The Blue Marble, NASA

Earth Rise, Christmas 1968, Apollo 8

Ask A Scientist

Sunday, January 9, 2011

Energy and the Environment

presented by Chuck Brown, Fermilab Staff Scientist,
who is definitely not an expert on this subject !!

Feel free to interrupt and ask a question at any time!

Energy
and the
Environment

Saturday Morning Physics, September 2010

(http://smp.fnal.gov/)

There are two spiritual dangers in not owning a farm.
One is the danger of supposing that breakfast comes from the grocery,
and the other, that heat comes from the furnace.
Aldo Leopold, A Sand County Almanac, 1949

1st hour - Energy

- Definition, Examples, Units
- Solar radiation, Green House Gases
- Photosynthesis
- Energy Use in the USA and World
- Heat Engines
- Efficiency of Heat Engines and other Energy Uses
- Other Sources of Energy
- Cost of Energy

2nd hour - Environment

- Does Energy Use Change the face of our World?
- Do Green House Gases contribute to Climate Change?
- How well do we understand Climate?
- What are the predictions of Climate simulations?
- What should we do about it?
- My personal take on all this.

Note: I'll try to be careful to separate fact from opinion

Energy

High School Physics: Energy – the capacity to do work

2010 reality – HUGE amounts of energy

The capacity to lead a comfortable life. ✓

The capacity to change the face of our planet !

The capacity to modify our climate and ecosystems ?

Power = Energy per unit of time

- 100 watts – light bulb, human being (joule=watt-sec)
- 1 kW – 1 horsepower, 1 toaster oven (kW-hr)
- 40 MW – Batavia, Geneva,…. (MW-hr)
- 1 GW (1000 MW) one typical power plant

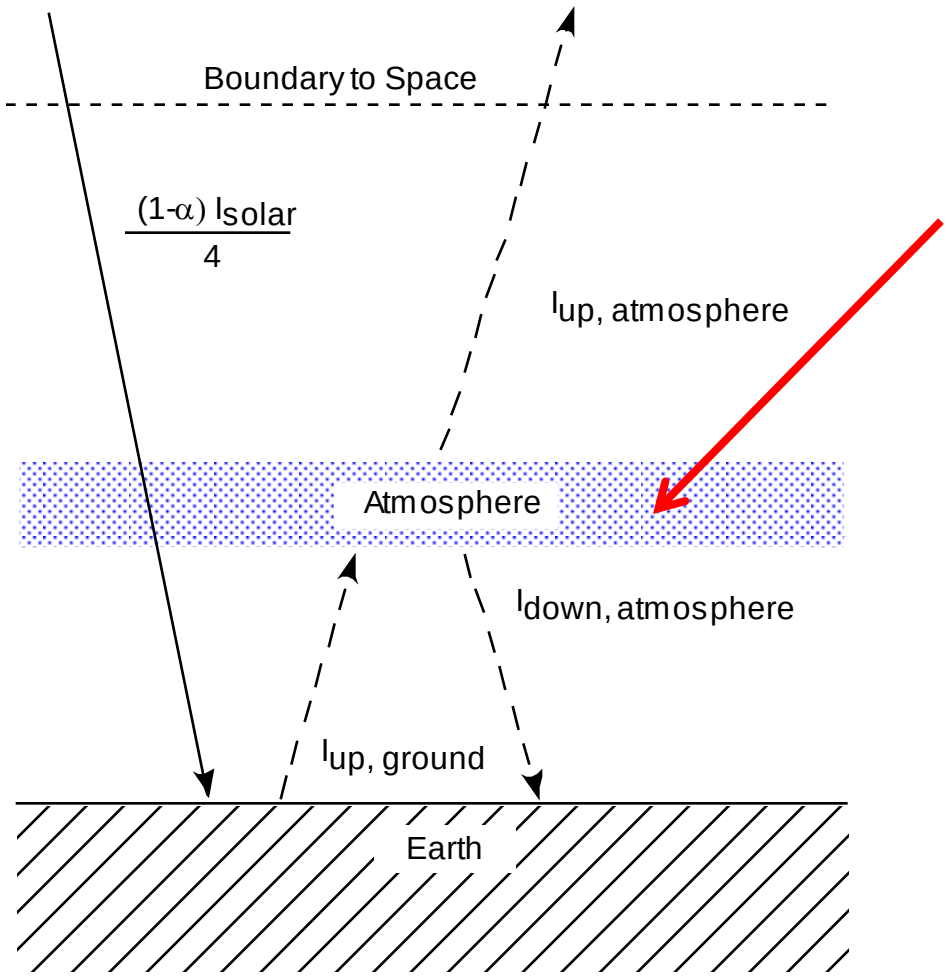
Solar Radiation, the Earth's source of Energy

- Some of the Solar Radiation is reflected by clouds, most is absorbed by, and heats, the land and oceans

- The land and oceans radiate heat (Infrared Radiation) back towards space.

- The atmosphere acts like a blanket and absorbs some of the infrared radiation, heats up, and radiates 1/2 of the heat back toward the earth. – its the Green House Gases that absorb the IR radiation!

The Greenhouse Effect!



The Greenhouse gases, H_2O, CO_2, CH_4(Methane) and O_3 absorb the outgoing infrared radiation and reradiate ½ back to earth

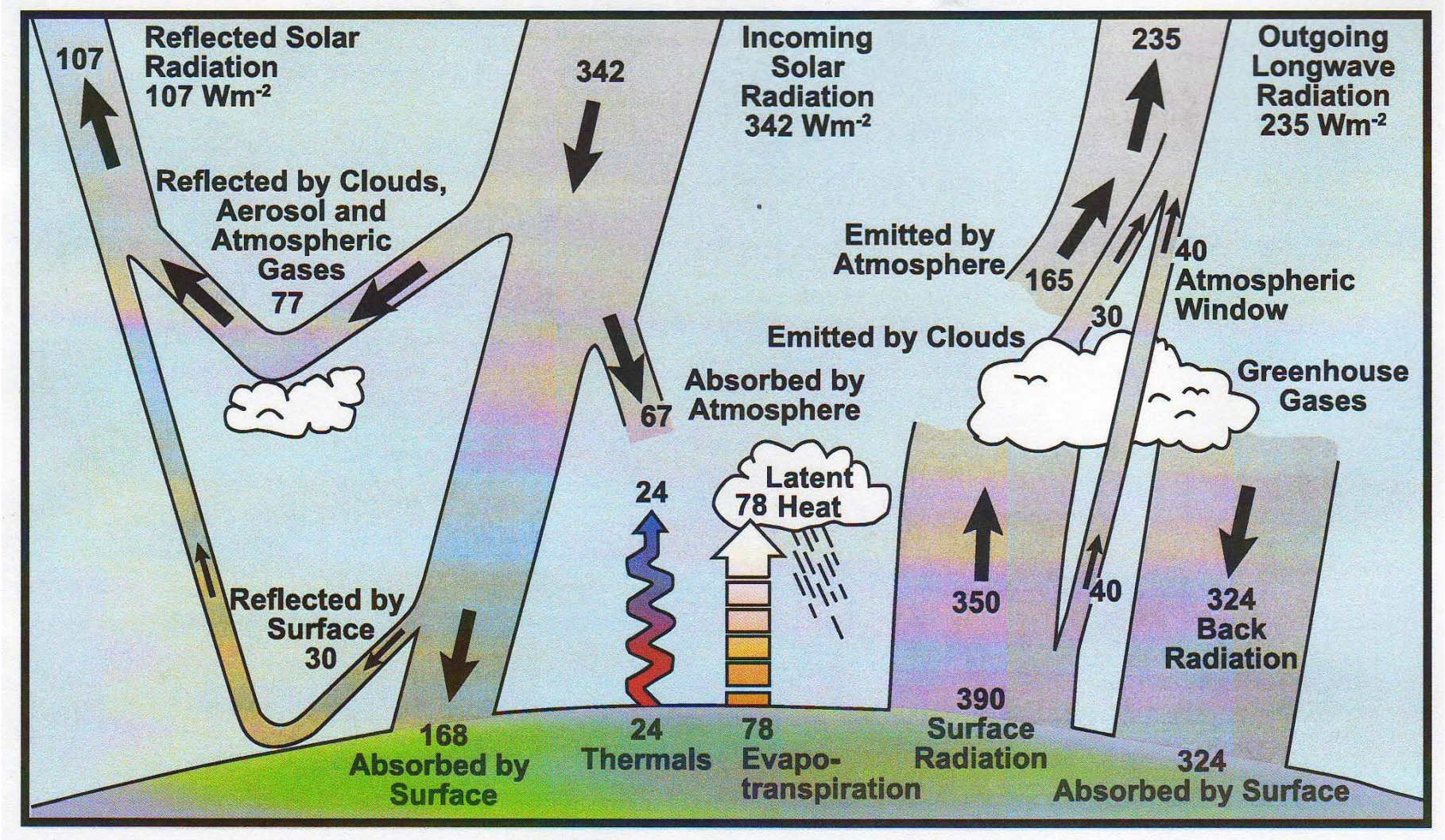
T_{atm} = 259 K

T_{earth} = 303 K
= 86° F

A very simplified picture of the atmosphere!

The Blue Marble, NASA

Complexity of modern computer simulations



Photosynthesis

Photosynthesis is, for humans, the most important source of stored solar energy on the earth.

$CO_2 + H_2O + \gamma$ (solar photon) $\rightarrow$ $CH_2O + O_2$

carbon dioxide + water + direct sunlight $\rightarrow$ carbohydrates + oxygen

Plants convert light into carbohydrates with an efficiency of 1 to 8%

Plants (and animals indirectly) have "stored" the energy from the sun by this process for the last many million years

The energy stored in carbohydrates, and long CH_2 chain molecules (as in fossil fuels), is our main source of energy!

Photosynthesis drives the food chain

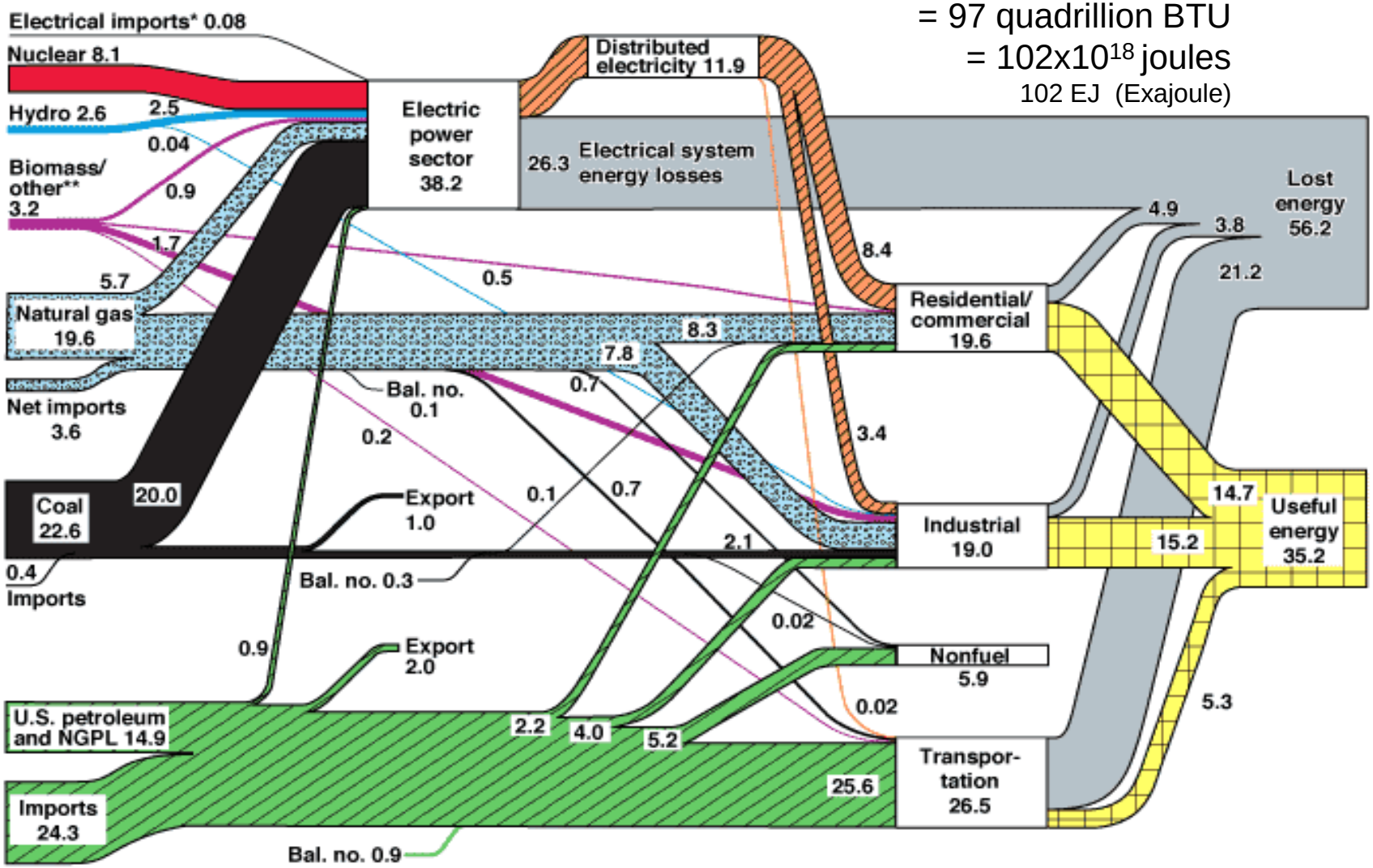
100% → 0.5% → 0.05% → 0.005%

Approximate energy conversion efficiency at each stage

U.S.A. Energy Economy: huge, complicated, and inefficient

U.S. Energy Flow Trends – 2002
Net Primary Resource Consumption ~97 Quads

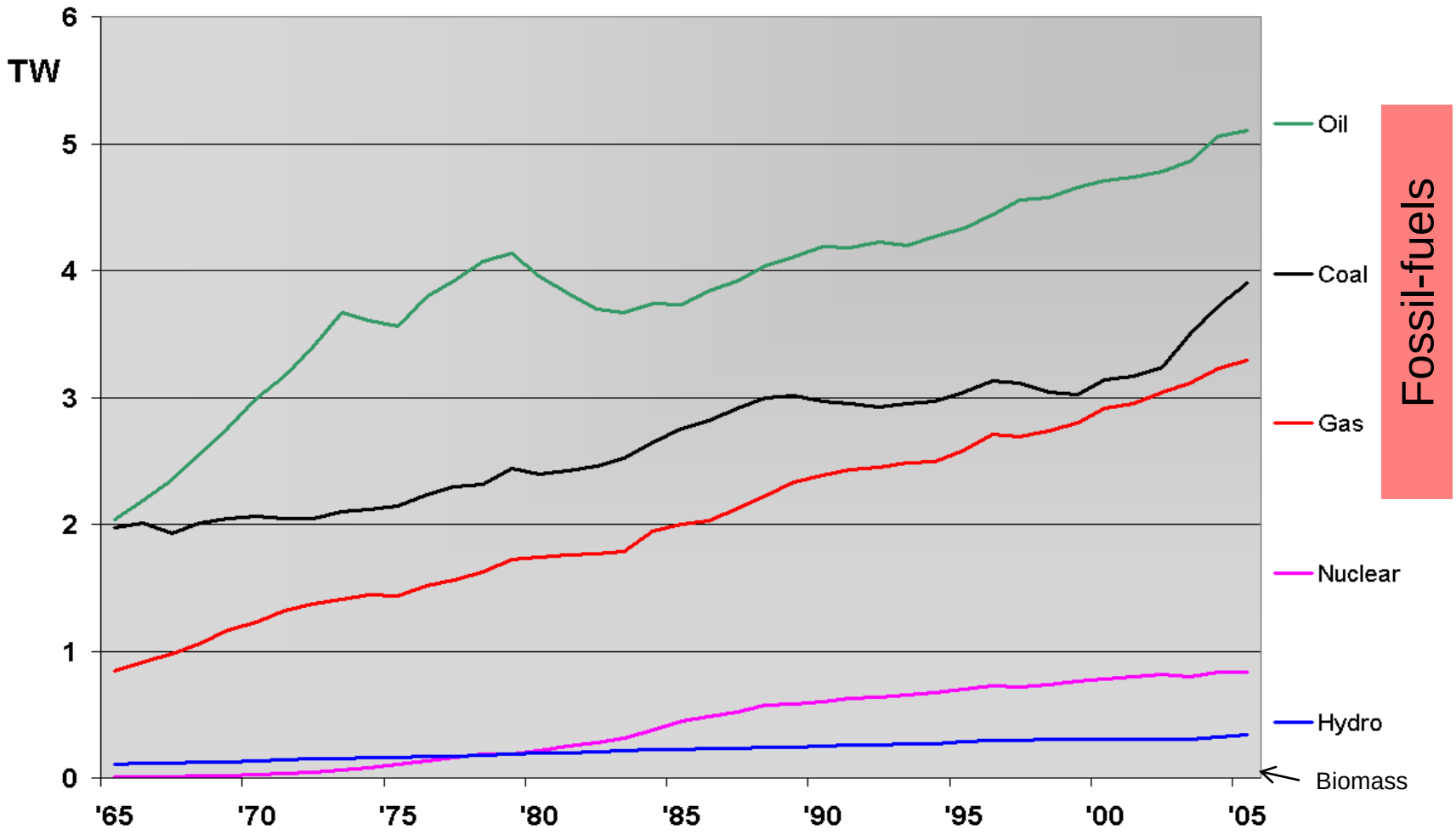
= 97 quadrillion BTU
= 102×10^{18} joules
102 EJ (Exajoule)



Source: Production and end-use data from Energy Information Administration, *Annual Energy Review 2002*.
*Net fossil-fuel electrical imports.

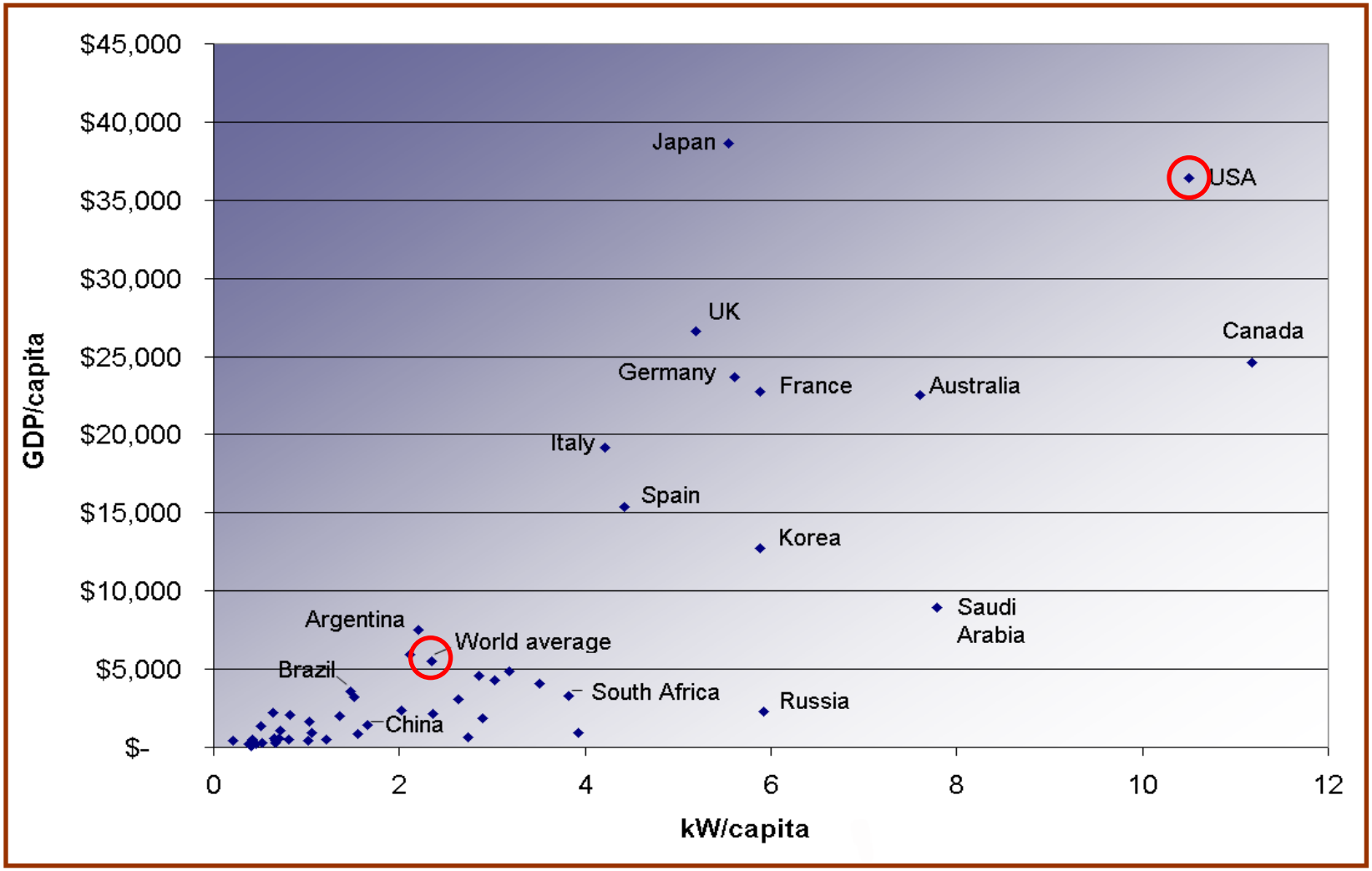
June 2004
Lawrence Livermore National Laboratory

The World's energy usage



USA, 5% of world population, 25% of world energy use!

Energy use appears to drive the World Economy



source: Frank van Mierlo from 2006 **Key World Energy Statistics** from the International Energy Agency.

How do we use the fossil-fuels?

- We burn them for heat (stove, furnace)
- We burn them in a heat engine to produce mechanical power and electrical power

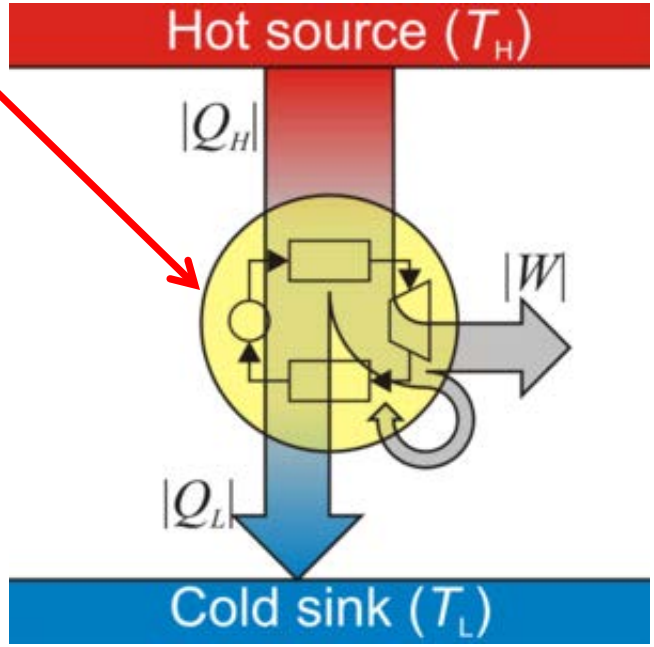
  A large fraction is used here Inefficiently!

  - Electricity (frig, air-conditioner, lights, communications)
  - Transportation (car, plane)
  - Pumps (water)
- We use the rich carbohydrate soup chemically
  - Industrial chemicals, plastics
  - Fertilizers
  - Pharmaceuticals

We burn fossil-fuels to produce work in a Heat Engine

Heat Engine using a thermodynamic cycle

Many different kinds of engines and thermodynamic cycles exist:
Diesel engine
Gas engine
Steam engine
Turbine engine
Jet engine …



1st Law of Thermodynamics: $W = Q_H - Q_L$

Efficiency = $W/Q_H = 1.0 - Q_L/Q_H = 1.0 - T_L/T_H$

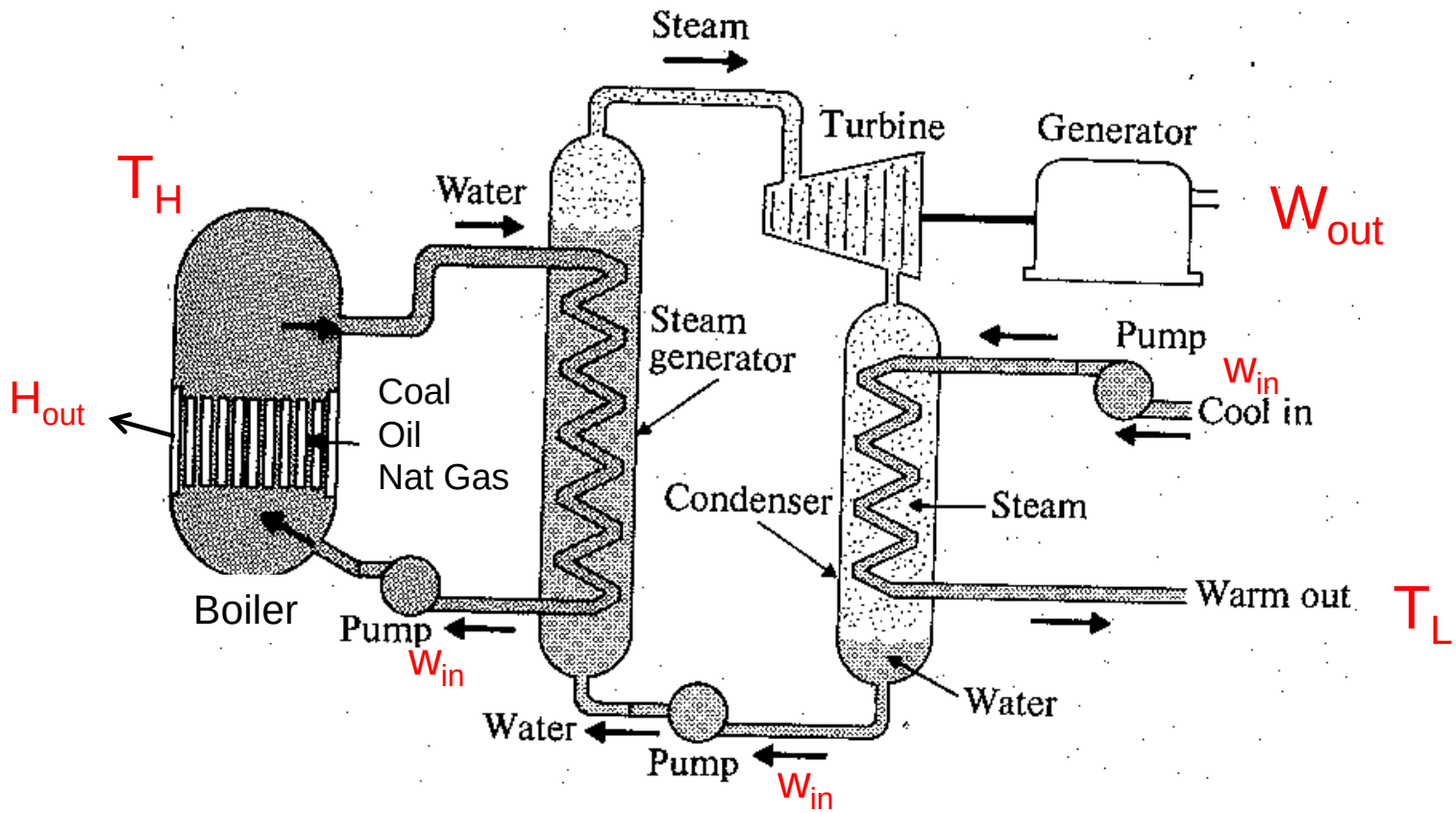
Typical efficiencies of energy transformation

• Electric generator	mech → elec	98%	
• Gas Furnace	chem → thermal	85%	
• Rechargeble battery	elec → chem → elec	75%	
• Small electric motor	elec → mech	70%	
• Fuel cell	chem → elec	60%	
• LED	elec → light	50%	
• Steam Turbine	chem → mech	45%	Heat Engine
• Diesel engine	chem → mech	35%	”
• Power plant	chem → elec	20-40%	”
• Automobile Engine	chem → mech	25%	”
• Fluorescent Light	elec → light	20%	
• Solar cell	sunlight → elec	8%	
• Incandescent light	elec → light	4%	

Energy transformation efficiencies are low and need to be improved

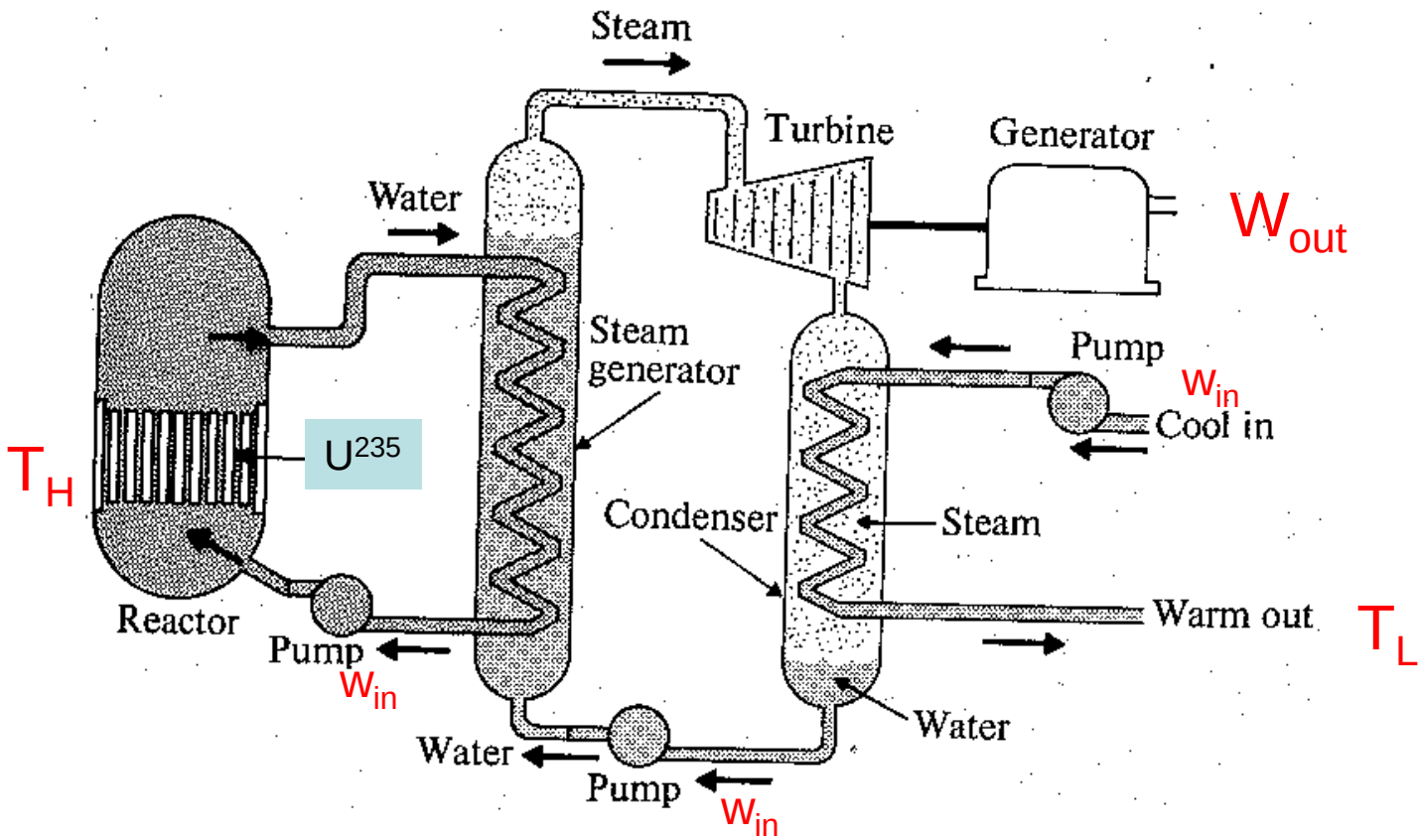
Fossil-Fuel Power in the USA

- Fossil-Fuel power plants provide about 3/4 of the electrical power in the USA
  - Notice the waste heat coming out at T_L and H_{out}. The inefficiencies of the thermal cycle can also be pollutants



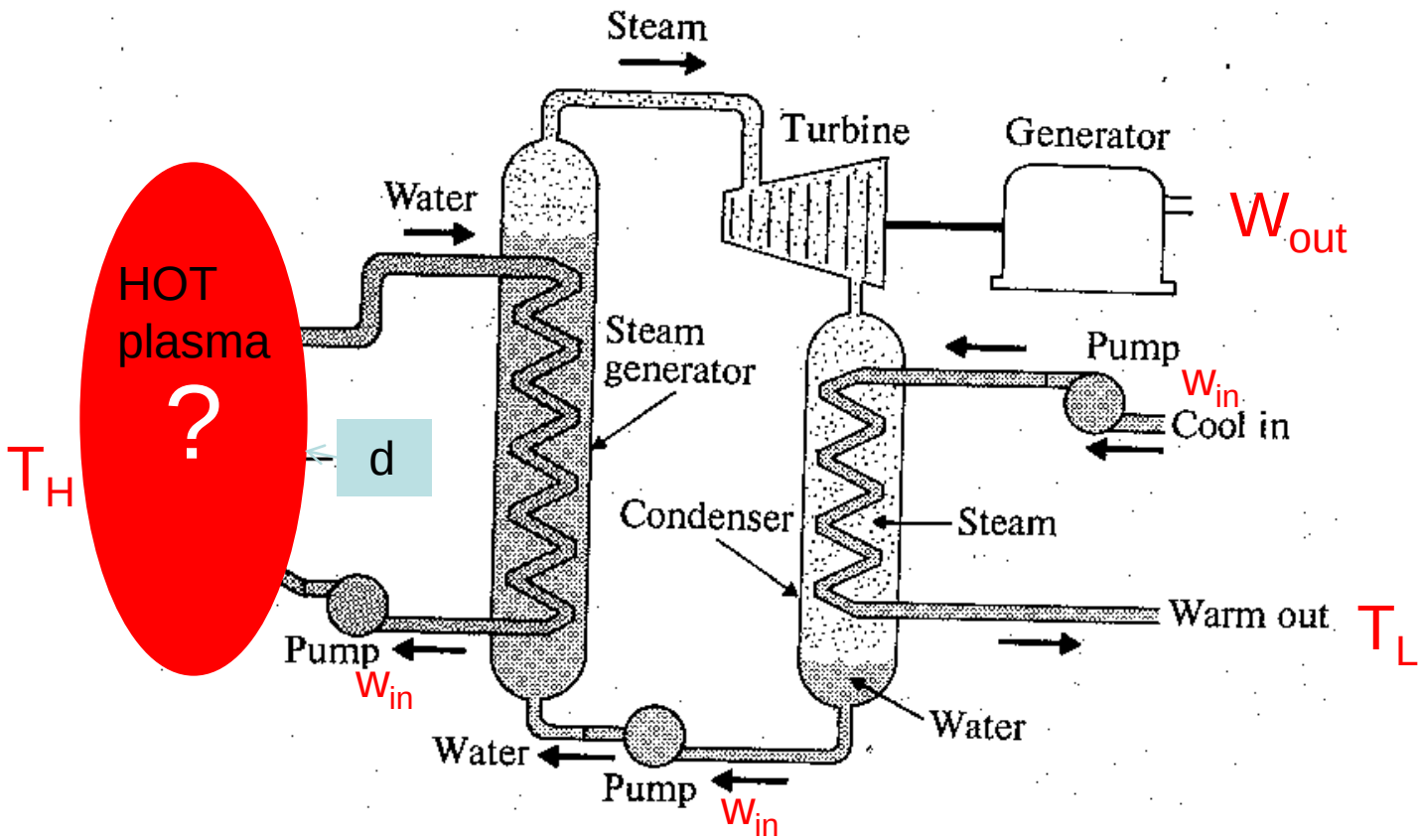
Nuclear Power in the USA

- Nuclear power plants provide about 20% of the electrical power in the USA
  - PWR (pressurized water reactors) and BWR (boiling water reactors) feed a standard heat engine



A fusion power plant

- Problem: we don't know how to build the reactor yet?
  - ITER, the International Tokomak Experimental Reactor being built in France may prove me wrong!



Renewable sources of energy!

- Biomass
  - Less energy density than fossil biomass?
- Wind
  - Only blows 1/3 of the time, needs distributed electric grid
- Solar
  - Only shines 1/5 of the time, very diffuse, needs lots of land
- Geothermal - Low temperature = low thermodynamic efficiency
- Tidal - lots of ideas, but no demonstration plants

Wind and Solar need large scale energy storage, and an extensive electric grid, to be useful on a National scale?

Renewable Energy = Homeland Security ?

Cost of Fossil Fuel Energy

- Cheap!

- per kW-hour (toaster or plow horse for 1 hour)
  - Electricity = 9¢
  - Gasoline = 9¢
  - Natural gas = 3¢

- Very hard to compete with this
- Are the indirect long-term environmental costs reflected in these prices?

Energy
and the
Environment
Part II - Environment

Saturday Morning Physics, May 2010

The "control of nature" is a phrase conceived in arrogance,
born of the Neanderthal age of biology for the convenience of man.
Rachel Carson, Silent Spring - 1962

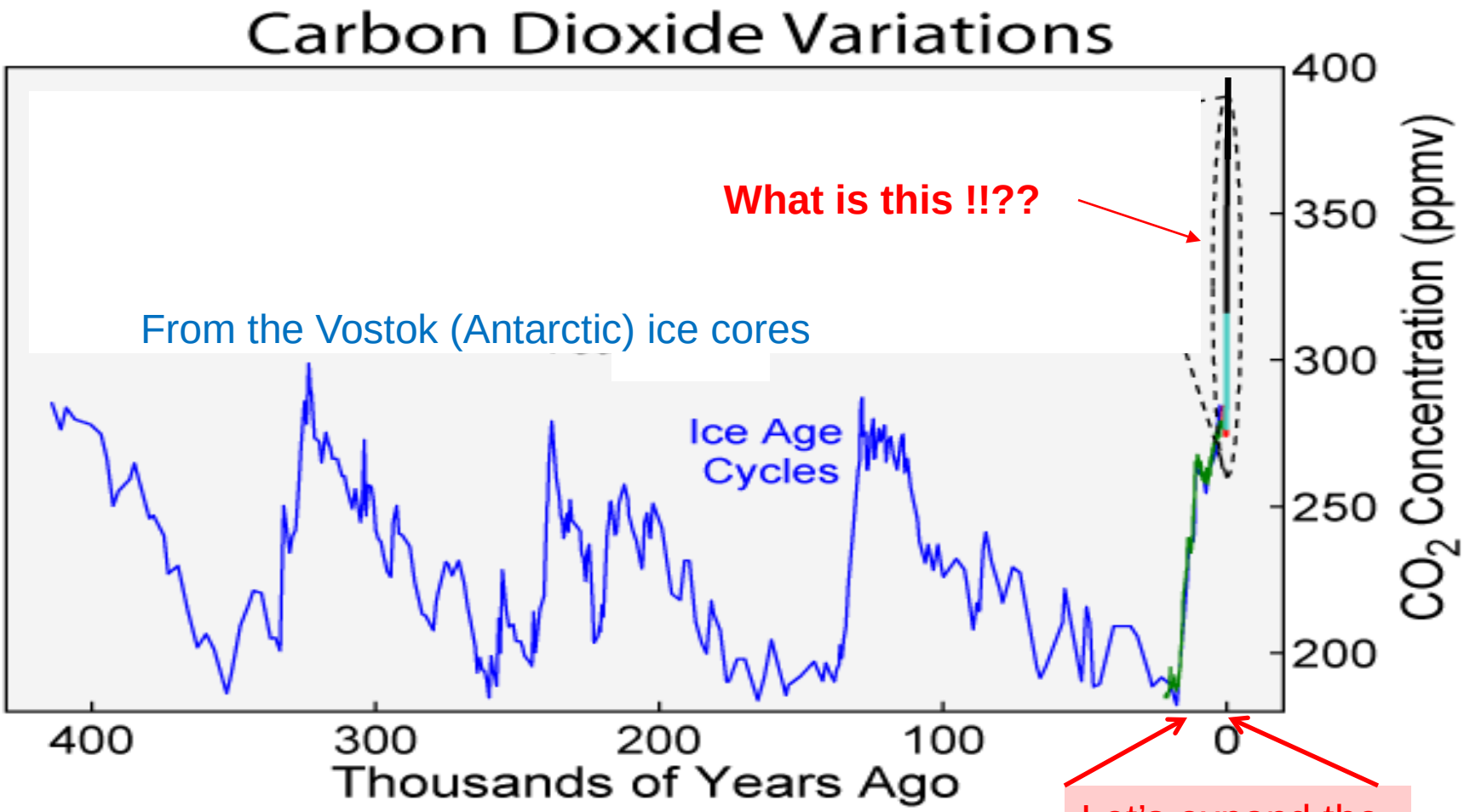
2nd hour - Environment

- Does Energy Use Change the face of our World?
- Do Green House Gases contribute to Climate Change?
- How well do we understand Climate?
- What are the predictions of Climate simulations?
- What should we do about it?
- My predictions?

Note: I'll try to be careful to separate fact from opinion

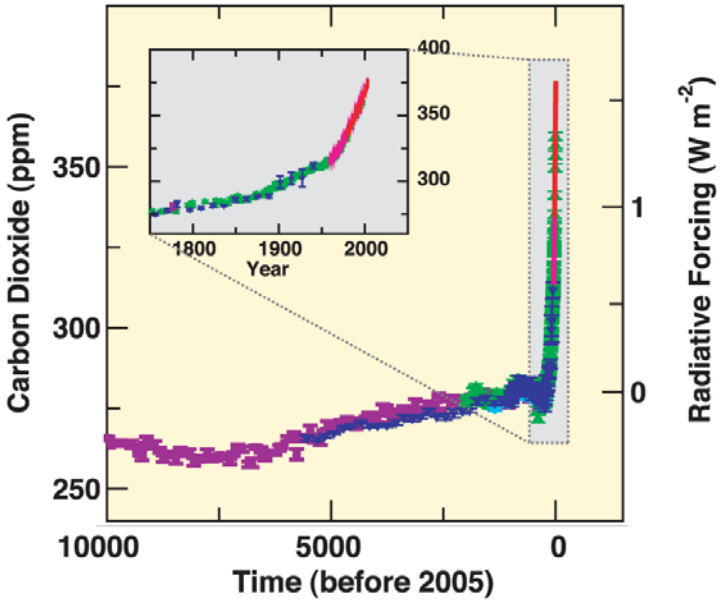
Energy Use Changes the face of our World
A place near here!

Is the CO_2 in the atmosphere increasing?



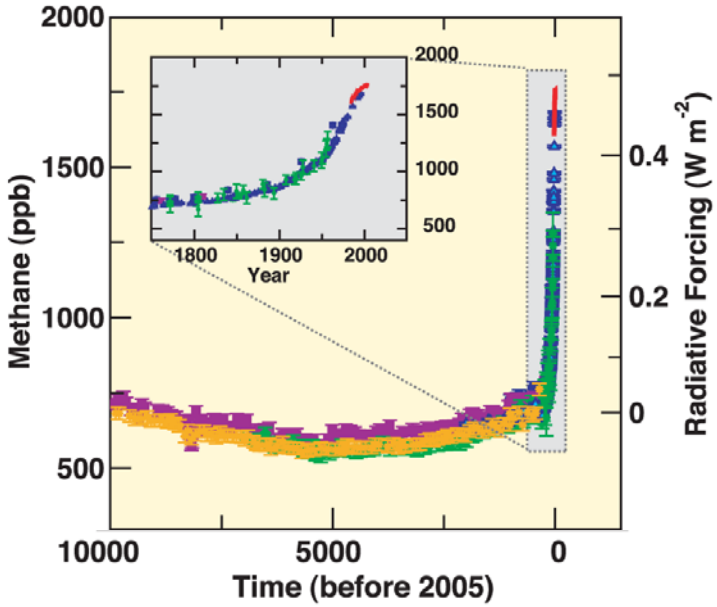
Let's expand the last 10,000 yrs

Green House Gases in the atmosphere are rising, recently!



CO_2

(For last 10,000 years)



Methane

Source: IPCC AR4

Are these GHGs causing Climate Weirding in the last 150 years?

- Some of the evidence for global climate weirding in the last 150 years:
  - Ocean levels and air temperatures are rising
  - Arctic ice is melting, most glaciers are retreating
  - Coral reefs are dying
  - Droughts, floods, fires, temperature extremes increase
  - Plant and Animal habitats are changing
  - Record heat in most of the USA this summer; record winter storms in Northeast and Europe (weather ↔ climate?)
- Much of what I will show next comes from the 3rd Intergovernmental Panel Report on Climate Change (2007)

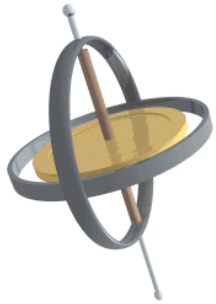
The earth wobbles and its orbit changes! The Milankovitch Cycles

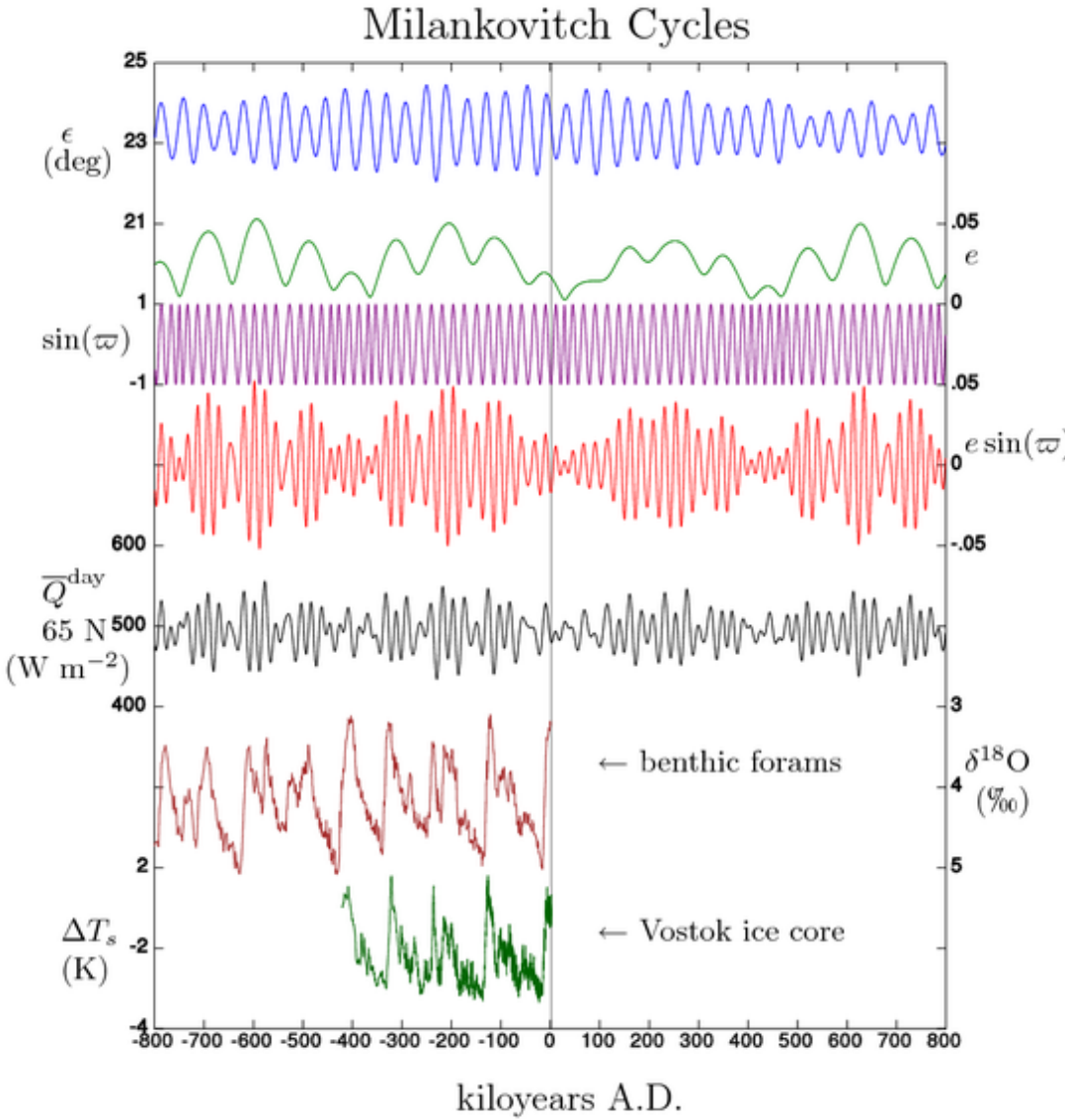
- It is widely believed that the Milankovitch cycles for average solar insolation dictate the timing of the Ice Ages.
- These cycles occur because of the details of the precession of the Earth's axis of rotation over a period of 20,000 years or so.

ε is obliquity (axial tilt).

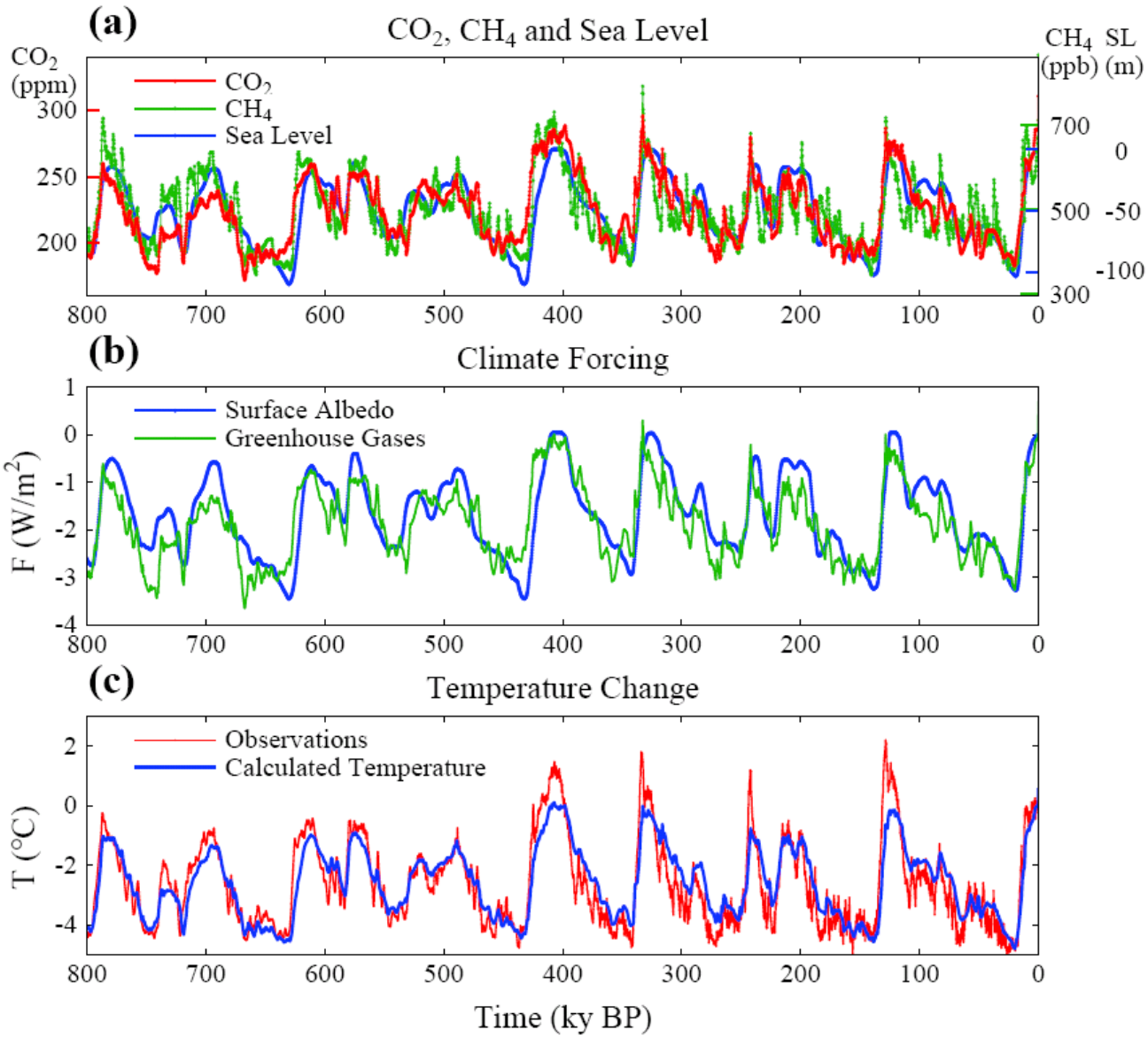
e is eccentricity.

ϖ is longitude of perihelion.





Modern climate models can account for the observations



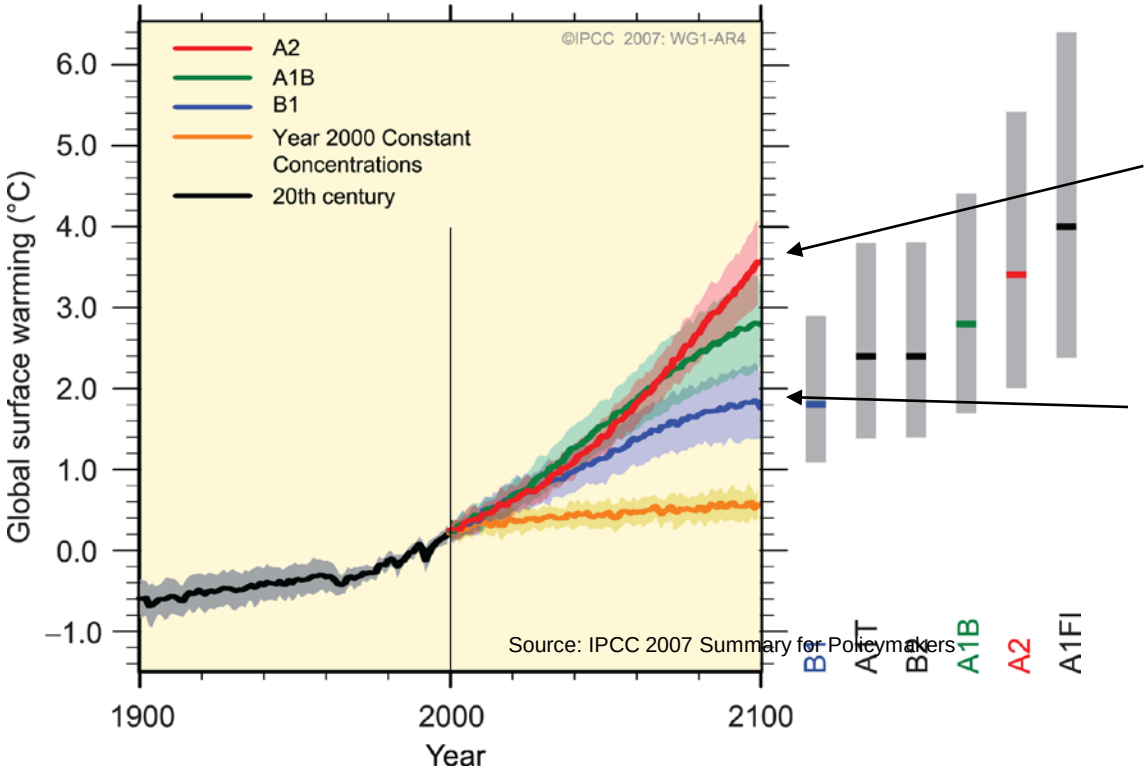
(a) CO_2, CH_4 and sea level for past 800,000 years

(b) Climate forcings due to changes of GHGs and ice sheet area,

(c) Calculated (fit?) global temperature change based on above forcings and climate sensitivity ¾°C per W/m^2. Observations are Antarctic T change divided by two.

The predictions of the IPCC include many different models, and different assumptions

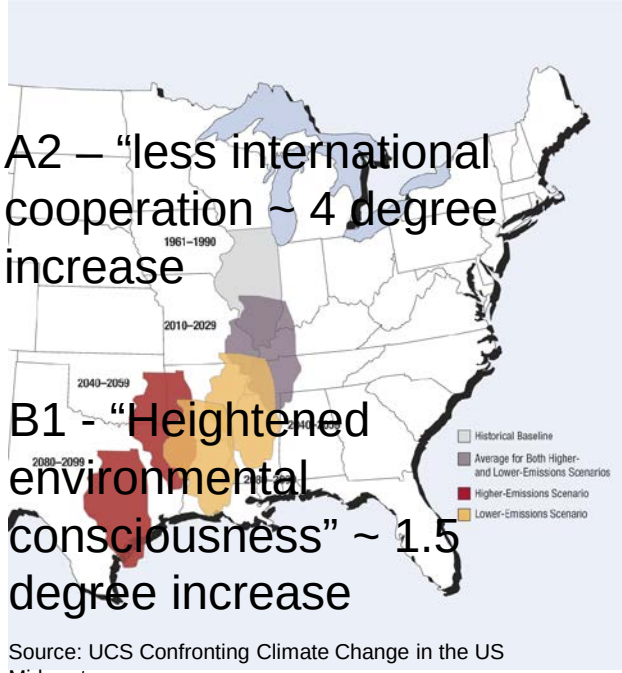
The answer depends on what action we take to reduce GHG, as well as the details of the global climate interactions.



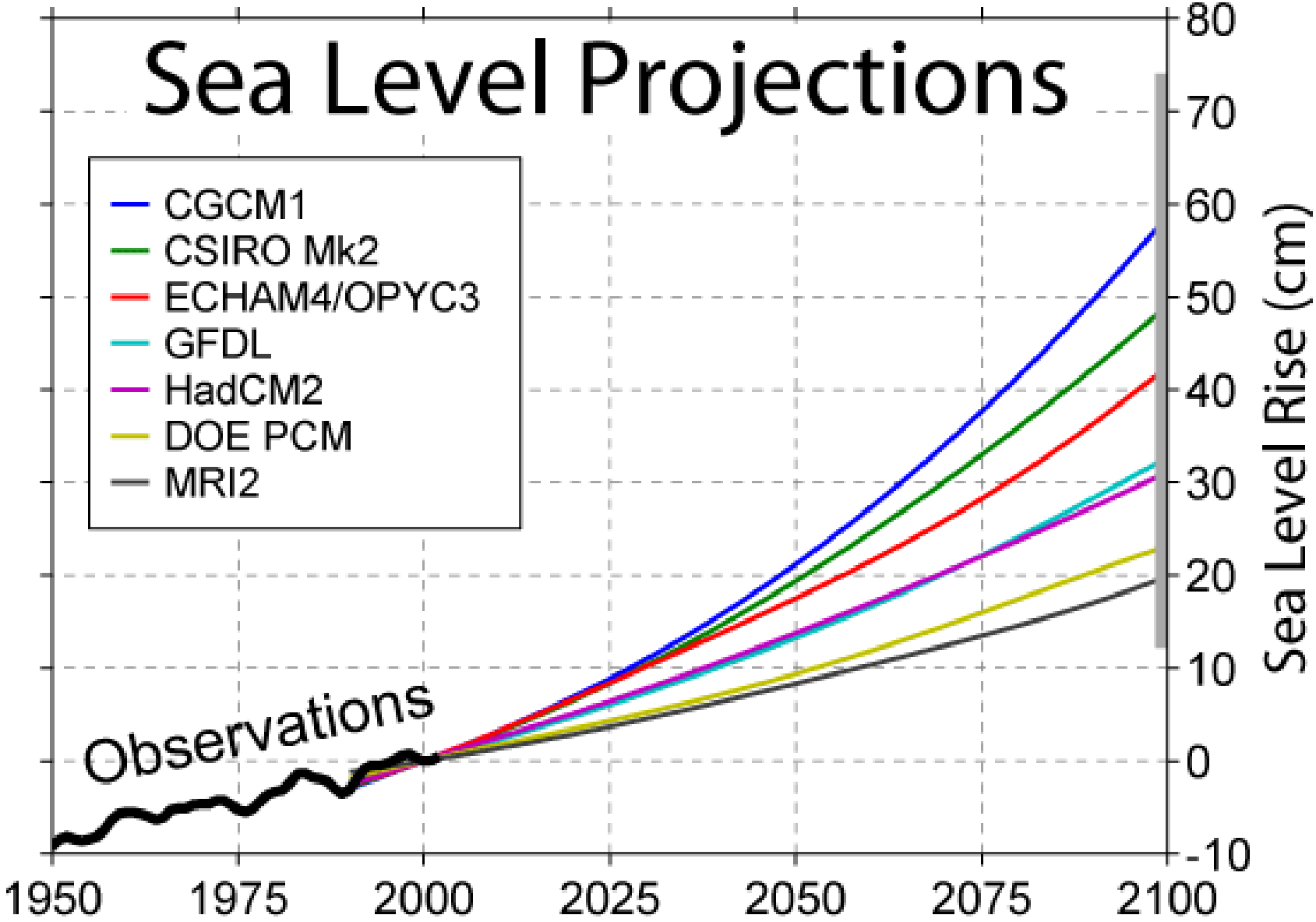
Source: IPCC 2007 Summary for Policymakers

A2 – "less international cooperation ~ 4 degree increase

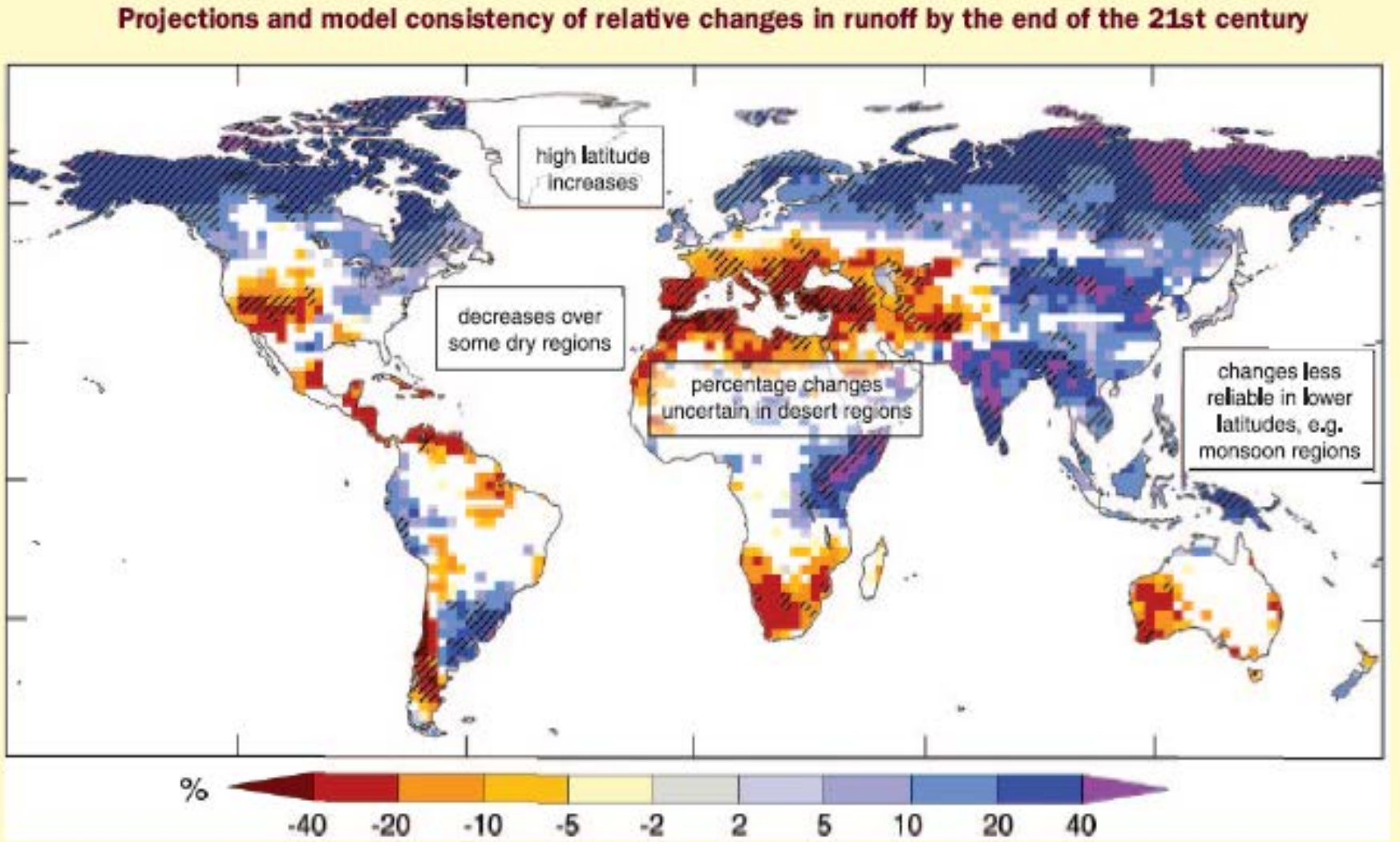
B1 - "Heightened environmental consciousness" ~ 1.5 degree increase



Source: UCS Confronting Climate Change in the US Midwest


Sea Level Projections
CGCM1
CSIRO Mk2
ECHAM4/OPYC3
GFDL
HadCM2
DOE PCM
MRI2
Observations
80
70
60
50
40
30
20
10
0
-10
Sea Level Rise (cm)
1950
1975
2000
2025
2050
2075
2100

But Water Scarcity is Relevant Only in Certain Areas



IPCC, projections on the impact on people.

With Very High Confidence (about 9 in 10 chance ?):

Coastal erosion and sea-level rise.
Ocean temperature rise leads to more frequent coral mortality.
Millions of people are flooded every year due to sea-level rise.

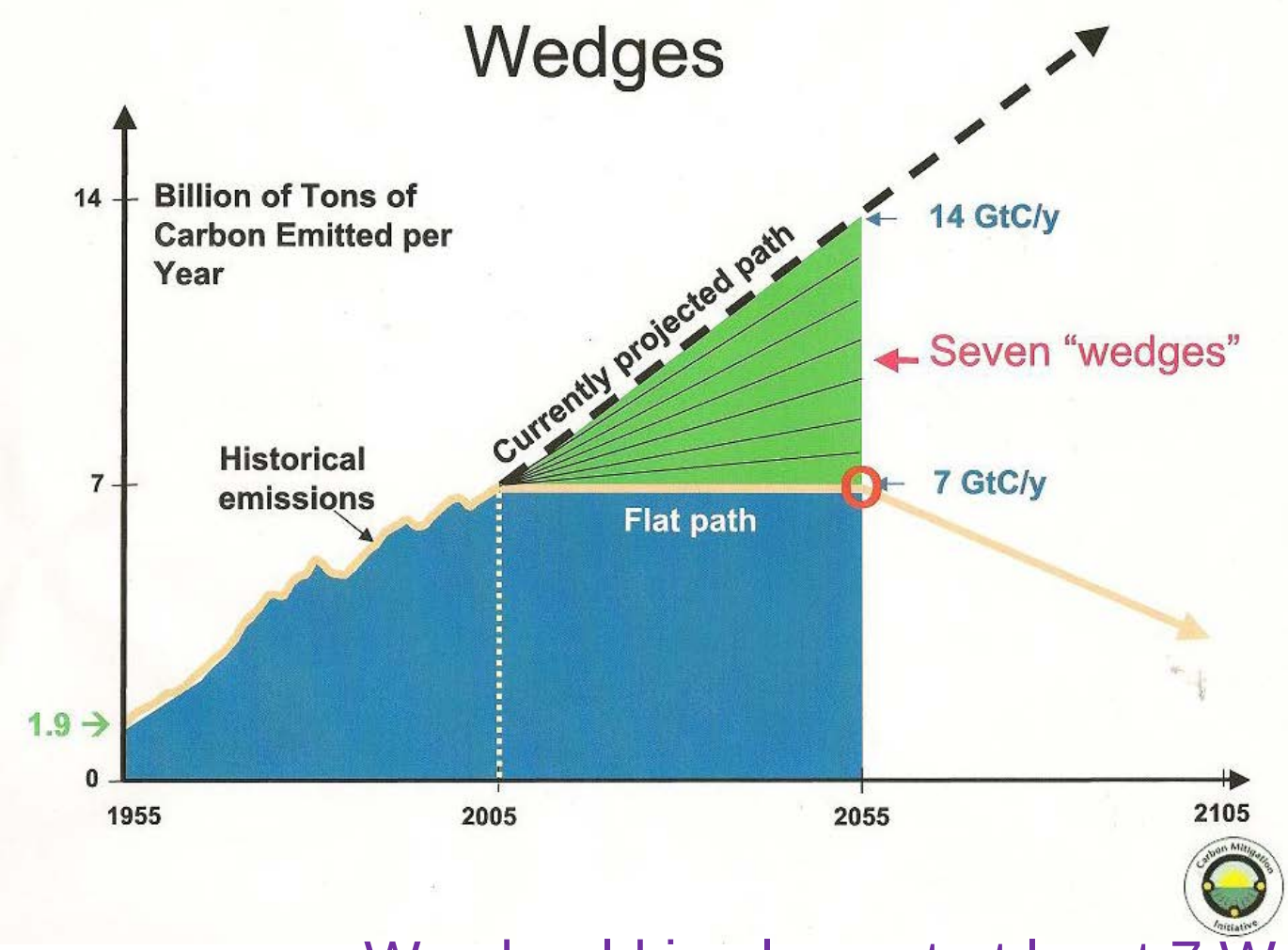
With High Confidence (about 8 in 10 chance ?):

Dry regions get drier, wet regions get wetter, drought areas larger.
Heavy precipitation and floods become more common.
Water supplies in glaciers and snow will be reduced.
Ecosystems will be stressed.
Carbon removal by terrestrial ecosystems will peak and then weaken.

With Medium Confidence (about 5 in 10 chance ?):

Globally food production will increase for temperature rises of 1-3 °C, but decrease for higher temperature ranges.

The Stabilization Triangle !!



Robert Socolow, Princeton University Has suggested Stabilization Wedges

What is a "Wedge"?

A wedge: a strategy to reduce carbon emissions that grows from zero to 1.0 GtC/yr in 50 years.

The strategy must have already been commercialized at scale somewhere.

We should implement at least 7 Wedges !!

Fifteen possible 1.0 GtC/yr Wedges (over 50 years)

Energy efficiency and conservation

1. **Increase** Vehicle Efficiency - 2 billion cars from 25 to 50 MPG
2. **Decrease** Vehicle Mileage - 2 billion cars from 10,000 to 5,000 Miles per Year
3. **Increase** Building Efficiency - by 33% in all new buildings and appliances
4. **Increase** Coal Plant Efficiency – increase coal plant efficiency by 50%

Fuel Shift

5. **Replace** 1400 Coal Power Plants with Natural Gas

CO_2 Capture and Storage

6. **Capture** the CO_2 at 800 Coal Plants
7. **Capture** CO_2 at coal-to-synfuels plant
8. **Store** CO_2 geologically

Alternate Fuels

9. **Double** the number of nuclear plants
10. **Add** 1 million (2TW) windmills
11. **Add** 2 TW of Solar power
12. **Generate** H_2 with 4 million windmills and use in fuel-cell cars
13. **Produce** 50 times more biomass ethanol (but not from Corn!)

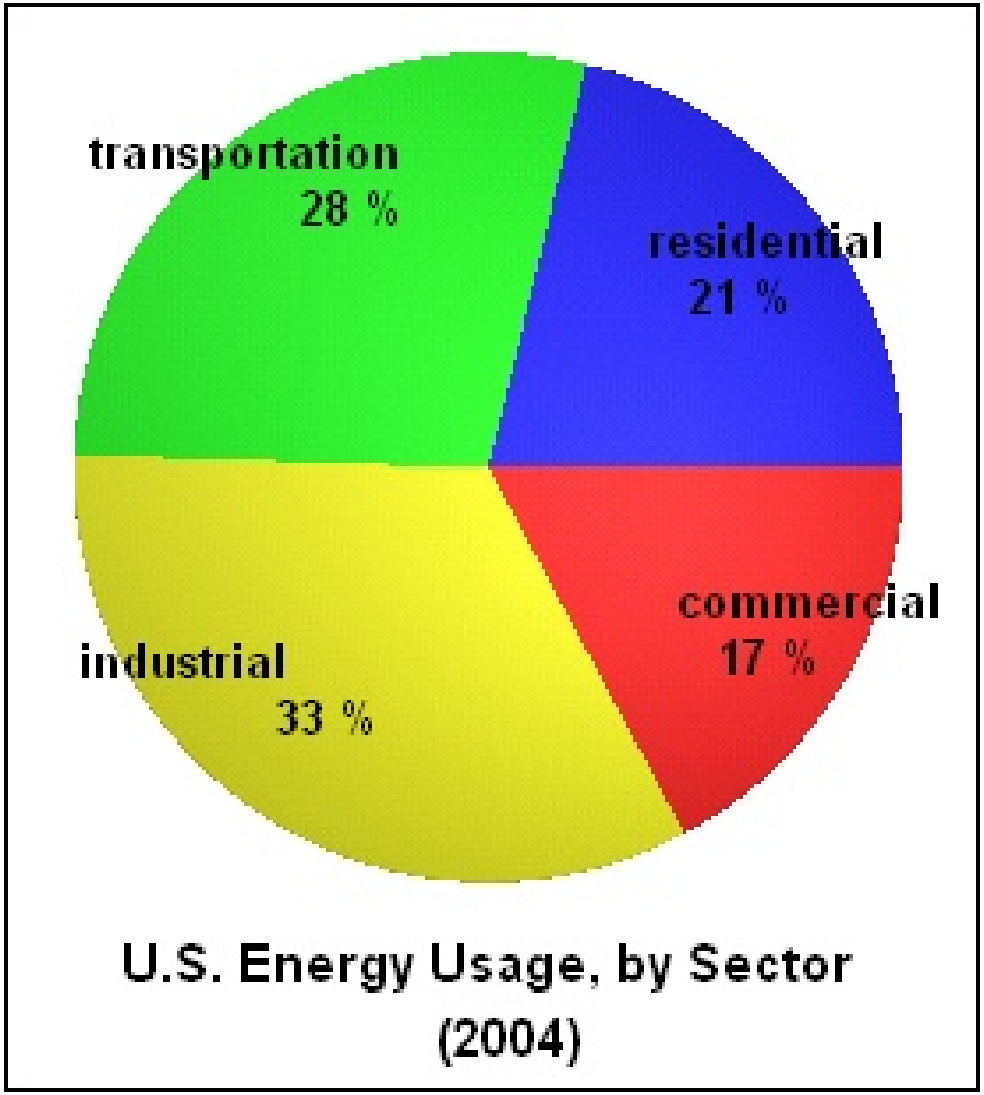
Forests and Soils

14. **Decrease** deforestation to zero
15. **Conservation** tillage 10 times current usage

How is Fermilab contibuting?

- Our “products”
  - Fundamental Knowledge
  - Trained people
  - Technical Innovation
    - Accelerator technology (fusion and fission)
    - Superconducting RF technology (fusion and fission)
    - Internet and GRID computing (efficiency, smart grid)
    - Electronics and Controls (efficiency, smart grid)
    - Safety!!

How can each of us attack the fossil-fuel problem?



Typical family energy use,
A rule of thumb

1/3 – at home

1/3 - transportation

1/3 - at work (or school)

Average US Residential Energy Usage

(2.7 people, 0.7 dog, 0.7 cat)

- 32% Space Heating
- 13% Water Heater
- 12% Lights
- 11% Air Conditioner
- 8% Refrigerator
- 5% Electronics
- 5% Dryer and Dishwasher
- ??% Food

My (Realistic?) Predictions

- Global emission of CO2 will not slow down significantly for the next 2 decades
- The melting of the summer Arctic polar ice cap will cause a change in global public opinion on the dangers of greenhouse warming.
- Canada and Russia will gain economically from global warming.
- Southern Europe will swelter.
- The U.S. will have winning regions and losing regions.
- Acidification and warming of the oceans will cause significant changes in plankton, fisheries, corals, etc.
- Life and civilization will endure, but we will be living in a much warmer and stormier world.
- Want to read more?

"An Inconvenient Truth"(2003), Al Gore

"Hot, Flat and Crowded"(2003), Thomas Freidman

Am I sounding too negative?

- The amount of new energy needed is staggering!
- 6.8 Billion people want an answer soon!
- The Industrial Revolution, that has given us the comfort that we enjoy today, has consumed Millions of years of stored solar energy in less than 100 years!
- Still, I'm an optimist
- If I had an answer, I'd be rich. Encouraging!!
- Everyone is talking about it. Encouraging!!
- Fossil fuel prices will surely rise (there is lots of fossil fuel still out there, but it is getting harder to extract). Encouraging!!

My Vision (Hope?)

- By 2050 all newer houses (and businesses) have:
  - 2 kW Solar panel array on south facing roof
  - 2 kW Windmill
  - ‘One Watt’ construction
  - Electric cars in the garage (energy storage for the grid!)
- Nation will have:
  - Smart grid (including two-way and time-of-day metering)
  - Distributed Energy Sources
    - 20% nuclear, 20% solar, 20% wind, 20% biofuel, 20% fossil-fuel, 20% fusion, 20% something else (energy security!)??

What’s your Vision?

"The best way to predict the future is to create it yourself."

– Peter Drucker

"It is not as if what needs to happen is plainly impossible for economic or other reasons. The challenge is political"

– League of Women Voters Report, 2008

It is also necessary to carry out,

and explain to the public,

a lot more good science and engineering!

Questions ??