Meeting the Energy Challenge:
Innovation for
Competitiveness, Security, and Sustainability

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The Challenge in Theory

The multiple aims of energy strategy

ECONOMIC AIMS

- reliably deliver fuel & electricity for basic human needs & economic growth
- limit consumer costs of energy
- limit cost & vulnerability from imported oil
- help provide energy basis for economic growth elsewhere

The multiple aims (continued)

ENVIRONMENTAL AIMS

- improve urban and regional air quality
- avoid nuclear-reactor accidents & waste-mgmt mishaps
- limit impacts of energy development on fragile ecosystems
- limit greenhouse-gas contribution to climate-change risks

The multiple aims (concluded)

INTERNATIONAL-RELATIONS AIMS

- minimize dangers of conflict over oil & gas, vulnerability to foreign-policy blackmail
- avoid spread of nuclear weapons from nuclear energy
- reduce vulnerability of energy systems to terrorist attack
- avoid energy blunders that perpetuate or create deprivation

Why energy strategy is difficult

- The aims are often in tension with each other.
- It’s an initial-value problem (not an equilibrium problem)
  - with initial values (and rates of change) unfavorable for desired outcomes;
  - especially in relation to the problems of oil dependence and global climate disruption from fossil-fuel use.
- There’s no technological silver bullet.

The primary tasks of energy policy in light of competing objectives are…

- to find and implement the best compromise among the most important economic, environmental, & security objectives, given the resources & technologies available at the time;
- to promote technological advances over time that reduce limitations of existing energy options, open new options, and reduce the tensions among energy-policy objectives.

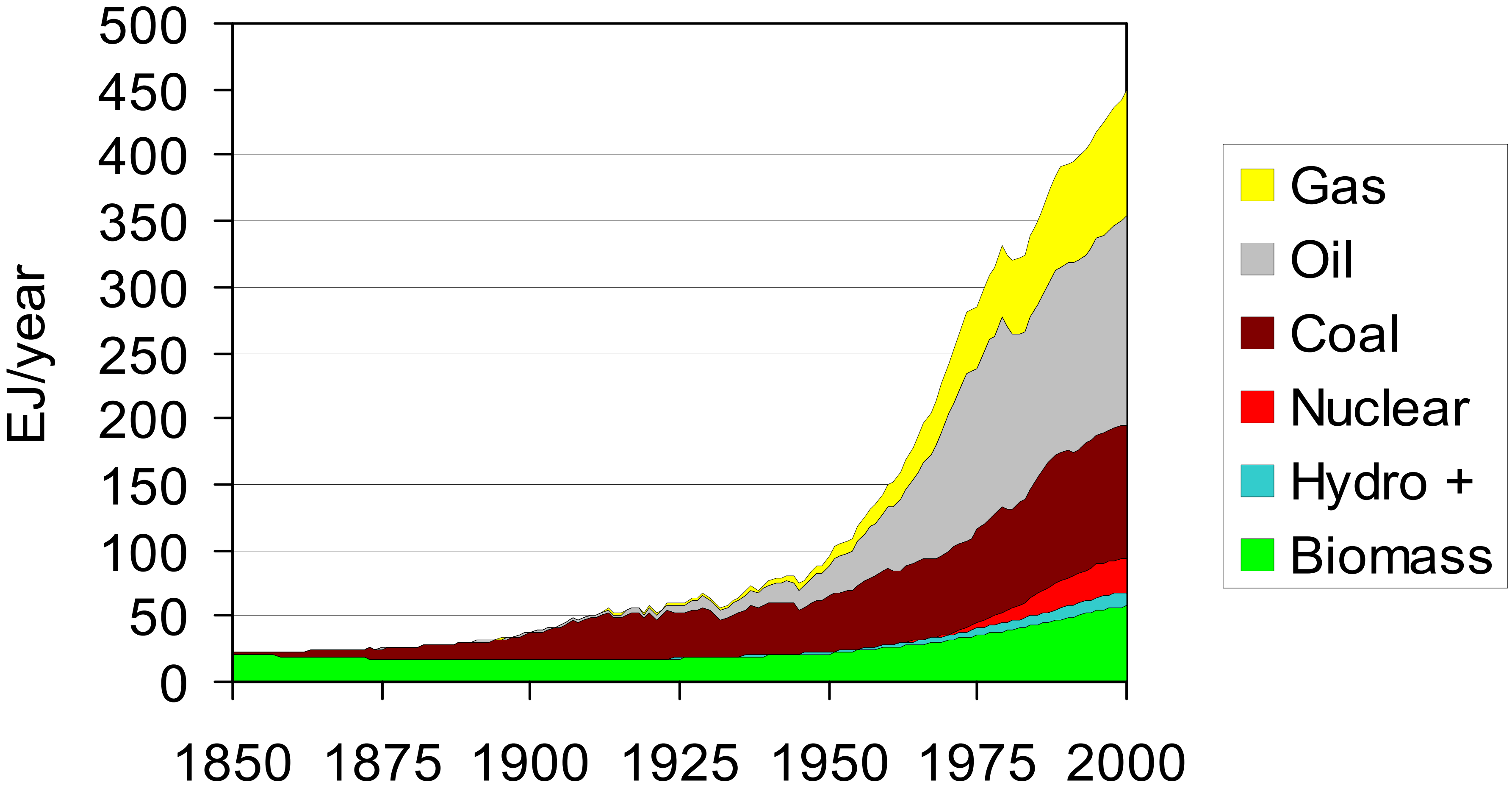
These ends cannot be achieved by markets alone, because...

- many of the objectives relate to public goods (like national security) & externalities (like pollution) that are not priced in markets unless policies achieve this;
- markets often also need other kinds of help to avoid “market failures” from abuse of monopoly power, lack of information, perverse incentives, short time horizons, etc.

The Challenge in Practice

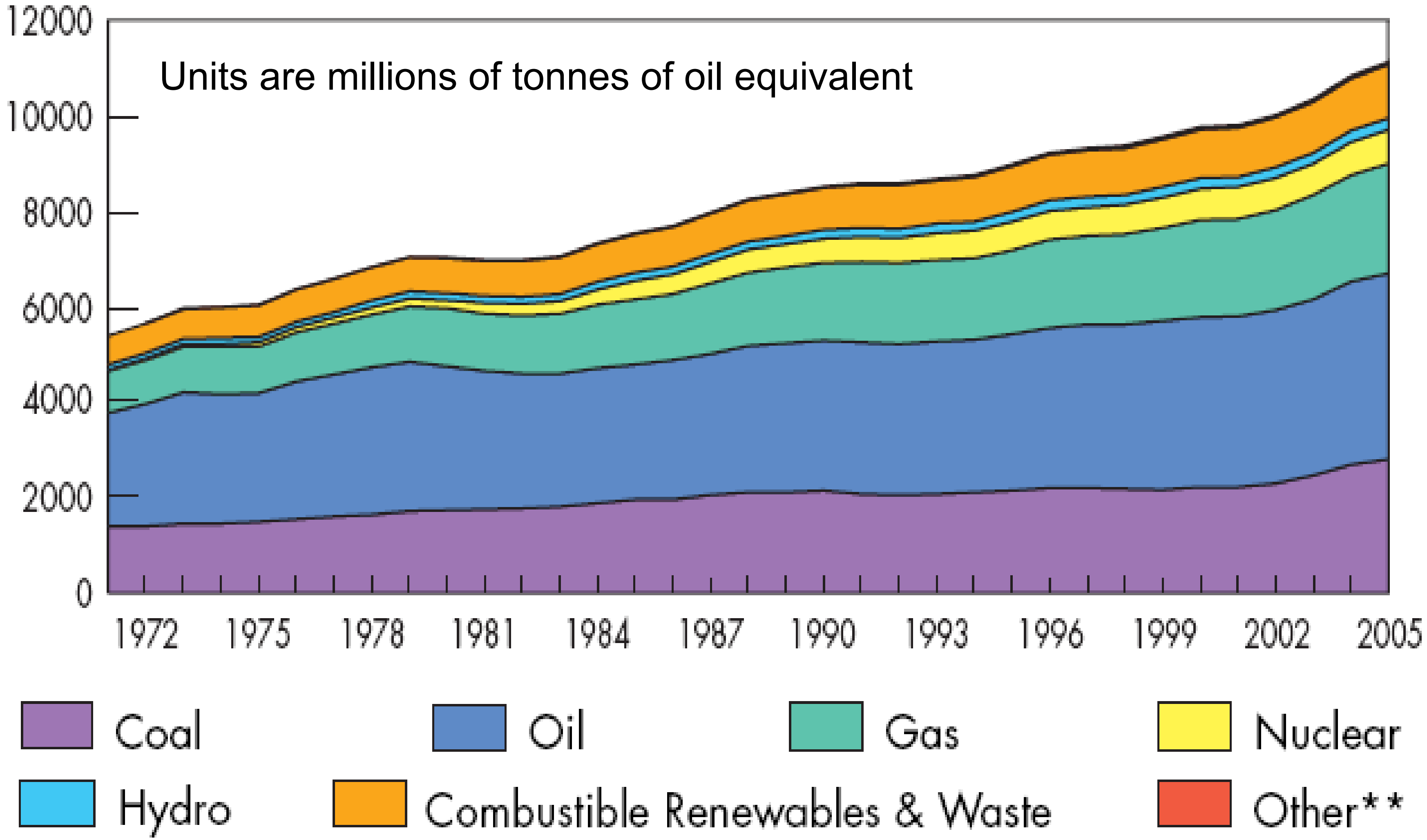
Where we've been
and where we're headed

Growth of world population & prosperity over past 150 years brought 20-fold increase in energy use



Growth rate 1850-1950 was 1.45%/yr, driven mainly by coal.
From 1950-2000 it was 3.15%/yr, driven mainly by oil & natural gas.

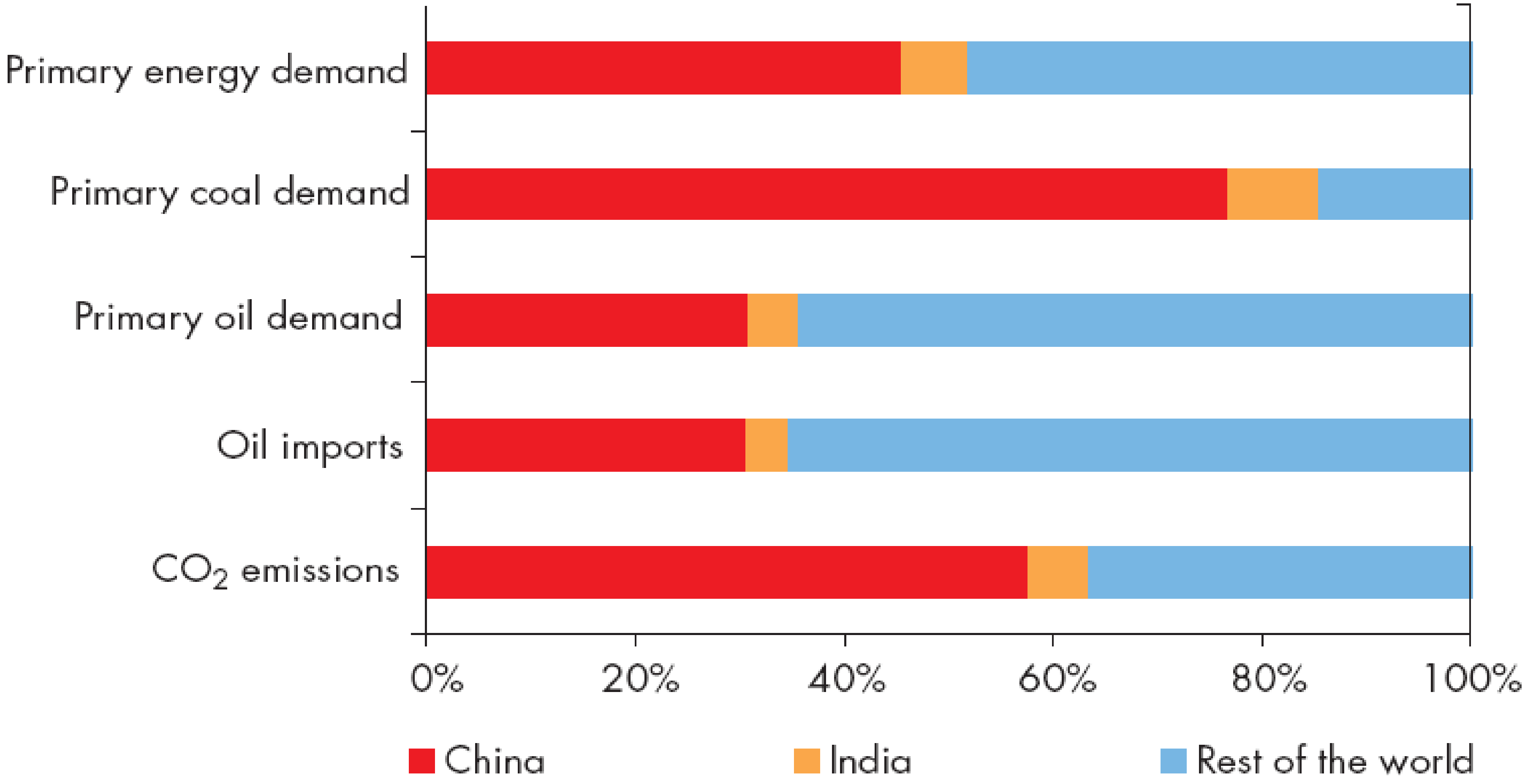
Rapid growth & high fossil-fuel dependence are continuing



Growth rate 2000-2006 averaged 2.7%/yr.

Much of the growth is in Asia

Bars show role of China & India in growth 2000-2006



* Based on preliminary estimates for 2006.

WEO 2007

Some comparative country data for 2006

	USA	*China*	*India*
Population, millions	299	1311	1122
GDP/pers, 2006$ (ppp)	44300	7900	3800
Total energy supply, EJ	106	86	29
of which fossil fuels	88%	84%	62%
Oil consumption, EJ	42	16	5
Oil imports, Mb/d	12.3	3.5	1.9
Electricity generation, TWh	4250	2830	730
of which coal generates	50%	80%	70%
Fossil C emitted in CO_2, MtC	1710	1640	380

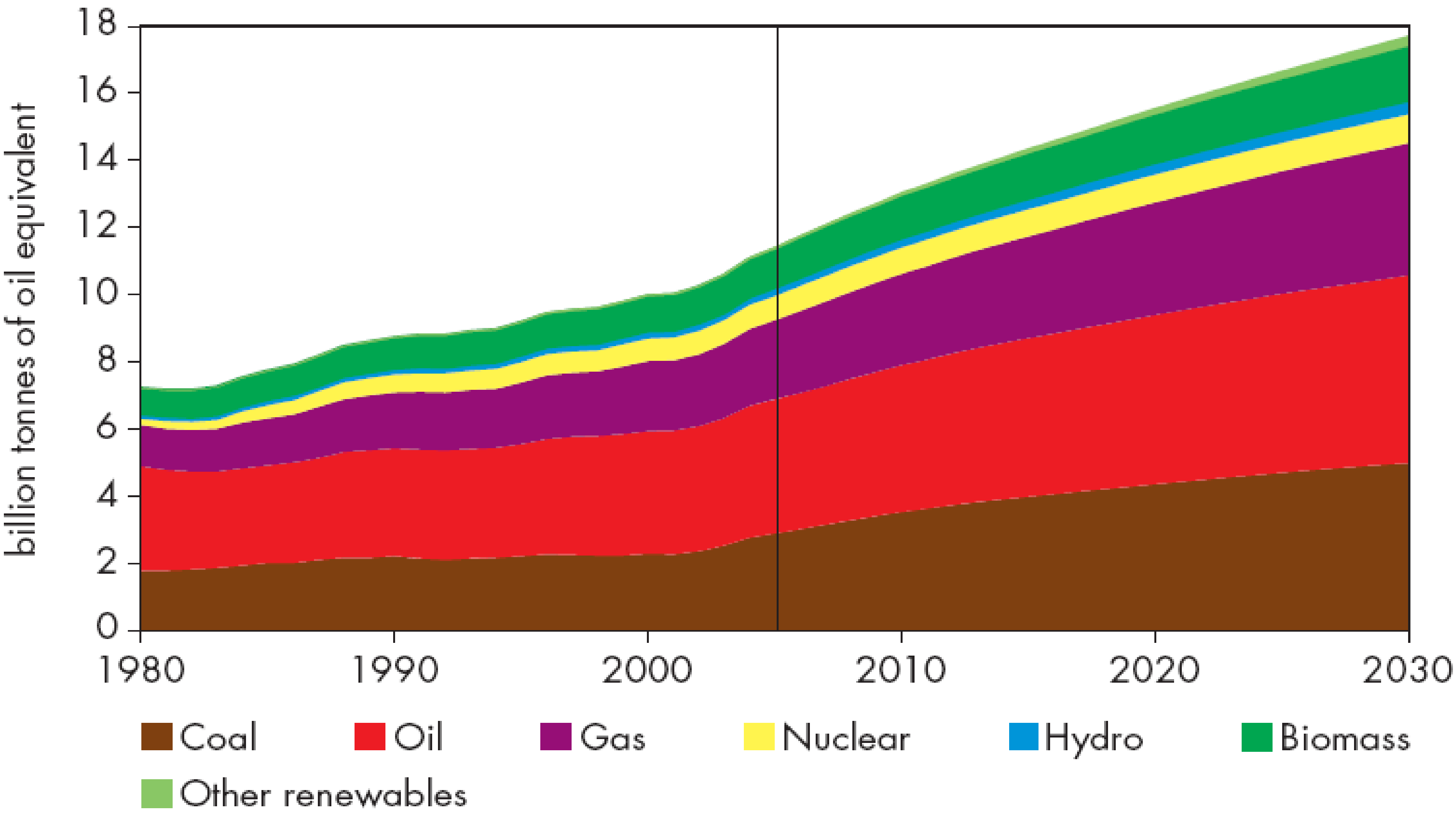
ppp = at purchasing-power parity, EJ = exajoules, TWh = terawatt-hours, MtC = megatons of carbon in CO_2. Total energy supply includes biomass fuels. Electricity generation is gross, not net.

Continued high growth is expected to 2030

US EIA 2007 and IEA WEO 2007 “reference” forecasts

	2006	2030
Primary energy, exajoules		
World	526	800
United States	106	150
China	86	175
Electricity, trillion kWh		
World	19.3	35
United States	4.3	6.0
China	2.8	7.5

Fossil fuels are expected to continue to dominate supply in the decades immediately ahead



WEO 2007

What's problematic about this future?

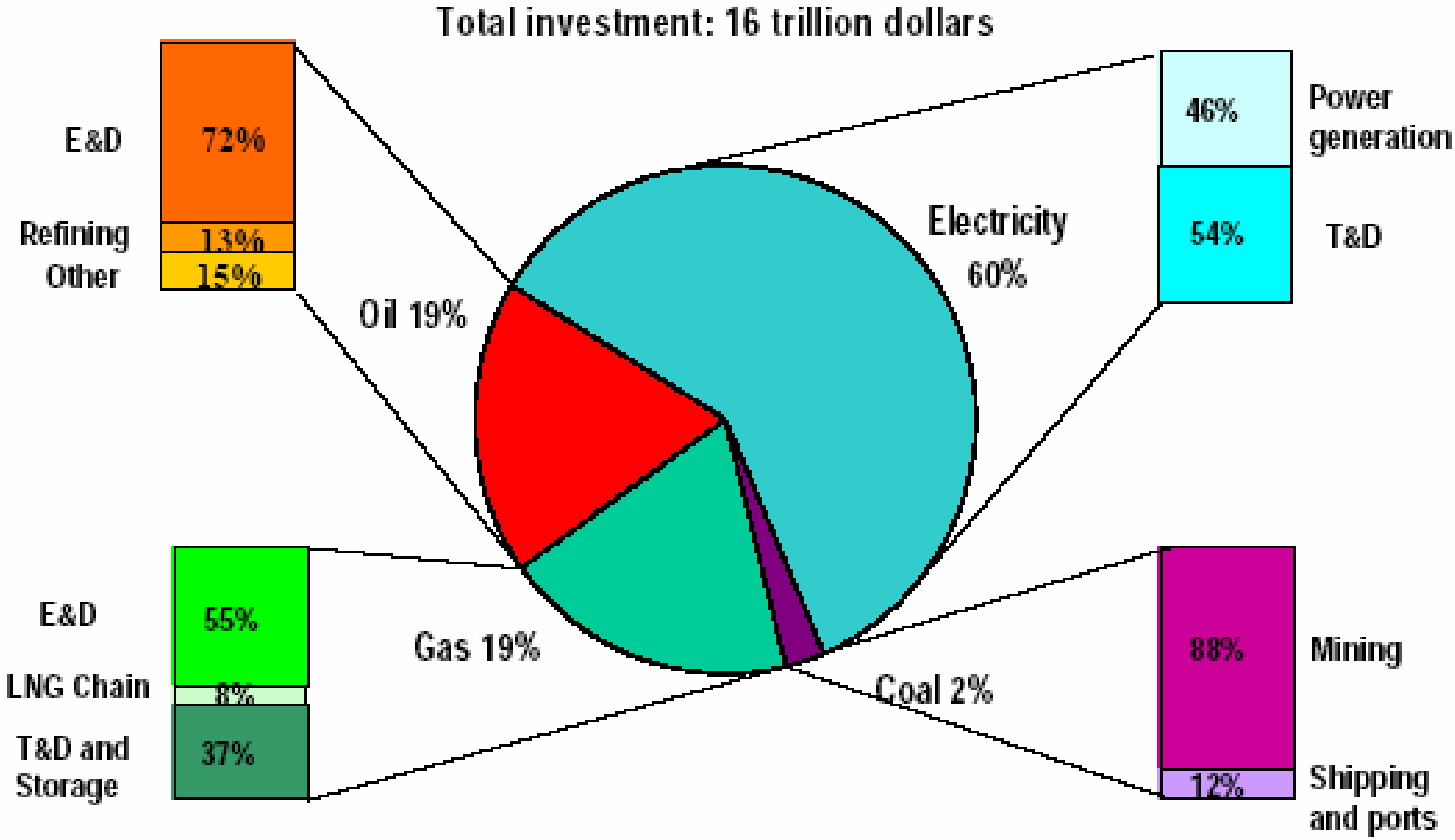
The problem is not "running out" of energy

Some mid-range estimates of world energy resources. Units are terawatt-years (TWy). Current world energy use is ~16 TWy/year.

OIL & GAS, CONVENTIONAL	1,000
UNCONVENTIONAL OIL & GAS (excluding clathrates)	2,000
COAL	5,000
METHANE CLATHRATES	20,000
OIL SHALE	30,000
URANIUM in conventional reactors	2,000
...in breeder reactors	2,000,000
FUSION (if the technology succeeds)	250,000,000,000
RENEWABLE ENERGY (available energy per year)	
sunlight on land	30,000
energy in the wind	2,000
energy captured by photosynthesis	120

Nor is the problem running out of money

Projected capital investment for energy supply 2001-2030



This is under 1% of projected Gross World Product for the period, and only about 5% of projected world investment. Could reach 15% of investment in developing countries.

Real problems: tensions among aims

- cost minimization *vs.*
  modernization, increased robustness & reliability, environmental improvements
- increased domestic fossil-fuel production (for security & economy) *vs.*
  protection of fragile ecosystems
- increased nuclear-energy production (for greenhouse-gas abatement) *vs.*
  reducing risks of accidents & terrorism

Real problems: the economic, political, & security risks of fossil-fuel dependence

- Increasing dependence on imported oil & natural gas means economic vulnerability, as well as international tensions and potential for conflict over access & terms.

- Coal burning for electricity and industry and oil burning in vehicles are main sources of severe urban and regional air pollution – SO_x, NO_x, hydrocarbons, soot – with big impacts on public health, acid precipitation.

- Emissions of CO_2 from *all* fossil-fuel burning are largest driver of global climate disruption, already associated with increasing harm to human well-being and rapidly becoming more severe.

Real problems: Alternatives to conventional fossil fuels all have liabilities & limitations

- traditional biofuels (fuelwood, charcoal, crop wastes, dung) create huge indoor air-pollution hazard
- industrial biofuels (ethanol, biodiesel) take land from forests & food production, increase food prices
- hydropower and wind are limited by availability of suitable locations, conflicts over siting
- solar energy is costly and intermittent
- nuclear fission has large requirements for capital & highly trained personnel, currently lacks agreed solutions for radioactive waste & links to nuclear weaponry
- nuclear fusion doesn't work yet
- coal-to-gas and coal-to-liquids to reduce oil & gas imports doubles CO_2 emissions per GJ of delivered fuel
- increasing end-use efficiency needs consumer education!

The two biggest challenges

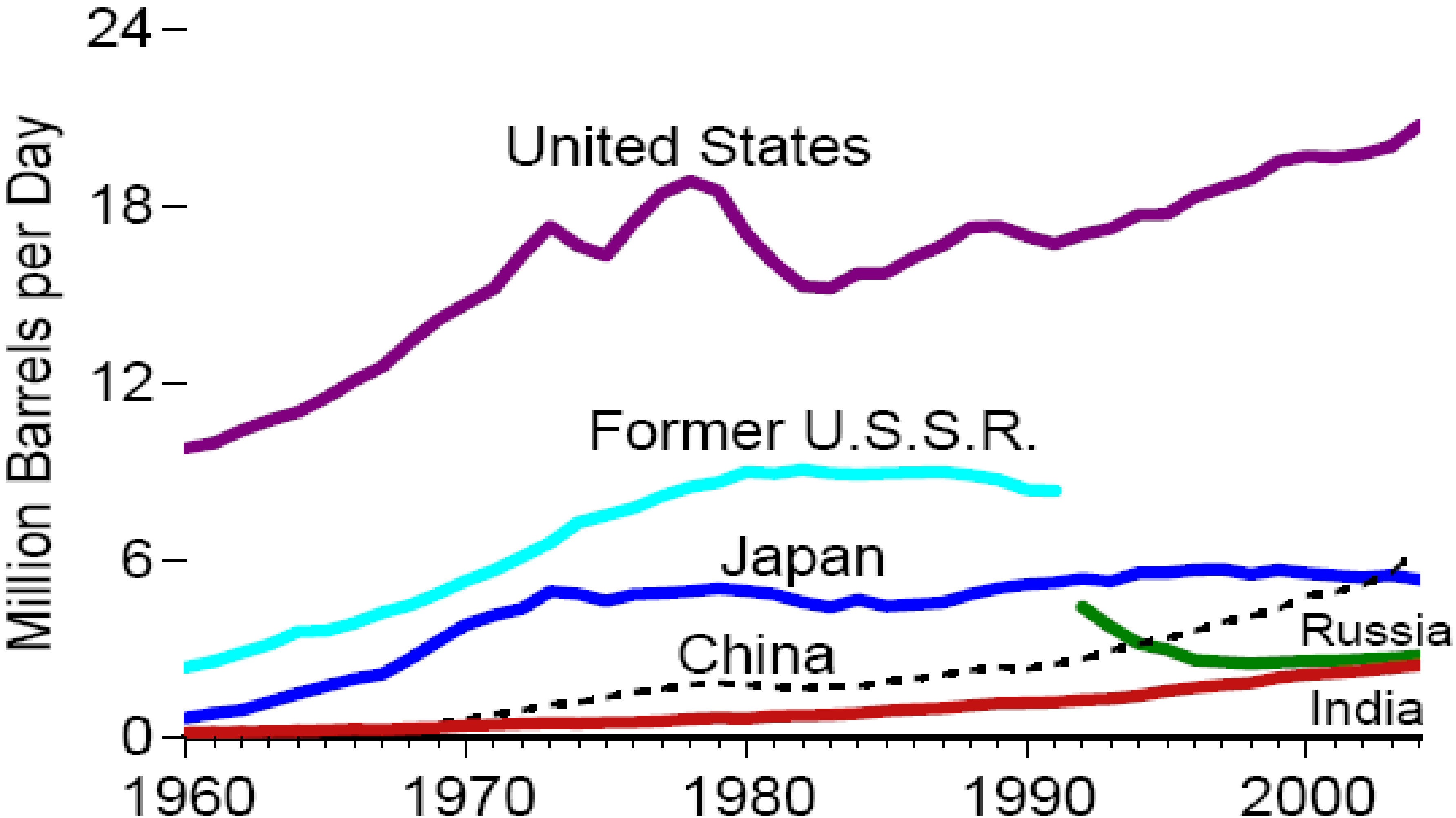
- Reducing urban & regional air pollution and the dangers of overdependence on oil despite growing demand for personal transportation

- Providing the affordable energy needed to create & sustain prosperity everywhere without wrecking the global climate with carbon dioxide emitted by fossil-fuel burning

The oil challenge: supply & security

- USA in 2006 used 21 million barrels per day of oil, importing 66% of it.
- Forecasts show US oil use rising to 28 Mb/d by 2030, with all of the increase coming from imports.
- World used 82 Mb/d in 2006, 63% of it traded internationally.
- Consumption forecasted to rise from 82 Mb/d in 2006 to 120 Mb/d in 2030.
- China's imports by 2030 expected to pass 12 Mb/d.
- It remains true that most of the world's known & suspected oil resources are in the Middle East.

USA is biggest guzzler, but Asia is growing



The Asia-Pacific region accounted for 30% of world oil consumption in 2005

The dangers of oil dependence

<u>import dependence</u> → worsening balance of payments

→ vulnerability to supply cut-offs

→ incentive for military action to maintain access

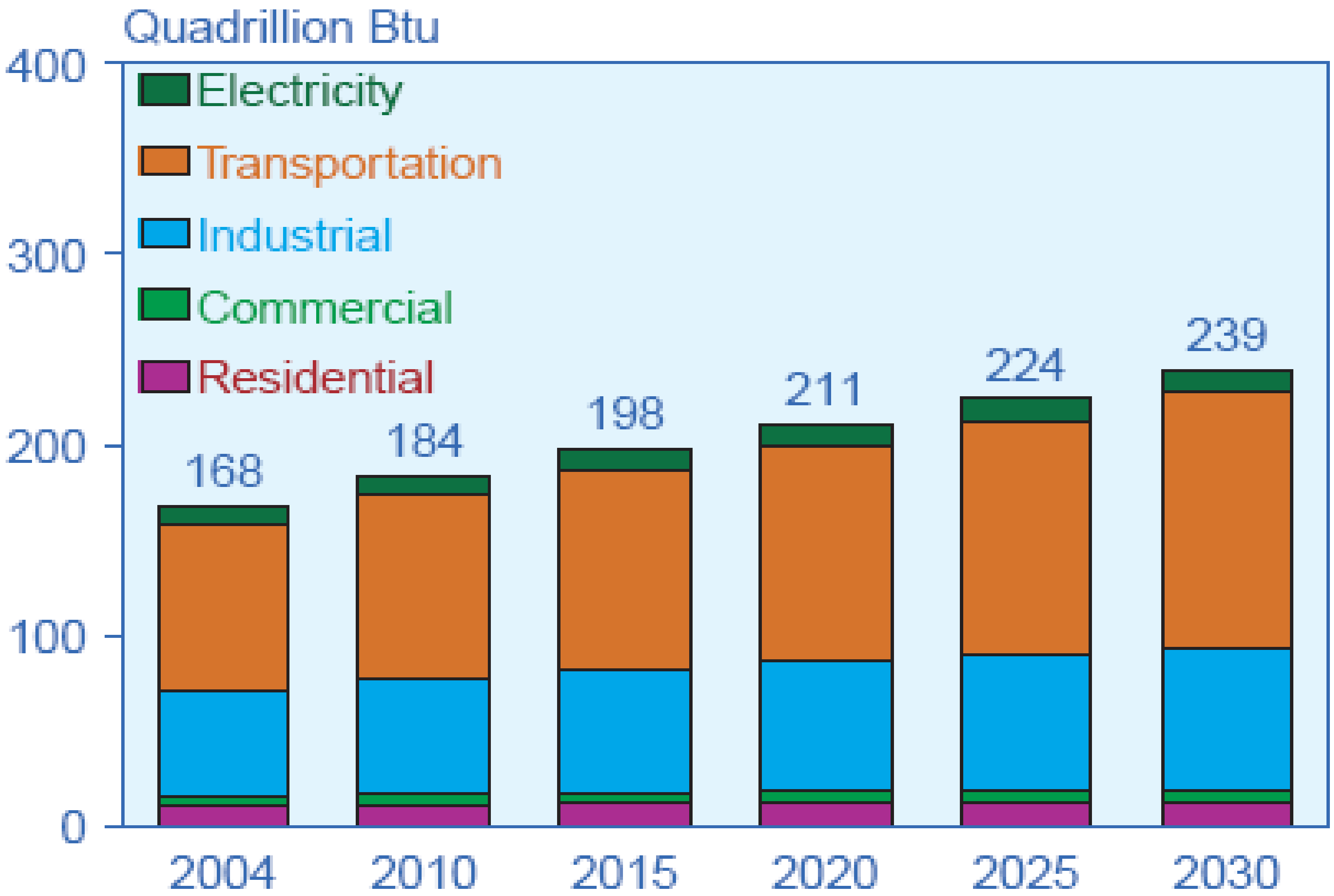
→ enrichment of oil-exporting regimes that may use the money to export terror & import nuclear weapons

<u>total oil dependence</u> → economic vulnerability to price shocks

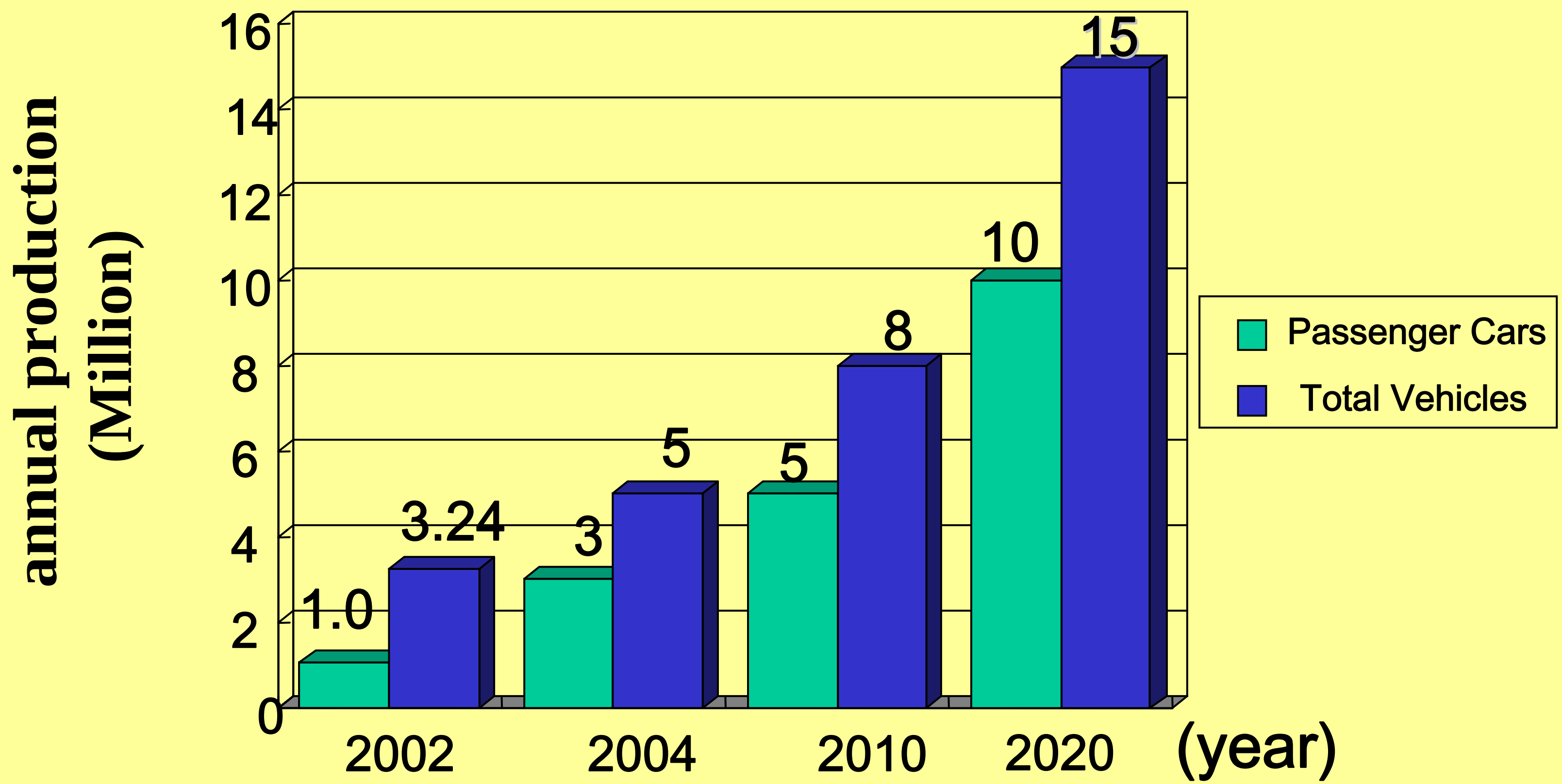
→ reduced freedom of action in foreign policy and counter-terrorism

→ air pollution from transport uses

Transport uses most of the oil

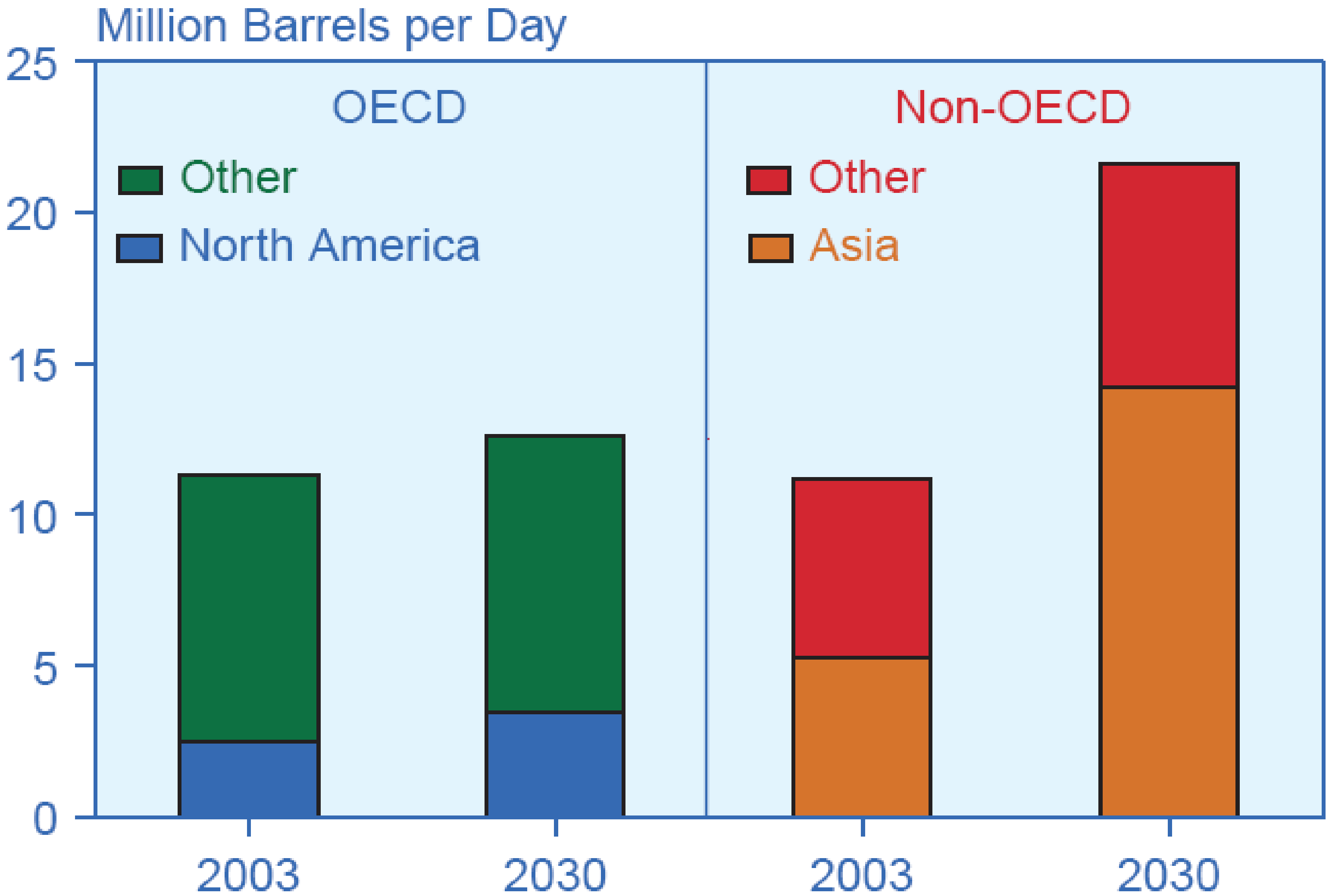


Past & projected vehicle production in China



Ouyang Minggao, Tsinghua University Automotive Research Center, 2006

Developing Asia oil imports from Persian Gulf…



Source: EIA International Energy Outlook 2006

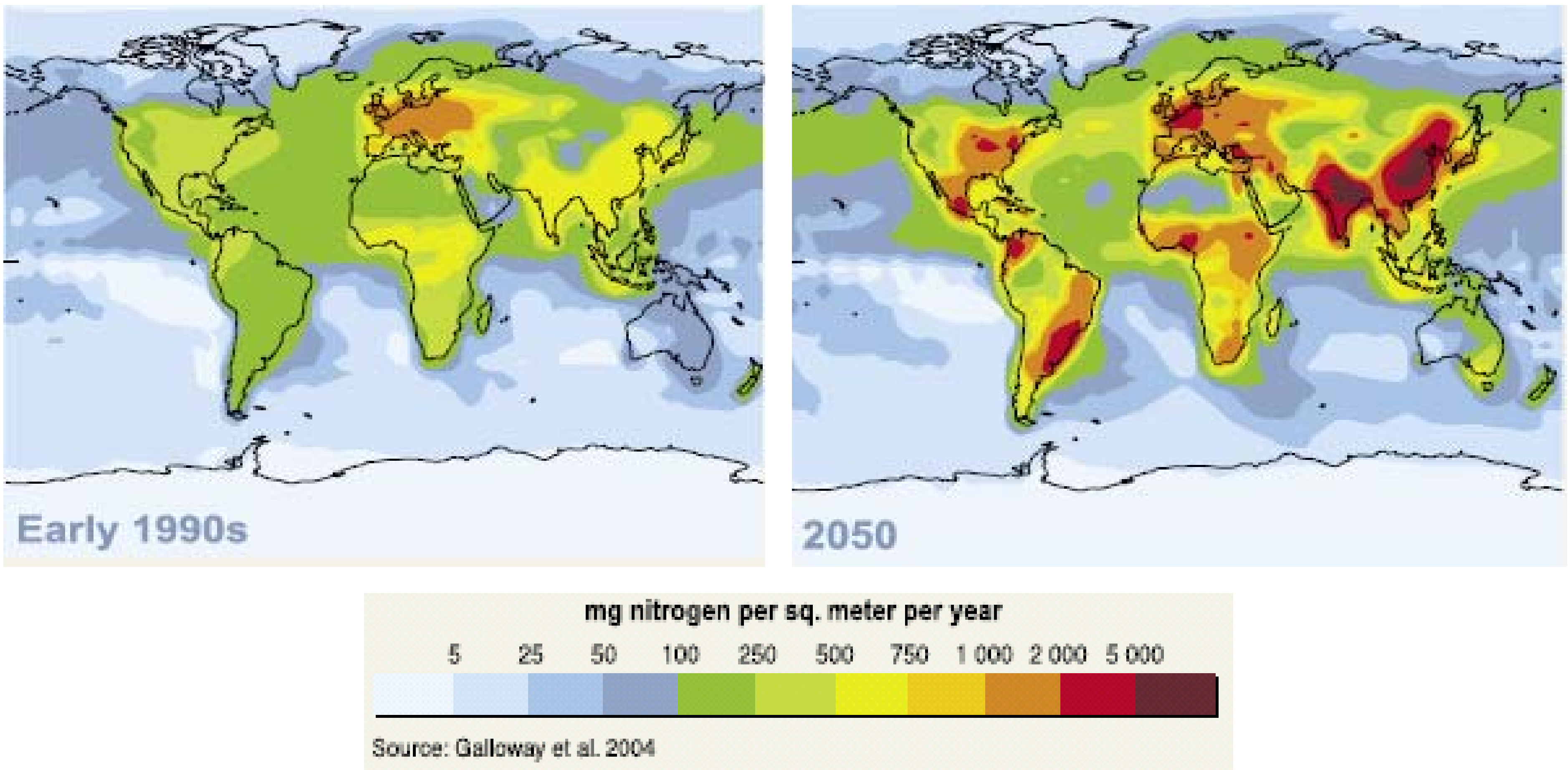
…are already bigger than North America's, growing faster

The oil challenge: environment

- Most oil is used in transport vehicles, and these are the largest sources of NO_x and hydrocarbon air pollution.
- The number of cars in the world is soaring, producing increased congestion and even more pollution.
- Combustion of petroleum fuels accounts for about 40% of CO_2 emissions from energy – same as coal – and this is expected to continue.

Acid precipitation under BAU energy growth

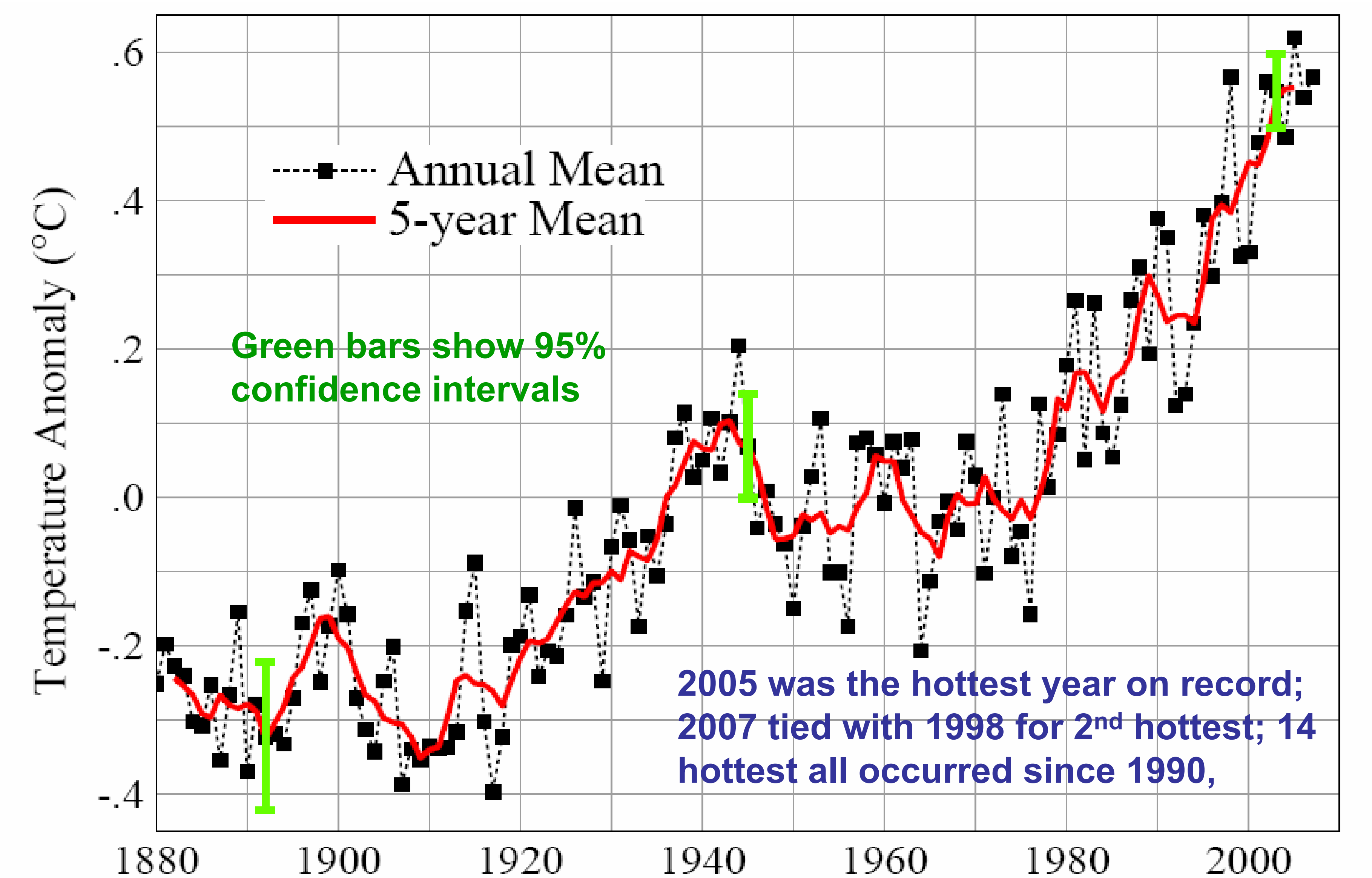
Wet and dry reactive nitrogen deposition from the atmosphere, early 1990s and projected for 2050



The climate-change challenge

- Global climate is changing rapidly and humans are responsible for most of the change.
- CO_2 emissions are the largest driver & 75-85% of these come from combustion of fossil fuels (the rest from deforestation).
- Fossil CO_2 emissions are immense (~30 billion tons/yr in 2006) & difficult to capture & store.
- The world's 80%-fossil-fuel-dependent energy system represents a $15 trillion capital invest-ment that takes 30-40 years to turn over.
- Avoiding biggest risks requires sharply reducing CO_2/energy ratio starting immediately.

The Earth is getting hotter.



http://data.giss.nasa.gov/gistemp/graphs/

We know why:

Human vs natural influences 1750-2005 (watts/m^2)

Human emissions leading to increases in…	
atmospheric carbon dioxide	+ 1.7
methane, nitrous oxide, CFCs	+ 1.0
net ozone (troposphere↑, stratosphere↓)	+ 0.3
absorptive particles (soot)	+ 0.3
reflective particles (sulfates, etc.)	- 0.7
indirect (cloud forming) effect of particles	- 0.7
Human land-use change increasing reflectivity	- 0.2
Natural changes in sunlight reaching Earth	+ 0.1

The warming influence of anthropogenic GHG and absorbing particles is ~30x the warming influence of the estimated change in input from the Sun.

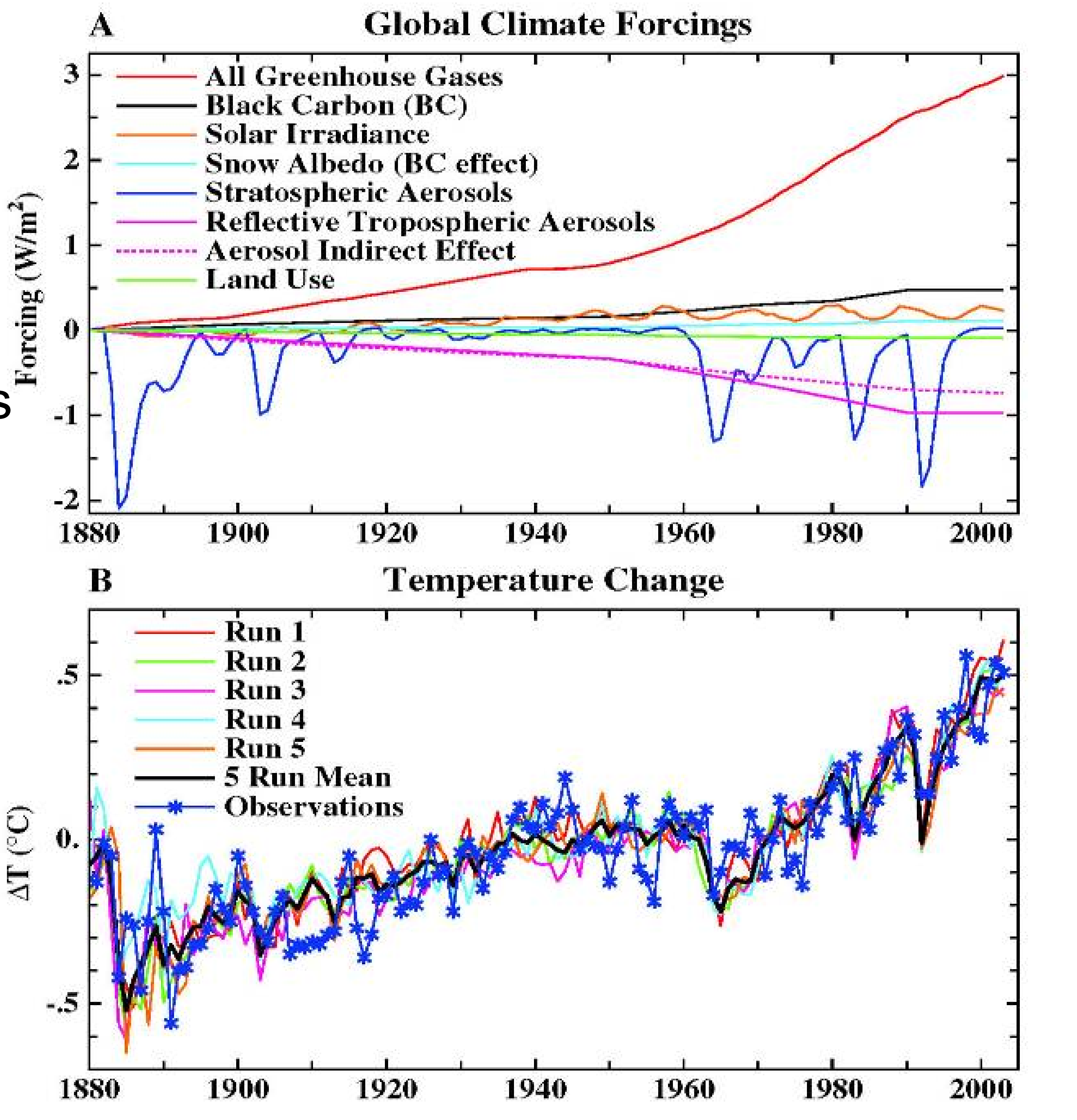
IPCC AR4, WG1 SPM, 2007

The smoking gun

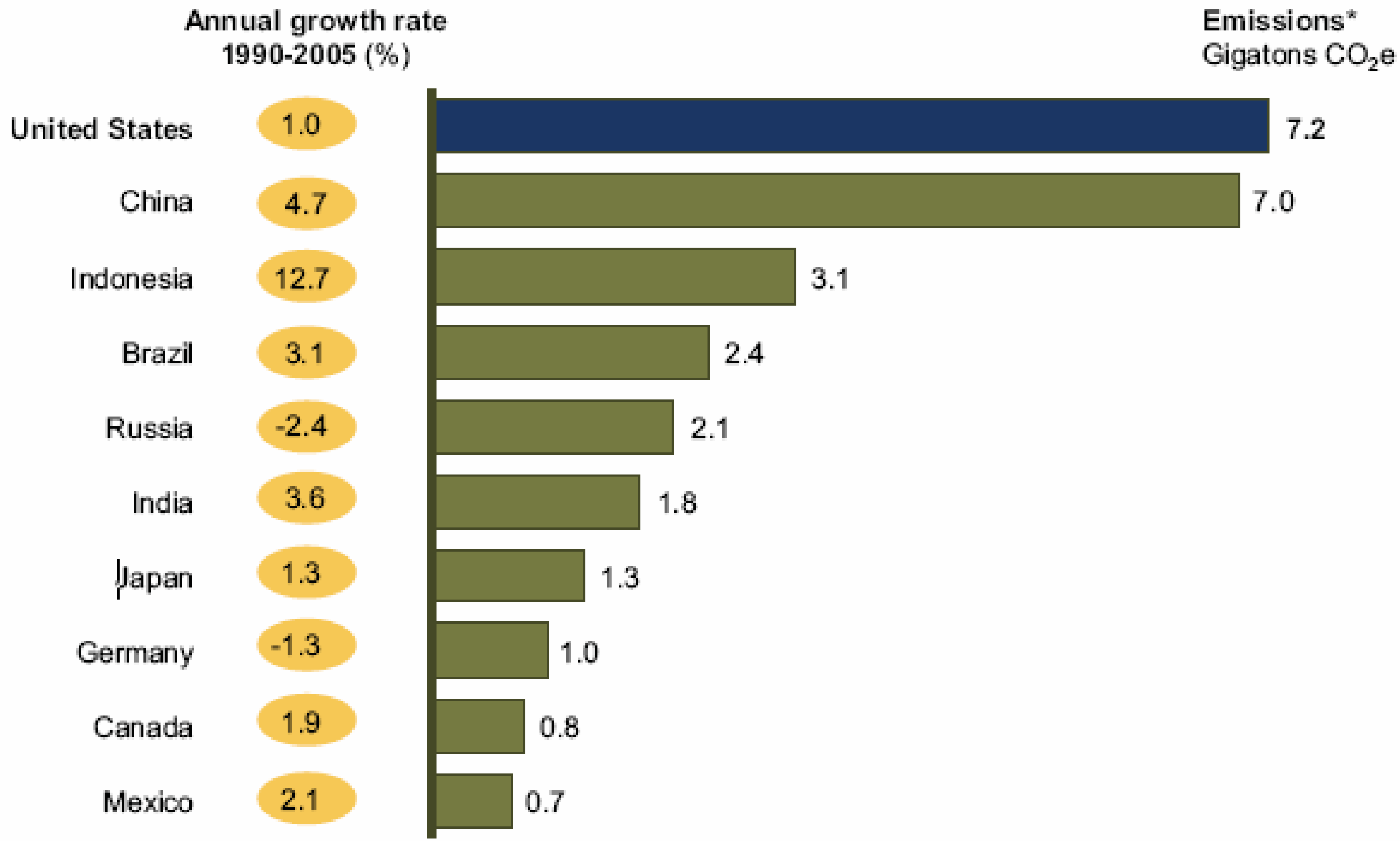
Top panel shows best estimates of human & natural forcings 1880-2005.

Bottom panel shows that state-of-the-art climate model, fed these forcings, reproduces almost perfectly the last 125 years of observed temperatures.

Source: Hansen et al., *Science 308*, 1431, 2005.



GHG EMISSIONS FOR SELECT COUNTRIES – 2005

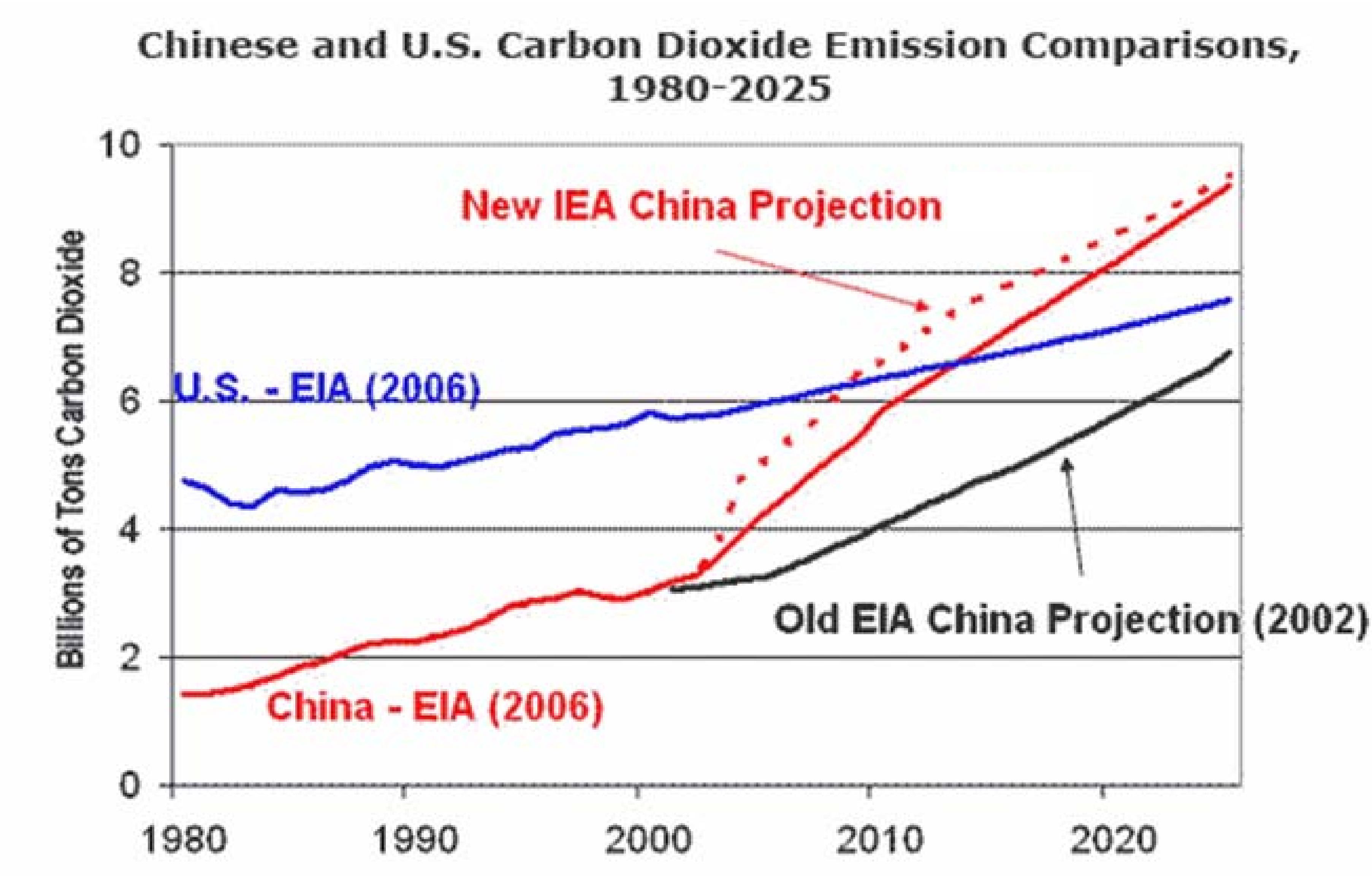


* Includes emissions associated with deforestation and land-use changes

Source: IEA; EPA; WRI; UNFCCC; McKinsey analysis

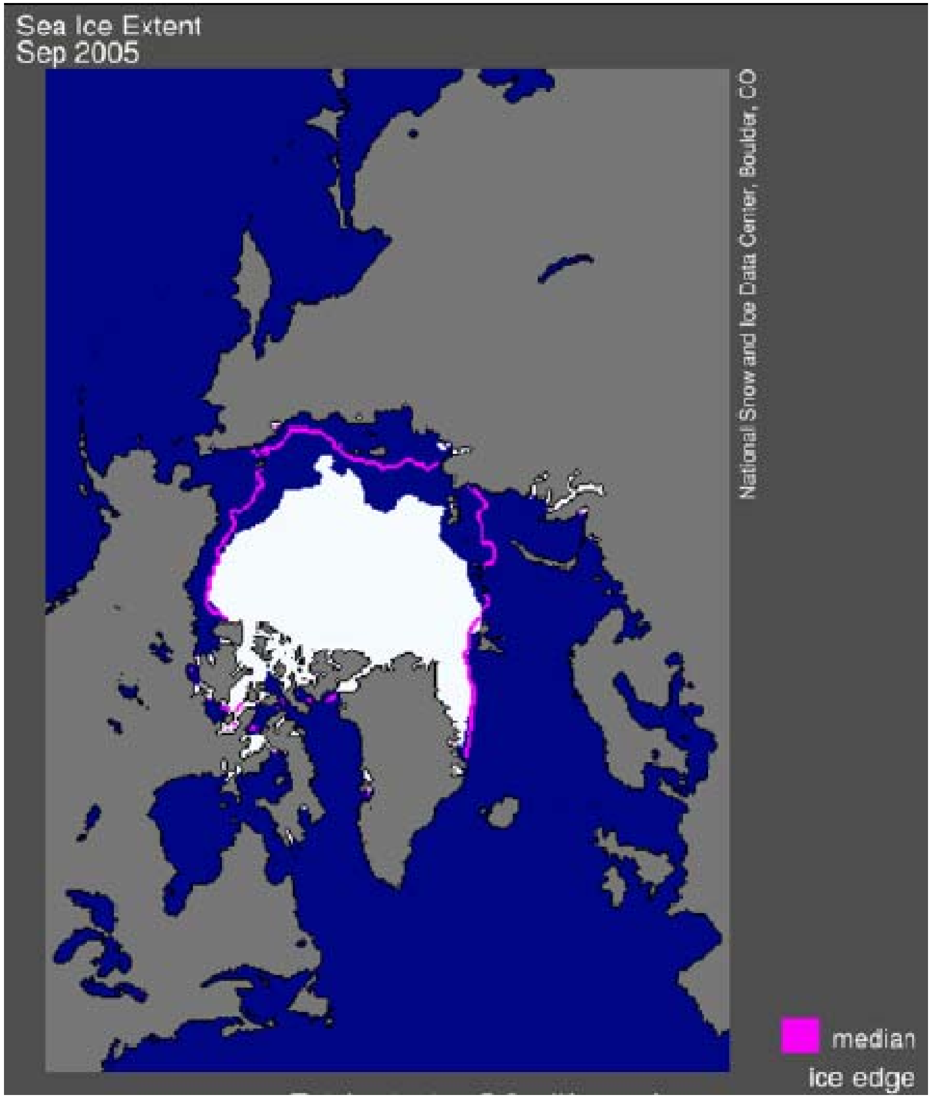
McKinsey, USGHG, 2008

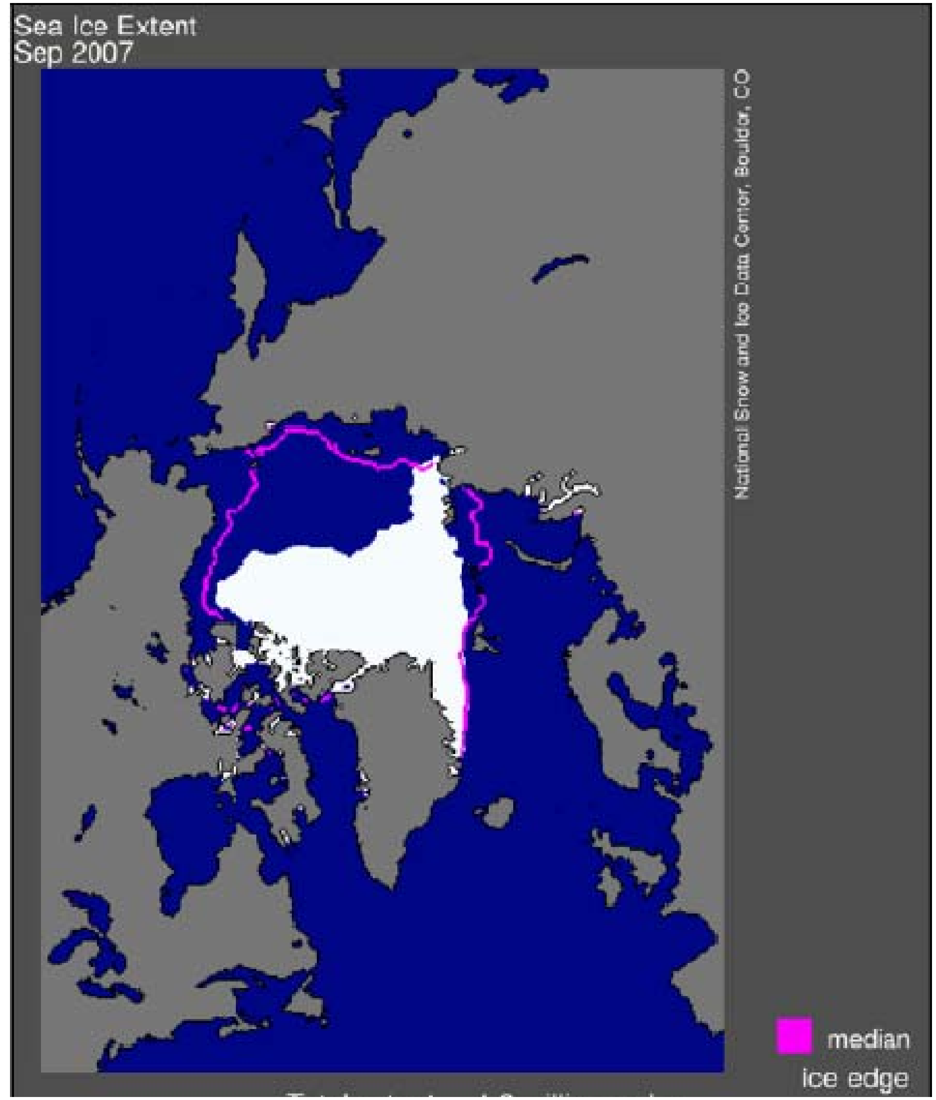
China passed USA as biggest CO2 emitter in 2007



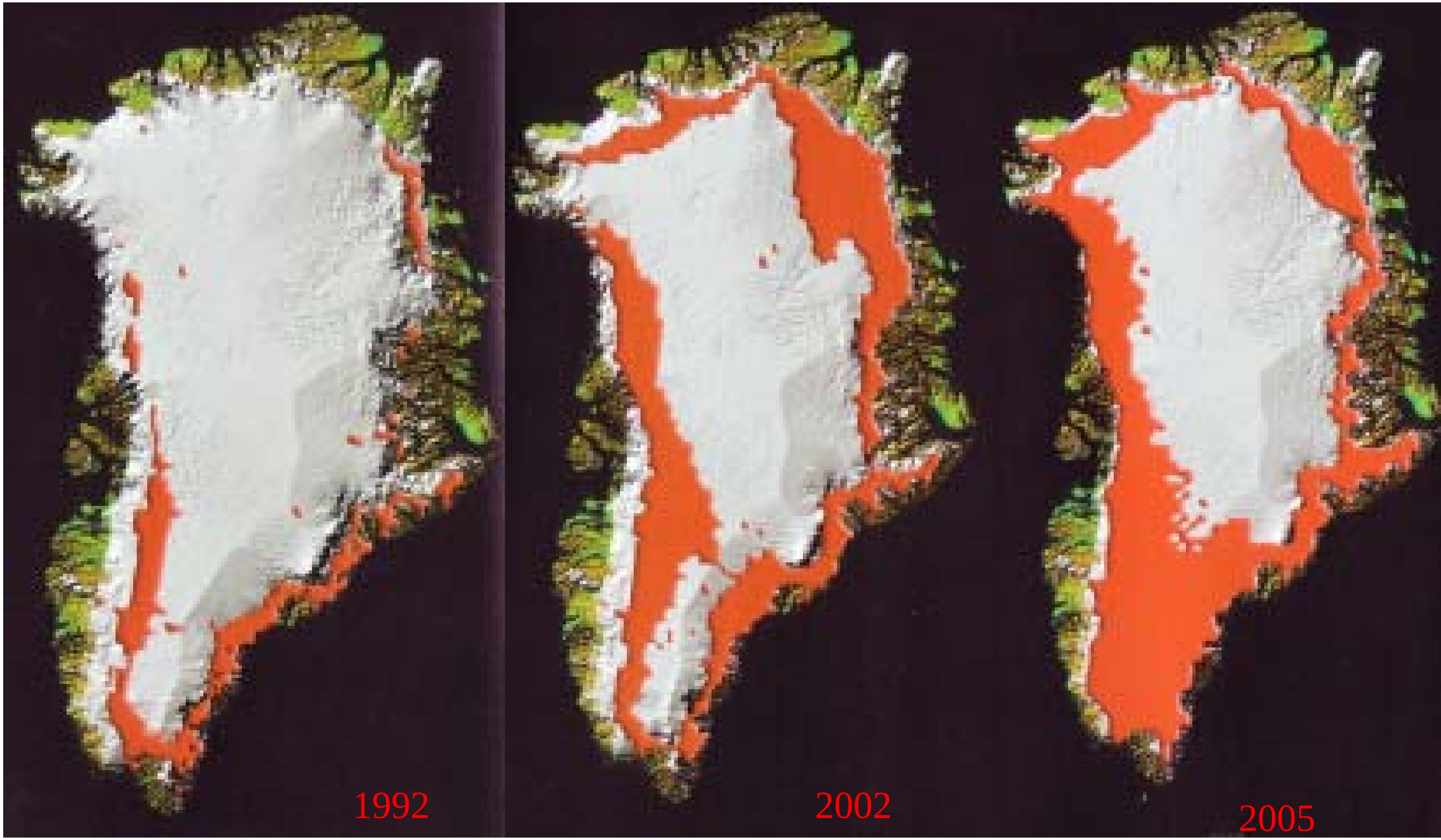
Sources: U.S. EIA *International Energy Outlook 2006*; World Resources Institute; Oak Ridge National Laboratory.

Meanwhile summer sea ice is disappearing





Surface melting on Greenland is expanding



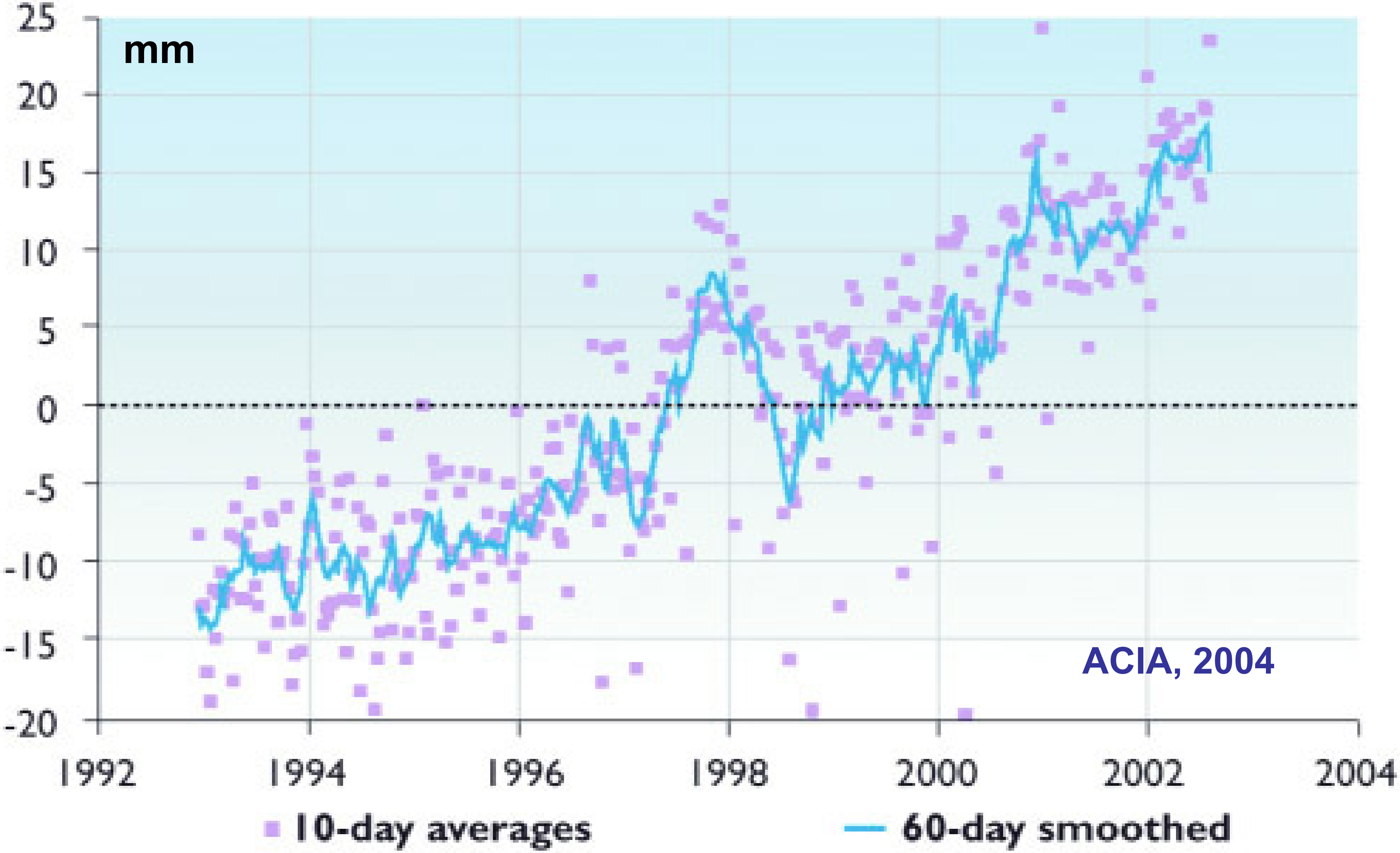
In 1992 scientists measured this amount of melting in Greenland as indicated by red areas on the map

Ten years later, in 2002, the melting was much worse

And in 2005, it accelerated dramatically yet again

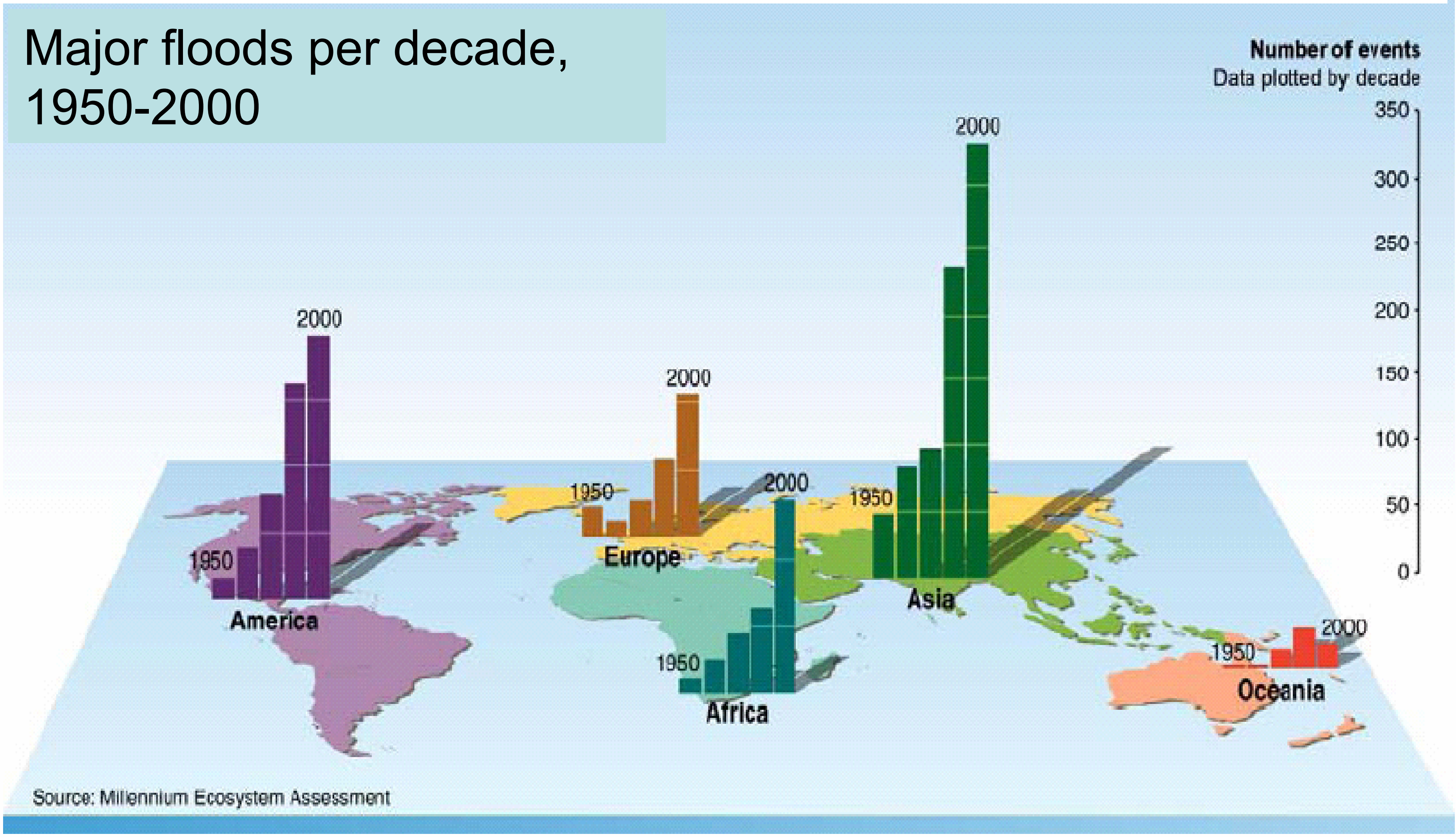
Source: ACIA, 2004 and CIRES, 2005

Sea-level rise is accelerating



1993-2003 ≈ 35 mm = 3.5 mm/yr; compare 1910-1990 = 1.5±0.5 mm/yr.

Harm is already occurring: floods have been increasing almost everywhere

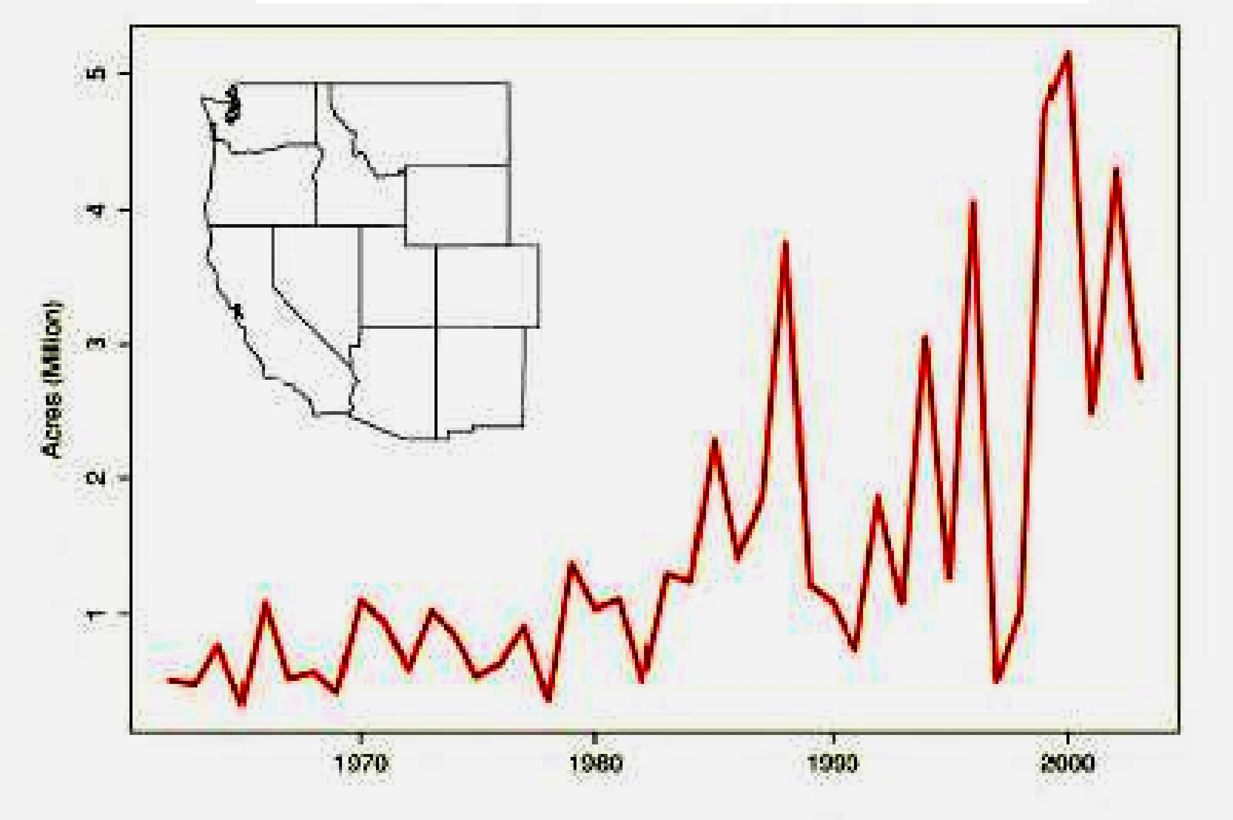


The most dramatic rising trend is in Asia.

…and regions prone to wildfires are getting more so

Wildfires in the Western USA have increased 4-fold in the last 30 years.

Western US area burned



Source: Westerling et al. 2006

Harm is already occurring (concluded)

WHO estimates climate change already causing ≥150,000 premature deaths/yr in 2000

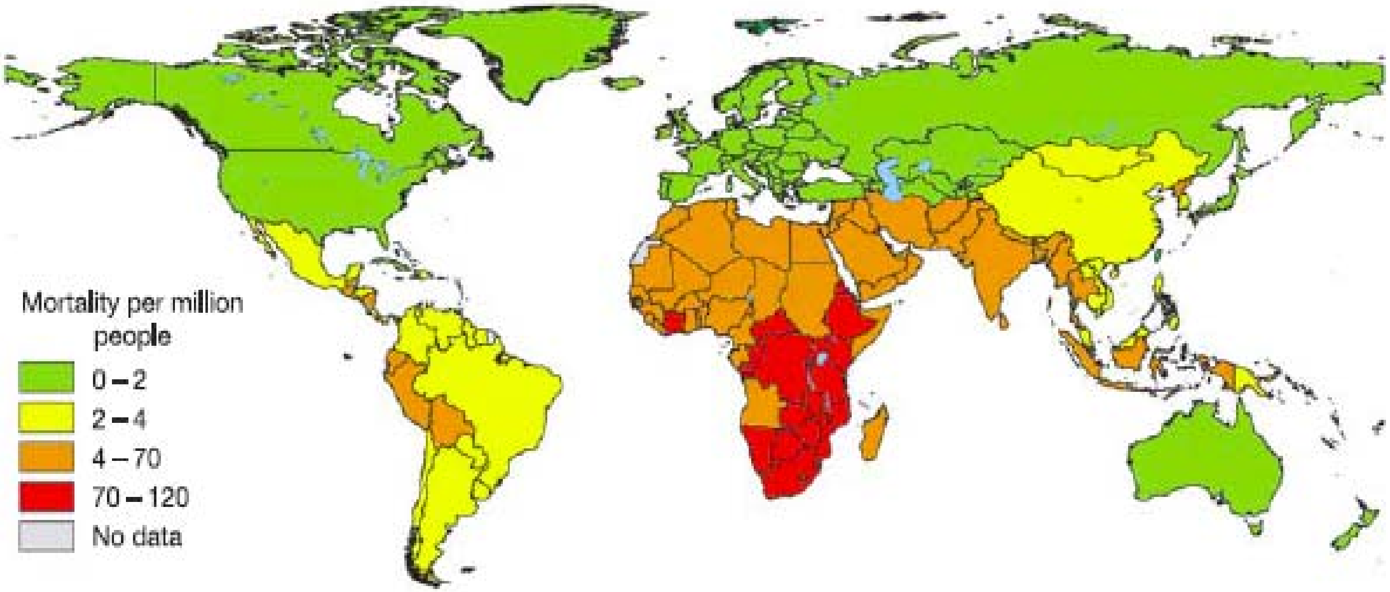
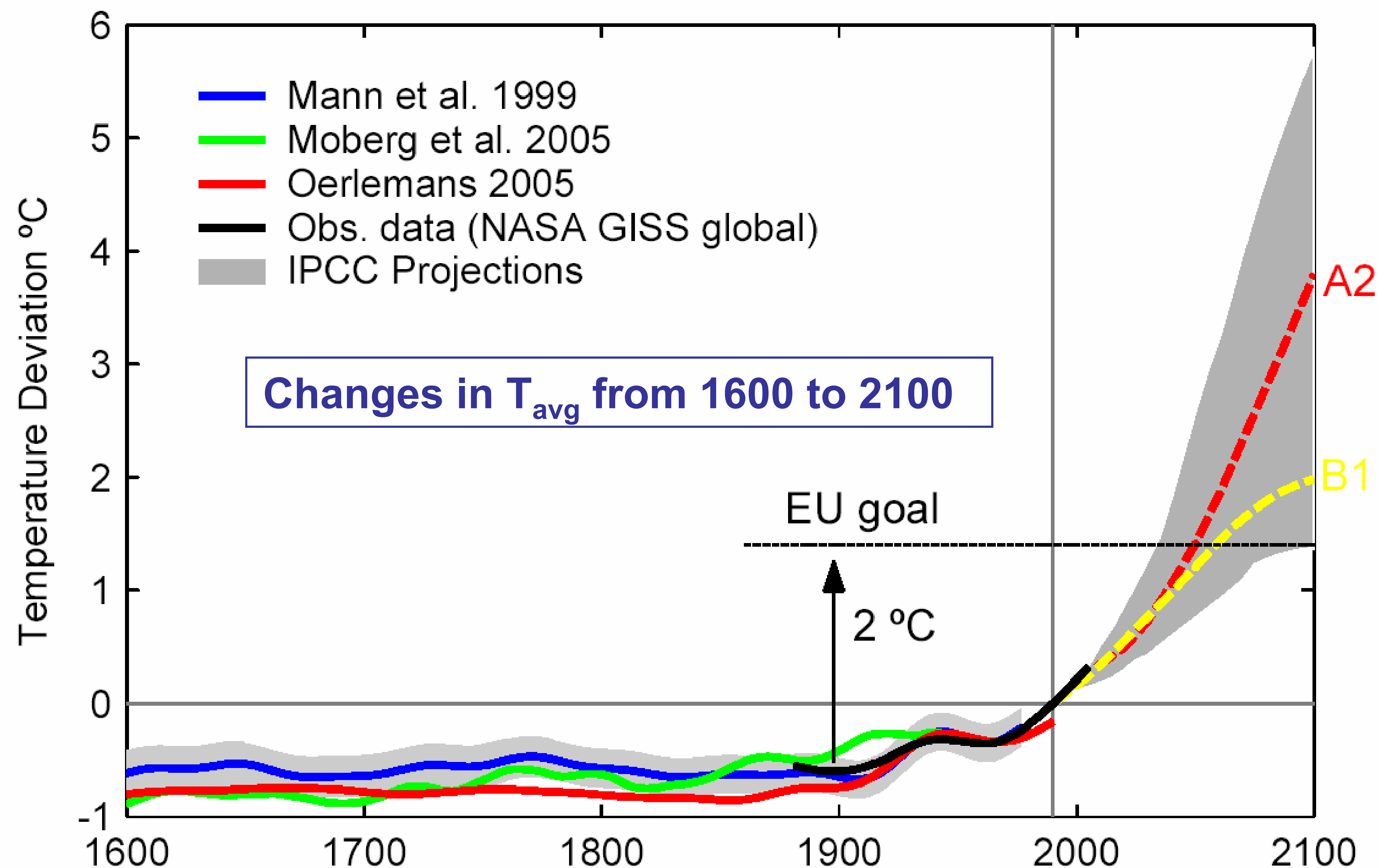


Figure 2 | WHO estimated mortality (per million people) attributable to climate change by the year 2000. The IPCC 'business as usual' greenhouse gas emissions scenario, 'IS92a' and the HadCM2 GCM of the UK Hadley Centre were used to estimate climate changes relative to 'baseline' 1961–1990 levels of greenhouse gases and associated climate conditions. Existing quantitative studies of climate–health relationships were used to estimate relative changes in a range of climate-sensitive health outcomes including: cardiovascular diseases, diarrhoea, malaria, inland and coastal flooding, and malnutrition, for the years 2000 to 2030. This is only a partial list of potential health outcomes, and there are significant uncertainties in all of the underlying models. These estimates should therefore be considered as a conservative, approximate, estimate of the health burden of climate change. Even so, the total mortality due to anthropogenic climate change by 2000 is estimated to be at least 150,000 people per year. Details on the methodology are contained in ref. 57.

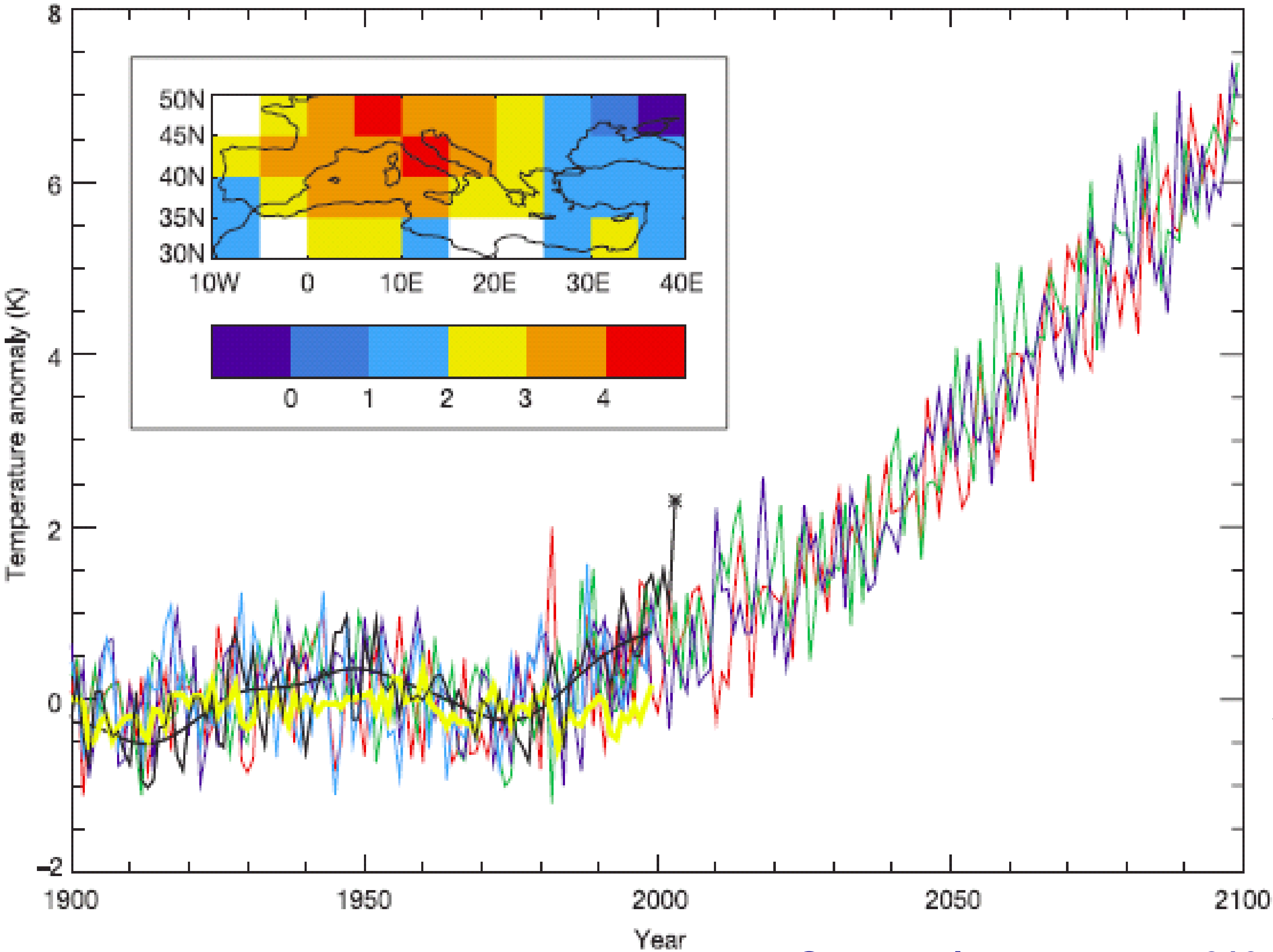
Bigger disruption is coming under BAU



Last time T was 2ºC above 1900 level was 130,000 years ago, and sea level was 4-6 m higher. Last time it was 3ºC above 1900 level was ~25 million years ago, and sea level was 20-30 m higher.

And there will be more harm: Heat waves

Extreme heat waves in Europe, already 2X more frequent because of global warming, will be "normal" in mid-range scenario by 2050



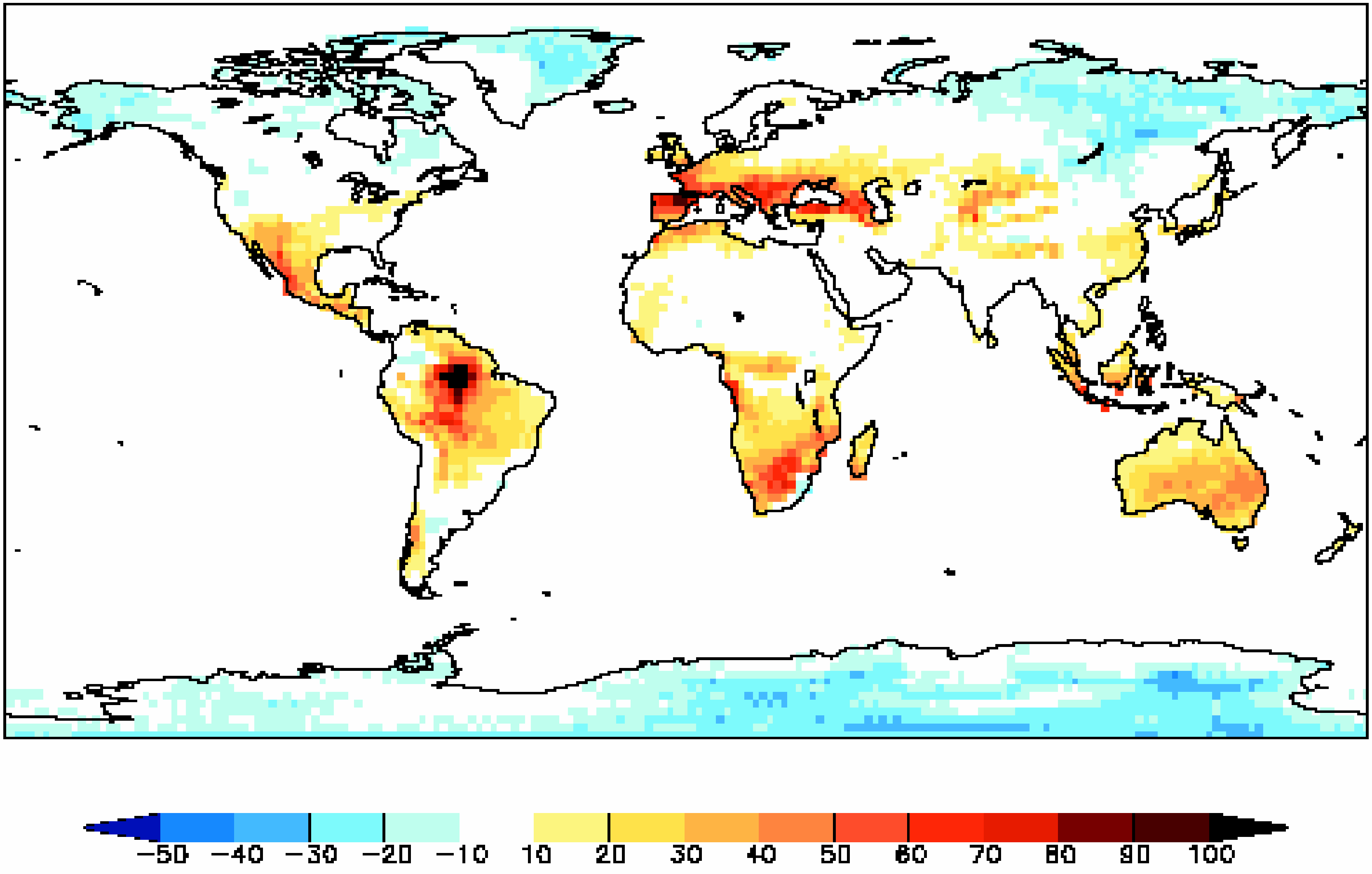
Black lines are observed temps, smoothed & unsmoothed; red, blue, & green lines are Hadley Centre simulations w natural & anthropogenic forcing; yellow is natural only.

Asterisk and inset show 2003 heat wave that killed 35,000.

Stott et al., *Nature 432*: 610-613 (2004)

More harm (continued): droughts

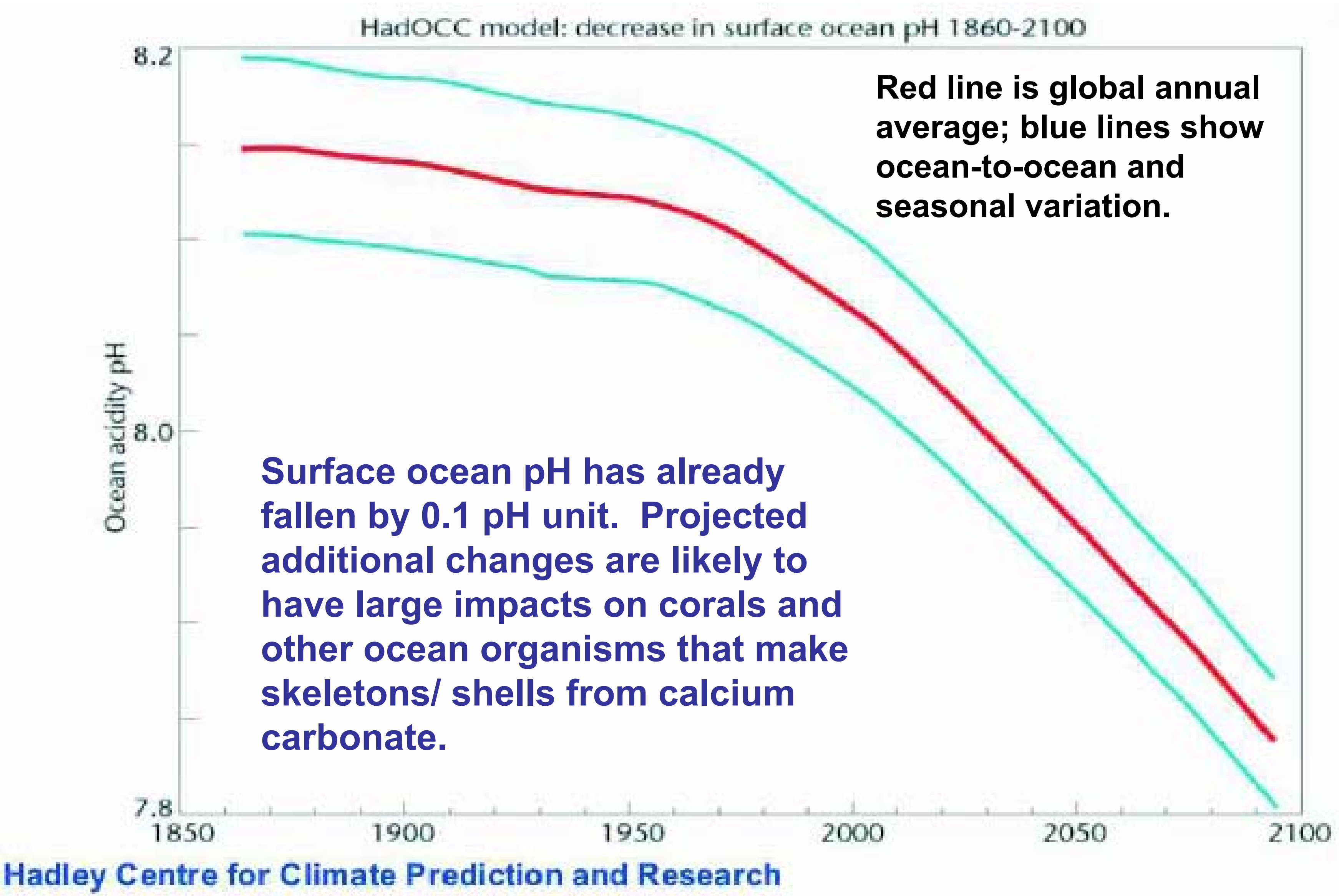
Drought projections for IPCC's A1B scenario



Percentage change in average duration of longest dry period, 30-year average for 2071-2100 compared to that for 1961-1990.

More harm (continued) : Oceans acidifying as well as warming

pH history and “business as usual” projection



Red line is global annual average; blue lines show ocean-to-ocean and seasonal variation.

Surface ocean pH has already fallen by 0.1 pH unit. Projected additional changes are likely to have large impacts on corals and other ocean organisms that make skeletons/ shells from calcium carbonate.

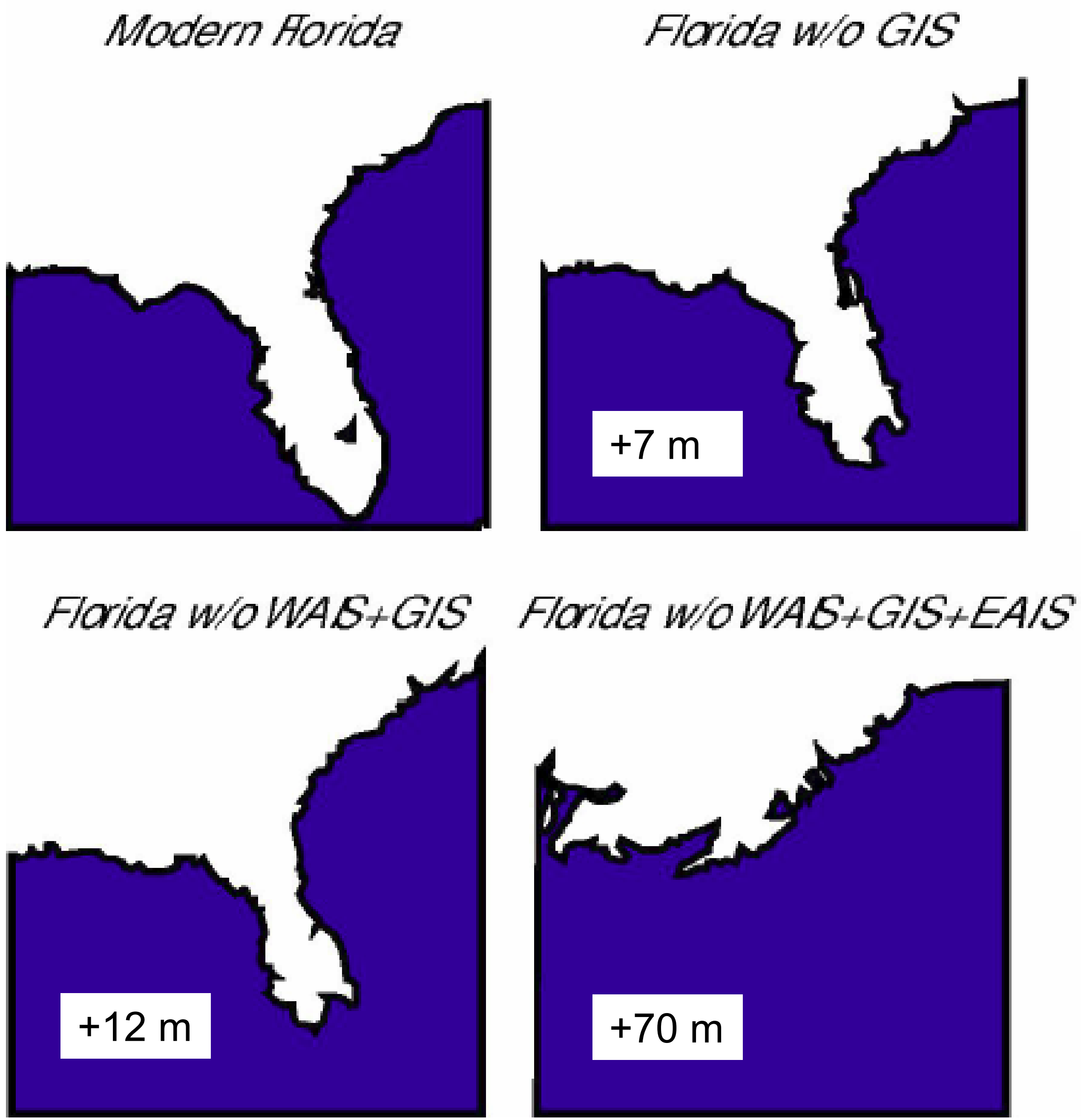
More harm (concl.)**: melting Greenland and Antarctic Ice Sheets would raise sea level up to 70 meters**

This would probably take 1000s of years, but rates of 5 m per century are possible.

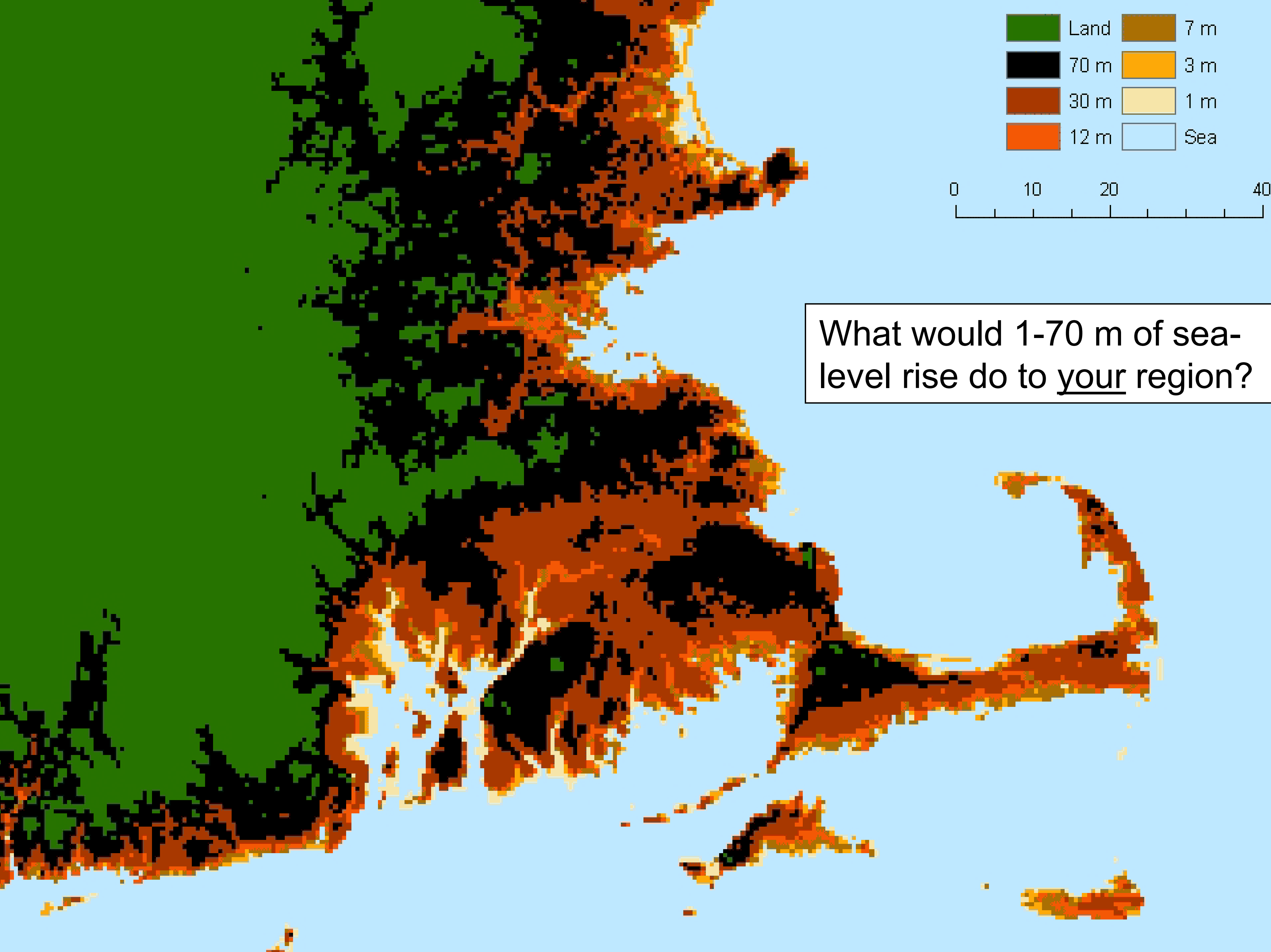
GIS = Greenland Ice Sheet

WAIS = West Antarctic Ice Sheet

EAIS = East Antarctic Ice Sheet



Dr. Richard Alley, 2005


Land
70 m
30 m
12 m
7 m
3 m
1 m
Sea
0
10
20
40
What would 1-70 m of sea-level rise do to your region?

What could we do about climate change?

There are 3 options:

- <u>Mitigation</u>, meaning measures to reduce the pace & magnitude of the changes in global climate being caused by human activities.
- <u>Adaptation</u>, meaning measures to reduce the adverse impacts on human well-being resulting from the changes in climate that do occur.
- <u>Suffering</u> the adverse impacts that are not avoided by either mitigation or adaptation.

Concerning the three options…

- We're already doing some of each.
- What remains to be determined is what the future mix will be.
- Minimizing the amount of suffering in that mix can only be achieved by doing a lot of mitigation and a lot of adaptation.

Adaptation options include…

- Changing cropping patterns & other agricultural practices
- Developing heat-, drought-, and salt-resistant crop varieties
- Strengthening public-health & environmental-engineering defenses against tropical diseases
- Building new water projects for flood control & drought management
- Building dikes and storm-surge barriers against sea-level rise
- Avoiding further development on flood plains & near sea level

Mitigation options could include

(CERTAINLY)

- Reduce deforestation; increase reforestation & afforestation
- Modify agricultural practices to reduce emissions of greenhouse gases & build up soil carbon
- Reduce emissions of greenhouse gases & soot from the energy sector

(POSSIBLY)

- “Scrub” greenhouse gases from the atmosphere technologically
- “Geo-engineering” to create cooling effects offsetting greenhouse heating

How much mitigation, how soon?

- The UN Framework Convention on Climate Change of 1992 is "the law of the land" in 188 countries (including the United States).
- It calls for

  "*stabilization of greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system*".

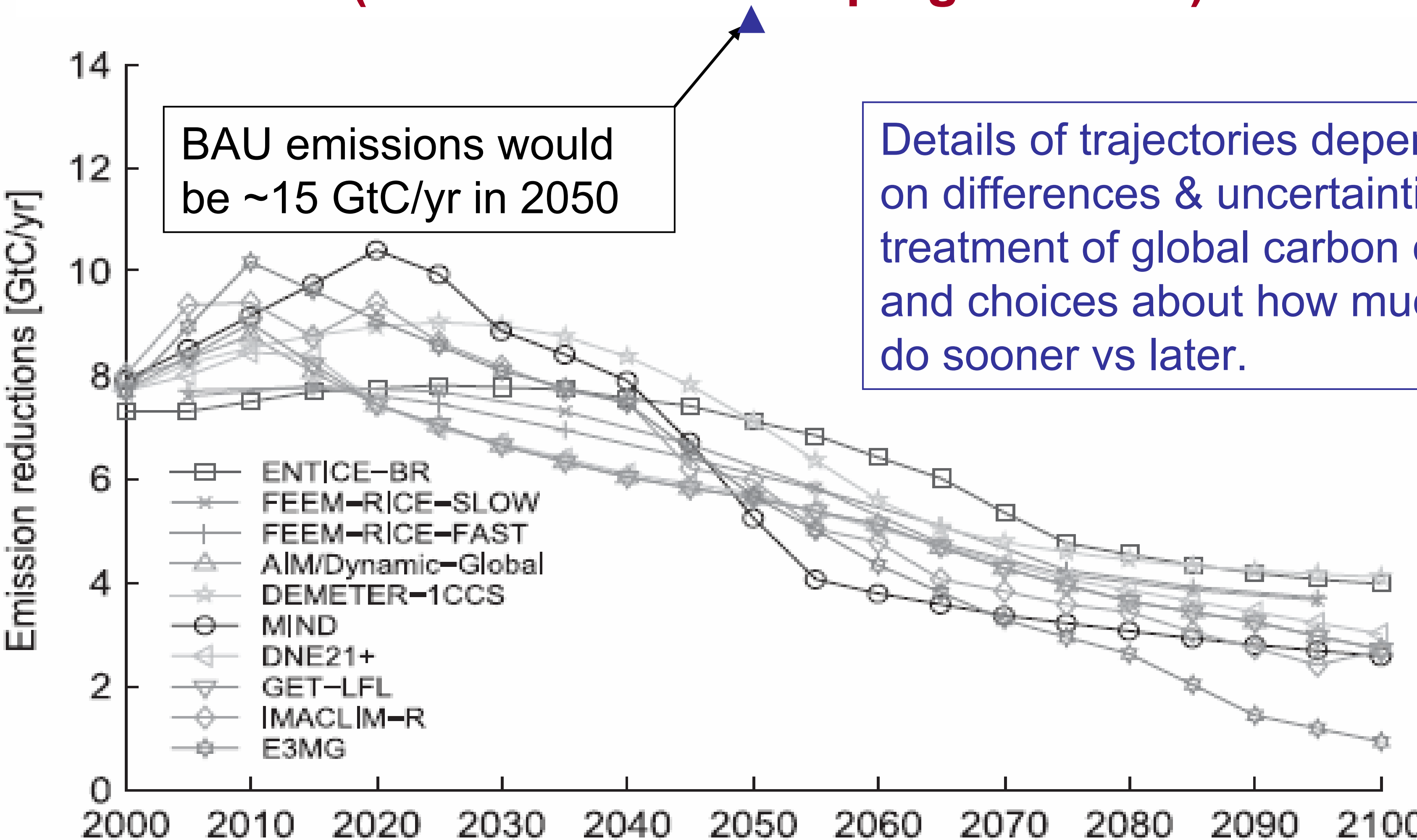
- But there was no formal consensus in 1992 as to what constitutes "dangerous anthropogenic interference" or what level of GHG concentrations will produce it.

How much, how soon? (continued)

- There's still no "official" consensus, but by any reasonable definition the current level of inter-ference is dangerous:
- T_{avg} would rise 0.6°C more (to 1.4ºC above pre-industrial) even if GHG concentrations were stabilized today.
- Chance of a tipping point into catastrophic change grows rapidly for T_{avg} more than 2ºC above pre-industrial (IPCC 2007, UNSEG 2007).
- For a better than even chance of not exceeding ΔT_{avg}=2ºC, CO_2 emissions must peak no later than 2020-2025 & fall steadily thereafter.

Global CO_2 emissions paths for stabilizing the concentration at 450 ppm

(50% chance of keeping $\Delta T < 2°C$)



Details of trajectories depend on differences & uncertainties in treatment of global carbon cycle and choices about how much to do sooner vs later.

Grubb et al., The Energy Journal, 2006

Realities re mitigation

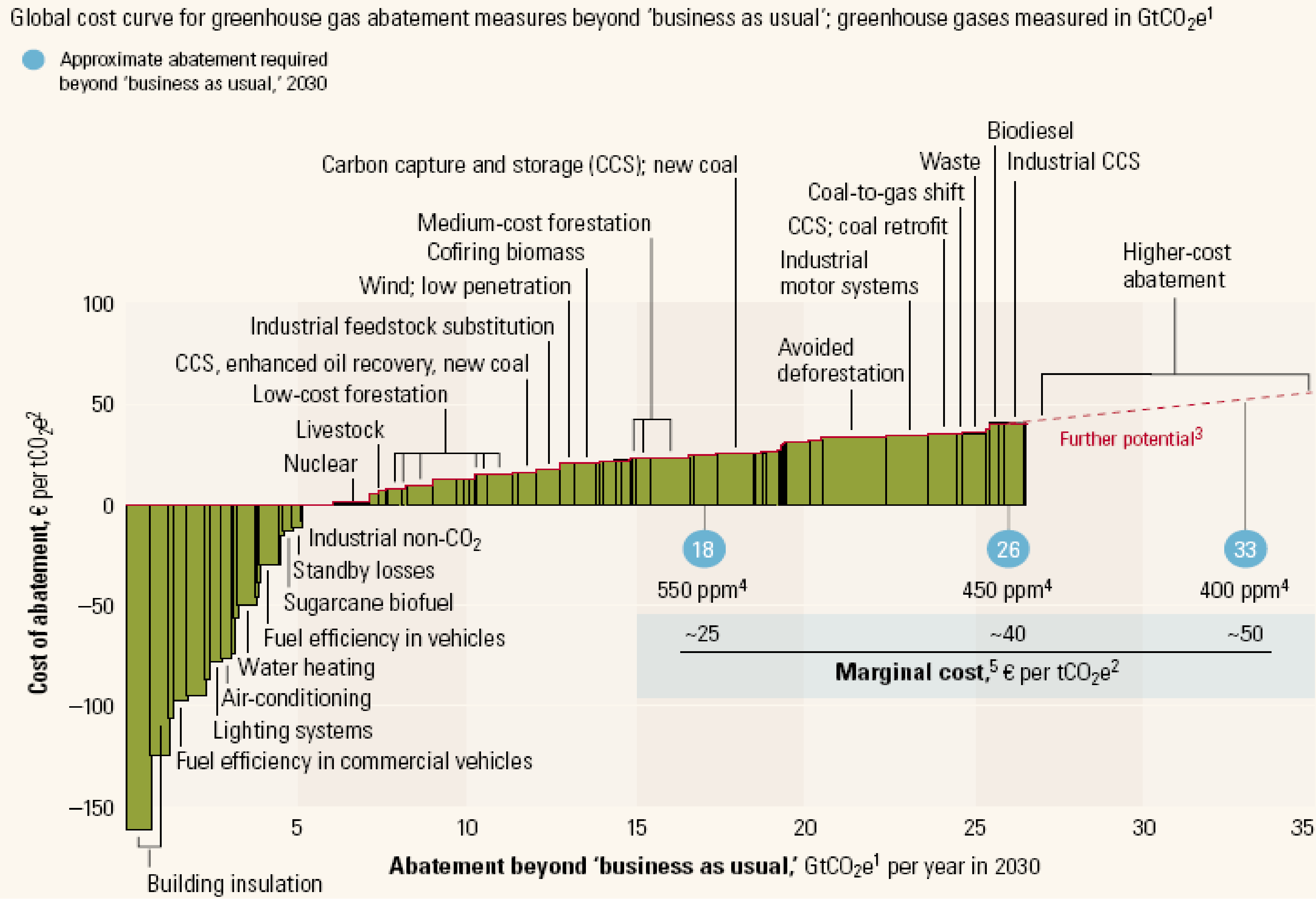
- The cheapest, fastest, cleanest, surest source of emissions reductions is to increase the efficiency of energy use in buildings, industry, and transport.

- Many such approaches are "win-win": their co-benefits in saved energy, increased energy security, reduced conventional pollution, etc., are more than worth their costs.

- Some supply-side mitigation options (wind, some biofuels) are also "win-win", as are many adaptation options.

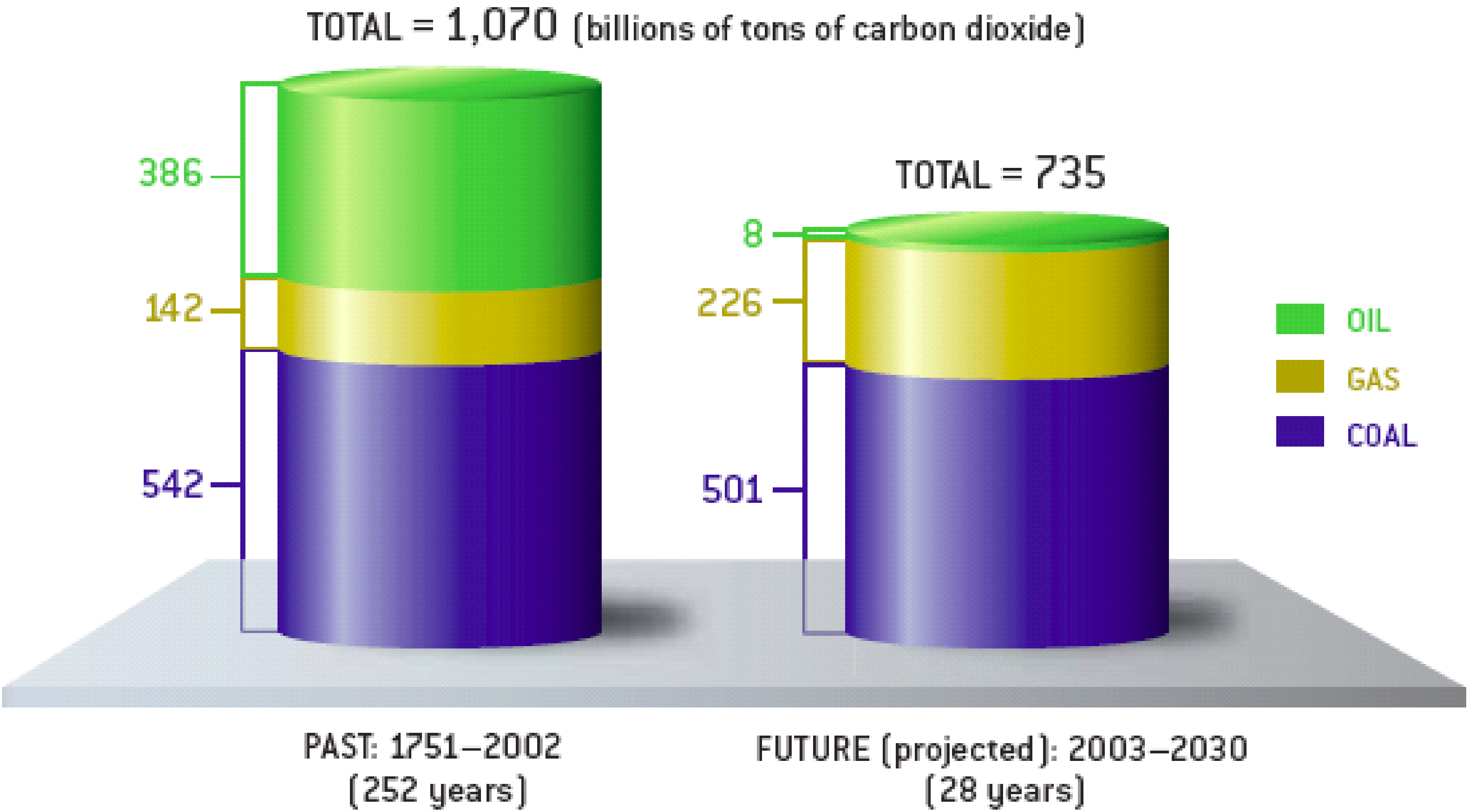
- The "win-win" approaches will not be enough by themselves. Adequate mitigation will require paying to reduce emissions of CO_2 & other greenhouse gases.

Supply curve for GHG abatement in 2030



McKinsey, 2007

Capturing CO_2 from power plants will be costly, but concentrations can't be stabilized soon enough unless we do it.



LIFETIME FOSSIL-FUEL EMISSIONS from power plants projected to be built during the next quarter of a century will be comparable to all the emissions during the past 250 years.

Courtesy David Hawkins, Rob Socolow, & Scientific American

What should we do?

What to do: technological innovation

ONLY WITH IMPROVED TECHNOLOGIES CAN WE

- limit oil imports & oil dependence overall without incurring excessive economic or environmental costs
- improve urban air quality while meeting growing demand for automobiles
- use the world's abundant coal resources without intolerable impacts on regional air quality, acid rain, and global climate
- expand the use of nuclear energy enough to make a difference for climate change and oil & gas dependence, while still reducing accident/terrorism & proliferation risks

Some needed technological improvements

- Cleaner, more fuel-efficient motor vehicles: hybrids (diesels, plug-in hybrids)
- More energy-efficient commercial & residential buildings and industrial processes
- Improved coal technologies to make electricity & hydrogen with CO_2 capture & storage
- Advanced nuclear reactors with increased safety and proliferation-resistant fuel cycles
- Improved batteries & fuel cells
- Biofuels that don’t compete with food & forests
- Cheaper photovoltaic cells

What to do: Oil policy

- Further strengthen CAFE standards
- Provide manufacturer & consumer incentives to promote domestic production & increased use of advanced diesel & hybrid-electric vehicles.
- Implement a variable tax to put a floor under oil price
- Accelerate development & deployment of non-petroleum transportation-fuel alternatives.
- Improve & promote public transportation + land-use planning for shorter commutes.
- Build international cooperation to promote alternatives to expanded oil use in <u>all</u> countries.

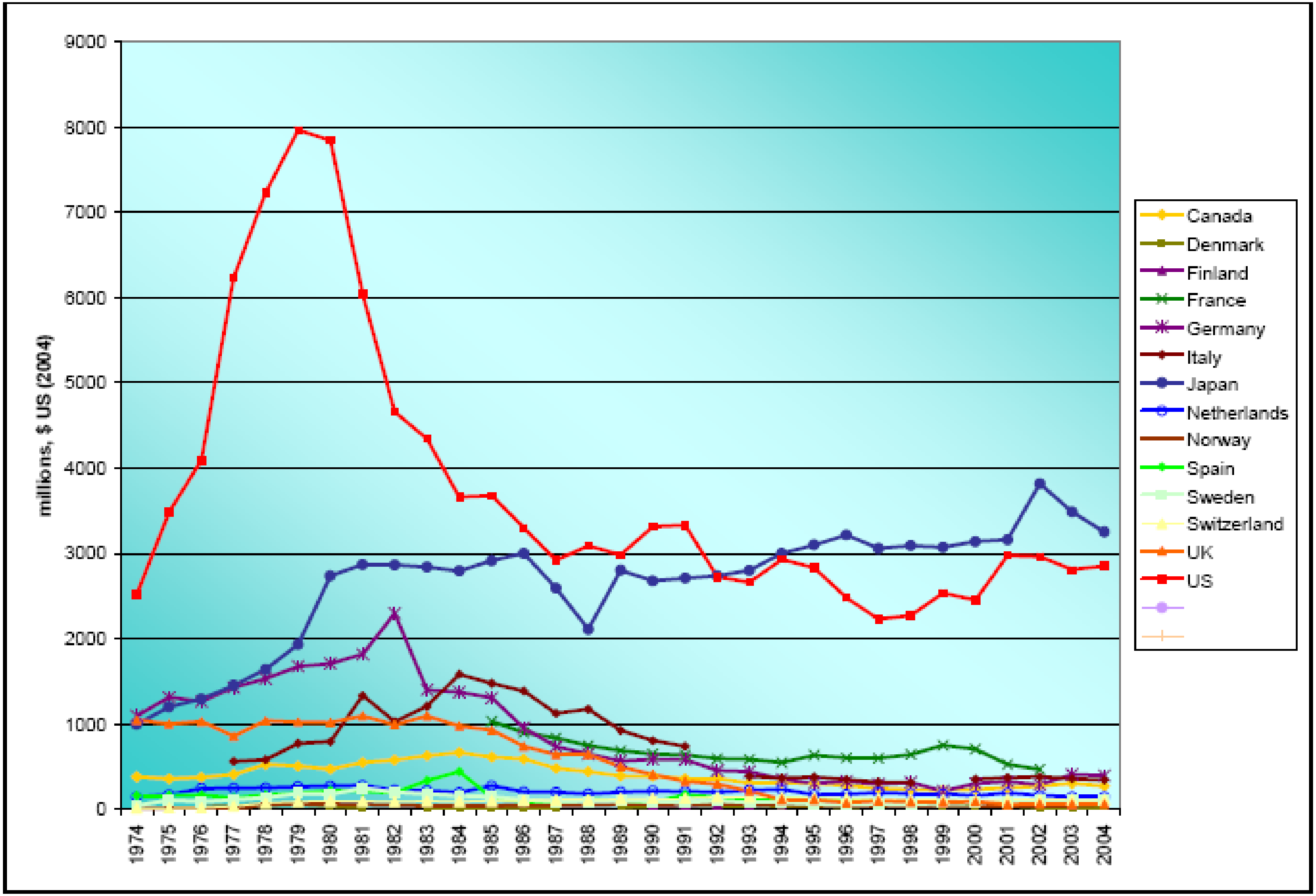
What to do: Climate policy

- Remove barriers to “win-win” solutions
- Put a price on carbon emissions so marketplace can work to find cheapest reductions
- Pursue a new global framework for mitigation and adaptation in the post-Kyoto period
- Increase investments in energy-technology research, development, demonstration
- Expand partnerships (public-private, inter-national) for deploying advanced energy technologies

Increased RD&D should be the easiest part

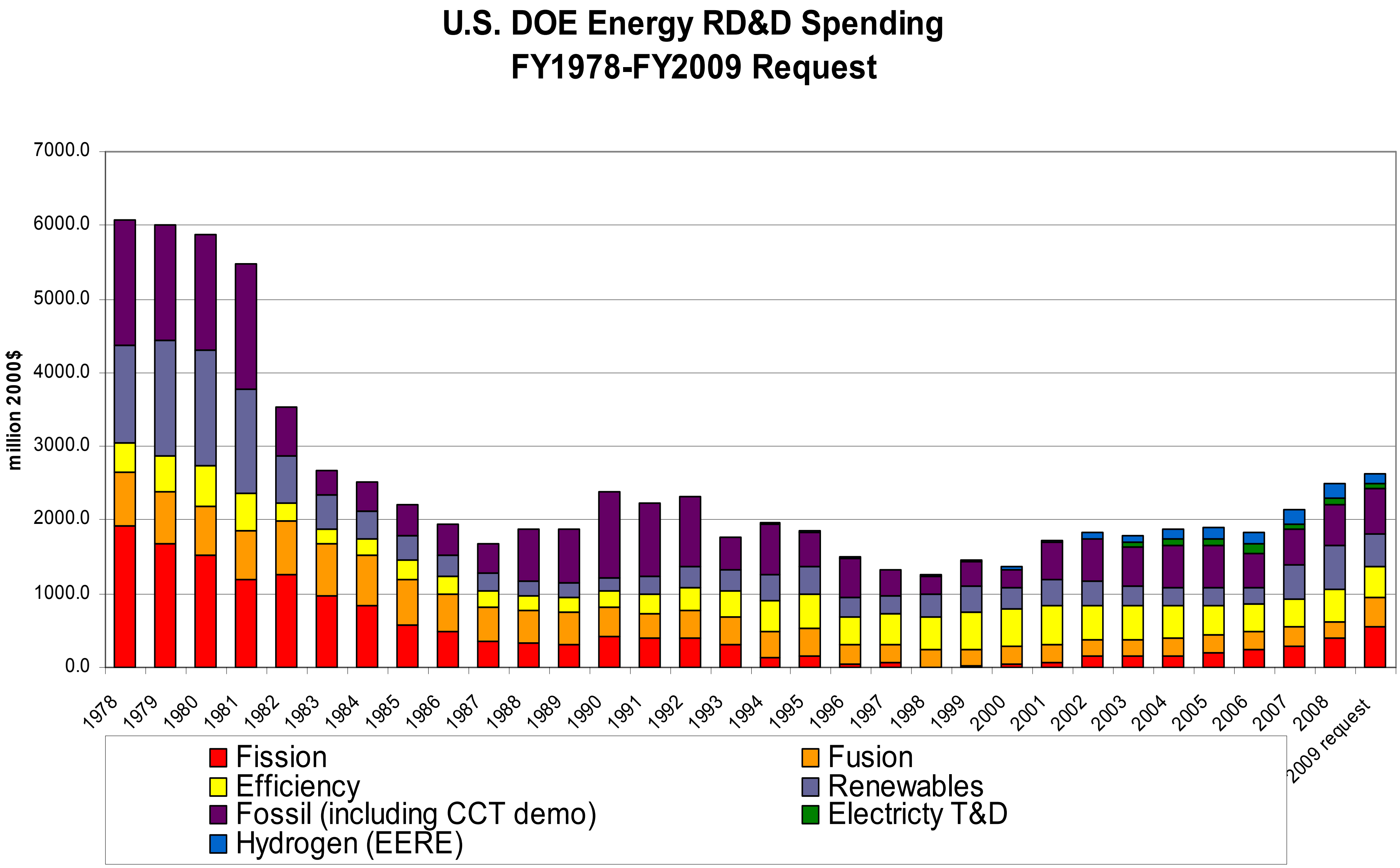
But so far we haven't even gotten that done.

IEA-country government ER&D expenditures



Paul Runci, Oct 2005

US federal energy-technology RD&D, 1978-2009



Kelly Gallagher, Harvard U, 2-14-08

Private-sector investments in ERD&D

- Data on this are much scarcer, less reliable than data on public ERD&D investments:

  Boundaries between energy & non-energy RD&D are hard to draw, in general and within particular firms

- Most assessments estimate that private ERD&D has more or less tracked public, falling through 1980s and 1990s, rising some since.
- A <u>very</u> rough estimate is that private ERD&D in the USA and worldwide is between 1X and 2X of the public figure; thus total public and private would be 2-3X public.

Spending for energy & ER&D in perspective

(estimates for 2005 in millions of 2005 US$, converted at ppp)

World economic product	59,000,000
…value of E-system capital stock	15,000,000
…retail expenditures on energy	5,000,000
…expenditure on all R&D	1,000,000
…investment/yr in E-supply system	800,000
…expenditure on energy R&D	<30,000
US economic product	12,500,000
…expenditure on energy	1,000,000
…expenditure on all R&D	320,000
…expenditure on ER&D	~6,000

Can we afford to do more?

- US federal energy R&D is a tiny fraction of all federal non-defense R&D, dwarfed by health, space, & general science, and exceeded even by agriculture.

- If US public & private energy R&D combined were <u>tripled</u>, the amount would still be under 2% of what US consumers pay for energy at retail. In most other high-tech industrial sectors, investments in R&D are 4-10% of revenues.

- If emissions permits for CO_2 were auctioned at $30/t$CO_2$, revenues in the USA in 2006 would have been ~$180 billion and worldwide revenues ~$900 billion. Just 5% of these revenues would allow tripling public investments in energy RD&D in the USA and worldwide.

We cannot afford <u>not</u> to do this.

Some key references

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