Global Warming: The Problem and Potential Solutions

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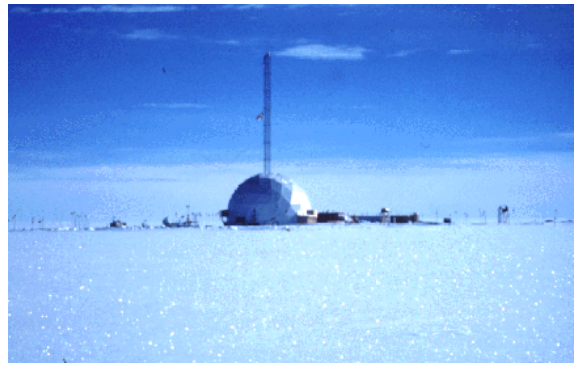
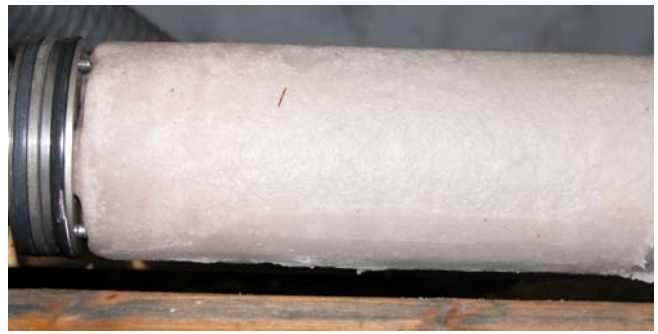
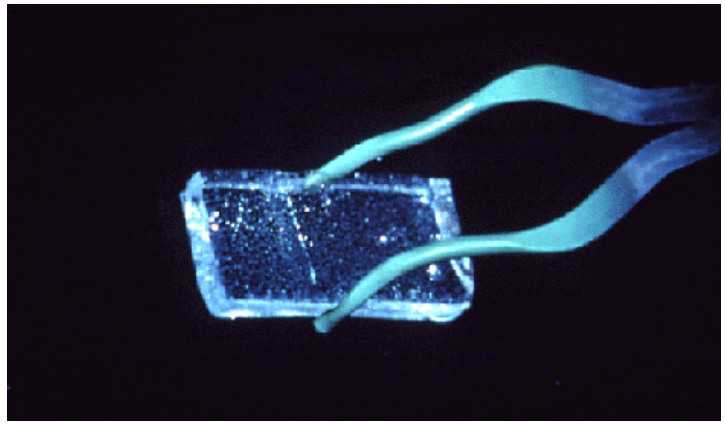
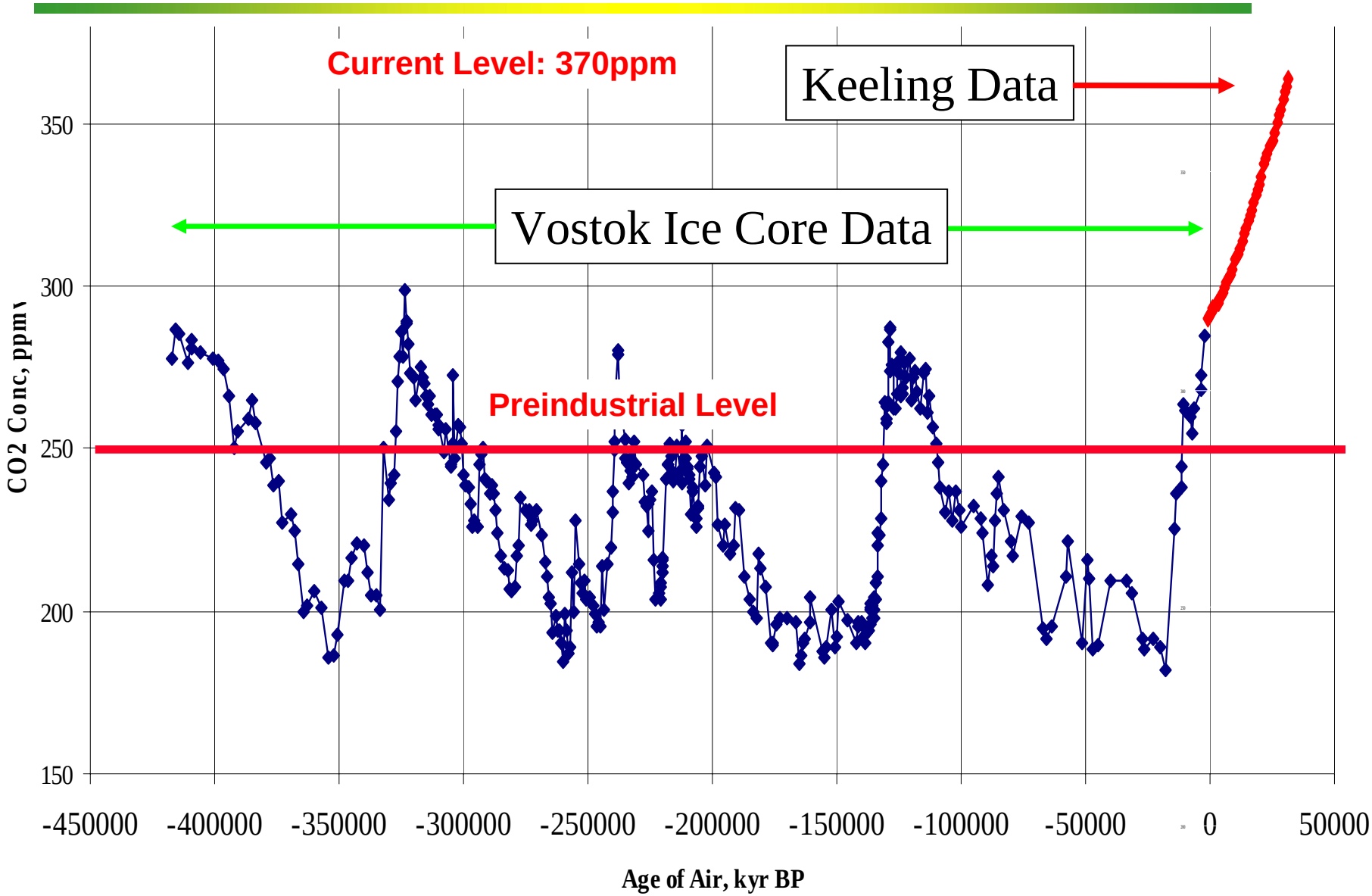
Ice Cores Capture Atmospheric History



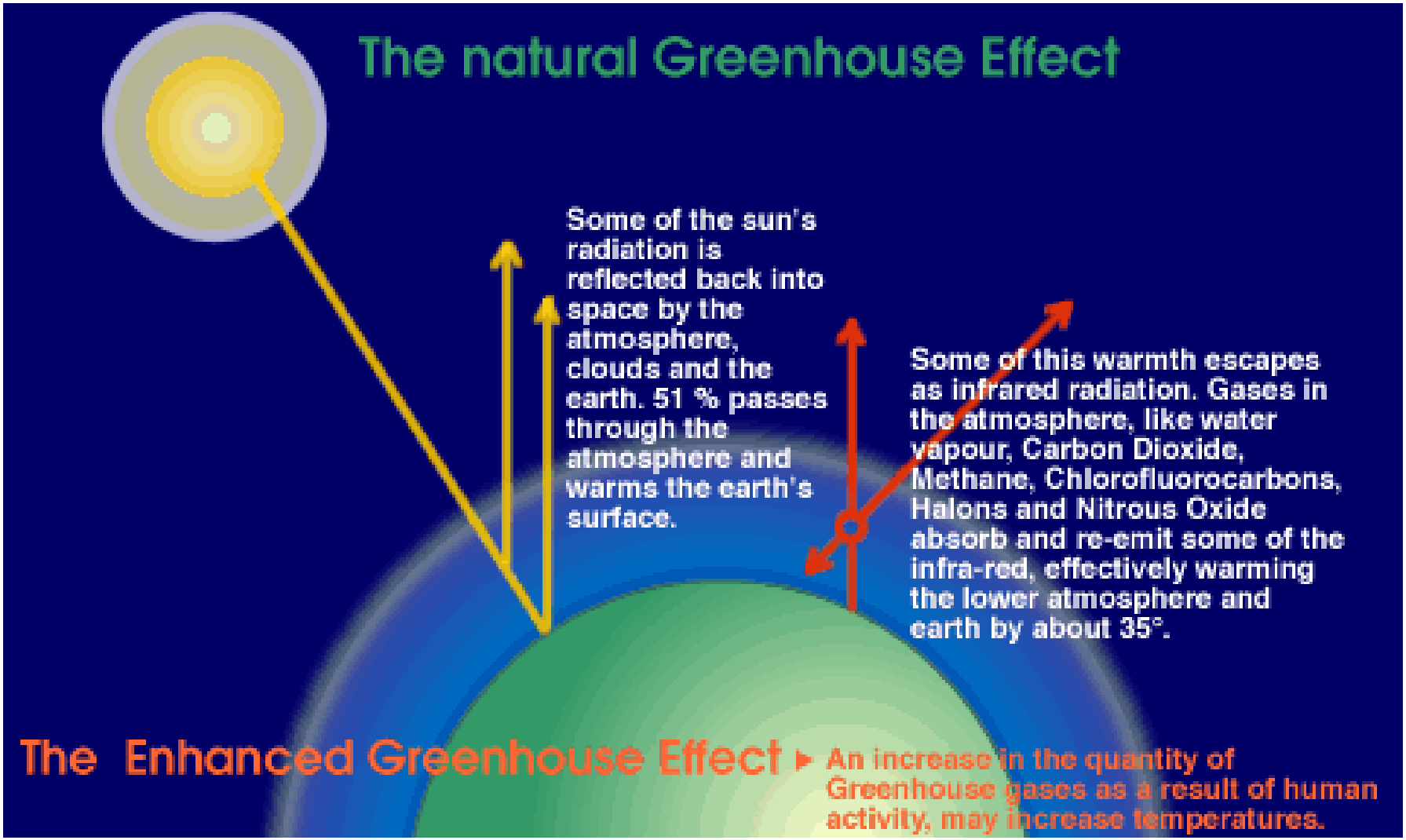




Historical CO_2 Levels



The Greenhouse Effect



The Greenhouse Gases

- Water vapor – responsible for some 60% of the GH effect
- Global Warming Potential
  - Carbon Dioxide - CO_2 – 1
  - Methane – CH_4 – 21
  - Nitrous Oxide - N_2O - 310
  - Freon 23 - CHF_3 – 11,700
  - Sulfur Hexafluoride - SF_6 – 23,900

Future BAU Emissions Trends

(*IS92a "Business As Usual" Scenario of IPCC*)

- **Increase in global energy use/capita, 1997-2100:**
  - For primary energy up 2.0X
  - For electricity up 2.6X
  - For "fuels used directly" up 1.4X
- **Annual global CO_2 emissions (not/capita):**
  - Total: 22.7 Gt CO_2, 1997(*37% coal*) → 73 Gt CO_2, 2100 (*88% coal)*
  - From electricity: 7 Gt CO_2, 1997 → 18 Gt CO_2, 2100
  - From fuels used directly: 16 Gt CO_2, 1997 → 55 Gt CO_2, 2100
- **Cumulative emissions, 1990-2100: 5,500 Gt CO_2**

(about the volume of Lake Michigan)

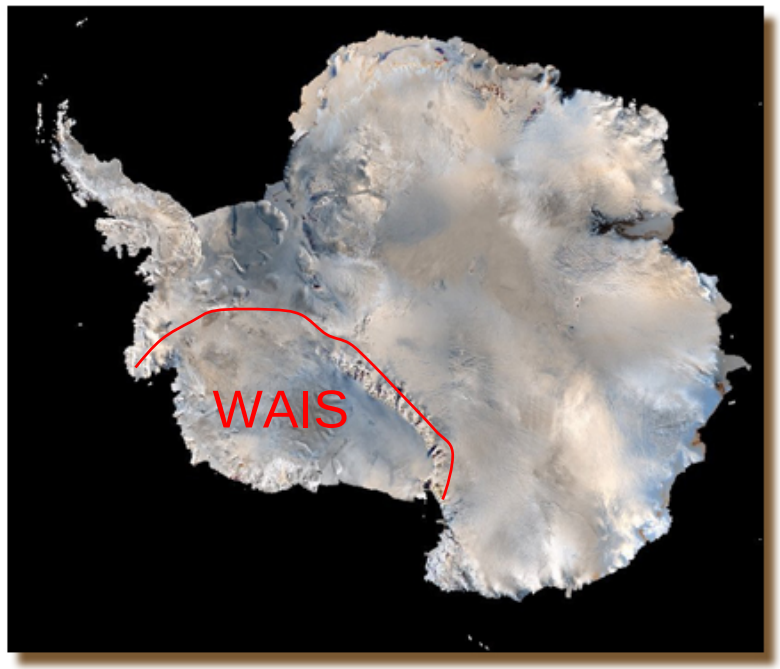
Mt Pinatubo, 1991 eruption = 42 M tonnes CO_2

Potential Consequences of BAU

Business As Usual

- **Sea Level Rise – West Antarctic Ice Sheet, Greenland**
- Thermohaline Circulation Belt
- Peats in Northern Latitudes
- Methane Hydrates
- Severe weather patterns

Antarctica



This ice is 90 percent of all Earth's ice and 70 percent of all its fresh water, amounting to about 6 million cubic miles. if it were returned to the oceans, it would raise global sea level about 200 feet.

Potential Consequences of BAU

- **Sea Level Rise –**
- **West Antarctic Ice Sheet, Greenland**
- Thermohaline Circulation Belt
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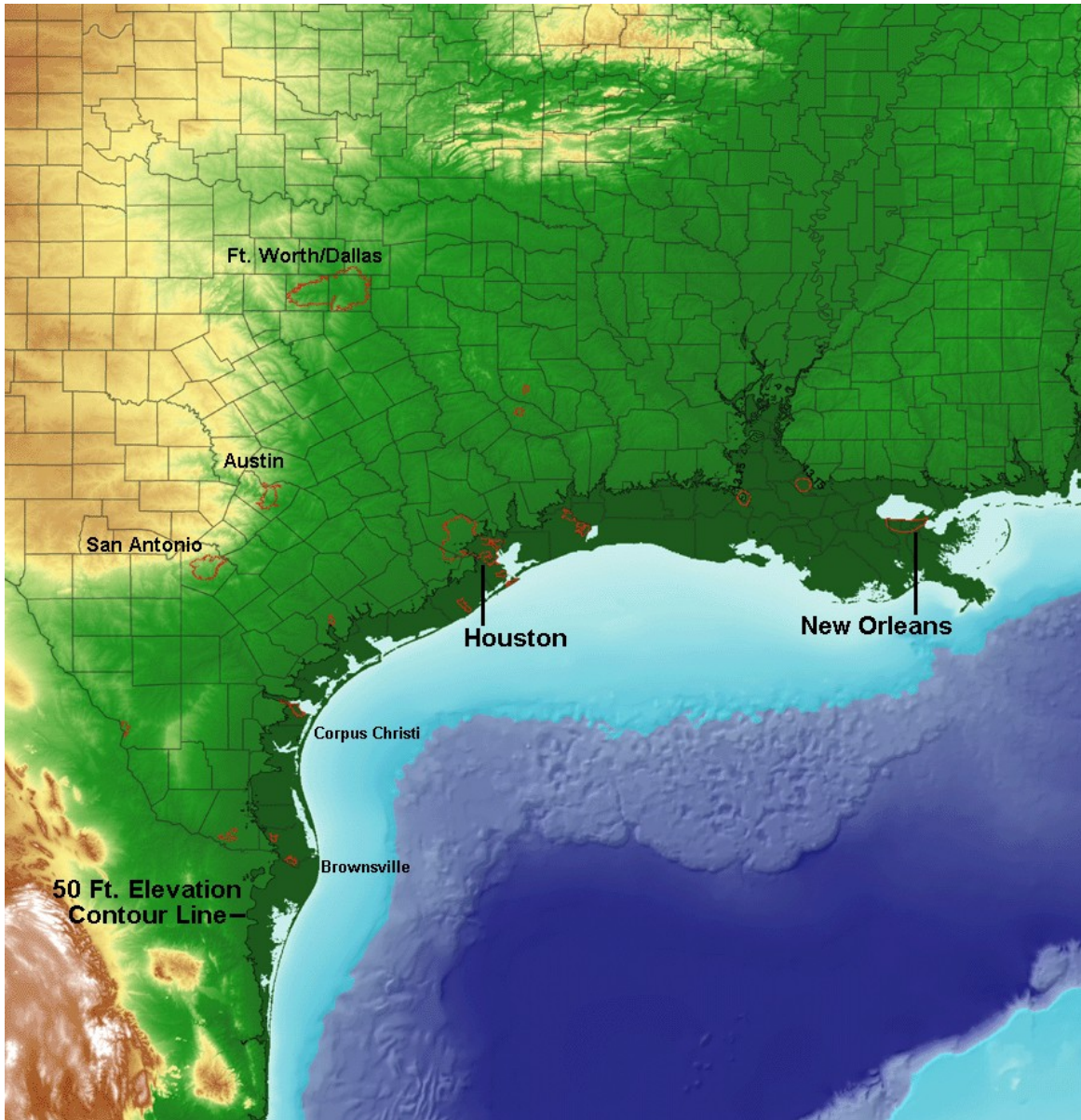
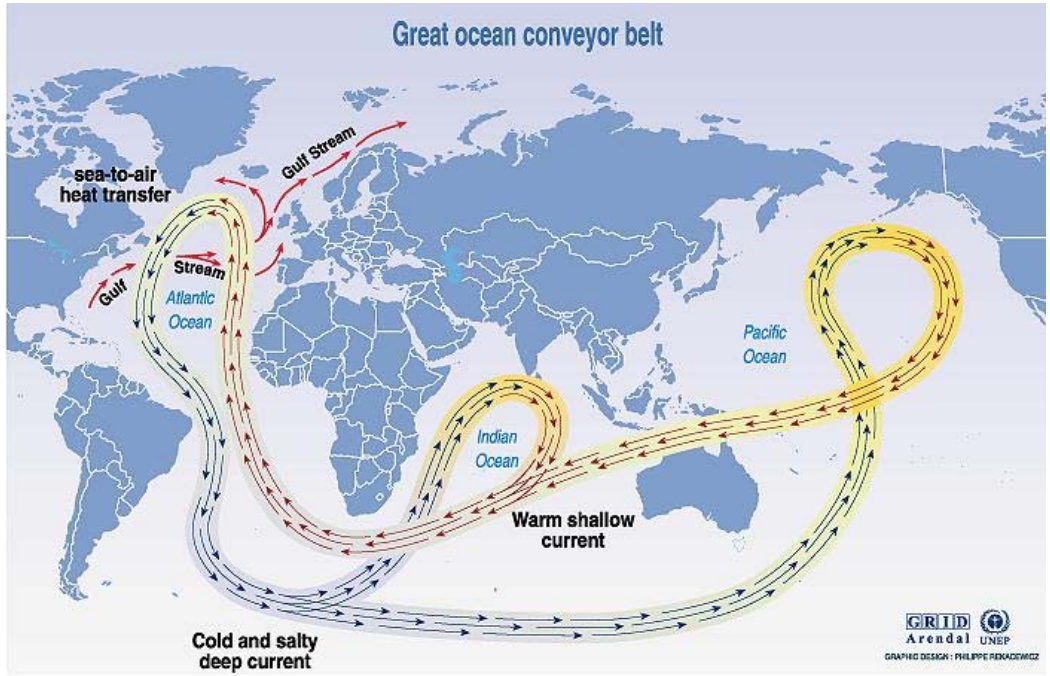


Potential Consequences of BAU

- Sea Level Rise – West Antarctic Ice Sheet, Greenland
- **Thermohaline Circulation Belt - THC**
- Peats in Northern Latitudes
- Methane Hydrates
- Severe weather patterns



Source: Broecker, 1991, in Climate change 1995, Impacts, adaptations and mitigation of climate change: scientific-technical analyses, contribution of working group 2 to the second assessment report of the intergovernmental panel on climate change, UNEP and WMO, Cambridge press university, 1996.

In addition to large effects on weather, upwelling may be responsible for 70% of the oceans' biological productivity.

Potential Consequences of BAU

- Sea Level Rise – West Antarctic Ice Sheet, Greenland
- Thermohaline Circulation Belt
- **Peats in Northern Latitudes**
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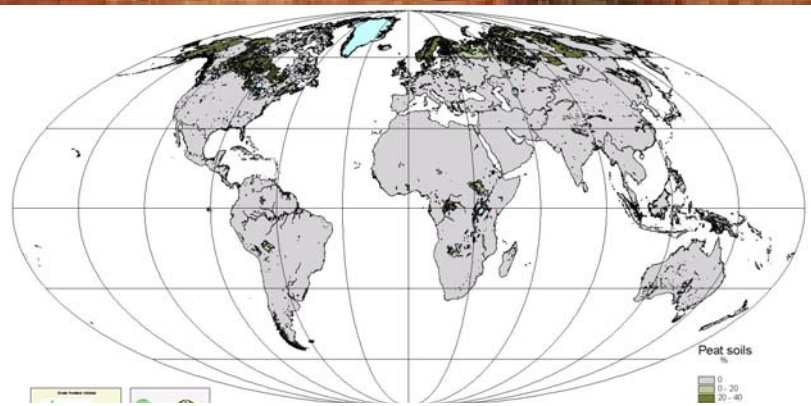
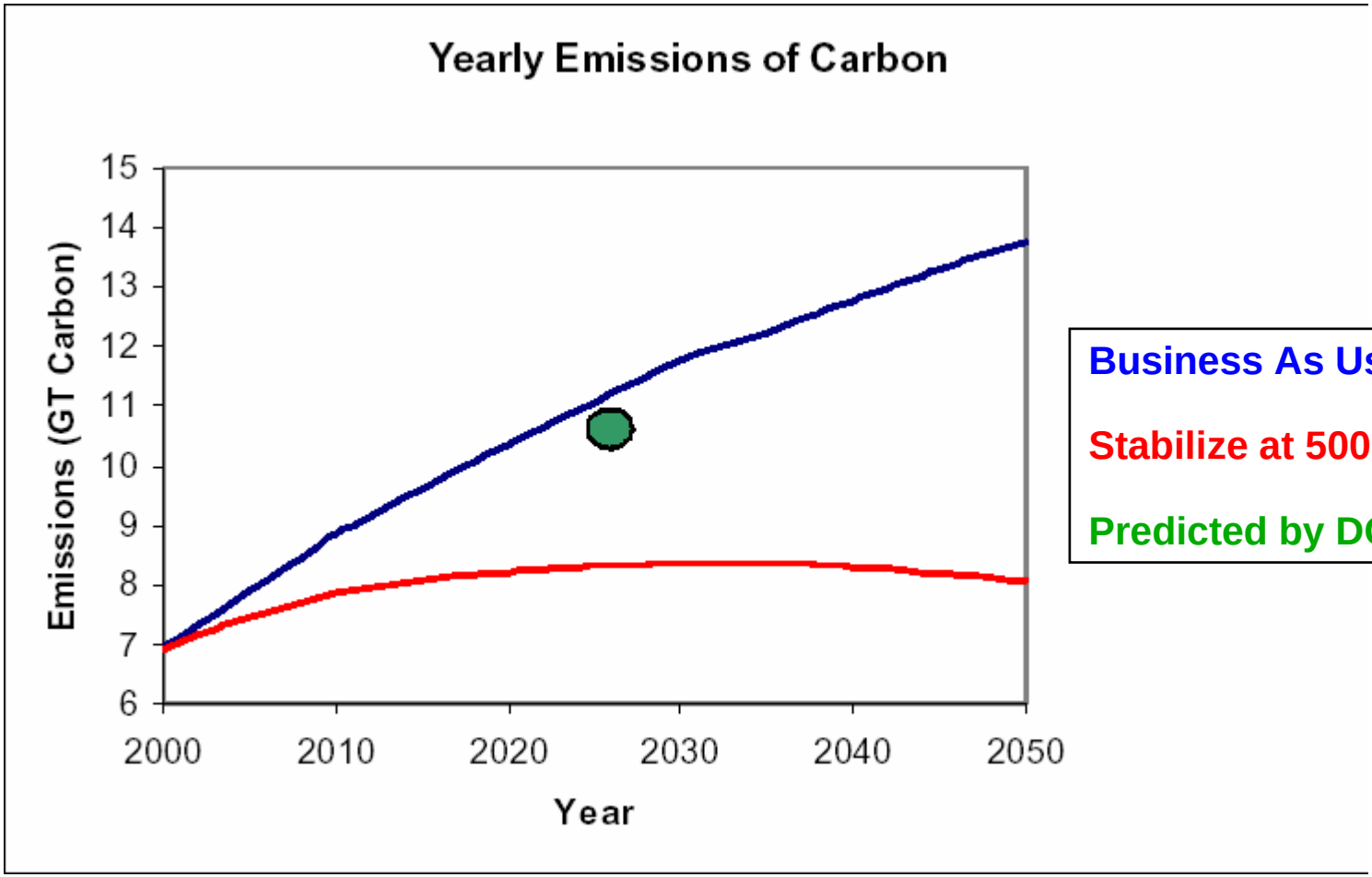


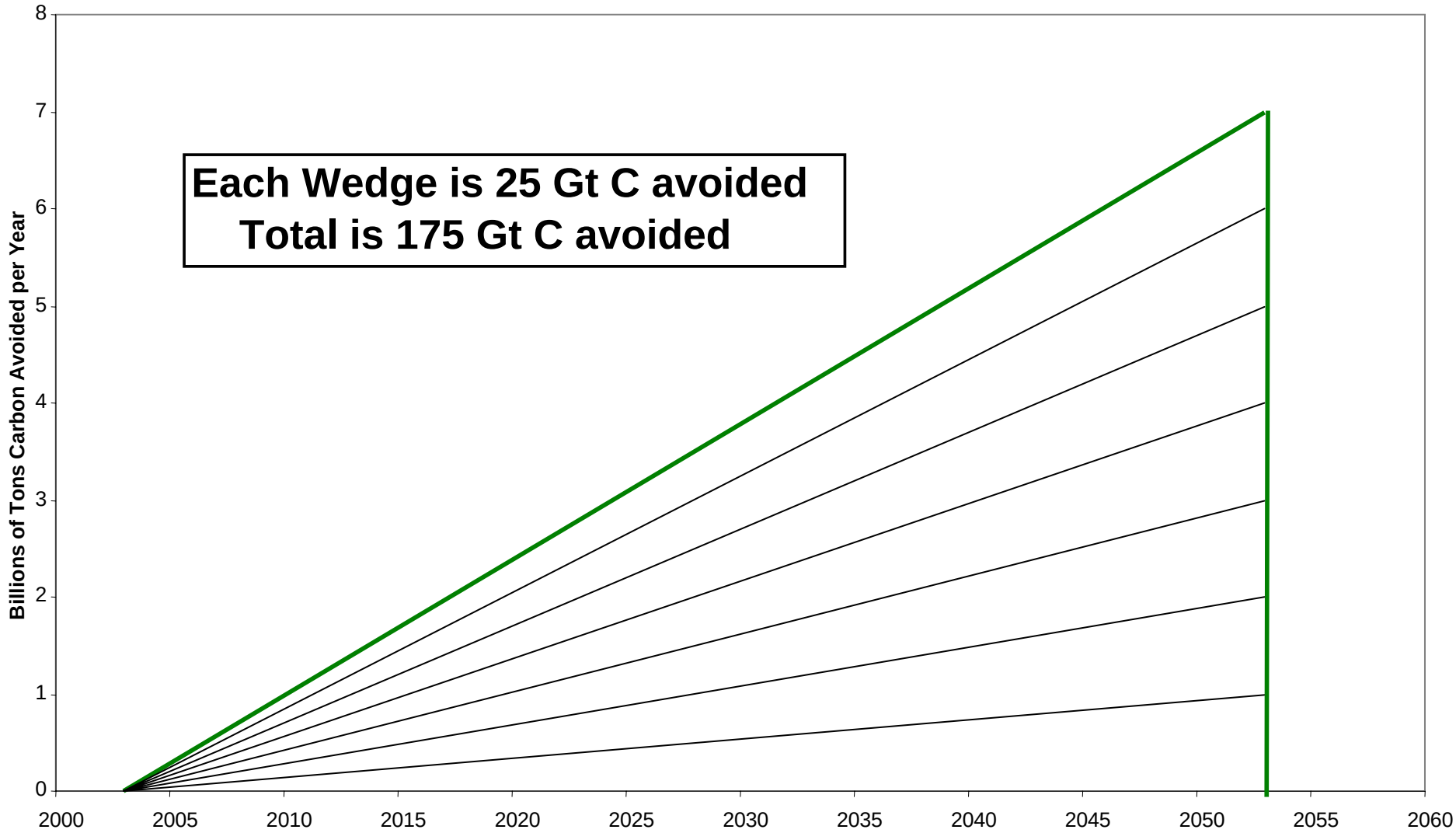
Russia and Canada alone have more than 2.7 million Km^2 = 67million acres of peat.

Business As Usual?



Emissions reductions required are the differences between the curves

Seven Slices of the Stabilization Wedge



After Pacala 2003

What Is Required to Achieve a Slice?

Category	Global Annual Increment	Total Capacity in 2050
Fuel shifting to replace coal	1) Build 28 GW of gas-fueled plants	1400 GW fueled by gas instead of coal (12% of current total)
Increased energy efficiency	2) Double efficiency of 40 million gas/diesel cars	2 billion gas/diesel cars at 60 mpg rather than 30 mpg
Displace Fossil Fuel in Electricity Gen	3) Wind 1.4x current	70x current
	4) Solar 20x current	1000x current; 12×10^6 acres
	5) Nuclear 4% current capacity	700 1 GW plants; 2x current cap
Substitute Renewables	6) Biomass 10 million acres	500 $\times 10^6$ acres = all US cropland
	7) Hydrogen from nuclear 20 1GW plants	1000 1GW plants
Forest and soil seq.	8) 35 million acres	1,500 million acres = total area of lower 48

2003 US Fleet Average = 20.8 mpg
World average 15 cars/1000 pop => 50/1000 by 2020

What Is Required to Achieve a Slice?

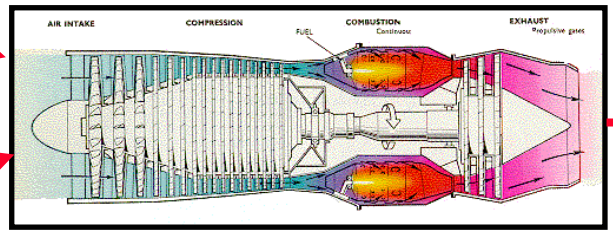
Category	Global Annual Increment	Total Capacity in 2050
Carbon Capture and Storage	9) Equip 14 coal plants with CCS	700 1 GW coal plants
	10) 70 Sleipners or Weyburns	3,500 Sleipners at 1 Mt CO_2/yr
	11) Displace 20 million gas/diesel cars with H_2 (CO_2 free)	1 billion H_2 cars (CO_2 free) displace 1 billion 30 mpg gas/diesel cars

But these are within today's technology

CO_2 – How to Get It, What to Do With It

Precombustion Decarbonization (Hydrogen)

Oxyfuels



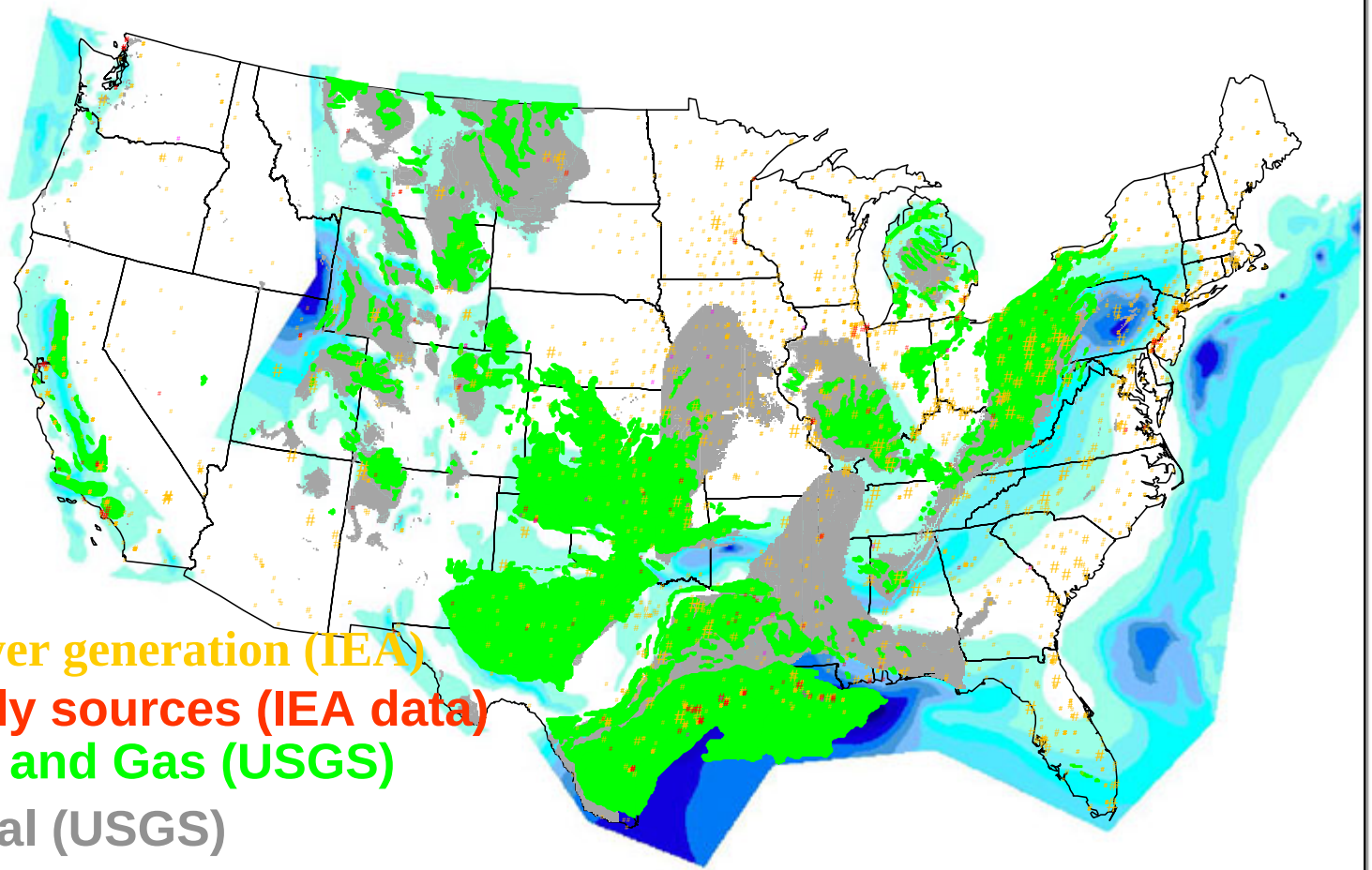
CO2 Capture

CO2

Geological Storage

CO2

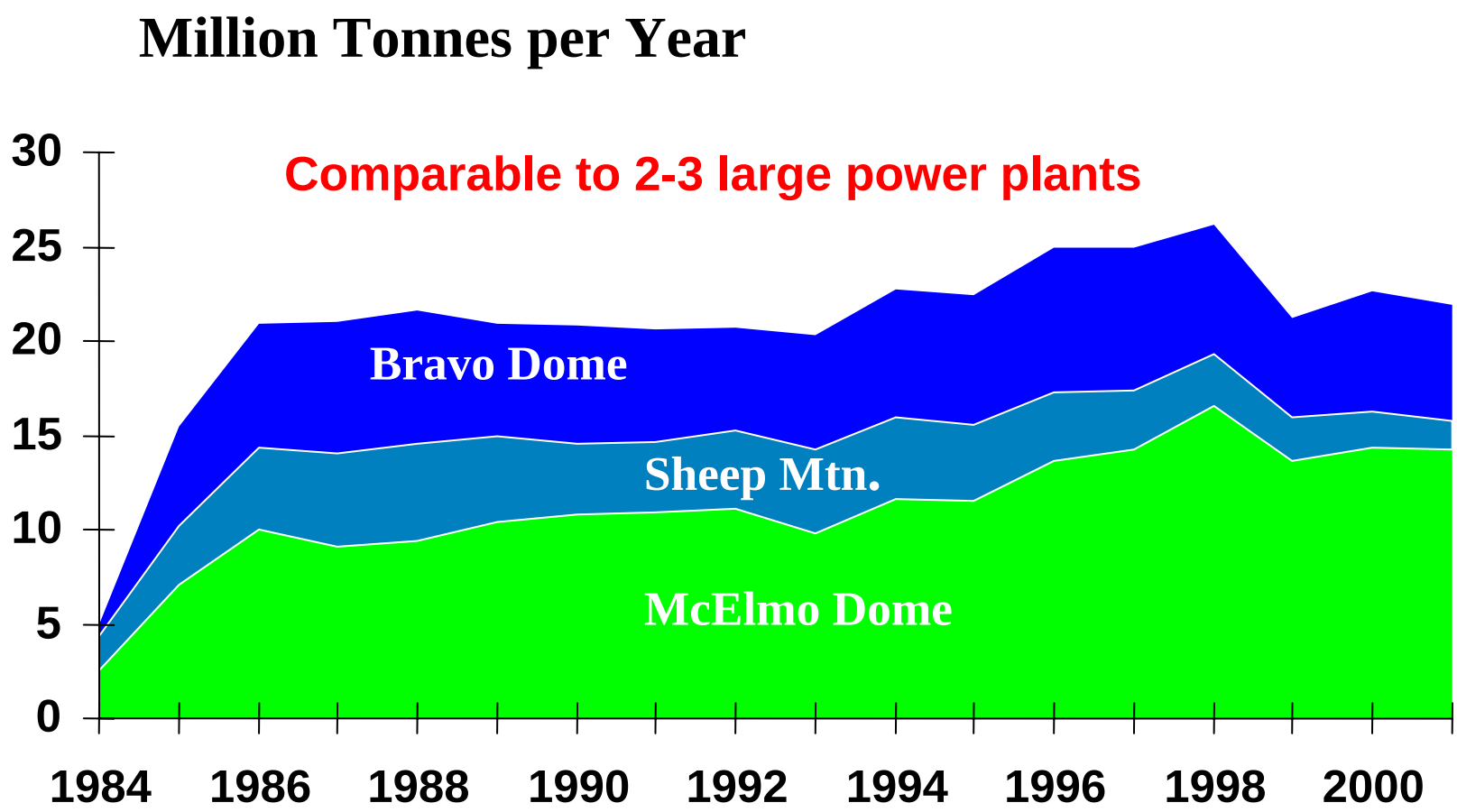
U.S. Geologic Storage Potential



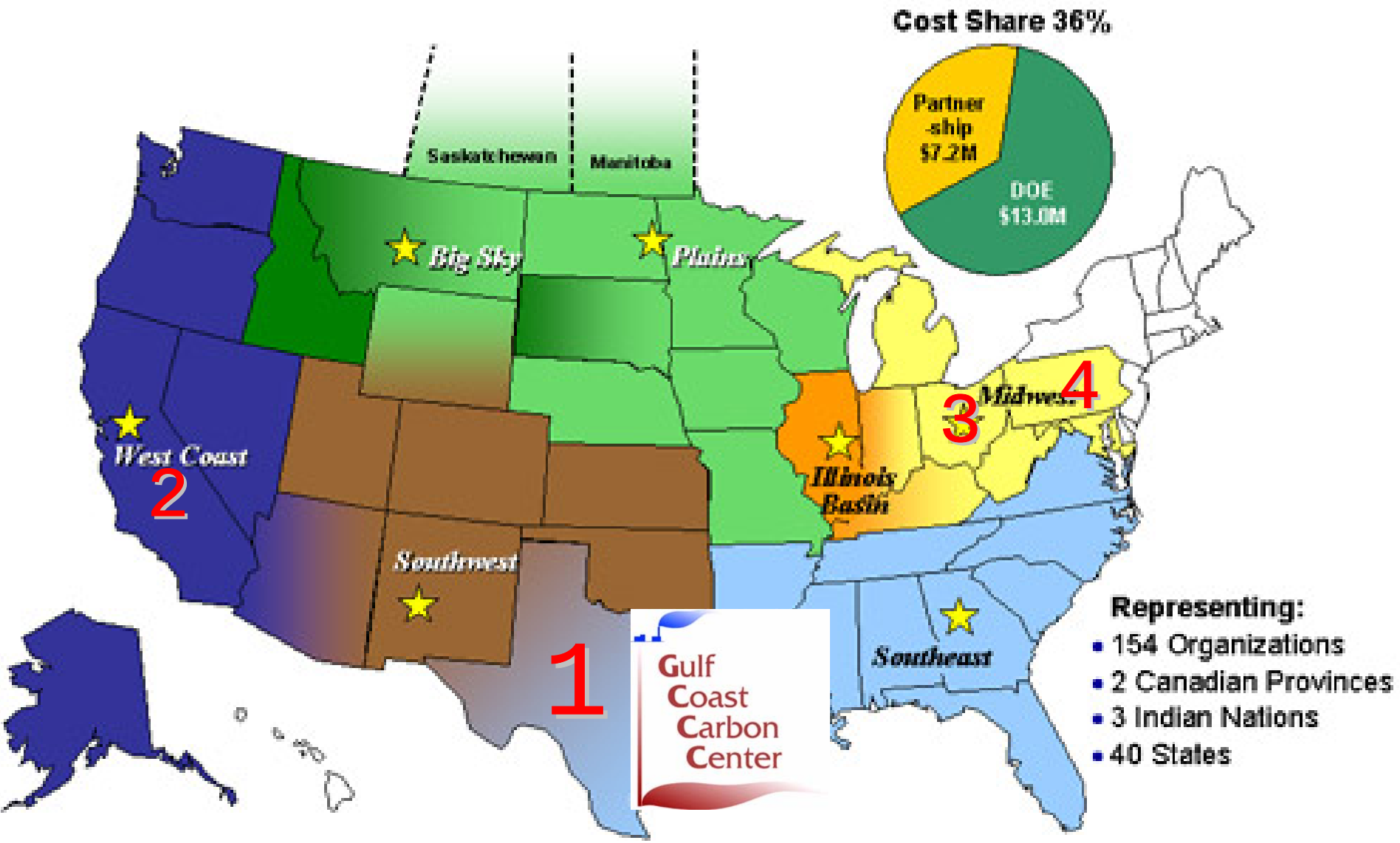
CURRENT US CO_2 SOURCES and PIPELINES
Industry knows how to handle CO_2

1561185 Ft/In

Permian Basin CO_2 Purchased for EOR



Dept of Energy Regional CO_2 Partnerships



The Business Case

- If public perceives this problem to be high priority, governments will act
- There will be a value for CO_2 at some point due to caps
- Current caps in Europe will affect multinationals in the US and elsewhere
- Those who plan for a carbon constrained future will benefit

Summary

- The scientific evidence is compelling that there is a link between CO_2 emissions and global warming.
- There are potentially very serious consequences if the BAU path is followed.
- There is no silver bullet - In order to meaningfully reduce CO_2 emissions, every means available, including capture and storage will be required.
- Industry has long experience handling CO_2.
- Regulatory caps will need to be in place to make it happen.

www.co2captureproject.com
www.princeton.edu/~cmi/
www.fe.doe.gov/programs/sequestration/