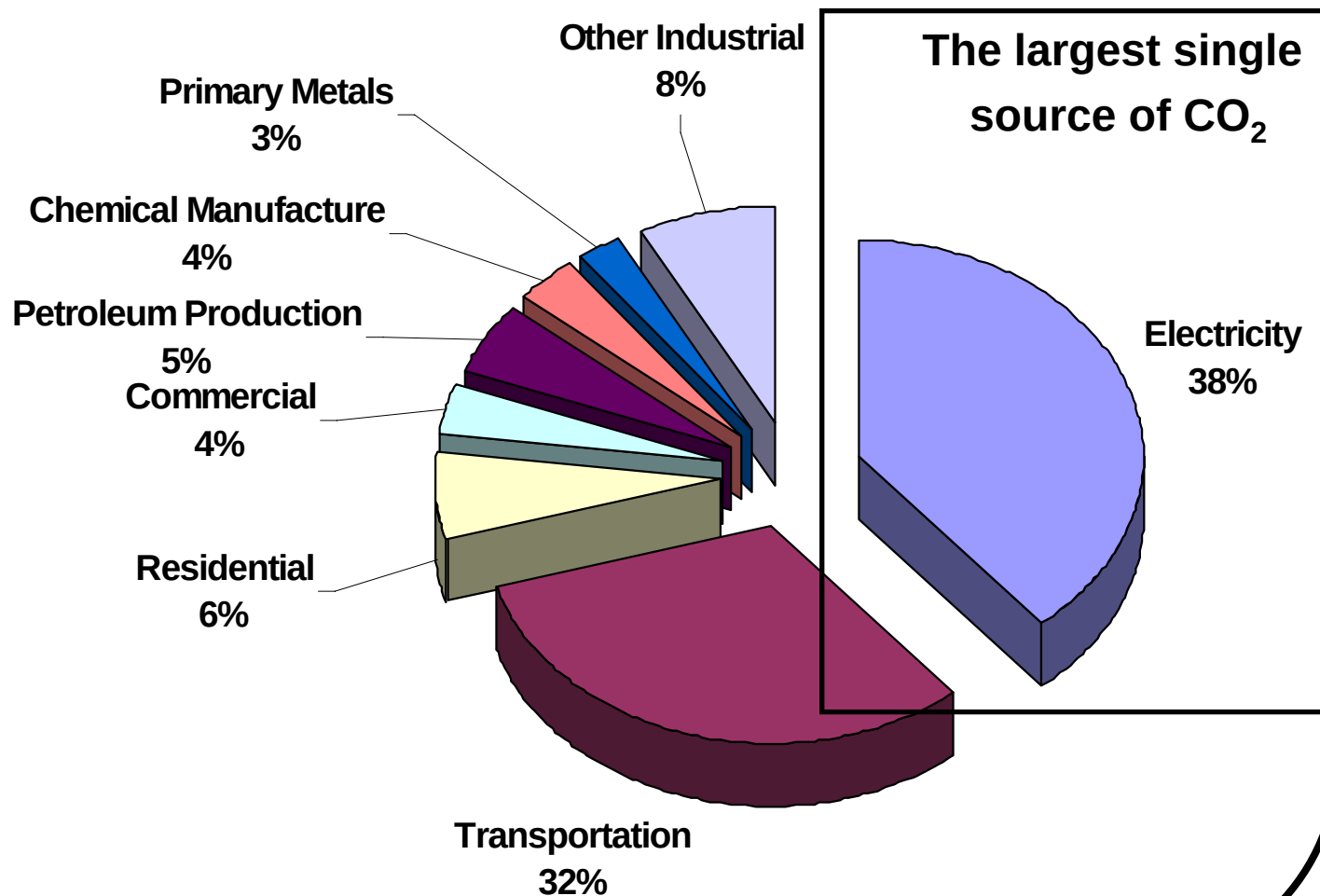




Carbon and Climate Issues

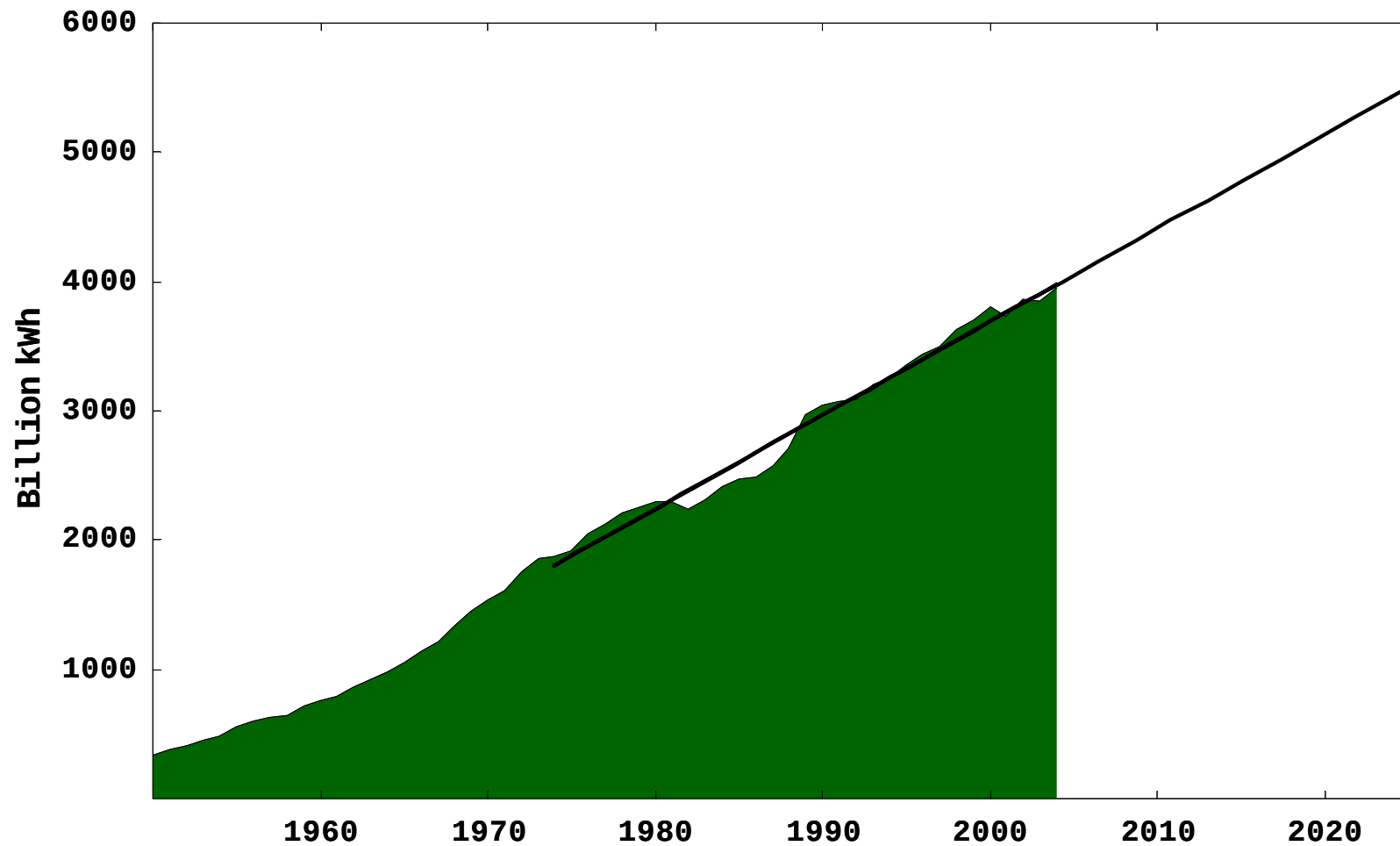
Jay Apt

Why target electric power?

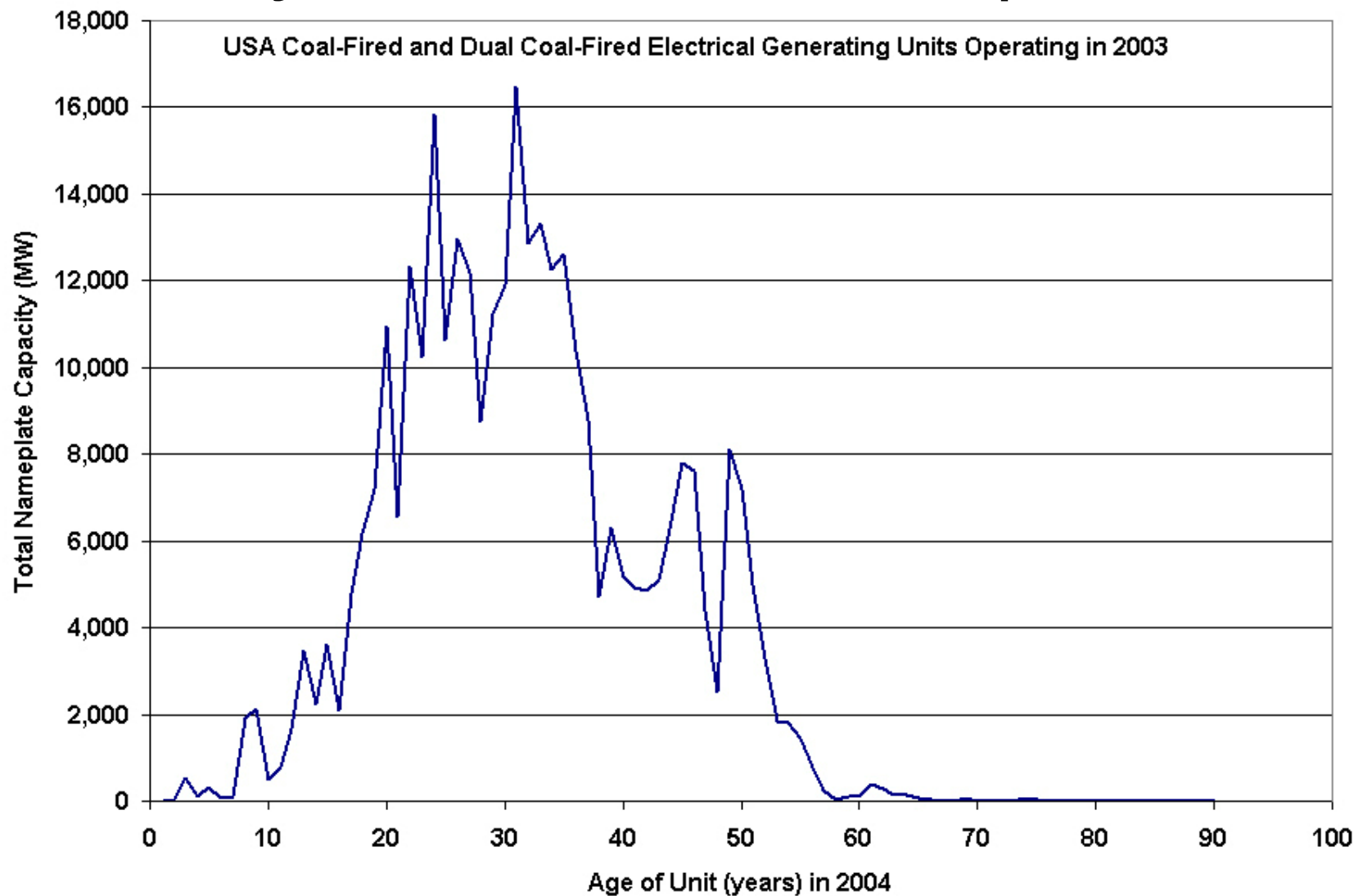


Source: U.S. EIA 2000

40% Demand Growth by 2025



Many coal units will be replaced



The climate issue on two slides

When fossil fuels are burned, carbon dioxide (CO₂) is created. Much of it remains in the atmosphere for ≥ 100 yrs. Since the beginning of the industrial revolution, atmospheric concentration has risen by about 30%.

Carbon dioxide is a natural trace constituent of the atmosphere. It, together with water vapor, traps infrared radiation, keeping the planet roughly 60°F warmer than it would otherwise be.

If we increase the amount of carbon dioxide a lot, the planet will get hot. Venus, with an atmosphere that has roughly one hundred times as much CO₂ as the earth's, has an average surface temperature of 885°F.

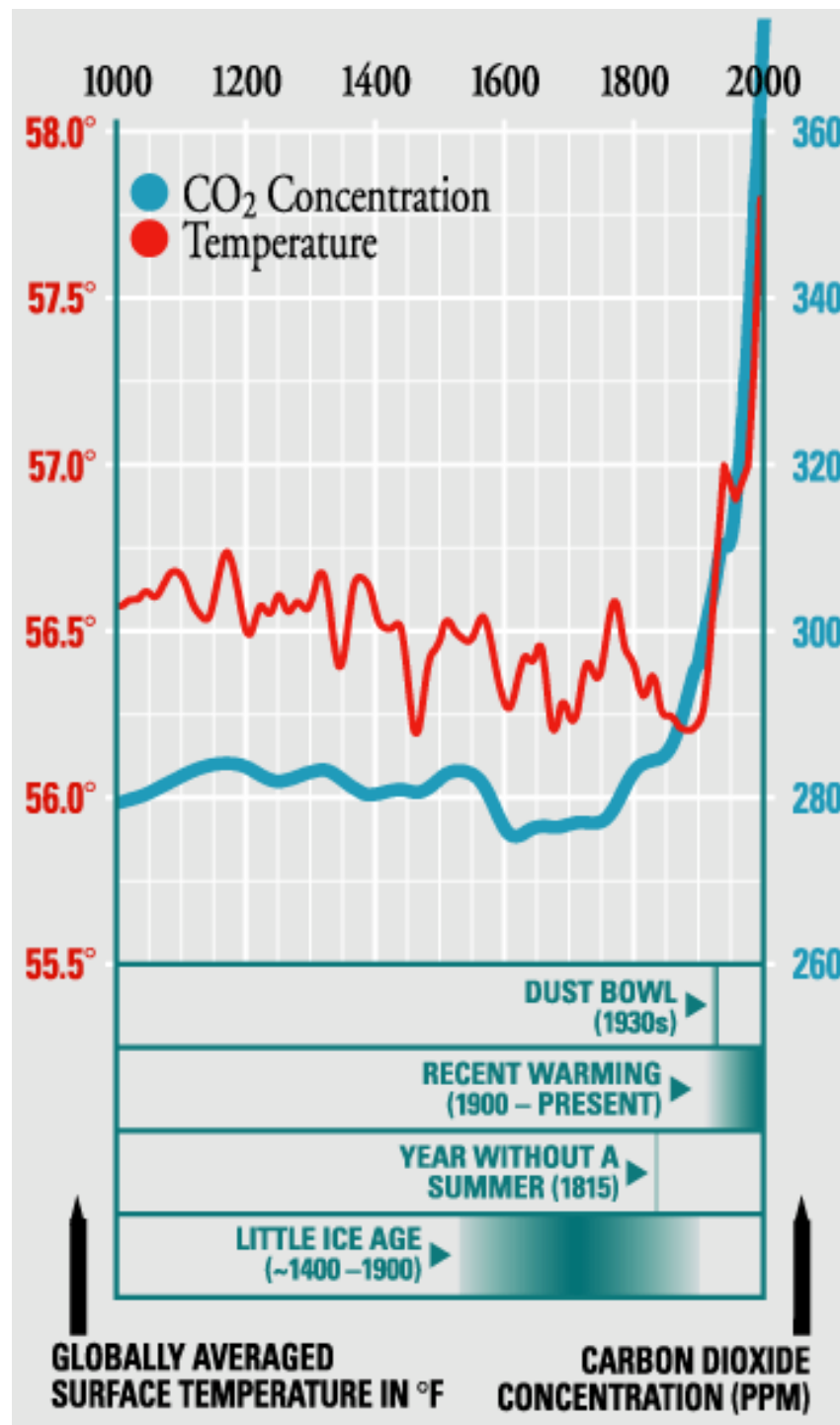
As a former planetary astronomer, I can tell you that the greenhouse effect is more than “just a theory.”

Slide 2 of the climate issue on two slides

The IPCC (Intergovernmental Panel on Climate Change) recently concluded that the earth has already warmed by about 0.6°C (1.1°F), and will experience an average warming of between 1.4 and 5.8°C (2.5 to 10.4°F) over the coming century.

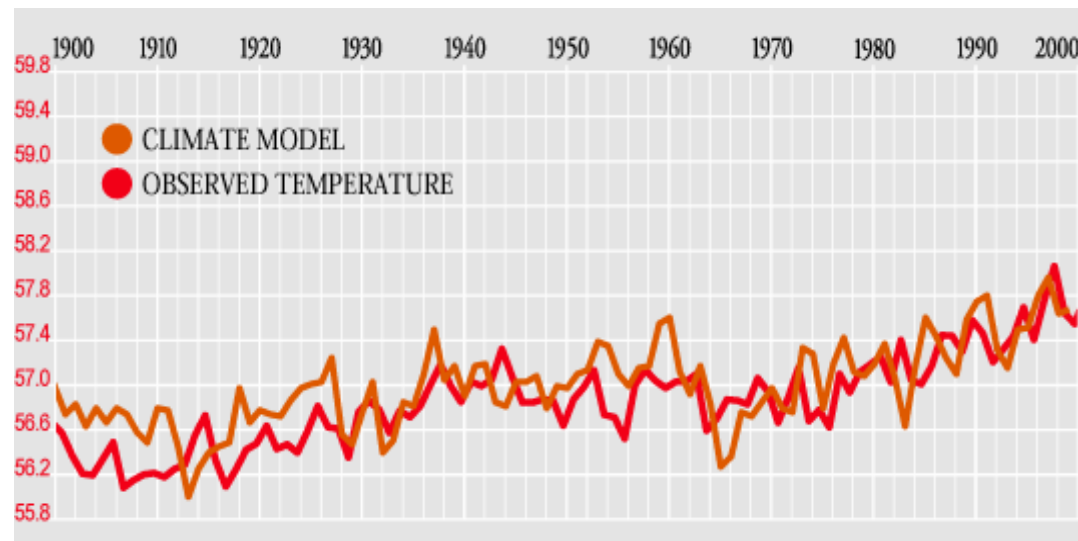
The impacts of such warming on the economy of developed countries will likely be just a few percent of GDP or less. The impacts on the economies of some developing countries will likely be much larger. The impacts on many natural ecosystems such as trees, alpine meadows, polar bears, and coral reefs will be large.

For details see: www.ipcc.ch
and www.usgcrp.gov/usgcrp/assessments.htm.



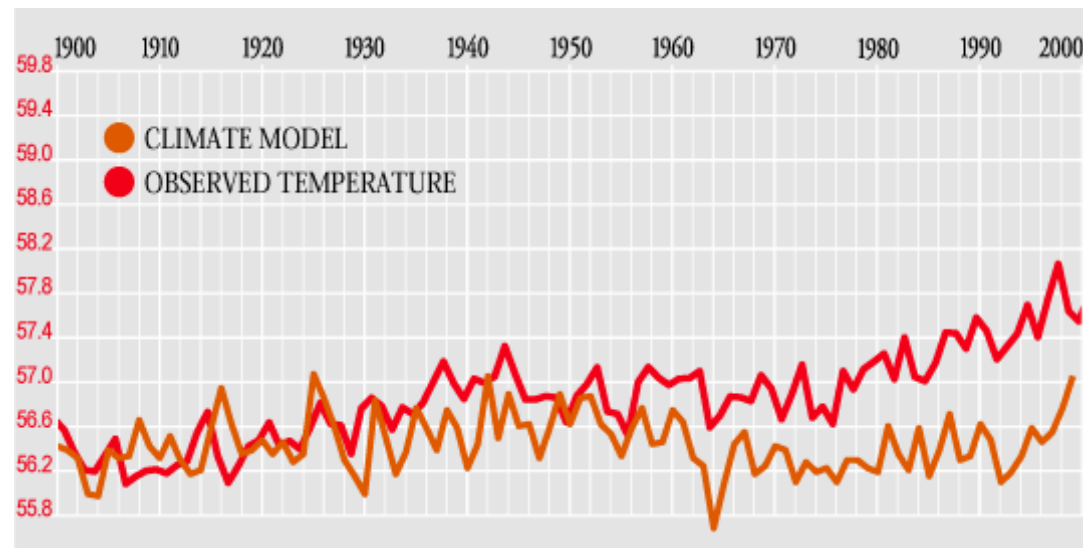
Are Humans the Cause?

Most probably, yes

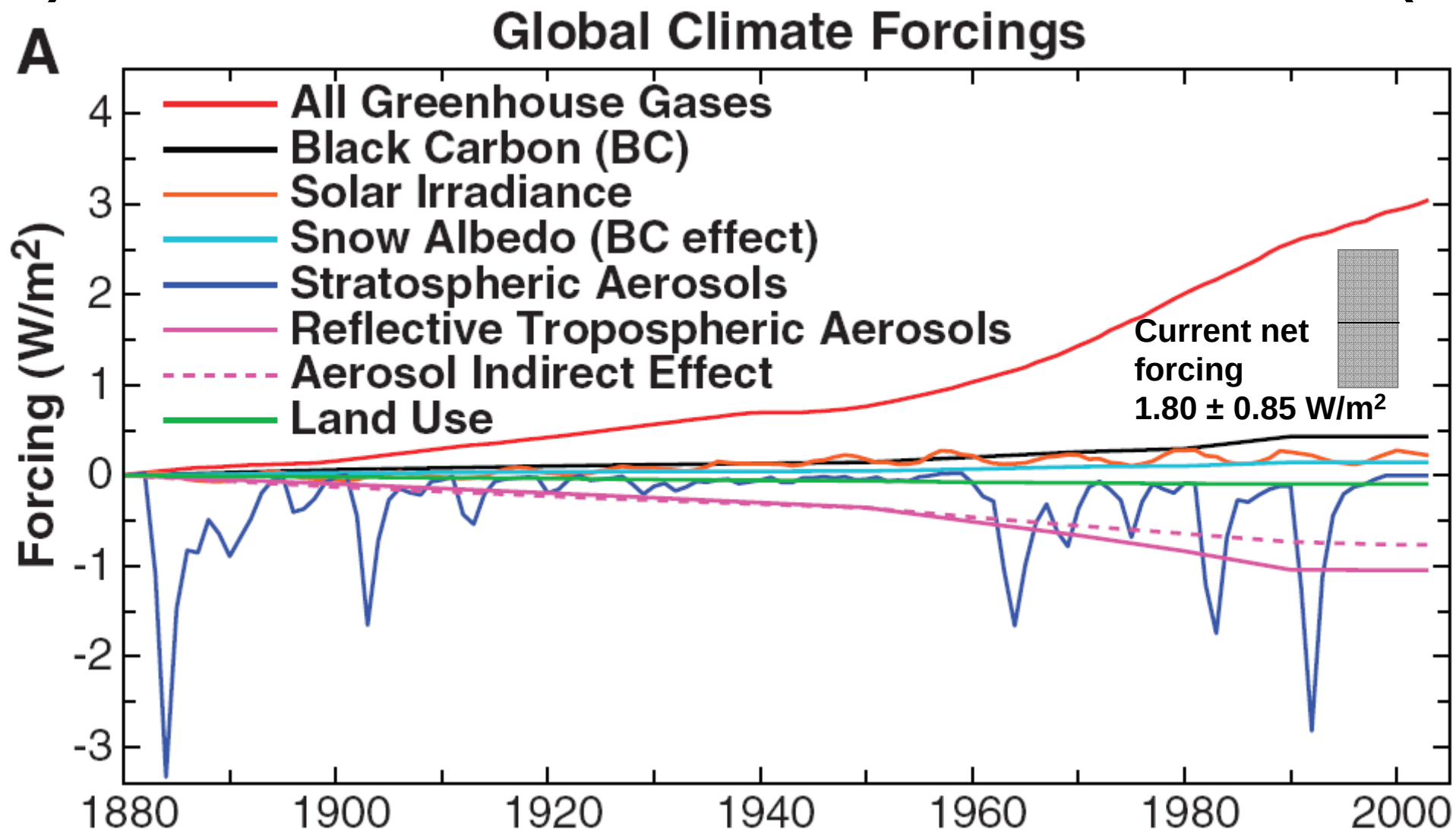


A climate model projection that includes both natural processes and human activities closely matches actual measurements of 20th-century temperature changes.

Are Humans the Cause?

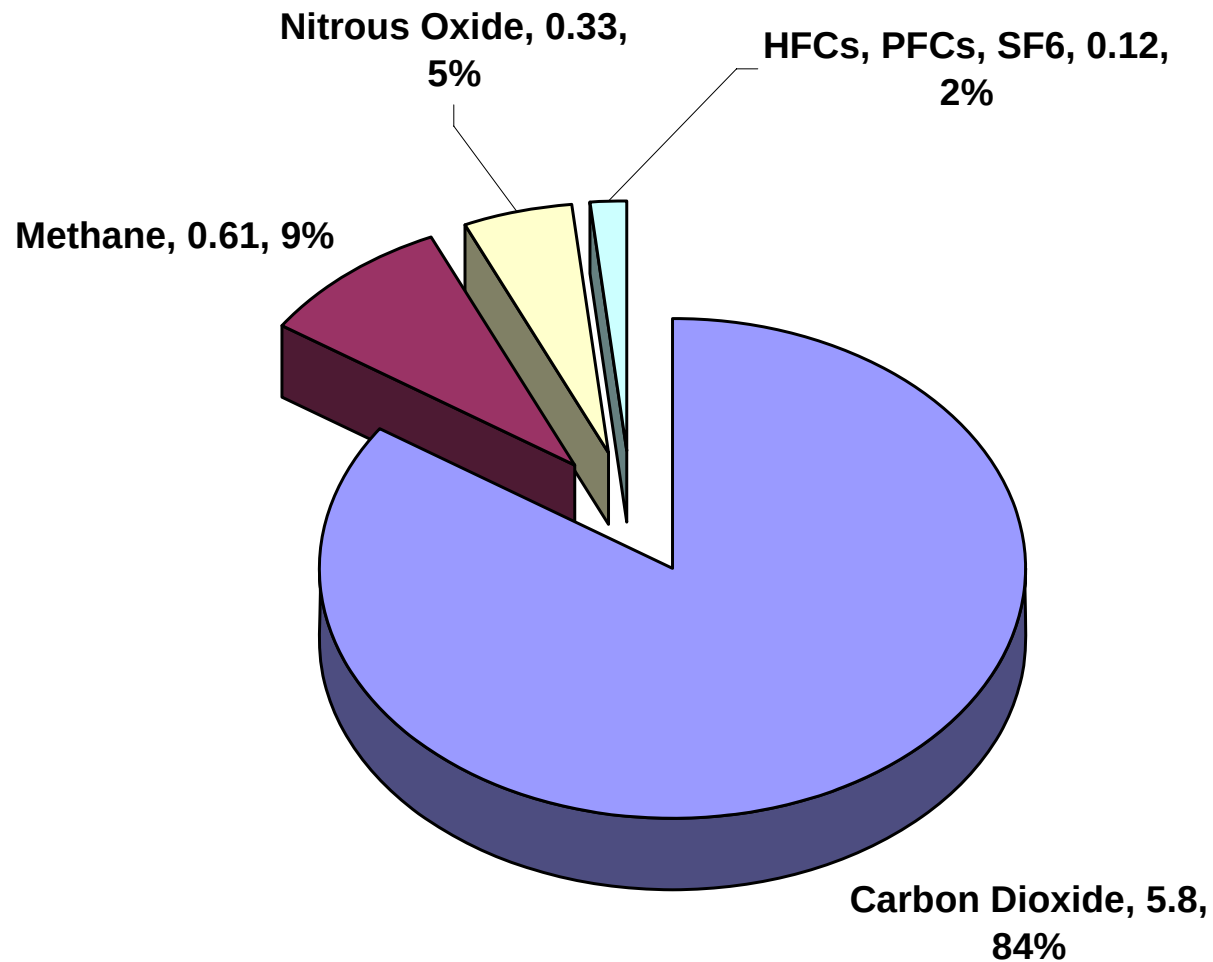


The same climate model without human activity (natural processes only) does not match the strong warming that occurred during the past few decades.



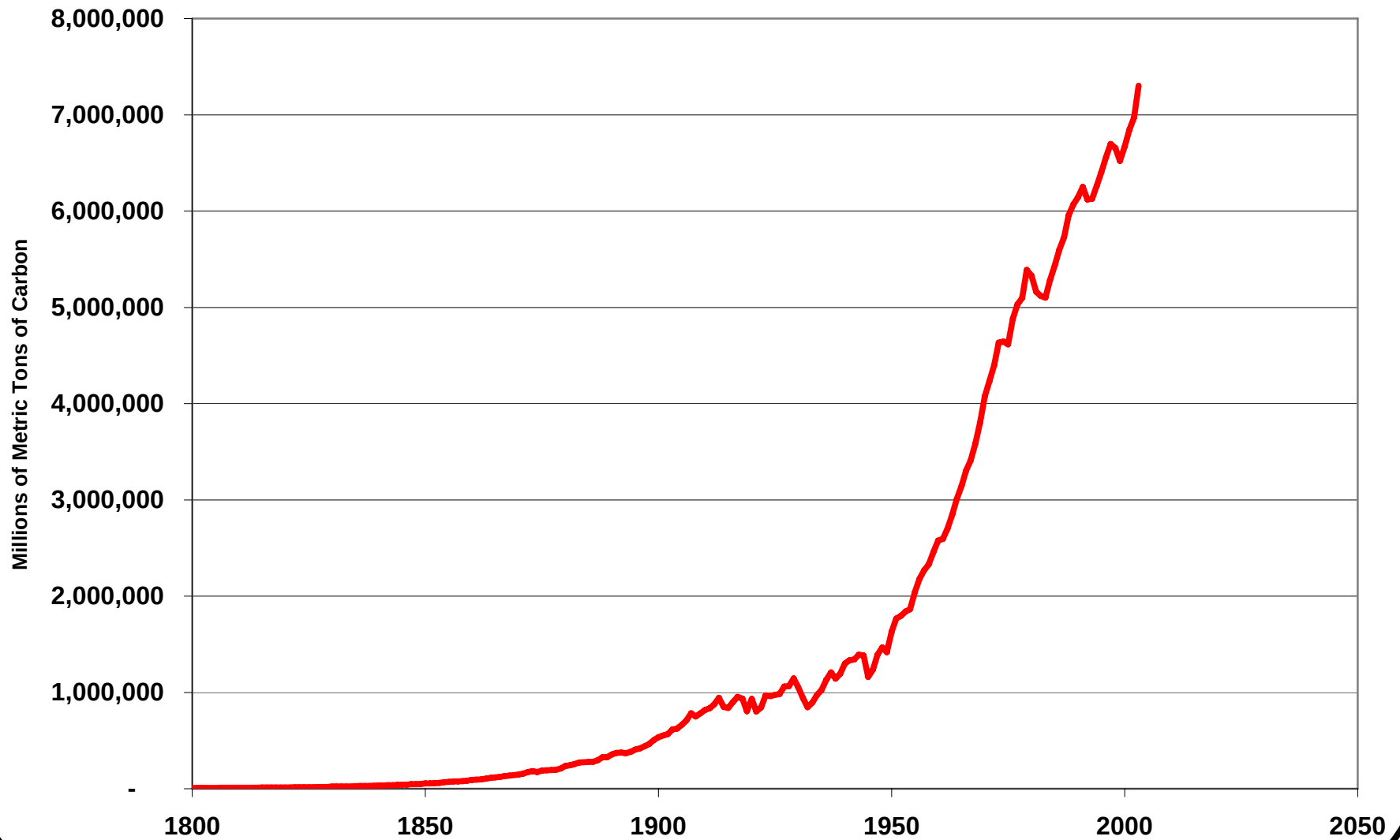
Source: Hansen et al. *Science* 308: 1431-1435 (2005)

**US Greenhouse Gas Emissions 2002
(Global Warming Potential in
Billion Metric Tonnes of CO2 Equivalent)**



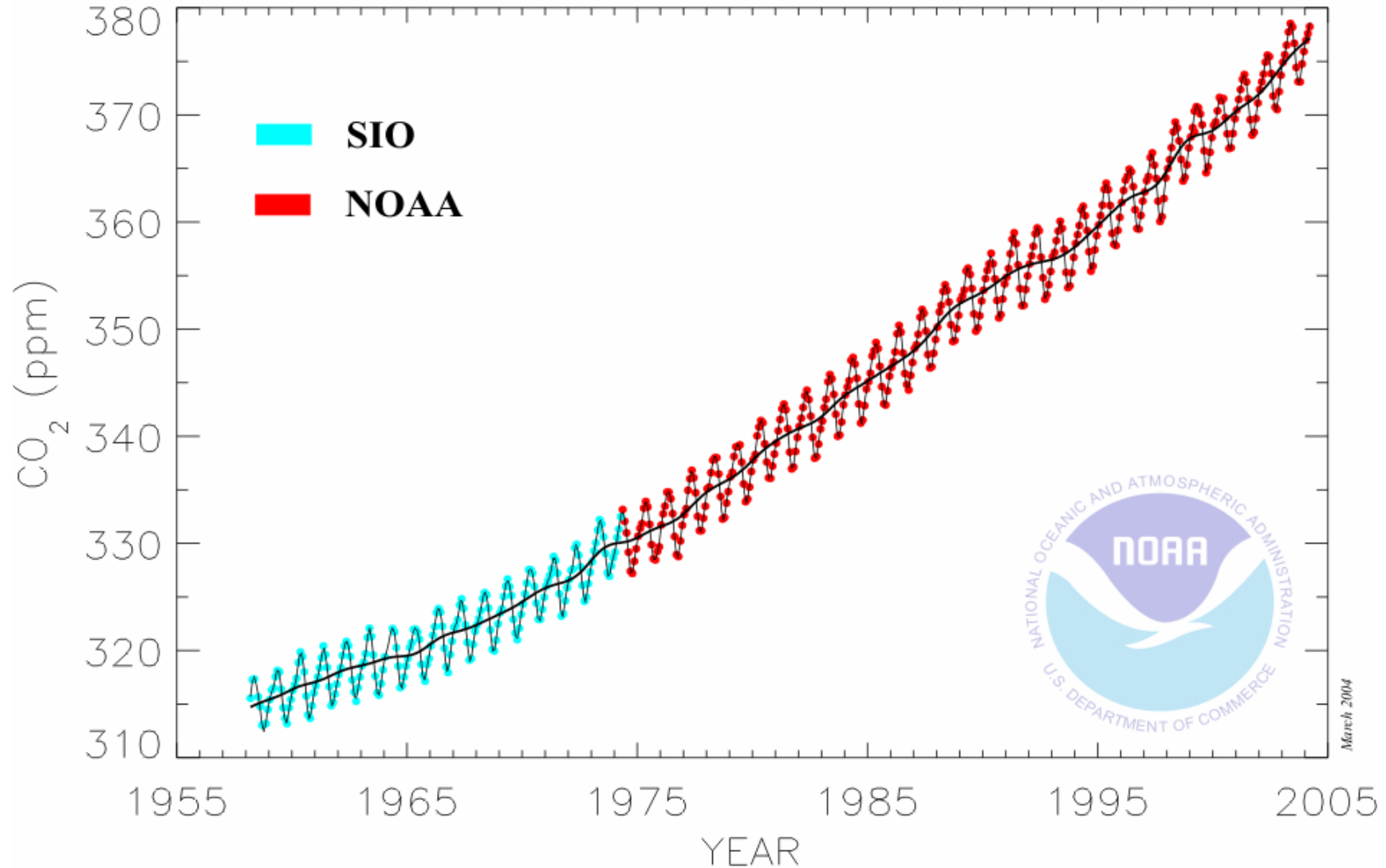
Source: EIA 2002 Annual Energy Review, Fig 12.1

Annual Global Emissions of Carbon from Fossil Fuels



Source: Oak Ridge National Laboratory http://cdiac.esd.ornl.gov/ftp/trends/co2_emis/weu.dat

Mauna Loa Monthly Mean Carbon Dioxide

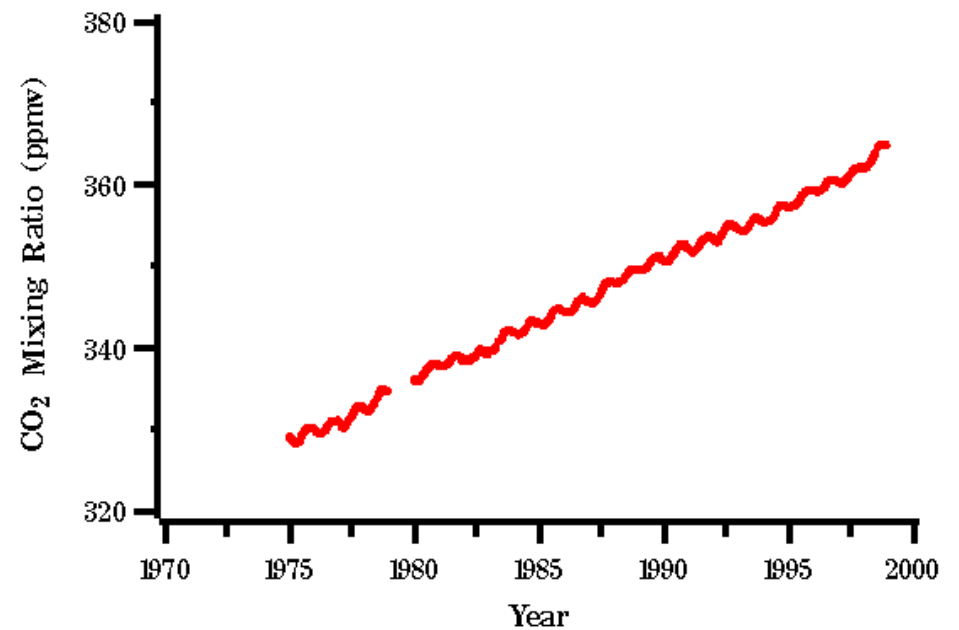
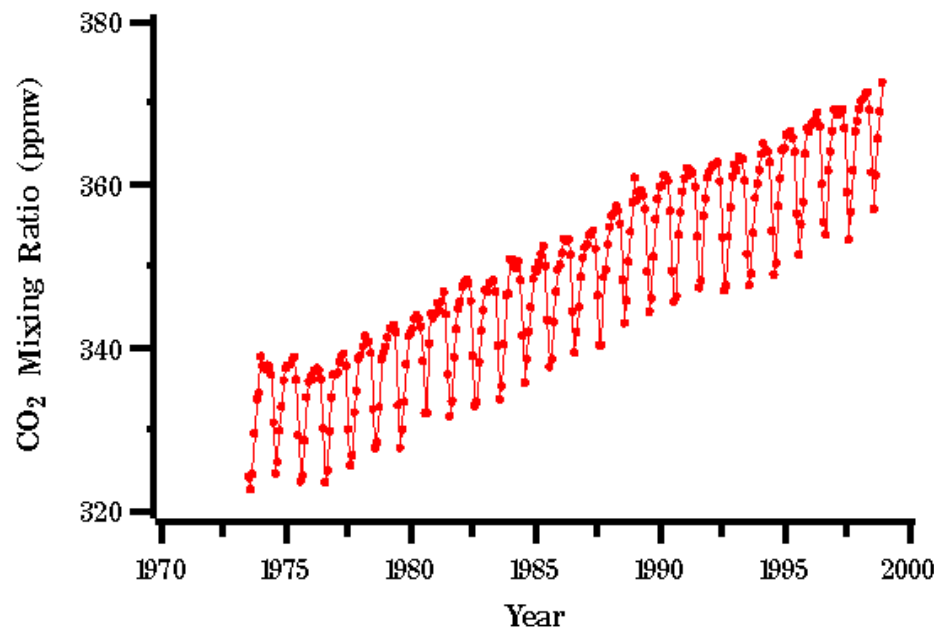
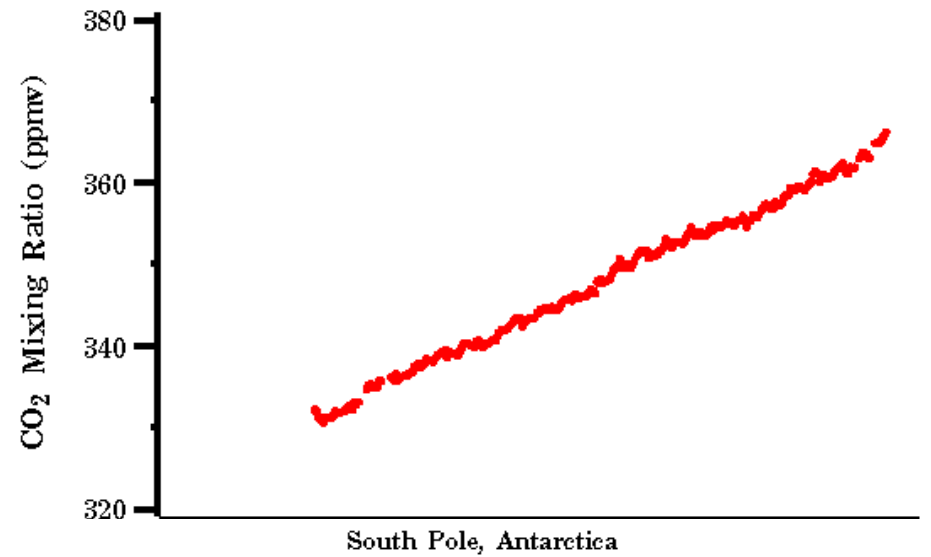
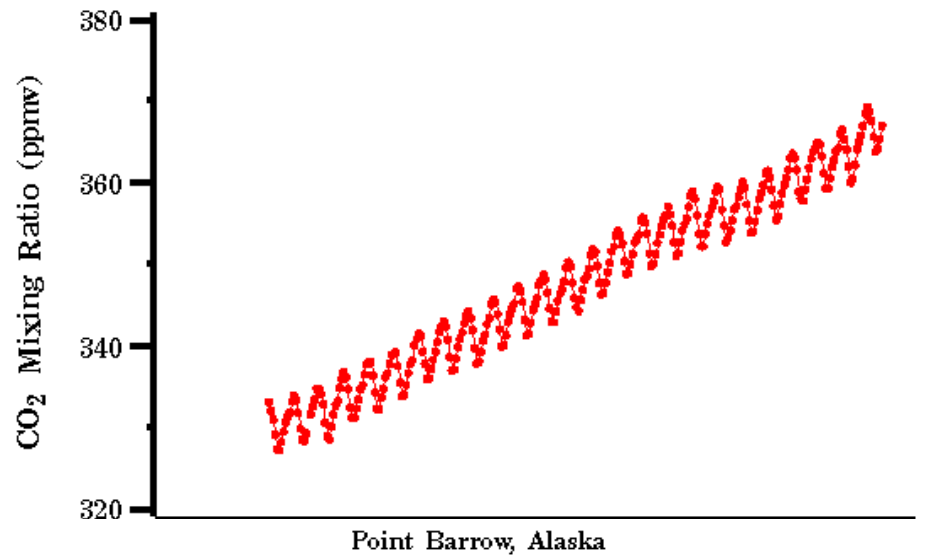


Atmospheric carbon dioxide monthly mean mixing ratios. Data prior to May 1974 are from the Scripps Institution of Oceanography (SIO, blue), data since May 1974 are from the National Oceanic and Atmospheric Administration (NOAA, red). A long-term trend curve is fitted to the monthly mean values. Principal investigators: Dr. Pieter Tans, NOAA CMDL Carbon Cycle Greenhouse Gases, Boulder, Colorado, (303) 497-6678, pieter.tans@noaa.gov, and Dr. Charles D. Keeling, SIO, La Jolla, California, (616) 534-6001, cdkeeling@ucsd.edu.

Mauna Loa, Hawaii

Cape Matatula, American Samoa

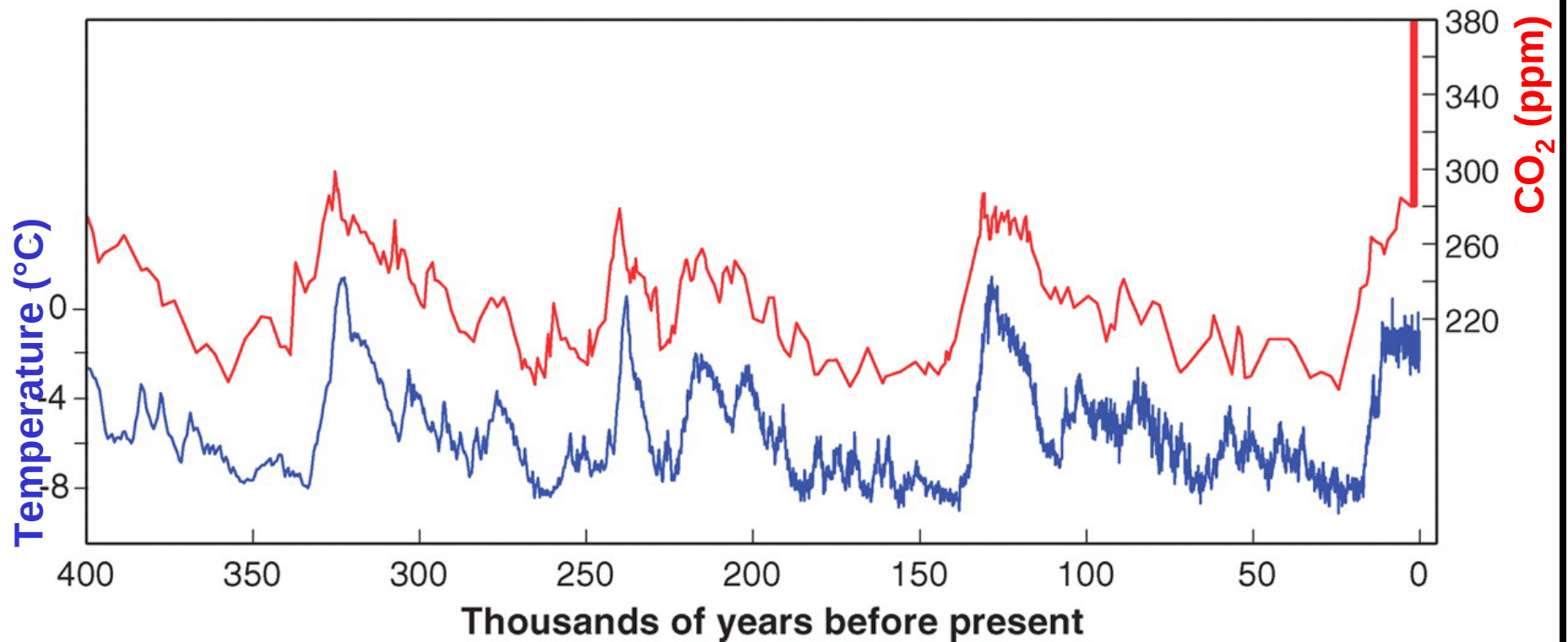
Observed atmospheric CO₂ concentrations



Source: Kirk Thoning and Pieter Tans (NOAA/CMDL)

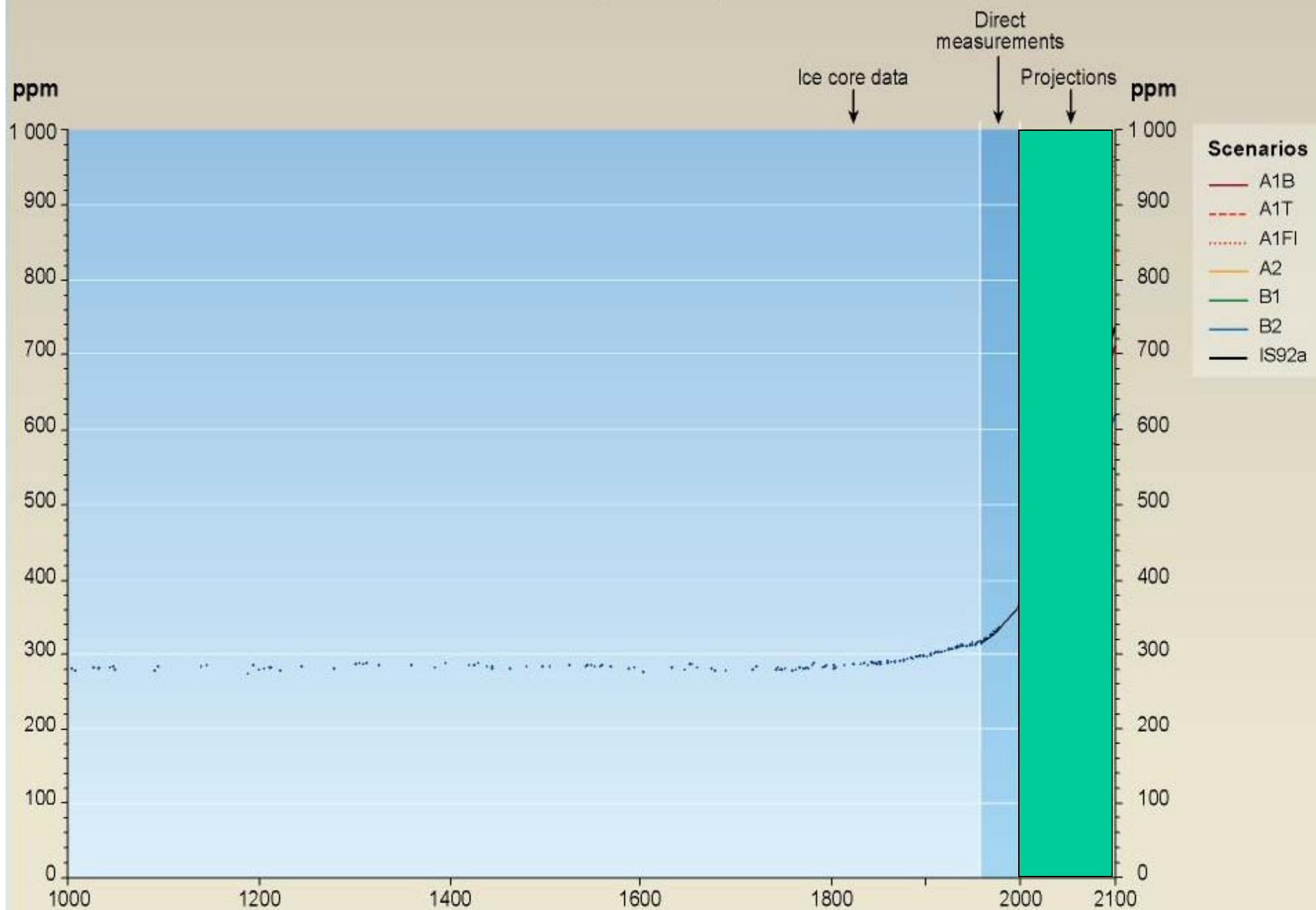
Source: Kirk Thoning and Pieter Tans (NOAA/CMDL)

CO₂ and Temperature



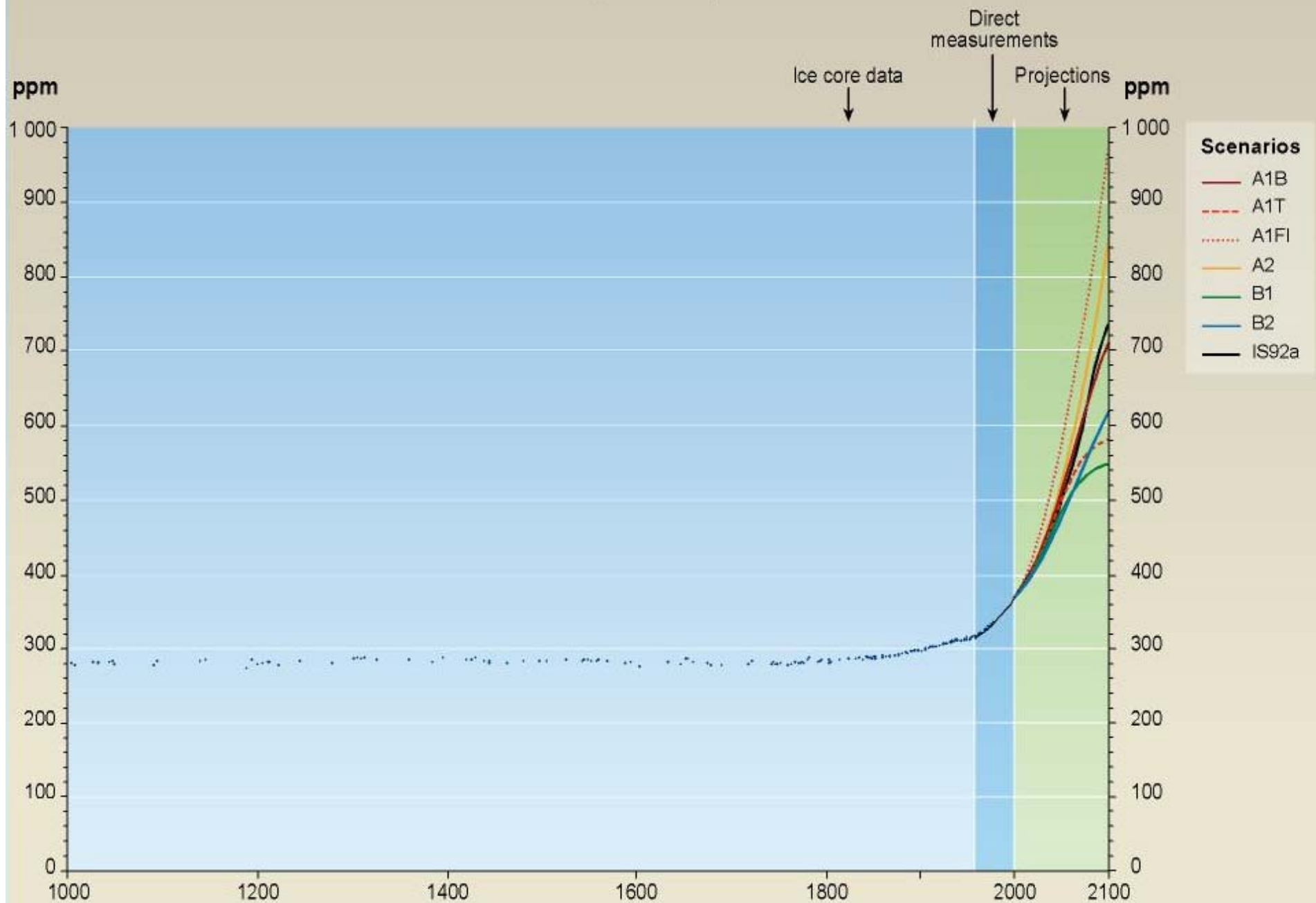
Source: A.V. Federov et al. (2006). *Science* 312 (5779), pp. 1485-1489.

Past and future CO₂ atmospheric concentrations

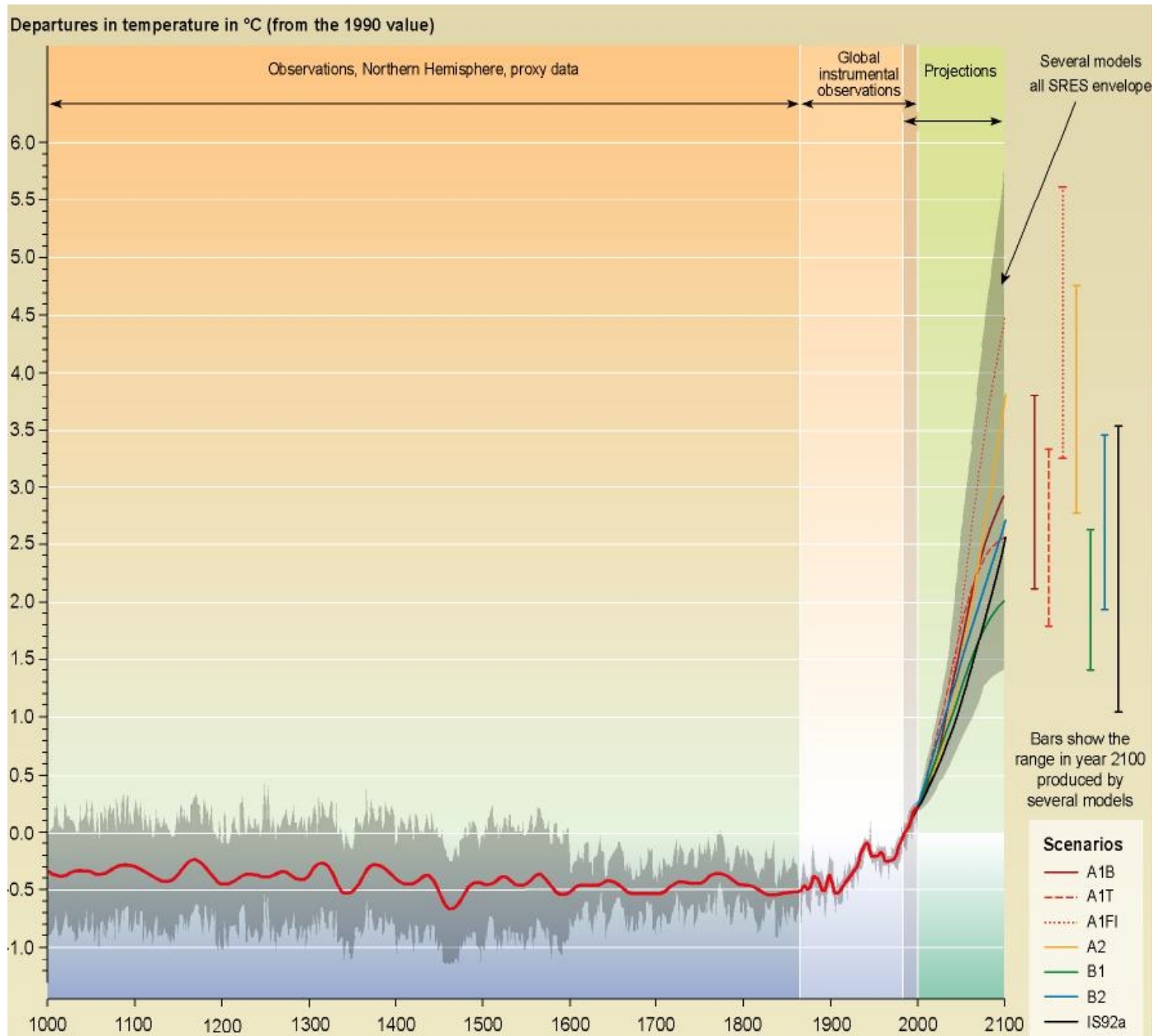


Source: Intergovernmental Panel on Climate Change, Climate Change 2001: Synthesis Report, Figure 9.1a

Past and future CO₂ atmospheric concentrations



Source: Intergovernmental Panel on Climate Change, Climate Change 2001: Synthesis Report, Figure 9.1a



Source: Intergovernmental Panel on Climate Change, Climate Change 2001: Synthesis Report, Figure 9.1b

Over the past 650,000 years

- "We find that CO₂ is about 30% higher than at any time, and methane 130% higher than at any time; and the rates of increase are absolutely exceptional: for CO₂, 200 times faster than at any time in the last 650,000 years."
 - EPICA project leader Thomas Stocker, University of Bern

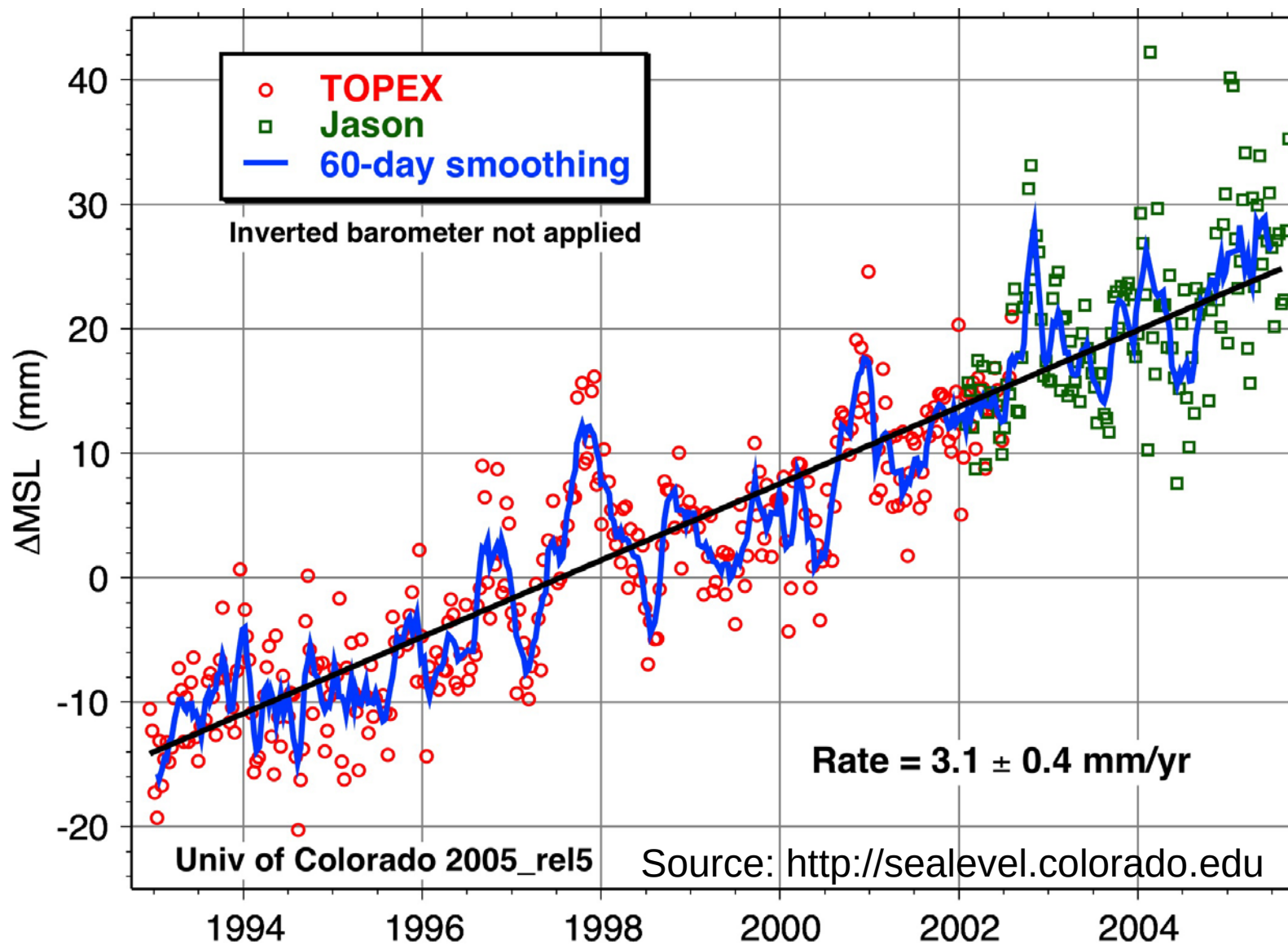


Ocean changes

- Decrease in surface water pH of 0.1 (from 7.8)
 - Detectable worldwide
 - Measurable change has penetrated to $>1000\text{m}$ depth
- Changes in pH may have a strong effect on the toxicity of metals, ammonia, and nitrite.
- Predicted deep ocean pH change of 0.3 and surface pH change of 0.5 by 2100
- Higher temperatures are correlated with coral reef “bleaching” at the 95% level
 - 100 million people depend on coral reefs

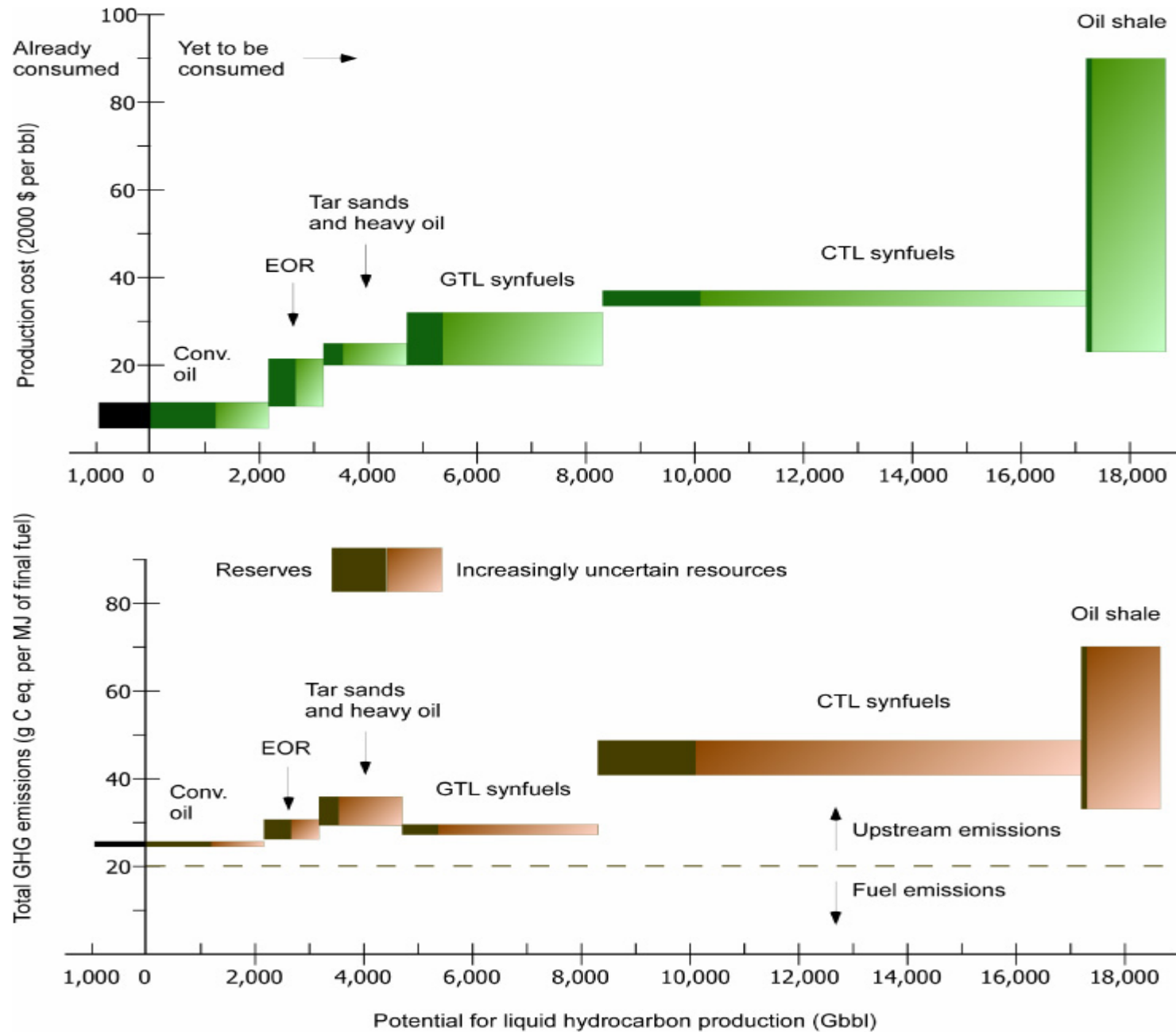


Sea Level Rise



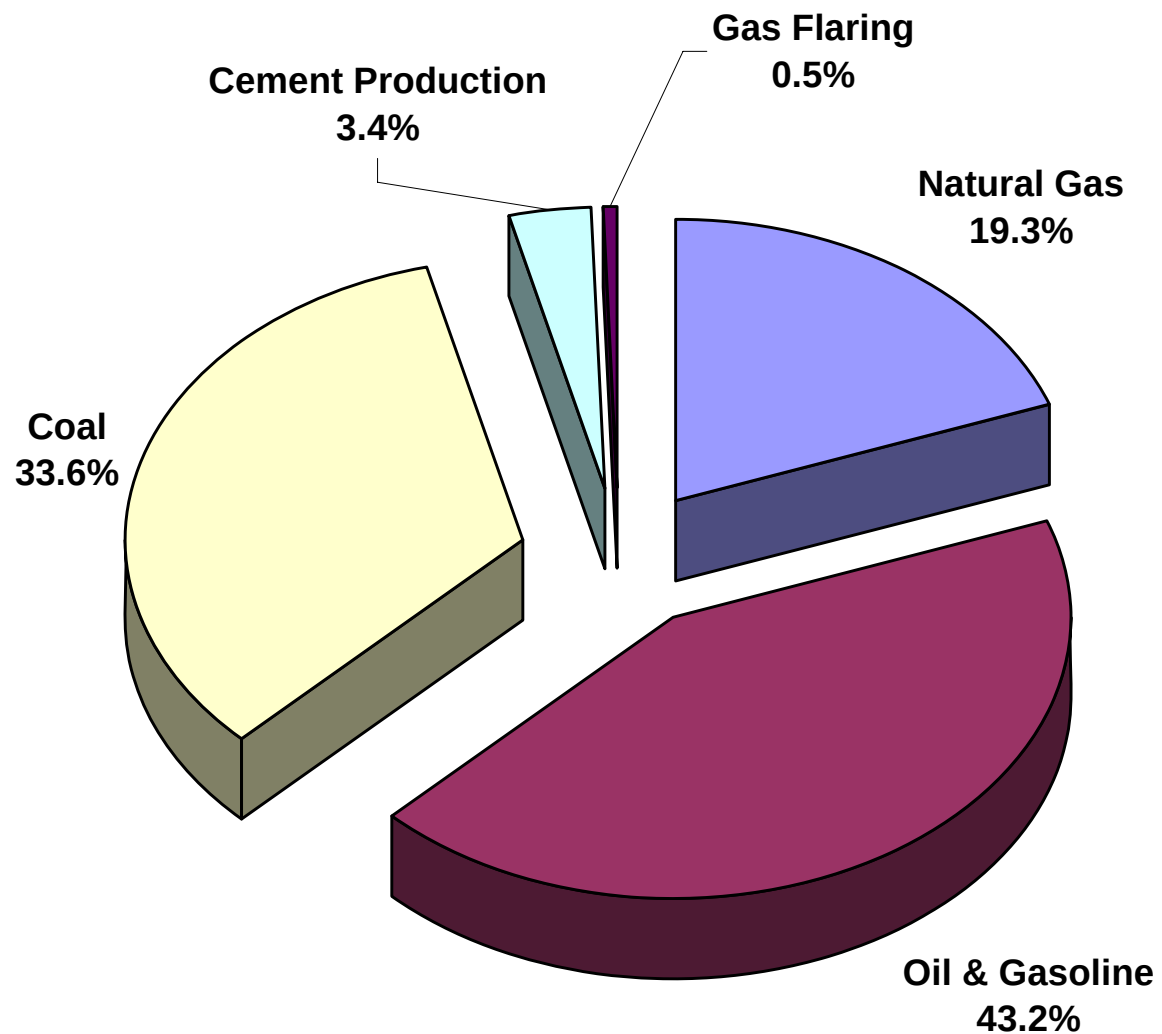
Air & ocean are the limits: not fuel

- We have released 300×10^9 tons (GT) of C.
- If we burn all the fossil fuels (releasing 6600 GT of carbon, of which 5200 is in coal), we would get to 3000 ppm, 10 times pre-industrial levels. That is 3 times the most extreme scenario on the previous graphs.
- pH change in the deep ocean would take $\sim 100,000$ years to recover.



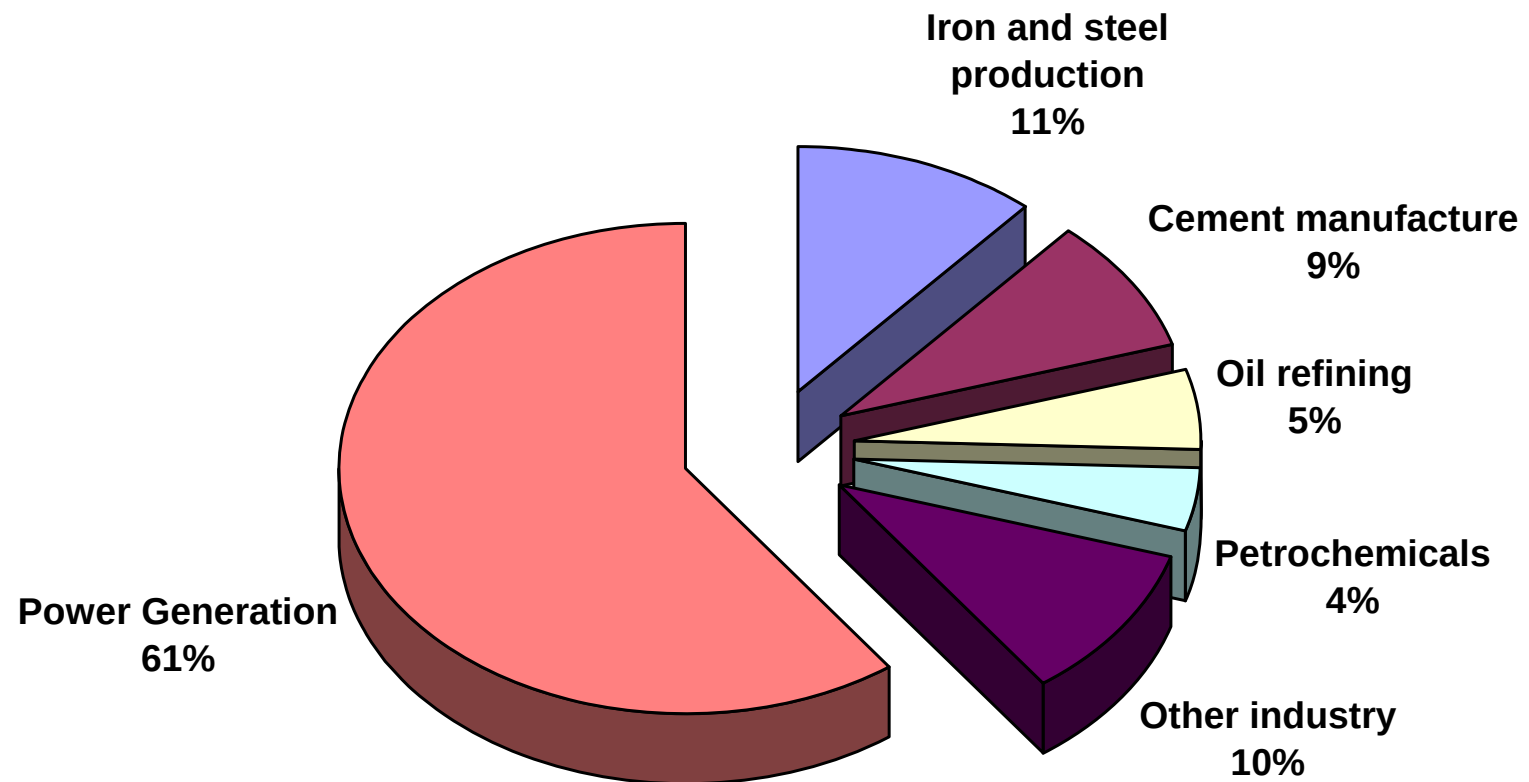
Source: A E Farrell and A R Brandt, *Risks of the oil transition*, Environmental Research Letters 1:1 (2006)

Sources of Global Fossil Fuel Carbon Emissions in 2000



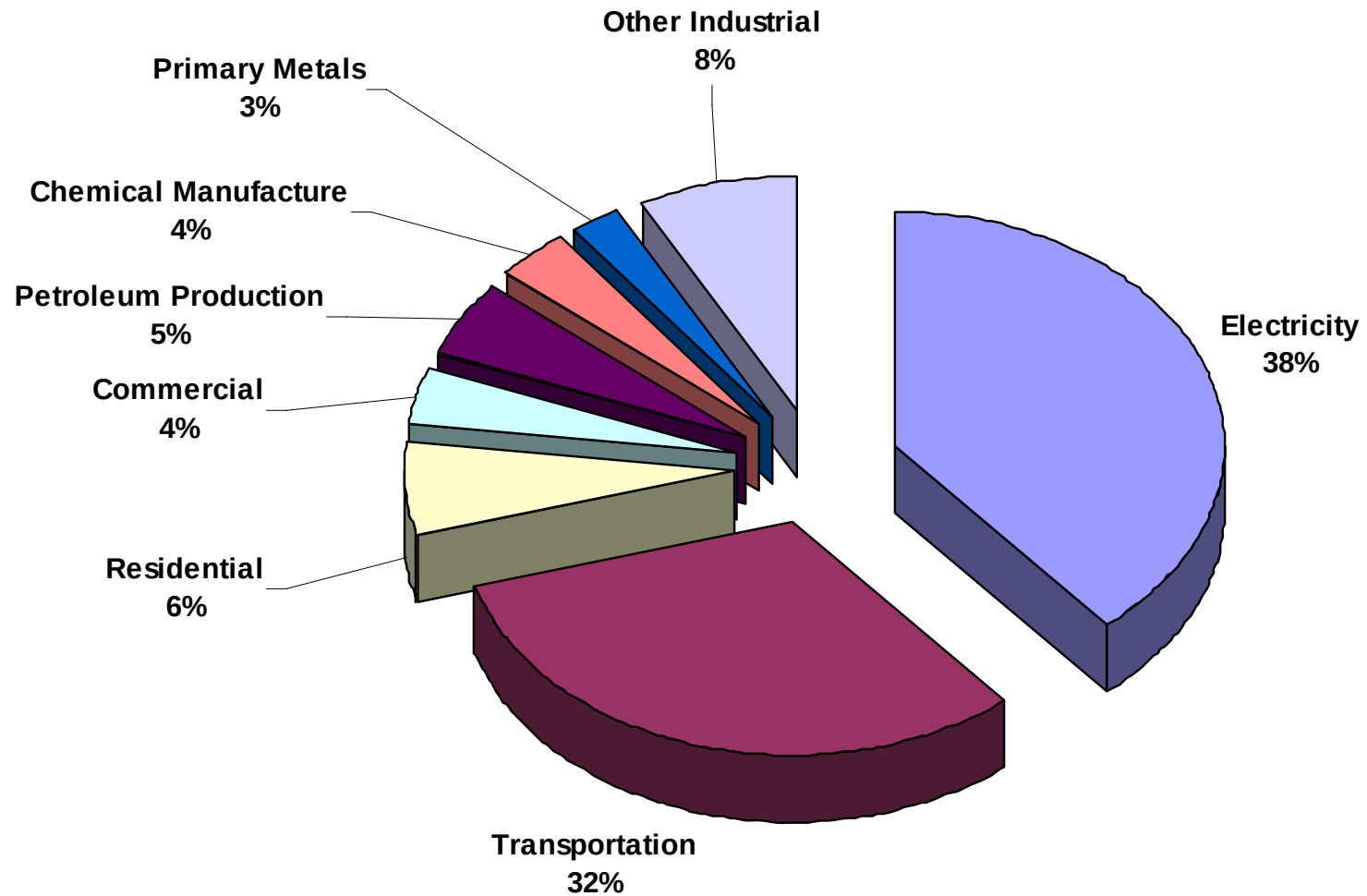
Source: Oak Ridge National Laboratory http://cdiac.esd.ornl.gov/trends/emis/tre_glob.htm

Global Carbon Emissions from Industry (1994-1996)
(Industry is 52% of total carbon emission)



Source: International Energy Agency Greenhouse Gas R&D Program <http://www.ieagreen.org.uk/capstorg.htm>

Sources of U.S. CO₂ Emissions, 2000

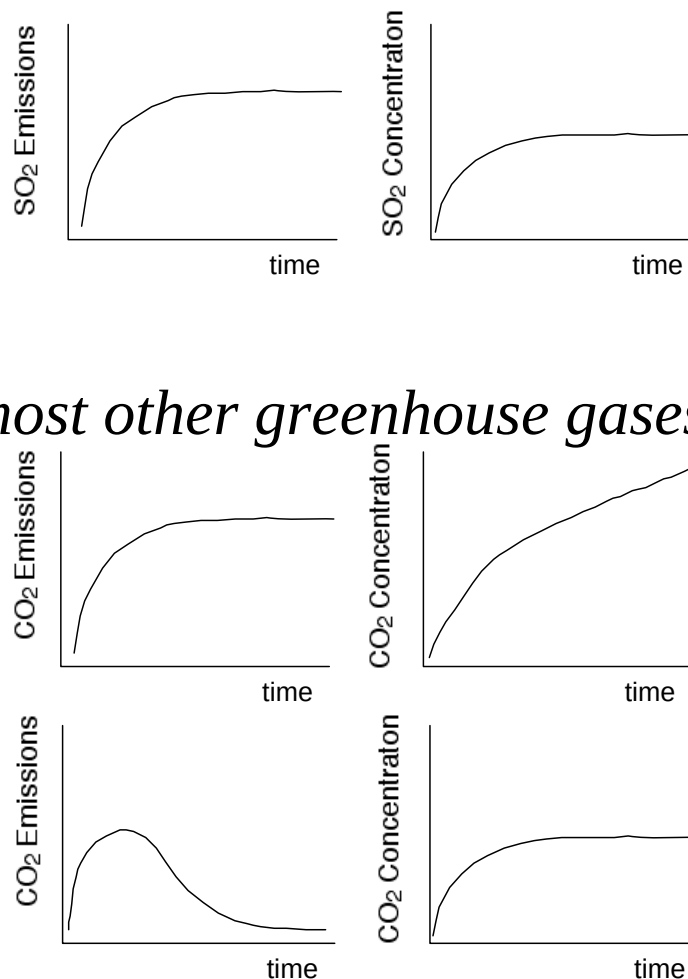


GHGs are not like conventional pollutants

Conventional pollutants like SO_2 or NO_x have a residence time in the atmosphere of just a few hours or days. Thus, stabilizing emissions of such pollutants results in stabilizing their concentration.

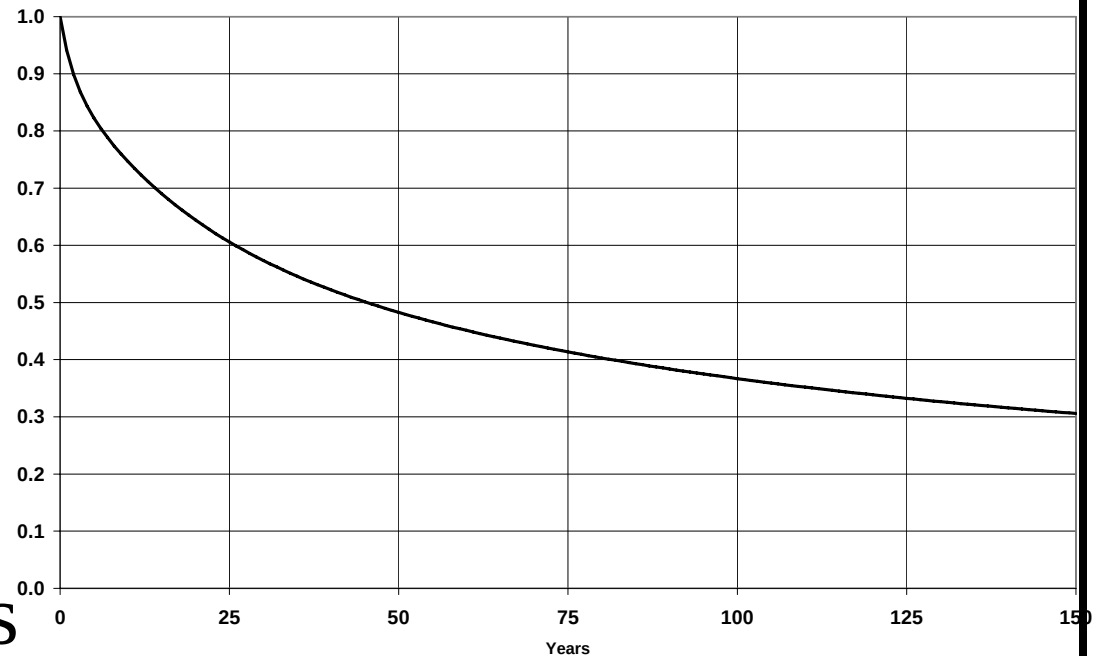
This is not true of carbon dioxide or most other greenhouse gases.

Because CO_2 lasts >75 years in the atmosphere, stabilizing atmospheric concentrations of CO_2 will require reductions in current emissions *by at least 90%*.



GHG Residence Times

CO₂ Atmospheric Decay

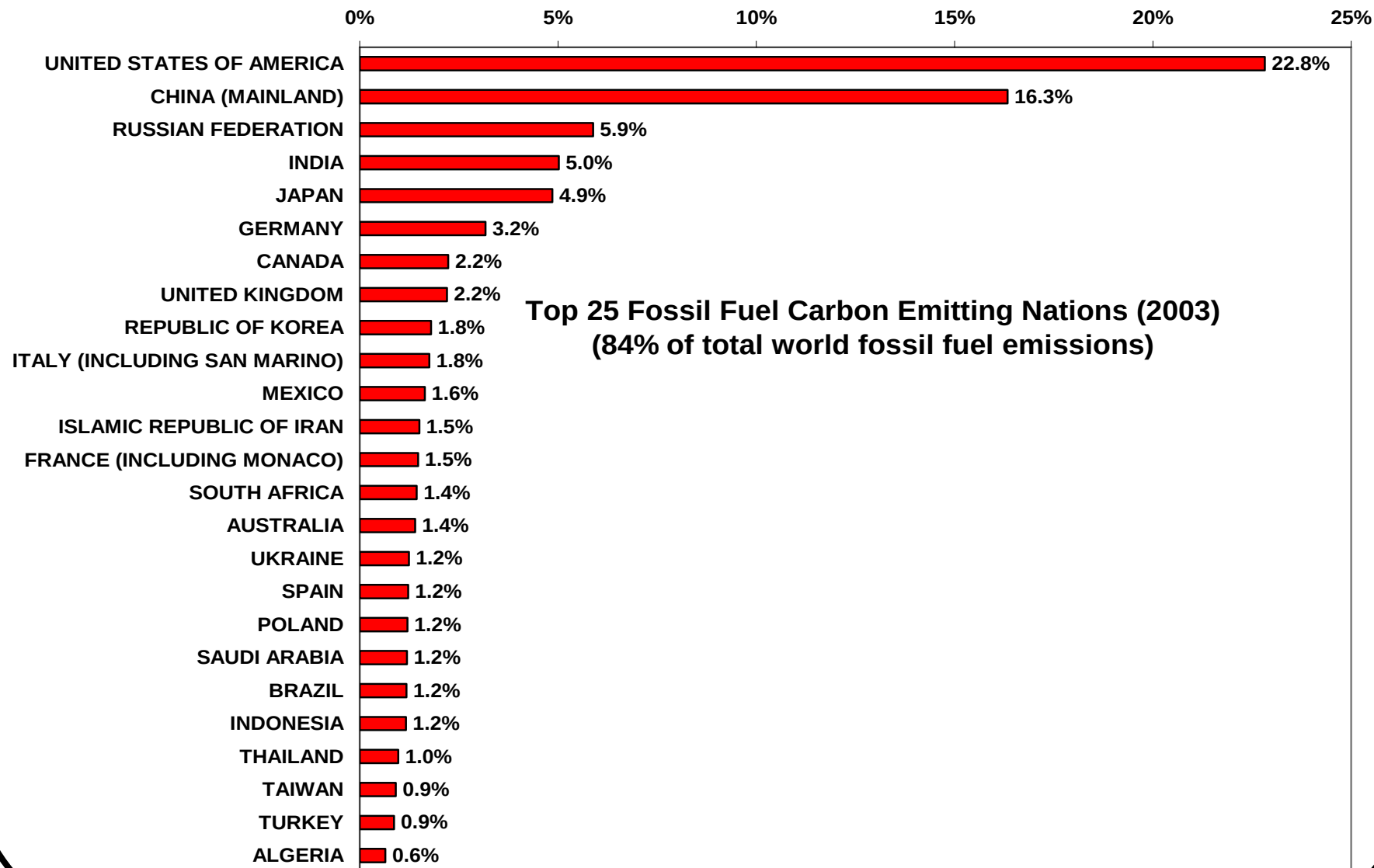


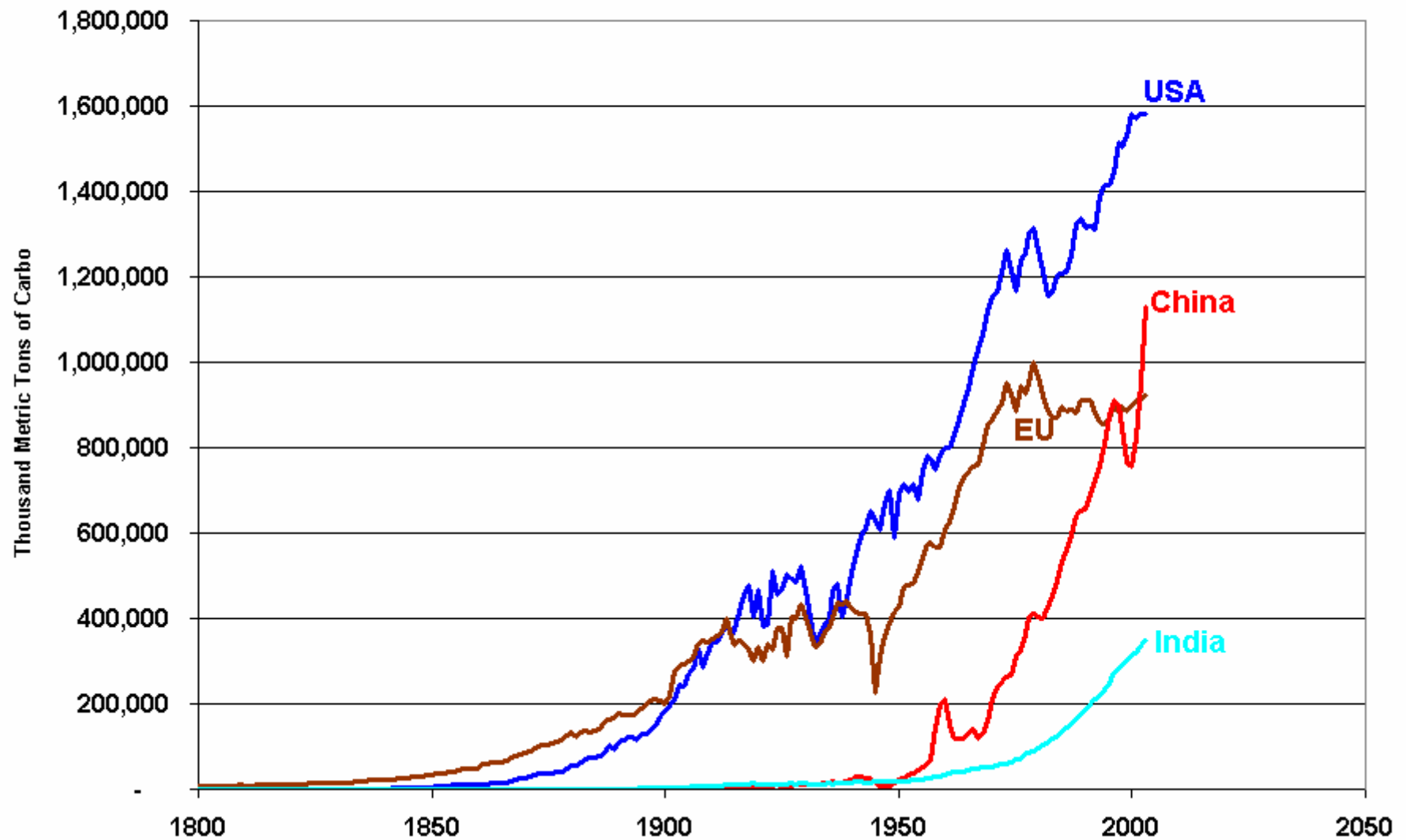
- CO₂: ~100 years
- CH₄: 9-15 years
- NO_x: 120 years
- CFC-12: 102 years
- HCFC-22: 12 years
- SF₆: 3,200 years
- Perfluoromethane: 50,000 years

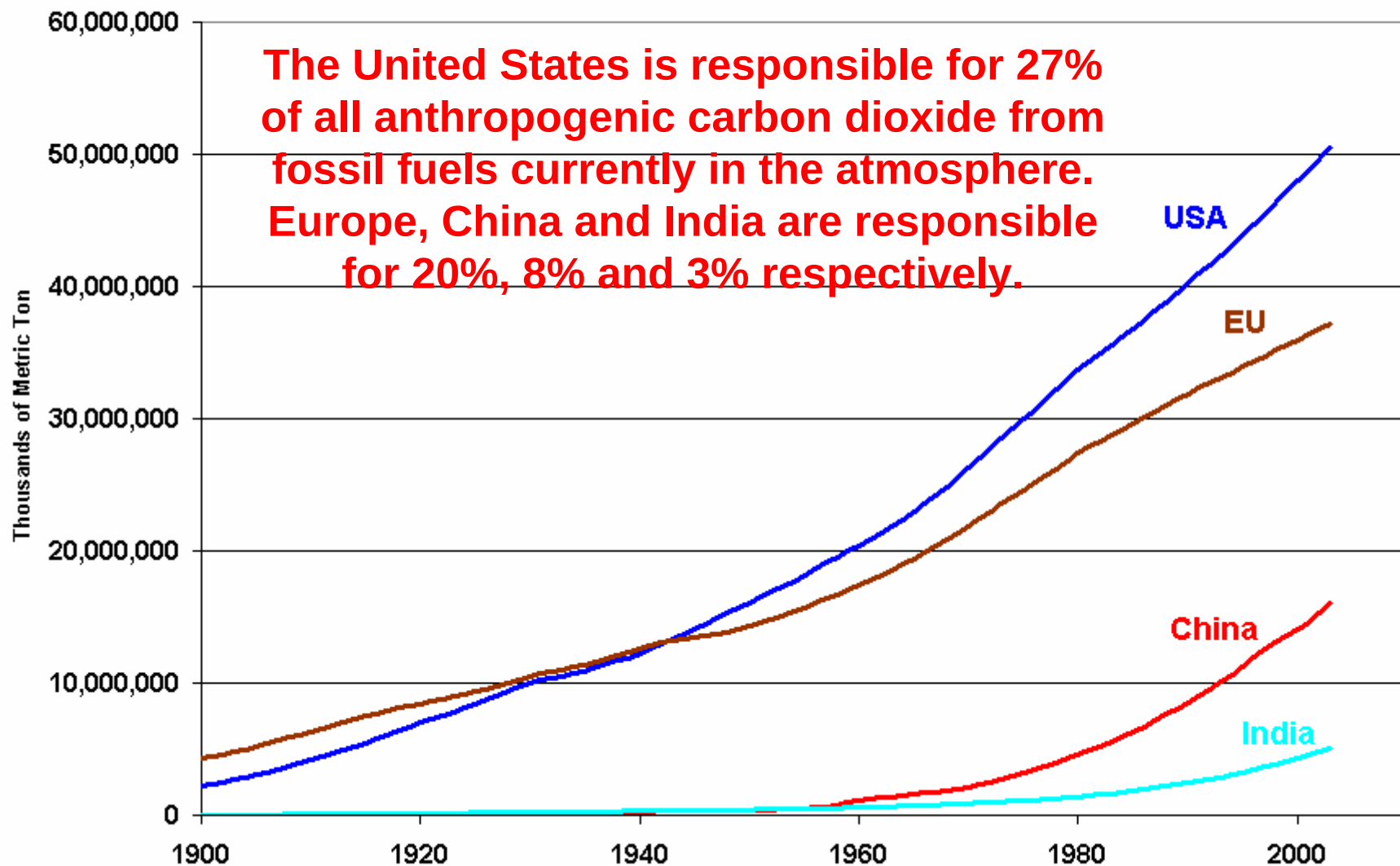
Because of this...

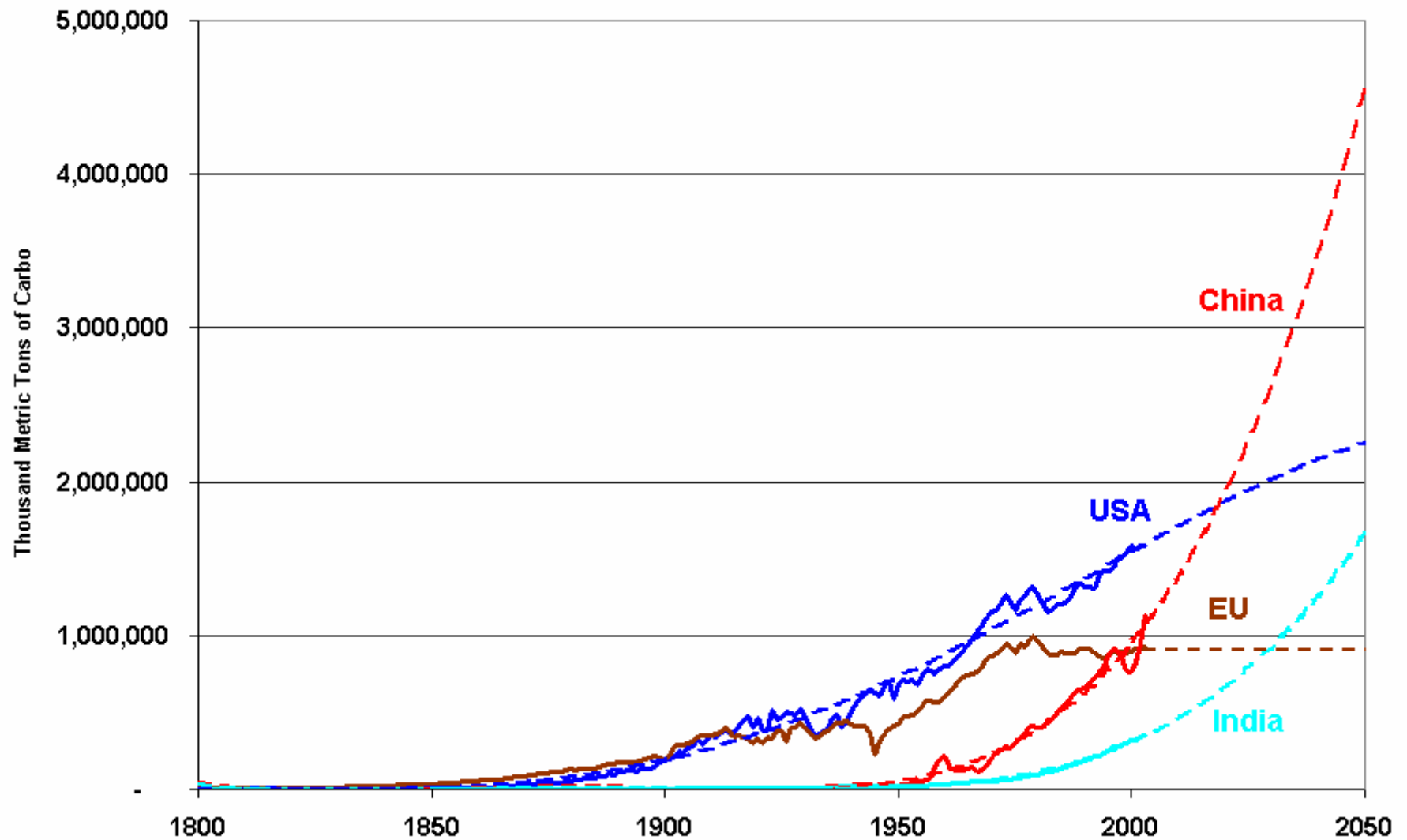
...most of the CO₂ in the atmosphere will be from N. America and Europe for years to come.

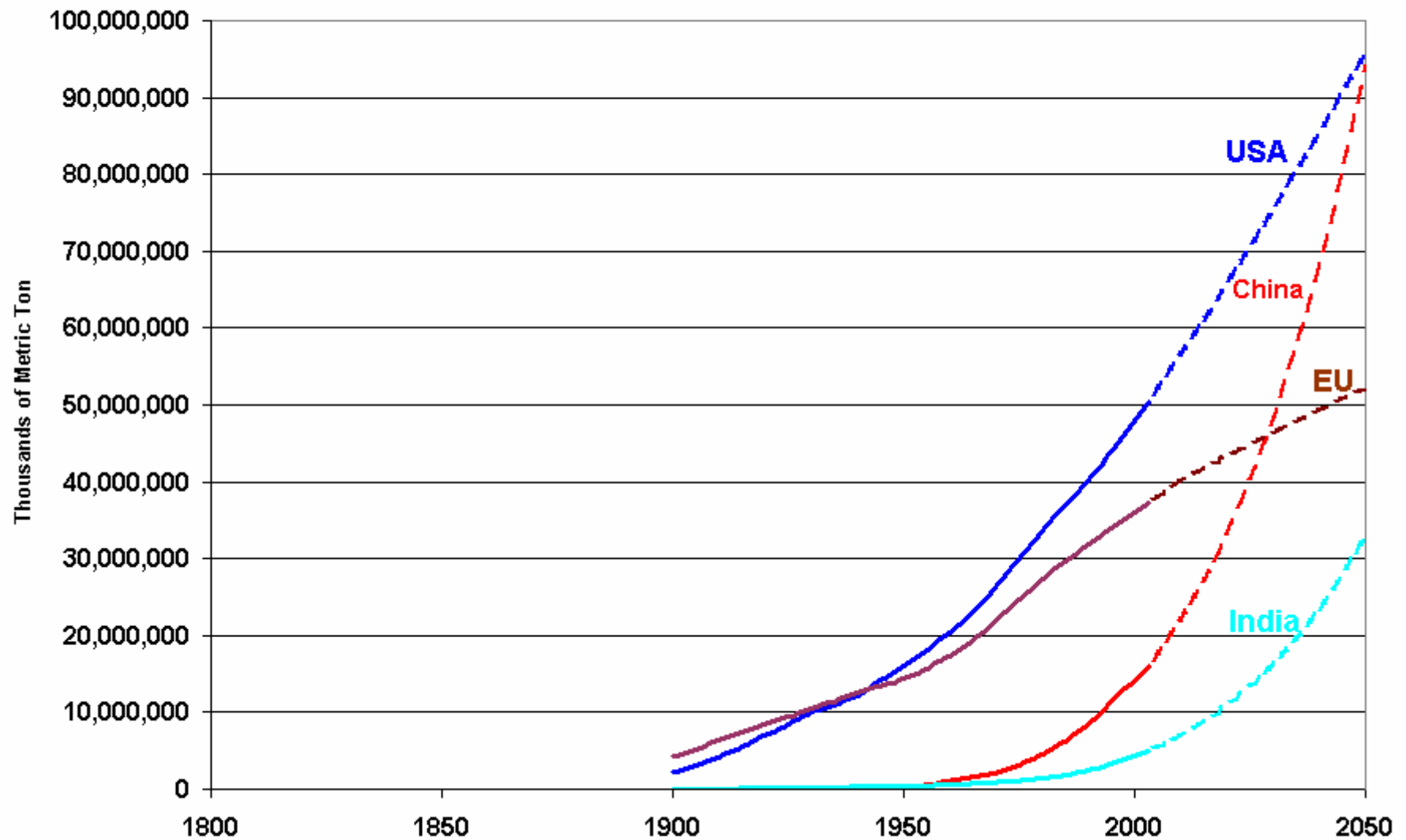
2003 Carbon Emissions from Fossil Fuels



Annual Fossil Fuel CO₂ Emissions

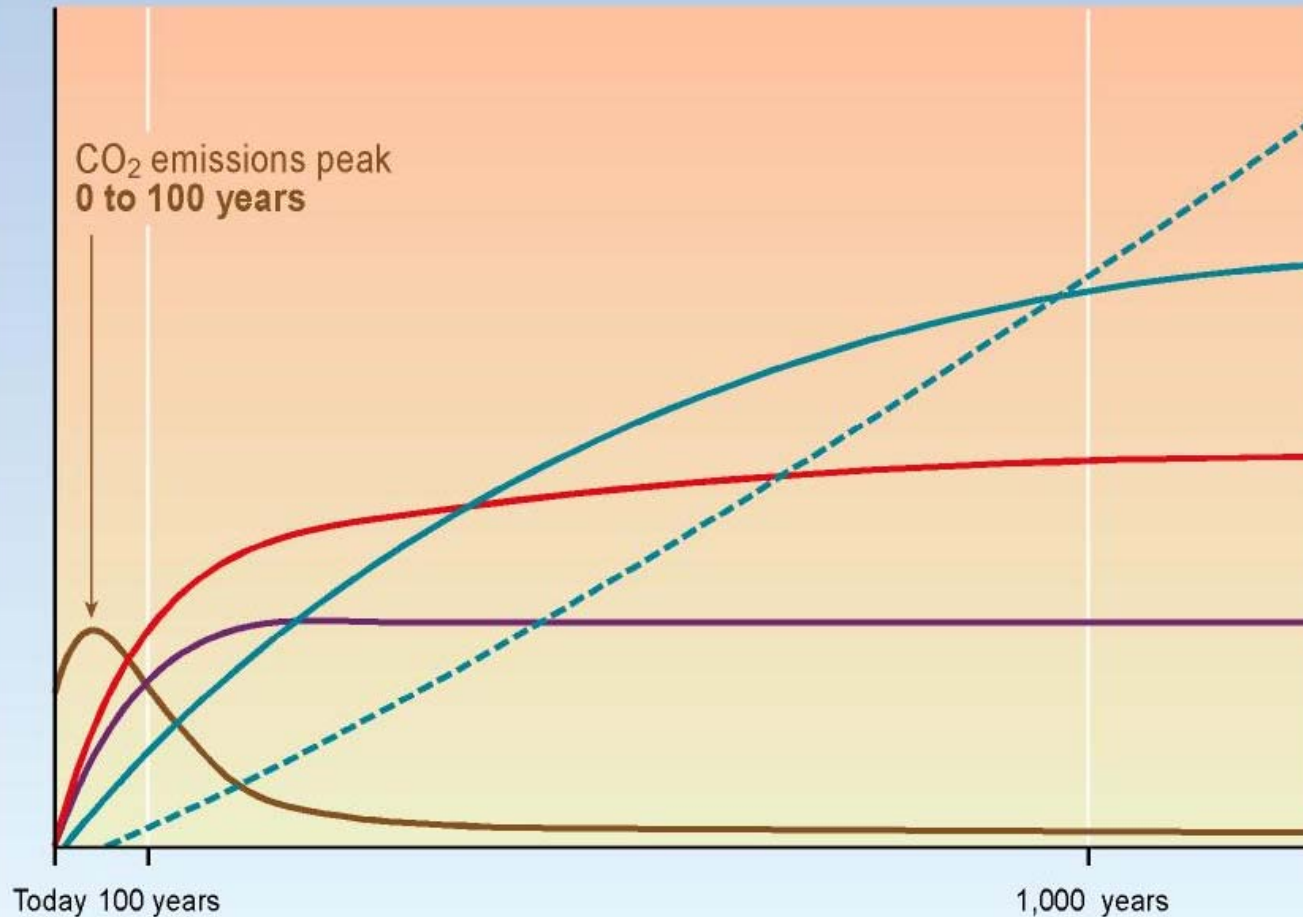
Atmospheric Fossil Fuel CO₂ Total Attribution by Nation

Annual Fossil Fuel CO₂ Emissions with Trends

Atmospheric Fossil Fuel CO₂ Total Attribution by Nation

CO₂ concentration, temperature, and sea level continue to rise long after emissions are reduced

Magnitude of response



Time taken to reach
equilibrium

Sea-level rise due to ice melting:
several millennia

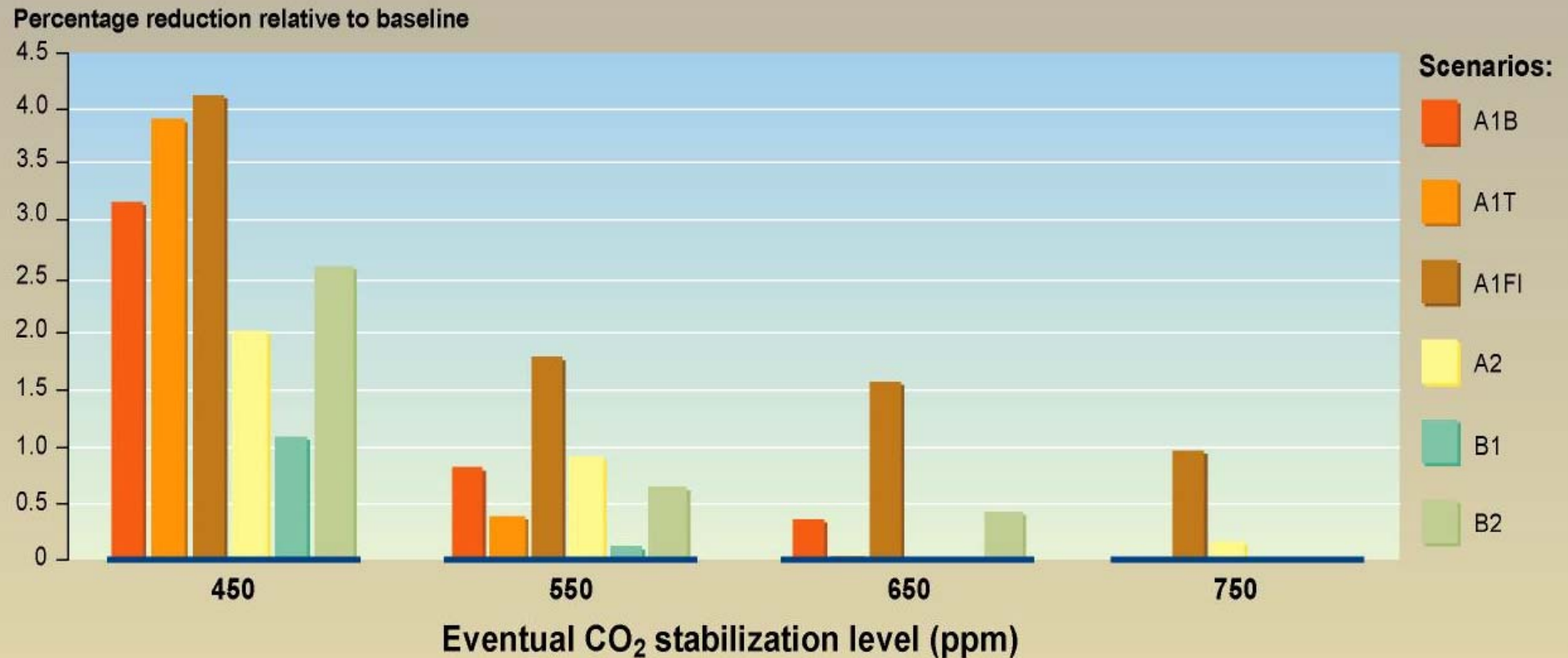
Sea-level rise due to thermal
expansion:
centuries to millennia

Temperature stabilization:
a few centuries

CO₂ stabilization:
100 to 300 years

CO₂ emissions

Global average GDP reduction in the year 2050



The US spent 1.5 – 2 % of GDP on air and water cleanup
in the 1980's and 1990's.
Best estimates for US carbon control are 0.2 – 0.6% of GDP.

I said that...

...over the coming century the *average* economic impacts of climate change in the industrialized world will be modest (probably $\leq 2\%$ of GDP).

BUT...that does not mean that *all* developed world economic impacts will be small. There will be winners and losers.

- Some coastal properties are likely to sustain large losses due to the combined effects of sea-level rise and storms.
- Some northern beach resorts will have a longer season.
- Most farmers will be able to adapt by changing cultivars, crops, and farming practice. Average yields over the next century will probably actually increase. But some will find that they can no longer economically farm in their locations.
- Some residents of arid regions may run out of water.
- Places like Austria and New England may lose their ski industries, but may spend less on winter snow/ice removal.
- etc.

Losers can "torque the system"

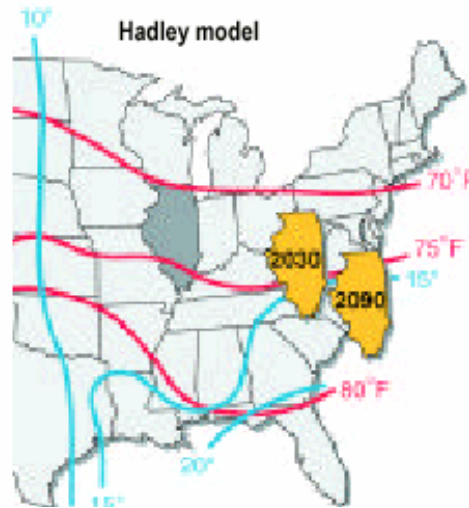
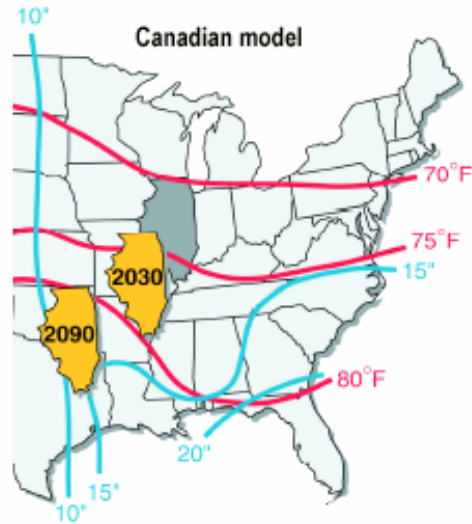
We need only look at recent histories of crop subsidies, hurricanes, floods and earthquakes, and associated insurance programs, to be reminded that in representative democracies a few politically well-connected citizens who are severely harmed, can induce large government responses and expenditures.

Currently inland property owners cross-subsidize insurance rates for coastal property owners in Florida.

Tax payers, rather than insurance, bail out many losses from predictable natural disasters.

US S&L bailout.

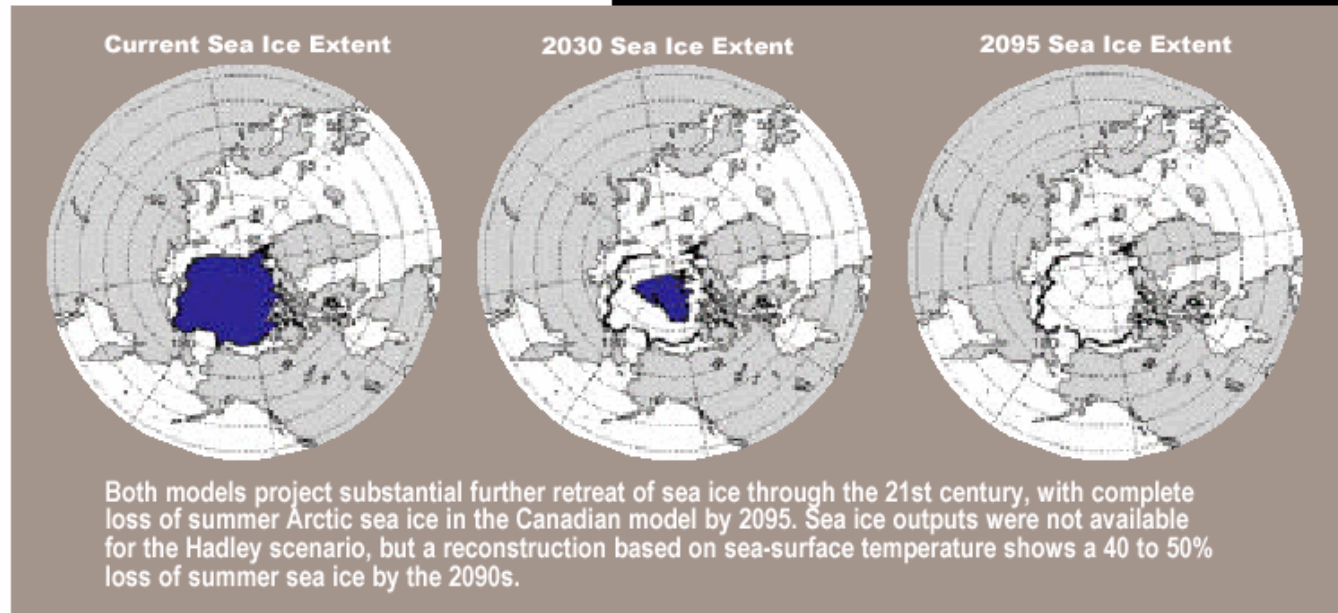
It's not hard to imagine a scenario under which the U.S. Corps of Engineers ends up constructing hundred million dollar sea walls along the south-east coast to protect million dollar homes...etc.



Projected Summer Sea Ice Change

Many environmental impacts will be dramatic

Canadian Model: an ice-free Arctic summer



Source: U.S.National Assessment

Ski Resorts and Climate Change



- Today 85% of Swiss ski areas are snow-reliable.
 - in 7 out of 10 winters, a snow cover of at least 30 to 50 cm is available on at least 100 days between December 1 and April 15.
- Modest warming causes the snow line to rise to 1500 meters (4900 feet). Only 63% of Swiss ski areas will be snow-reliable.
- At 1800 meters (5900'), 44% are reliable.

Bottom line

Increasing levels of greenhouse gases - and the climate change they are causing - are real *and they are a major problem.*

To stabilize concentrations, the world is going to have to reduce its emissions of CO₂ and other GHGs by *at least an order of magnitude.*

Even if it is fully implemented, Kyoto will be just a very small first step.

Over the coming decades there will be pressure for *enormous changes in the nature and operation of the global energy systems.*

Possible Policies

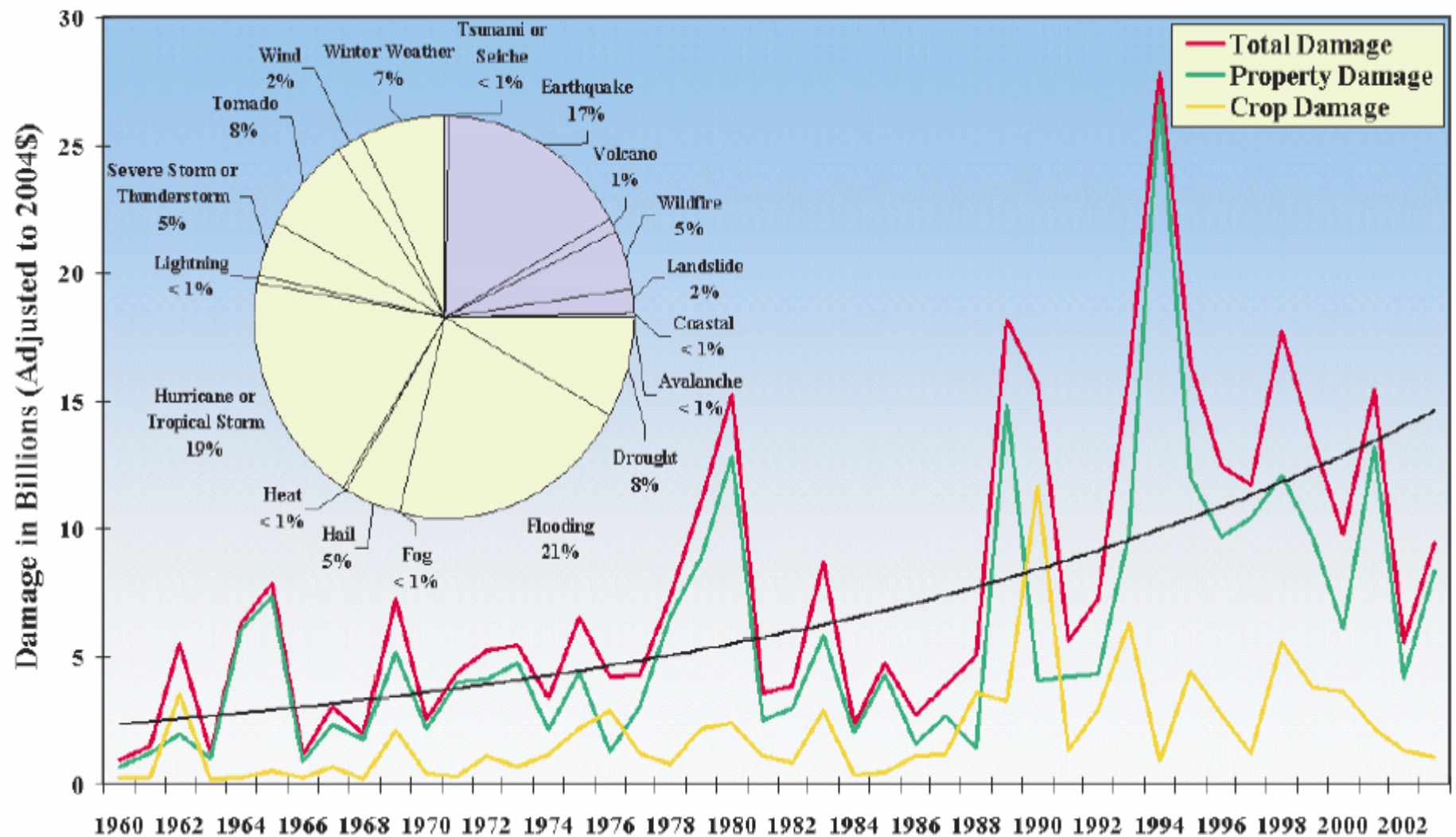
- Ignore
- Accept
- R&D
- Geoengineering
- Carbon control

Types of adaptation to climate change

	Anticipatory	Reactive
Natural Systems		• Changes in length of growing season • Changes in ecosystem composition • Wetland migration
Human Systems		
Private	• Purchase of insurance • Construction of houses on silts • Redesign of oil rigs	• Changes in farm practices • Changes in insurance premiums • Purchase of air-conditioning
Public	• Early-warning systems • New building codes, design standards • Incentives for relocation	• Compensatory payments, subsidies • Enforcement of building codes • Beach nourishment

Source: IPCC Climate Change 2001: Working Group II: Impacts, Adaptation and Vulnerability Figure TS-9

Actual: maladaptive



Geoengineering

Geoengineering method	COM*	Technical uncertainties	Risk of side effects	Nontechnical issues
Injection of CO ₂ into the ocean	50–150	Costs are much better known than for other geoengineering schemes. Moderate uncertainty about fate of CO ₂ in ocean.	Low risk. Possibility of damage to local benthic community.	Legal concerns: London dumping convention. Like abatement, this scheme is local, with costs associated with each source. Potential legal and political concerns over oceanic disposal.
Injection of CO ₂ underground	50–150	Costs are known as for CO ₂ in ocean; less uncertainty about geologic than oceanic storage.	Low risk.	Is geologic disposal of CO ₂ geoengineering or a method of emissions abatement?
Ocean fertilization with phosphate	3–10	Uncertain biology: Can ecosystem change its P:N utilization ratio? Can there significant long-term carbon capture?	Moderate risk. Possible oxygen depletion may cause methane release. Changed mix of ocean biota.	Legal concerns: Law of the Sea, Antarctic Treaty. Liability concerns arising from effect on fisheries; possibility that fisheries might be improved.
Ocean fertilization with iron	1–10	Uncertain biology: When is iron really limiting? Can there significant long-term carbon capture?	Moderate risk. Possible oxygen depletion may cause methane release. Changed mix of ocean biota.	Legal concerns: Law of the Sea, Antarctic Treaty. Liability concerns arising from effect on fisheries; possibility that fisheries might be improved.

* COM = \$/tonne CO₂

From GEOENGINEERING THE CLIMATE: History and Prospect, by David W. Keith, Annual Review of Energy and the Environment 2000. 25:245–84, Table 2.

Geoengineering

Intensive forestry to capture carbon in harvested trees	10–100	Uncertainty about rate of carbon accumulation, particularly under changing climatic conditions.	Low risk. Intensive cultivation will impact soils and biodiversity.	Political questions: how to divide costs? Whose land is used?
Solar shields to generate an increase in the Earth's albedo	0.05–0.5	Costs and technical feasibility are uncertain. Uncertainty dominated by launch costs.	Low risk. However, albedo increase does not exactly counter the effect of increased CO ₂ .	Security, equity and liability if system used for weather control.
Stratospheric SO ₂ to increase albedo by direct optical scattering	≪1	Uncertain lifetime of stratospheric aerosols.	High risk. Effect on ozone depletion uncertain. Albedo increase is not equivalent to CO ₂ mitigation.	Liability: ozone destruction.
Tropospheric SO ₂ to increase albedo by direct and indirect effects	<1	Substantial uncertainties regarding aerosol transport and its effect on cloud optical properties.	Moderate risk: unintentional mitigation of the effect of CO ₂ already in progress.	Liability and sovereignty because the distribution of tropospheric aerosols strongly effects regional climate.

From GEOENGINEERING THE CLIMATE: History and Prospect, by David W. Keith, Annual Review of Energy and the Environment 2000. 25:245–84, Table 2.

Geoengineering

- Reforestation: 2.4×10^8 tonnes CO₂ per year
 - \$8 / tonne CO₂
 - 15% of the US total CO₂ year 2000 emissions
 - Requires 75 million acres, and water

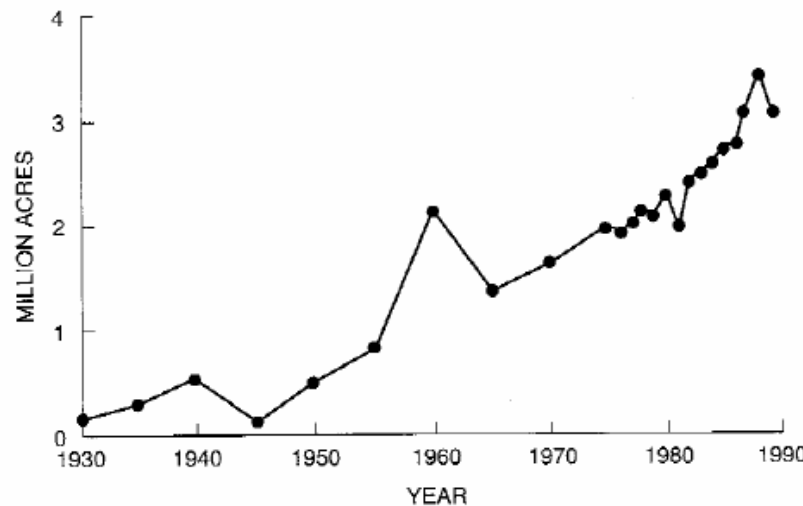
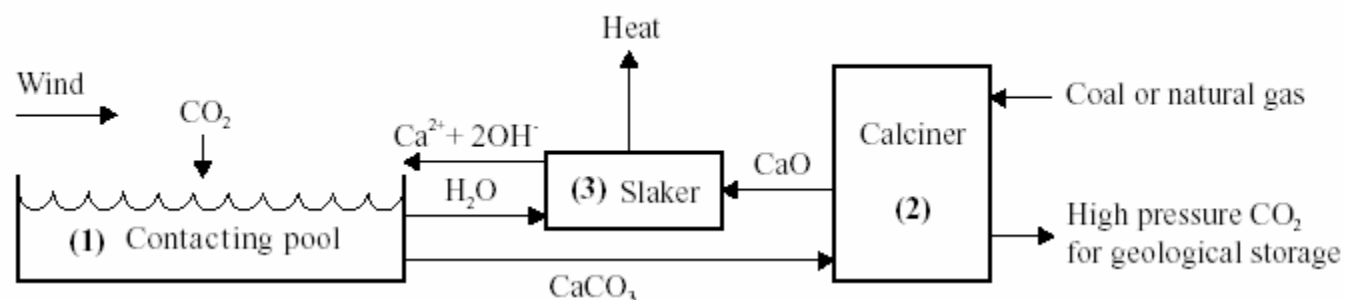


FIGURE 28.1 Historical summary of U.S. forest planting.
SOURCE: U.S. Forest Service (1990).

Geoengineering

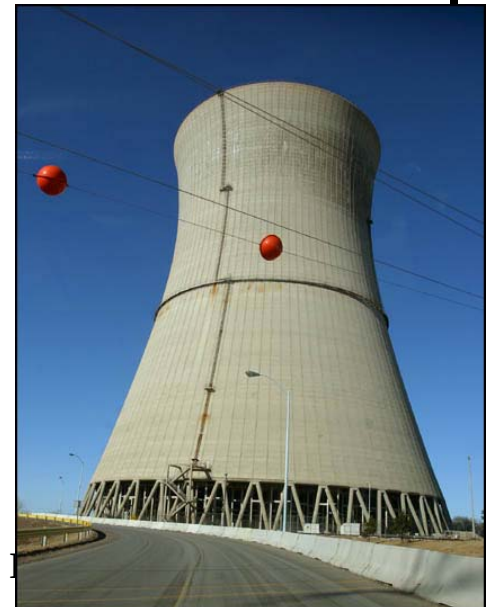
- Enhance albedo by creating clouds
- Stratospheric scatterers (sulfates or coated dye)
- Shade (diffraction grating on sun-Earth line)
- Direct carbon capture from the air



	Reaction	Enthalpy of reaction	
		kJ/mol-C	GJ/tC
(1)	$\text{CO}_2(\text{g}) + \text{Ca}^{2+} + 2 \text{OH}^- \rightarrow \text{CaCO}_3(\text{s}) + \text{H}_2\text{O}(\text{l})$	-96	-8
(2)	$\text{CaCO}_3(\text{s}) \rightarrow \text{CaO}(\text{s}) + \text{CO}_2(\text{g})$	179	15
(3)	$\text{CaO}(\text{s}) + \text{H}_2\text{O}(\text{l}) \rightarrow \text{Ca}^{2+} + 2 \text{OH}^-$	-83	-7

Direct Carbon Capture

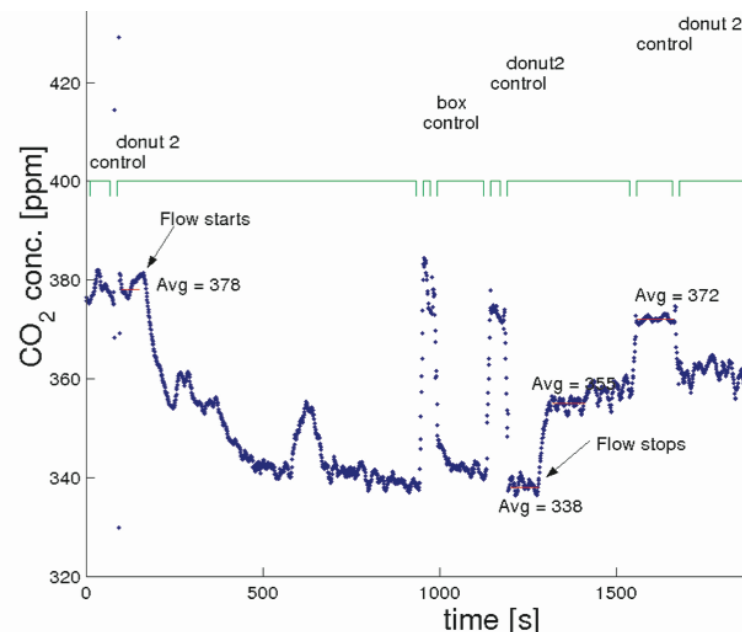
- \$80 - 250 / tonne CO₂
- Cost-effective for CO₂ from vehicles
- 8000 towers required for US auto CO₂
- Total area required for all US CO₂: ~100 mi²
 - 1/56,000th of all US farmland





Ph.D. student Josh Stolaroff is exploring the technical and economic feasibility of directly scrubbing CO_2 from the air (with NaOH).

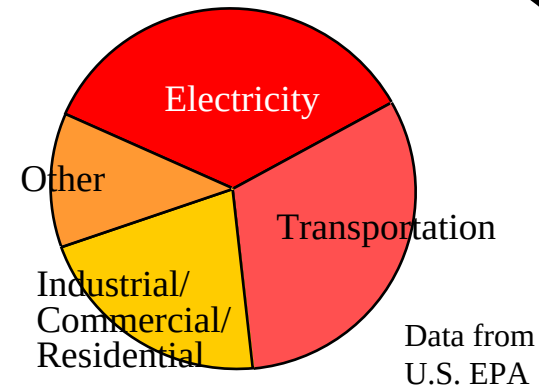
In 2004 he demonstrated the feasibility in a bench scale experiment. In 2005 he built a pilot scale system.



Geoengineering - Verification

- Will the gas stay where you put it ?
- Will trees release their carbon ?
- Are there side effects to stratospheric particles ?
- Direct control of planetary temperature without CO₂ control may leave ocean pH unchanged.

CO₂ Control Options:



For Electricity:

Today

Conservation

Nuclear

Wind ($\leq 15\%$)

Biomass ($\leq 10\%$)

In 10 years

Coal w/carbon capture
and sequestration

Perhaps in 50 years

Solar photovoltaic

For Cars:

Today

Tighter CAFE standards

Hybrids (*not* muscle cars)

Biomass fuel ($\leq 15\%$)

In 10 years

Grid charging hybrids

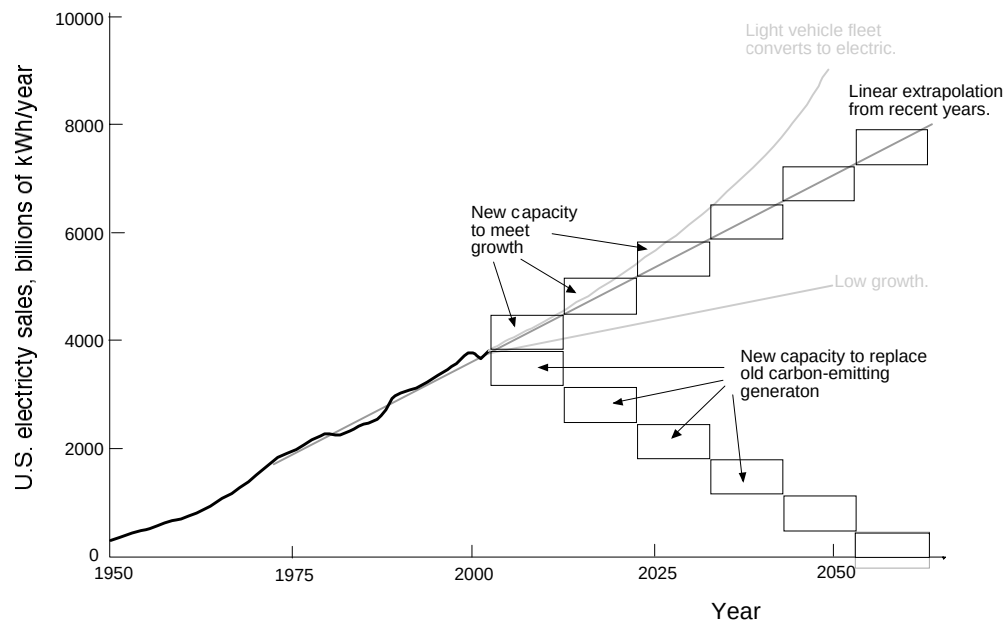
Fuel cells

Perhaps in 50 years

Hydrogen

But first, assuming...

...a set of affordable energy technologies with no CO₂ emissions how long would it take to *efficiently* de-carbonize the electricity sector?

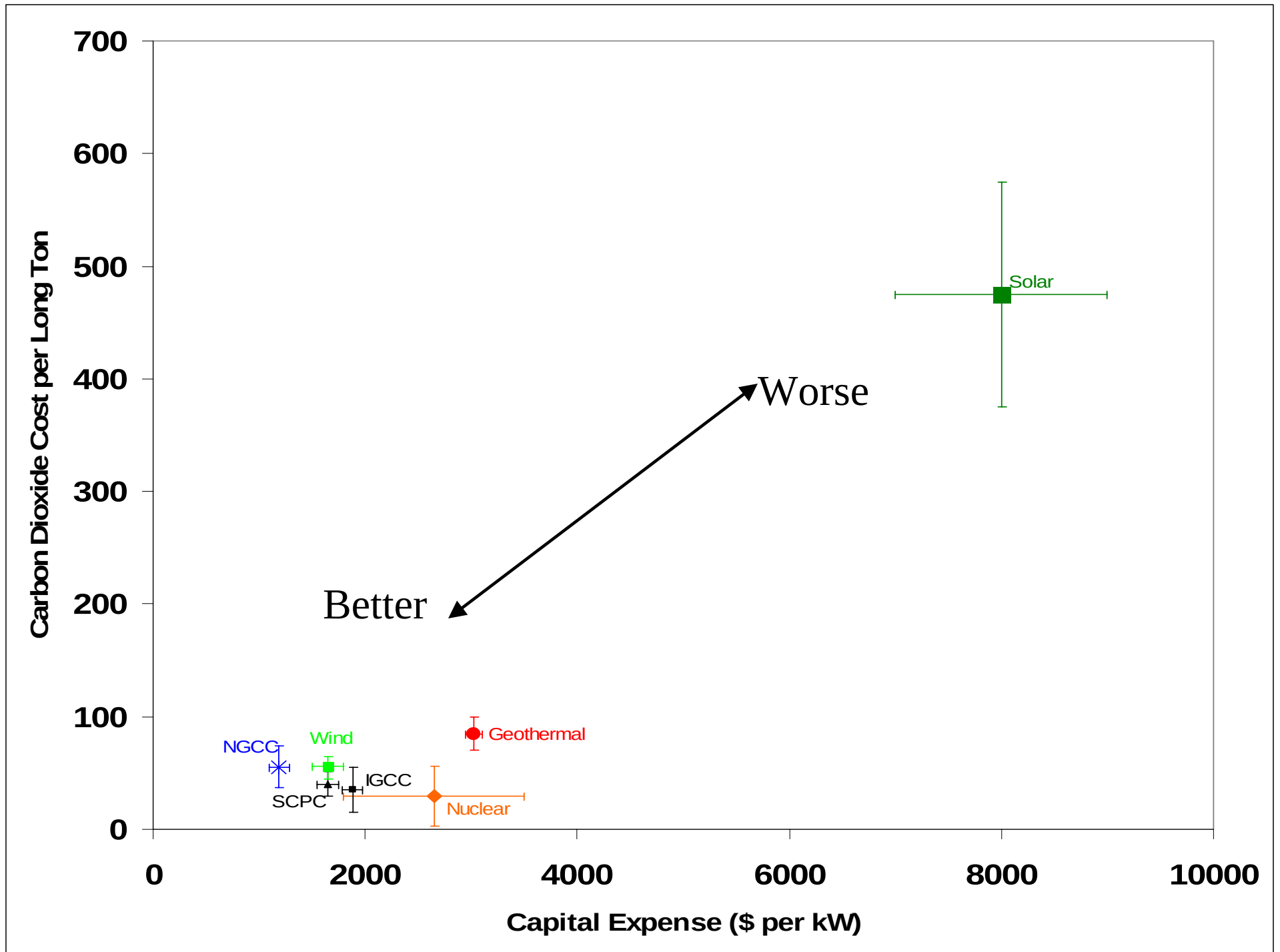


For details see the report by Morgan, Apt, and Lave prepared for the Pew Climate Center, "The U.S. Electric Power Sector and Climate Change Mitigation," available at <http://wpweb2k.gsia.cmu.edu/ceic/papers/USElectricPower.pdf>

About 50 years. If we wait a long time and then have to do it quicker, it will be much more expensive because we'll be replacing plants with substantial useful life.

Metric: Carbon Cost

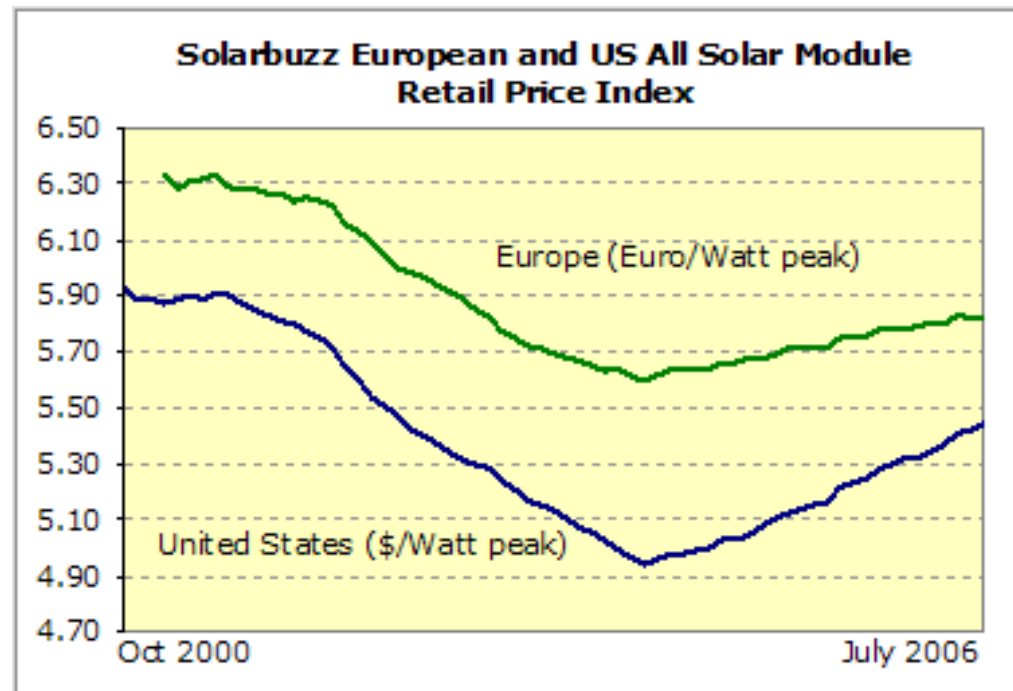
<u>Technology</u>	<u>Cost / tonne CO2 avoided</u>
Nuclear (with waste storage cost)	\$3 – \$56
Coal gasification with capture and sequestration	\$15 – 55
Supercritical pulverized coal with capture and sequestration	\$29 – 51
Wind power in Texas	\$56
Natural gas with capture and sequestration	\$37 – 74
Geothermal	\$70 – 100
Direct Capture from the Air	\$80 - \$250
Utility Conservation Programs	\$225 - \$350
Solar	\$475



Those are the costs.
What about the risks?

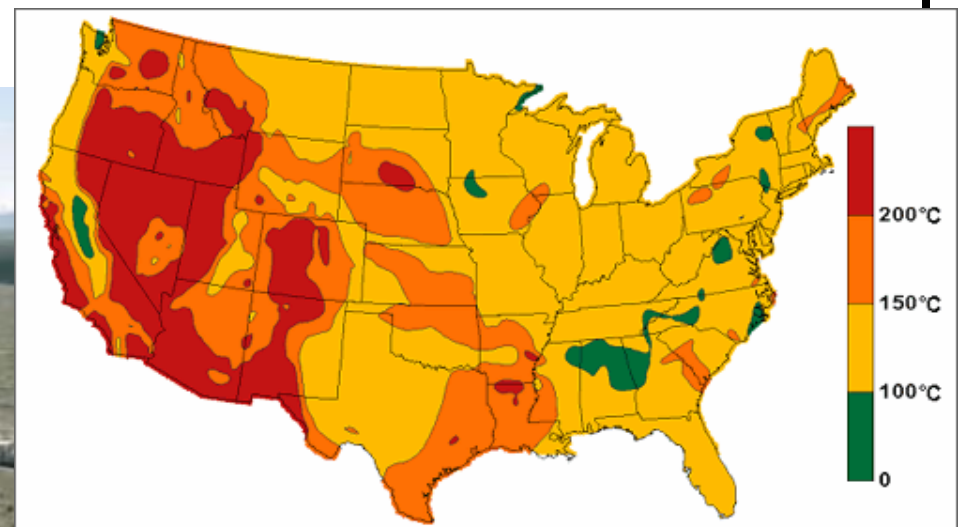
Solar

- Cost is ~\$0.30 per kWh, 10 times the cost of electricity produced by a conventional coal-fired power plant.
- Cost of the solar cells has been increasing.
- Other components are required also.



Geothermal

- “How a geothermal reservoir will perform over several decades provides another significant risk in geothermal development. A complete understanding of the reservoir can only be obtained by withdrawing fluids from the reservoir over a sustained period.” – World Bank <http://www.worldbank.org/html/fpd/energy/geothermal/>

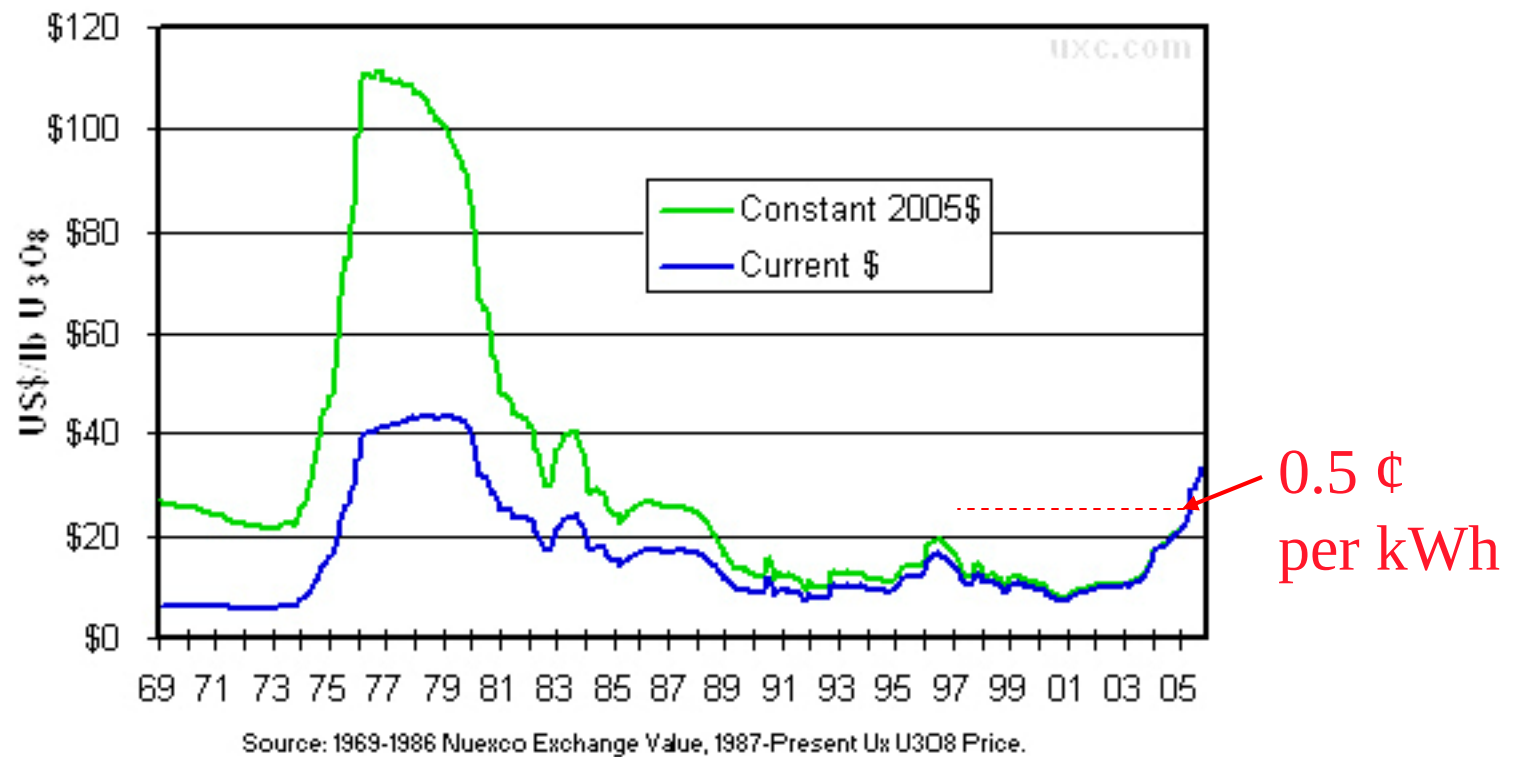


Nuclear

- Standardized design-for-safety; costs
 - Risk that the AP-1000 is a minor step, and will not receive public acceptance
- Risk that the NRC/EPA/DOE bureaucratic quagmire will not be fixed
 - A new organization, without the baggage of the old, might be required for new plants
- Risk that spent fuel and components will not have safe storage
 - monitoring can reduce risks
- Proliferation risk

Nuclear

Constant 2005 US\$ vs. Current US\$ Spot U_3O_8 Prices

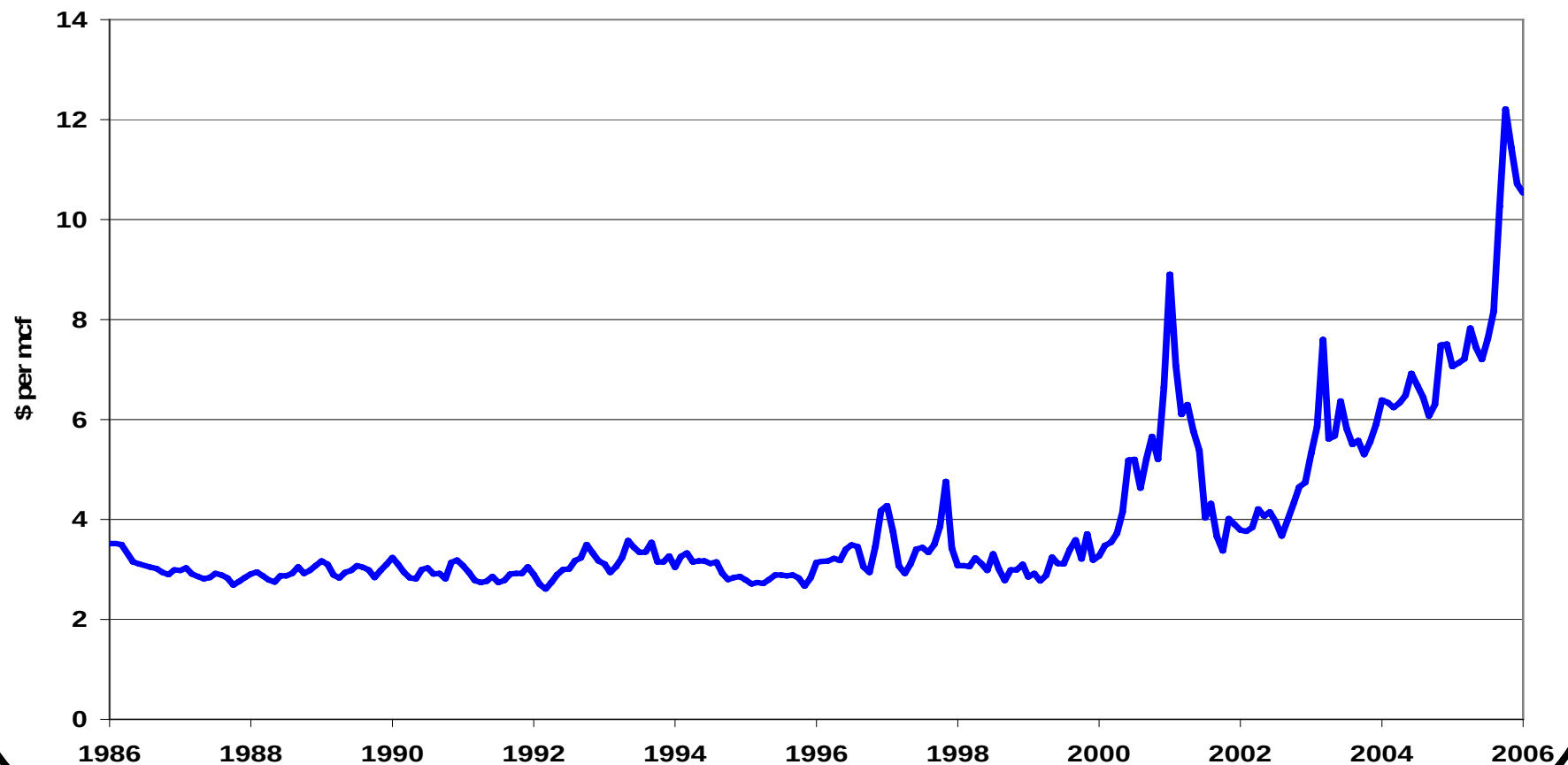


Source: The UX Consulting Company, LLC

Natural Gas

- 2/3 the carbon per kWh of coal

Monthly Natural Gas City Gate Price



Does wind have risks?

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Can large wind farms affect local meteorology?

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“...the wind farm significantly slows down the wind...
usually leading to a warming and drying of the surface air...”

The influence of large-scale wind power on global climate

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Communicated by Stephen H. Schneider, Stanford University, Stanford, CA, September 19, 2004 (received for review April 16, 2004)

Large-scale use of wind power can alter local and global climate by extracting kinetic energy and altering turbulent transport in the atmospheric boundary layer. We report climate-model simulations that address the possible climatic impacts of wind power at regional to global scales by using two general circulation models and several parameterizations of the interaction of wind turbines with the boundary layer. We find that very large amounts of wind power can produce nonnegligible climatic change at continental scales. Although large-scale effects are observed, wind power has a negligible effect on global-mean surface temperature, and it would deliver enormous global benefits by reducing emissions of CO₂ and air pollutants. Our results may enable a comparison between the climate impacts due to wind power and the reduction in climatic impacts achieved by the substitution of wind for fossil fuels.

Global wind-power capacity is growing by $\approx 8 \text{ GW}\cdot\text{yr}^{-1}$, making wind the fastest growing nonfossil source of primary energy (1). The cost of electricity from wind power is now ≈ 40 dollars per

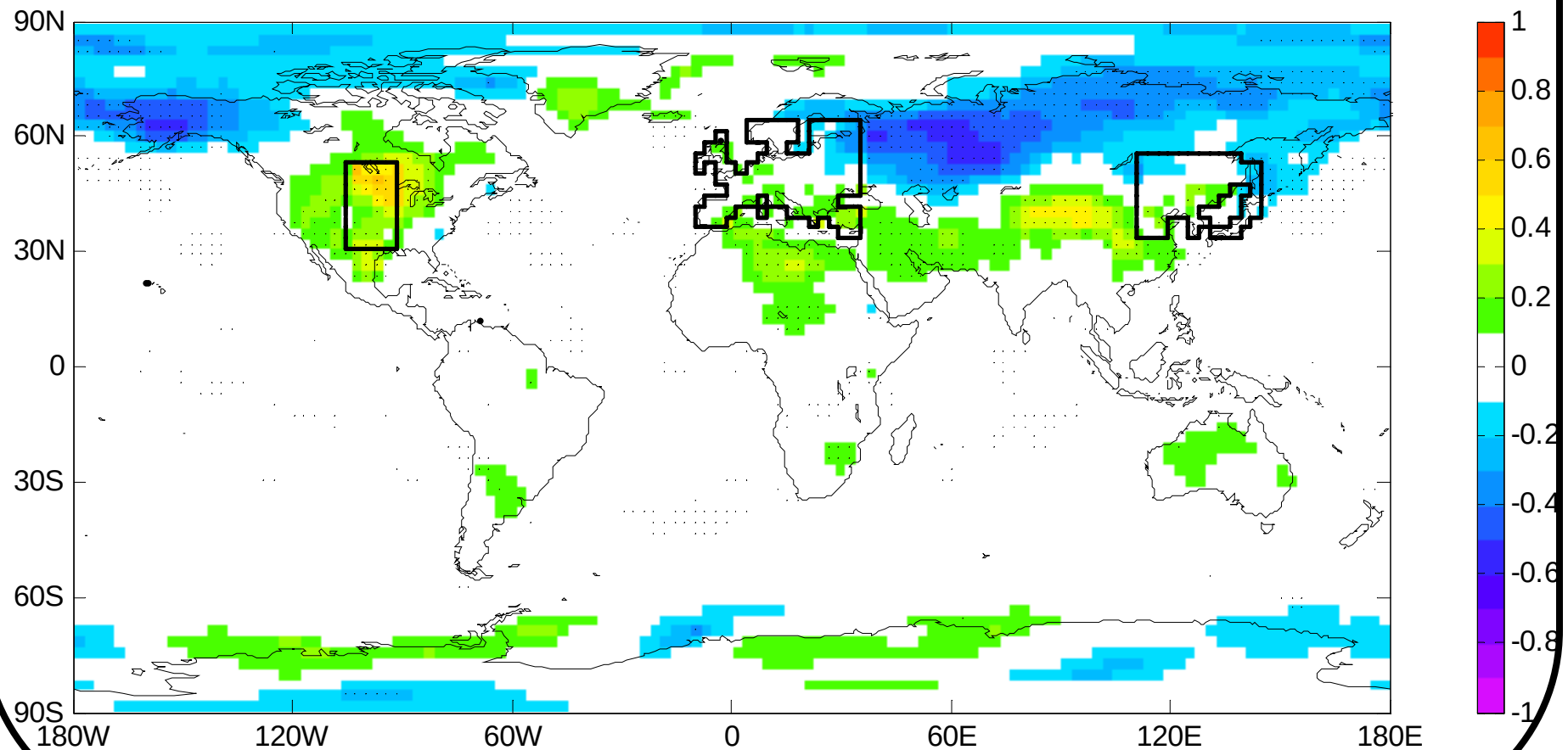
experiment, the drag coefficients were perturbed uniformly over an area defined by one of three wind-farm arrays, denoted A, B, and C (outlined in black in Figs. 1, 5A, and 5B, respectively). The reason for choosing these arrays is discussed below.

We used two methods to parameterize the additional drag due to the turbines. The first method was a modification of the roughness length, z_0 . In the boundary-layer parameterizations of the models (6, 7), z_0 determines the drag coefficient C_D , and ultimately, the surface fluxes through the following:

$$C_D = f(Ri) \frac{k^2}{\ln(z_1/z_0)^2}, \quad [1]$$

where z_1 is the height of the first-layer midpoint, $k = 0.4$ is the von Karman constant, and f is function that modifies C_D because of the influence of buoyancy on shear-driven turbulent mixing, which is parameterized by the Richardson number Ri . To simulate the effect of a uniform increase in drag, δC_D , we

Models show wind causes temperature changes



Units: °K

Wind risks (continued)

- Cost was \$1000 / kW two years ago; now \$1300 - \$1800.
- Cape Winds, LIPA public opposition.
- Intermittency costs for large amounts of wind still undefined.

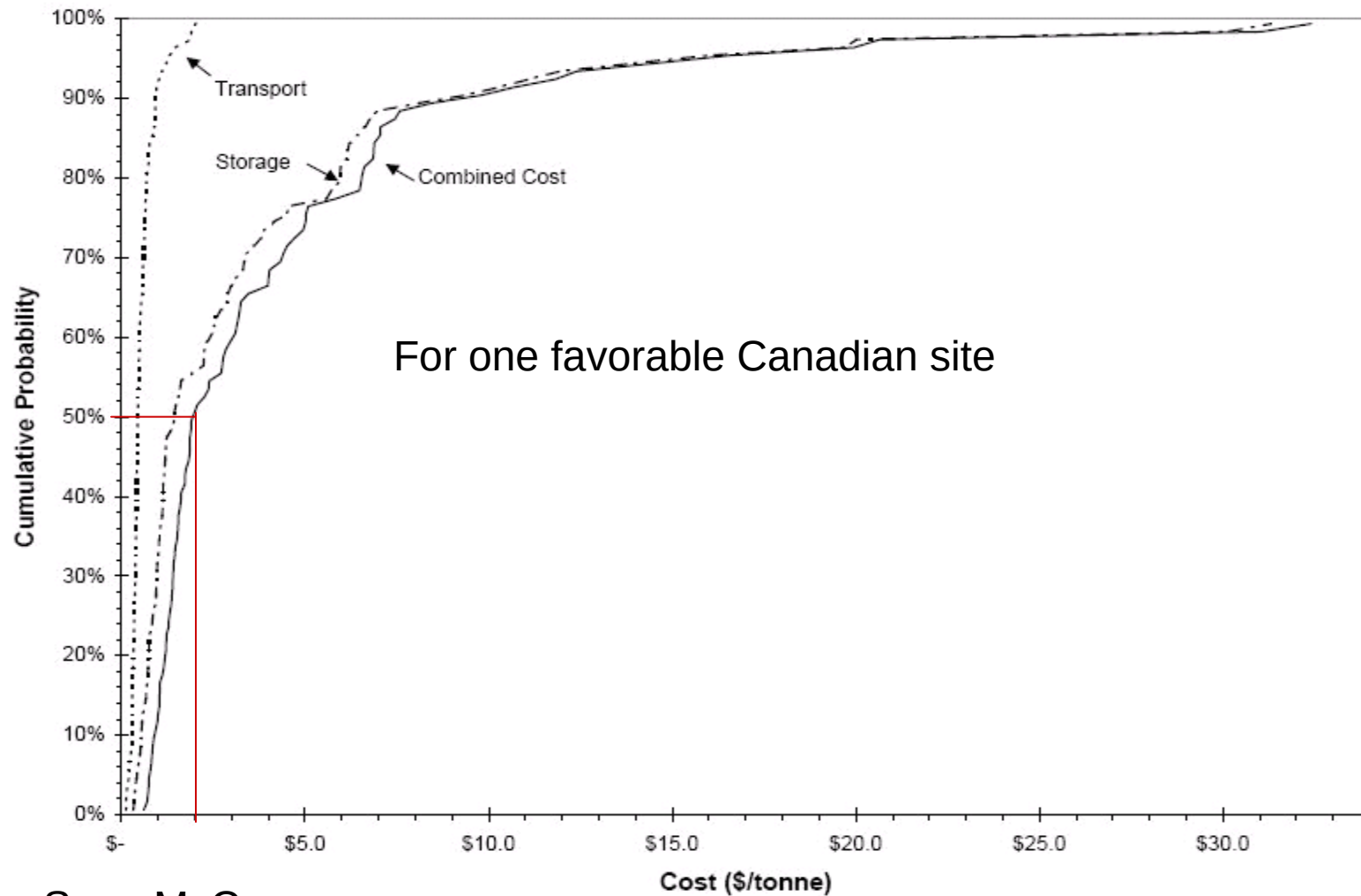
Coal Gasification Risks

- Capital cost risk
- Capacity factor
- But, there are over 100 operating worldwide, and additional plants will soon be built in the U.S.

Carbon Sequestration Risks

- Costs
- Regulatory framework
- Public perception

Transport & Sequestration Cost



Source: Sean McCoy

Developing CCS Regulations

The current U.S. regulatory structure for underground injection cobble together many different Federal and State agencies and regulatory authorities.

Even within the same jurisdiction, the injection of identical fluids is treated differently, depending on their source.

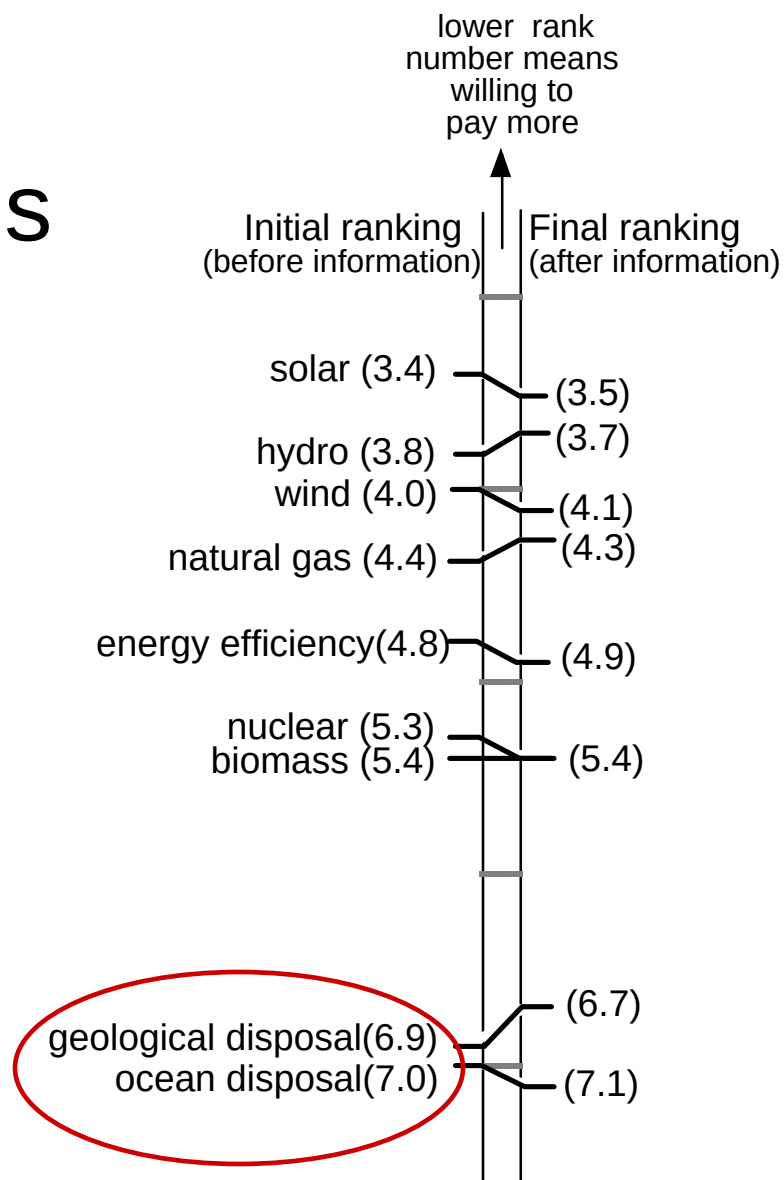
Current regulation is largely procedural. The regulatory regime for carbon disposal will need to be performance based and must accept limited leakage.

Technological capability alone will not be sufficient. There is an urgent need to address the risks, crafting an appropriate regulatory environment, and address public perceptions.

Public Perceptions

Options used different generation mixes (base of coal) in order to reduce CO₂ emissions by 50%.

Source: Palmgren et al., "Initial Public Perceptions of Deep Geological and Oceanic Disposal of Carbon Dioxide," *Environmental Science & Technology*, **38**, pp. 6441-6450, 2004.



Now...Back to CCS

The Basic Problem:

Electric utilities are the single largest stationary source of U.S. CO₂ emissions (~ 38%).

Controls on emissions are already beginning to be applied at the state level.

Many industry leaders agree that there will be significant Federal controls on power plant CO₂ emissions some time in the next two decades.

Many in the industry and in the NGO community see CCS playing a *major* role in meeting the challenge the electricity industry is about to face.

Strategies for CCS

For separation:

- Post-combustion separation of the dilute CO₂ stream after combustion in air (typically using Amine-based scrubbing).
- Pre-combustion separation (typically using coal gasification).
- Combustion in oxygen (yielding a high concentration CO₂ stream).

For disposal:

- Deep (>1km) geological under impermeable cap rock.
- Dissolution in the deep (>1km) ocean.

Carbon capture and sequestration (CCS)

There has been a recent revolution in thinking about CCS that has resulted from the realization that we are already doing much of what is needed *at commercial scales*:

- The U.S. currently uses about 1.7% of its primary energy to produce H_2 from fossil fuel.
- Many around the world are gasifying coal and coke.
- We move CO_2 distances of hundreds of kilometers in large pipelines.
- We inject large quantities of CO_2 into deep geological formations for secondary oil recovery. And we inject even larger quantities of other fluids for other reasons.

Three examples of existing IGCC facilities

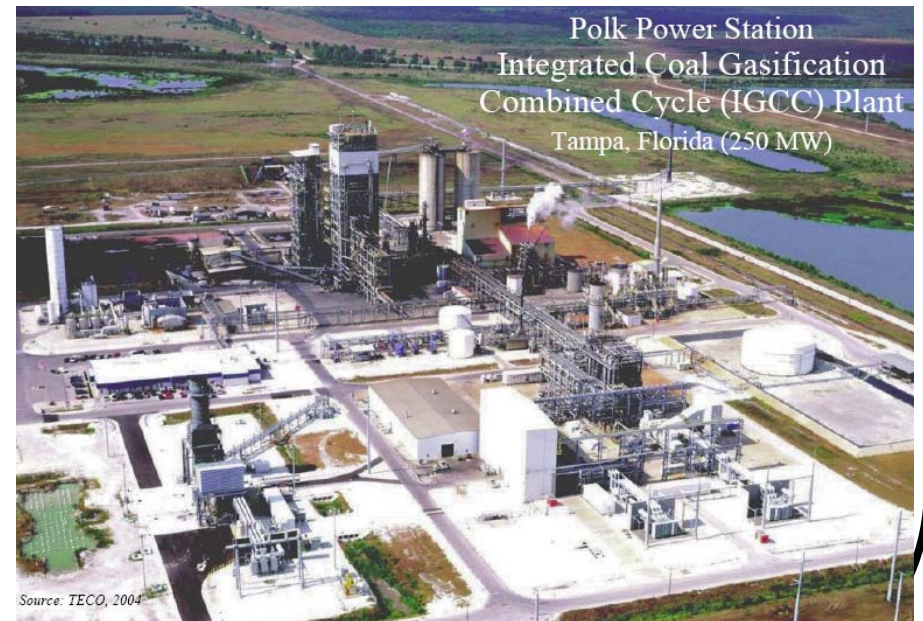
Great Plains Synfuels Plant, North Dakota



Source: DoE

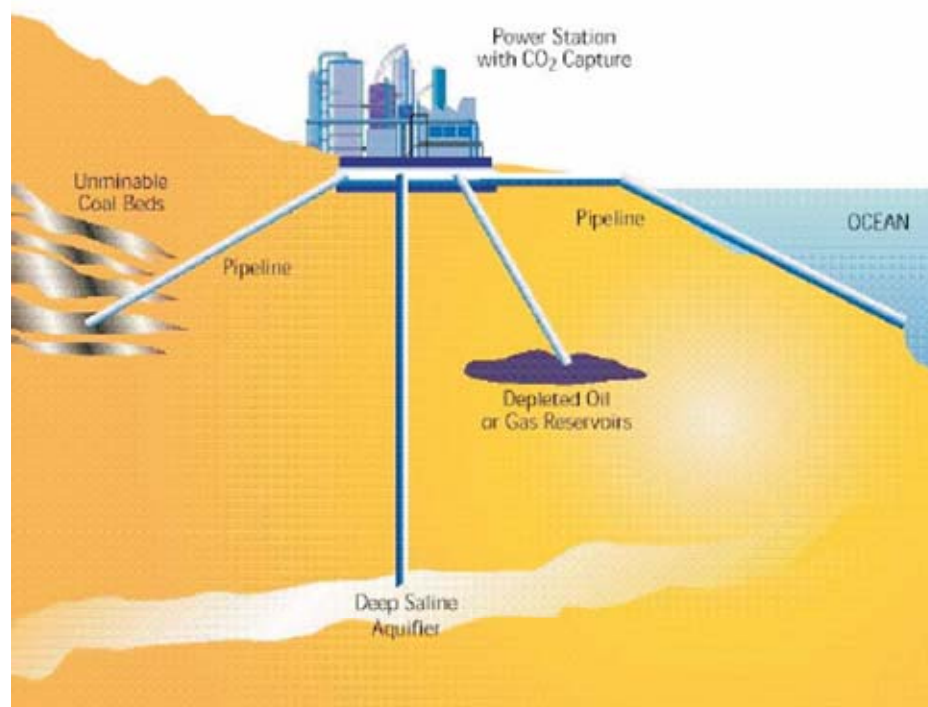


Source: DoE



Source: IECC, 2004

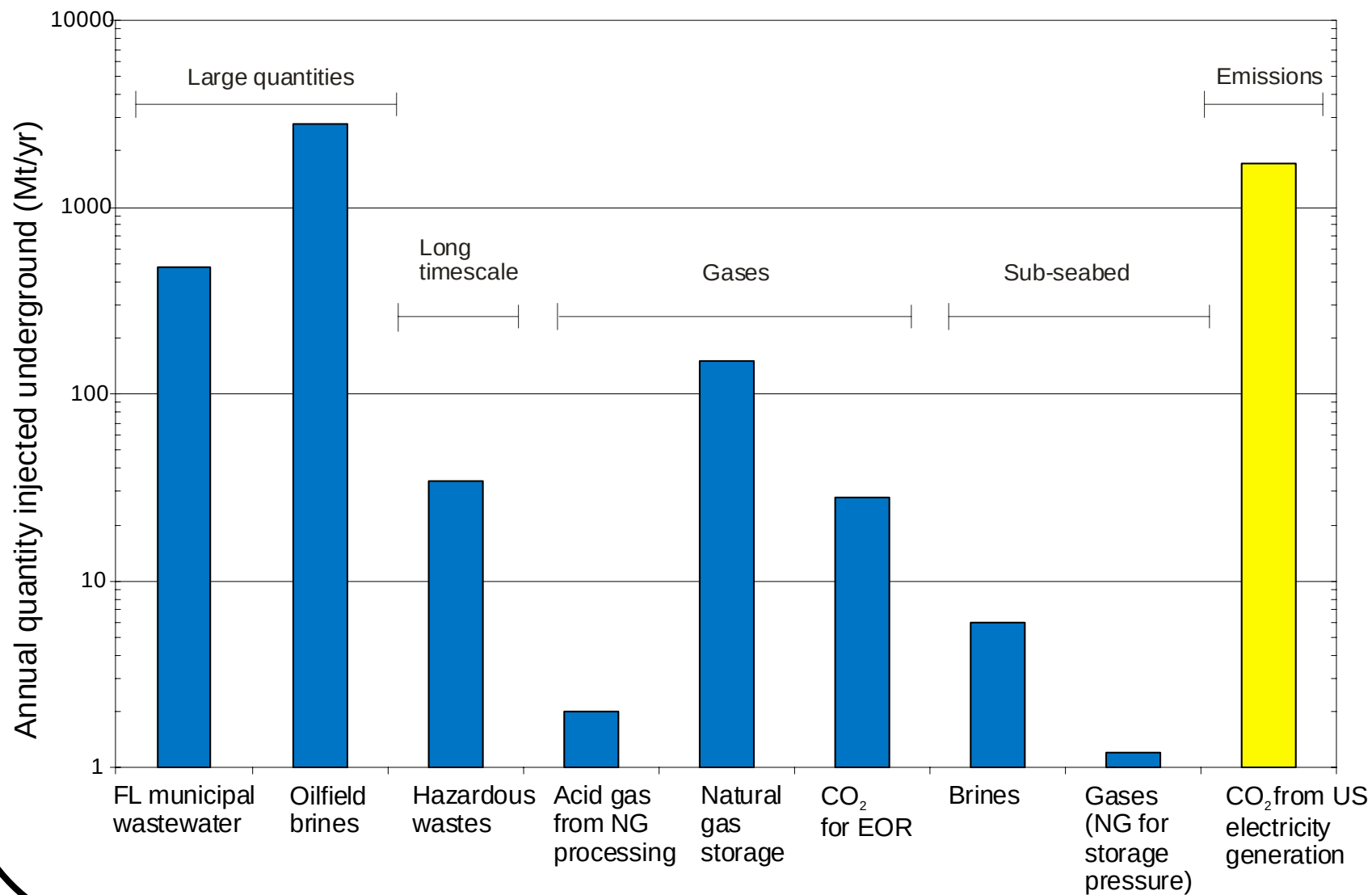
Carbon Capture and Storage



Storage option	Global capacity	
	Gt CO ₂	% of emissions to 2050
Depleted oil and gas fields	920	45
Deep saline reservoirs	400 - 10 000	20-500
Unminable coal measures	>15	>1

The estimates for deep saline reservoirs were made in the early 1990s. More recent estimates suggest the capacity for storage in geological reservoirs in North West Europe alone could be as much as 800 GtCO₂ (most of this is in deep saline reservoirs). Further research is required to assess the potential storage capacity of deep saline reservoirs.

U.S. experience with underground injection



General conclusions

Technology for CCS can probably be made economically and environmentally viable.

CCS technology could be disruptive to industry structure. Major petrochemical companies appear to have a comparative advantage over traditional utilities in doing CCS.

The current regulatory system is inadequate and will need to be improved.

Public perception could be a major obstacle. Public education about CCS and about alternative ways to reduce CO₂ emissions needs to start now.

Bottom line

Increasing levels of greenhouse gases - and the climate change they are causing - are real *and they are a major problem.*

To stabilize concentrations, the world is going to have to reduce its emissions of CO₂ and other GHGs by *at least 90%.*

Over the coming decades, there will be pressure for *enormous changes in the nature and operation of the global energy systems.*

A global system for control can be built up over time from separate regional efforts. A global agreement is not the necessary first step.

Thank You.

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