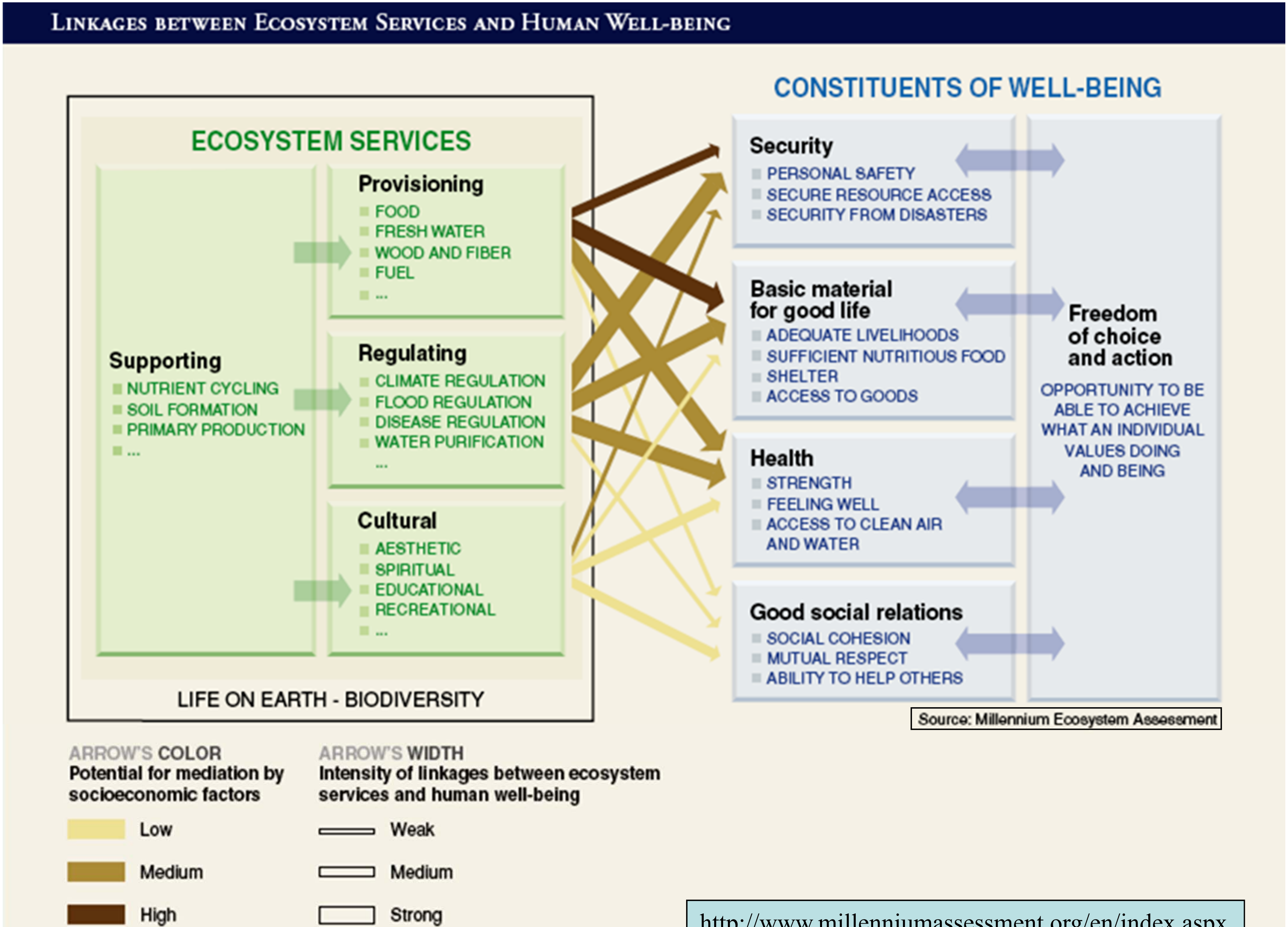
Fusion Plasmas –
http://www.plasma.org/photo-fusion.htm

Population

Global Population Status and Projected Growth



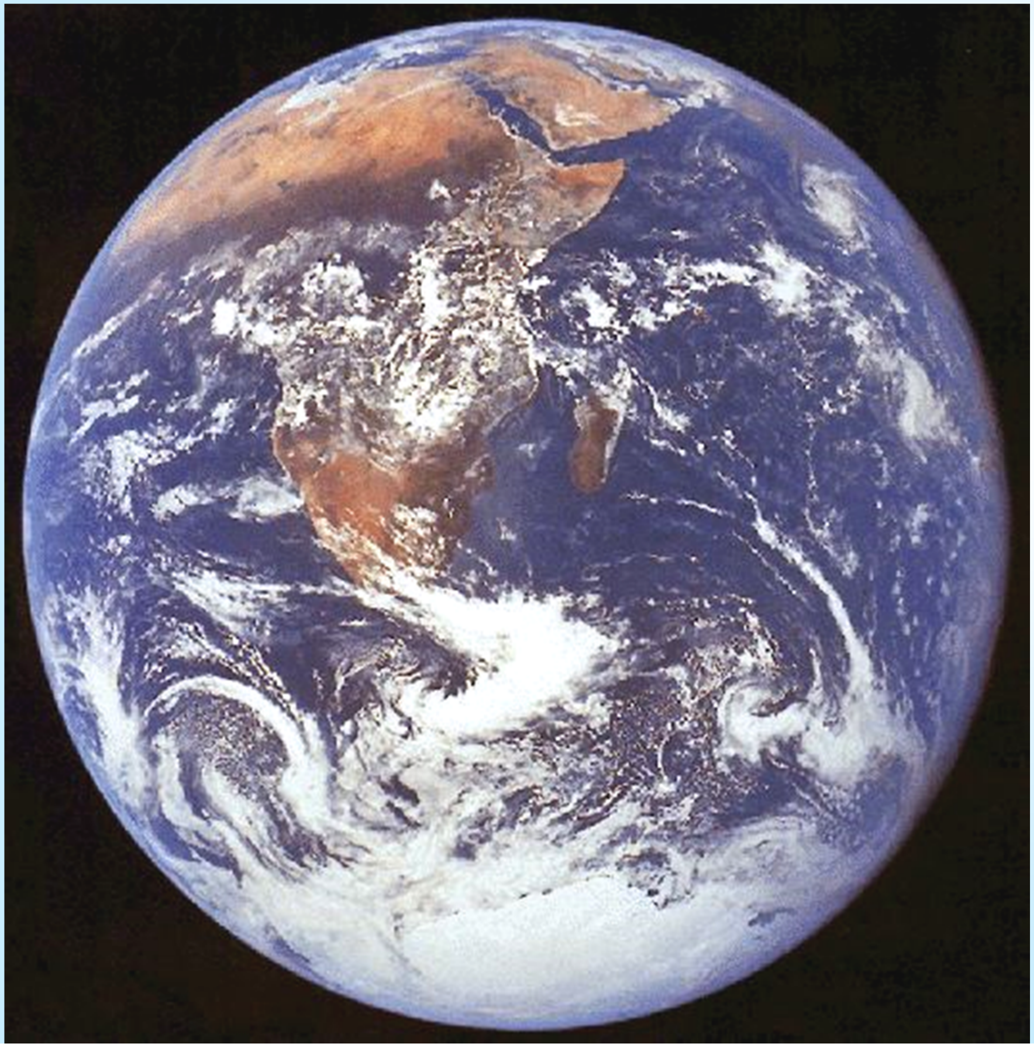
Scientific American, September 2005



http://www.millenniumassessment.org/en/index.aspx

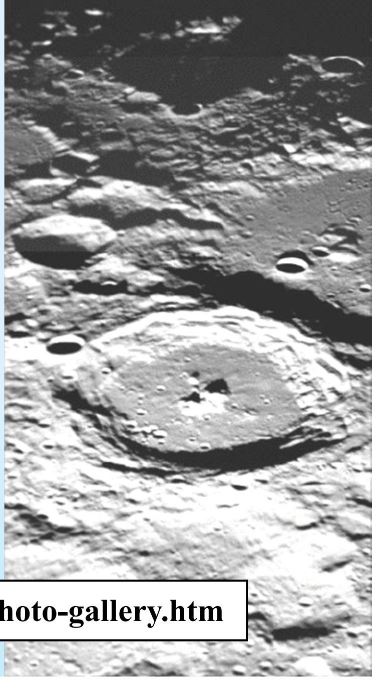
The activities of man are changing the face of our planet. The resources of our planet are stretched. The quality of air, water and earth are deteriorating.

We must become better stewards of our Earth home.



Population
Air
Water
Land
Biodiversity
Energy

A view of fragile Earth



http://nssdc.gsfc.nasa.gov/photo-gallery.htm

What can you do?

Become environment steward

Electricity, Water, Recycle

Improve use of energy resources

Use computer for paperless society

Plan for conservation

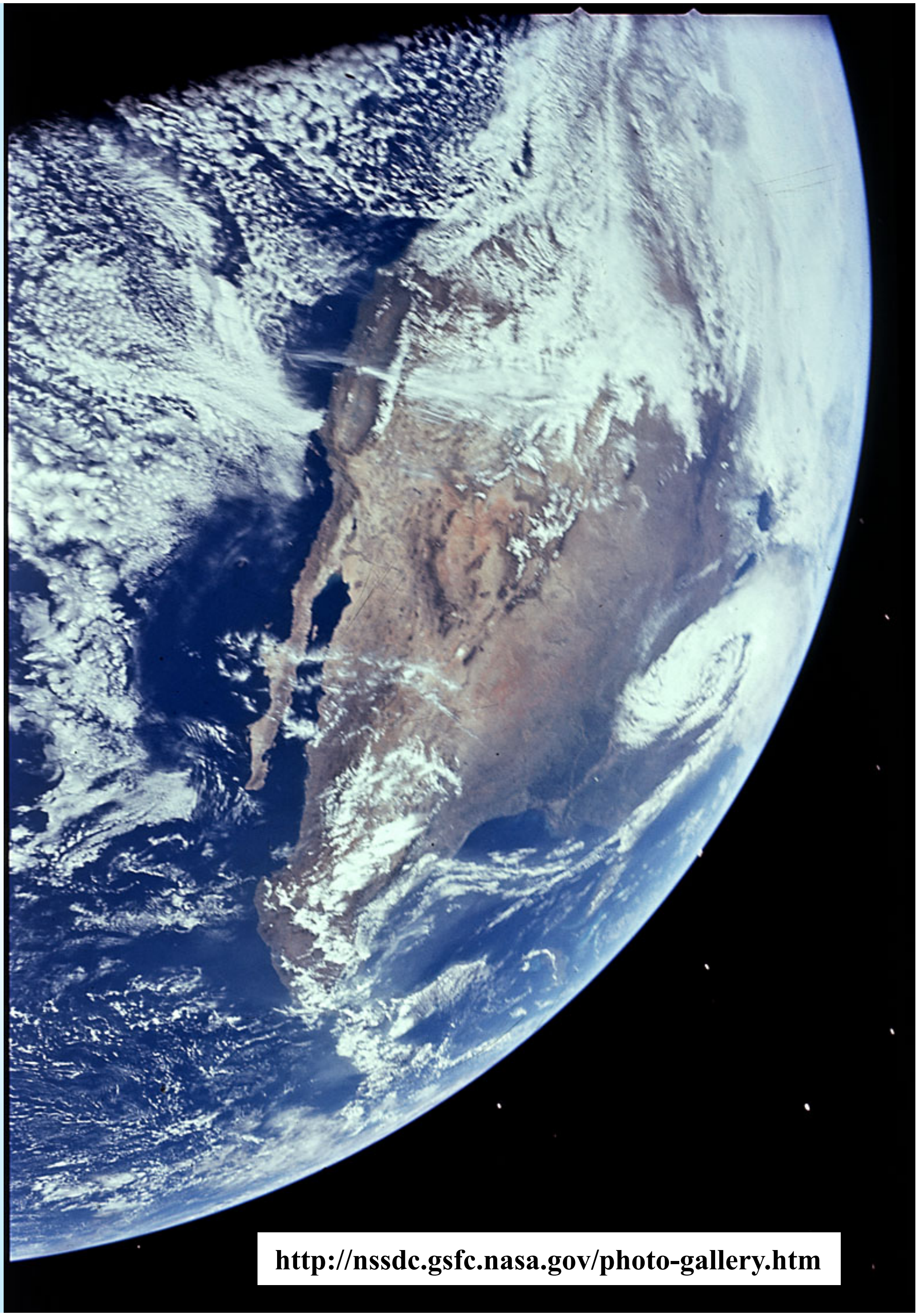
Consider the life cycle

Plan for resource preservation

Teach others, educate young and adult

Practice personal conservation

Be an example



http://nssdc.gsfc.nasa.gov/photo-gallery.htm

What can I do as an individual to conserve resources?

Olympus Photo Deluxe, 2000

- Use low phosphate detergent
- Use low flow faucet aerator
- Reuse containers
- End junk mail
- Use unbleached paper
- Use sponge or cloth to wipe spills
- Use less heating and AC
- Reduce water use in toilet
- Low-flow showerhead
- Shower-soap-shower (30-35%)
- Water flow – brush teeth – water
- Conserve electricity use
- Insulate home
- Reduce travel by car – use public
- Recycle glass, plastic, metal, paper
- Plant a tree (avg use is 7 per year)
- Eat low on food chain
- Teach others to conserve
- Support conservation with your pen

50 Simple Things You Can Do to Save Earth, Earth Works Press, 1991.

EACH OF US CAN MAKE A DIFFERENCE!

Olympus Photo Deluxe, 2000

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