Global Energy Challenges and the Role of Increased Energy Efficiency in Addressing Them

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Remarks at the Symposium on

The Rosenfeld Effect

Honoring Arthur Rosenfeld on the Occasion of his 80^{th} Birthday

Berkeley, California

28 April 2006

The multiple aims of energy policy

ECONOMIC AIMS

- meet basic energy needs of the poor
- reliably meet fuel & electricity needs of growing economies
- limit consumer costs of energy
- limit cost & vulnerability from imported oil

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)

HOMELAND- & NATIONAL-SECURITY AIMS

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

Remaining Ultimately Recoverable Resources

	TWy
FOSSIL	
conventional oil	500
conventional natural gas	500
unconv oil (excluding low-grade oil shale)	700
unconv gas (excluding clathrates, geopressured gas)	400
coal	5,000
methane clathrates, geopressured gas	30,000
low-grade oil shale	30,000
NUCLEAR	
uranium in LWRs	1,500
...in LMFBRs	1,500,000

TWy = terawatt-year = 31.5 exajoules; world in 2005 used ~16 TWy

Renewable energy resources

SUNLIGHT: 100,000 TWy/y reaches Earth's surface, 30% on land.

> 1% of land area receives 300 TWy/y → conversion to usable forms @ 20% efficiency yields 60 TWy/y.

WIND: Solar energy flowing into the wind is ~2,000 TWy/y.

> Harvestable wind-energy potential expressed as generated electricity estimated at 20,000-50,000 TWh/y (containing circa 2-5% of the 2000 TWy/yr), or 1.3-3x 2005 world electricity generation.

BIOMASS: Solar energy is stored by photosynthesis on land at a rate of about 60 TWy/y.

> Energy crops at 2x avg terrestrial photosynthetic yield would give 12 TW from 10% of land area (equal to current use for agriculture). Converted to liquid biofuels at 50% efficiency, this gives 6 TWy/y, more than world oil use in 2004.

Tensions among energy-policy aims

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

There's no "silver bullet": No known energy option is free of liabilities, uncertainties

• oil & gas…	not enough resources?
• coal, tar sands, oil shale…	not enough atmosphere?
• biomass…	not enough land?
• wind & hydro…	not enough good sites?
• photovoltaics…	too expensive?
• nuclear fission…	too unforgiving?
• nuclear fusion…	too difficult?
• hydrogen…	energy to make it? means to store it?
• end-use efficiency…	not enough smart end-users?

A successful energy policy must…

1. help society identify and deploy a suitable mix of energy-supply and energy end-use options from the currently available menu

   i.e., one that yields a good compromise among the competing economic, environmental, & security objectives

2. promote technological advances that improve the menu over time

   reducing the limitations of existing energy options, opening new options, & reducing the tensions among energy-policy objectives.

Improved technologies would help…

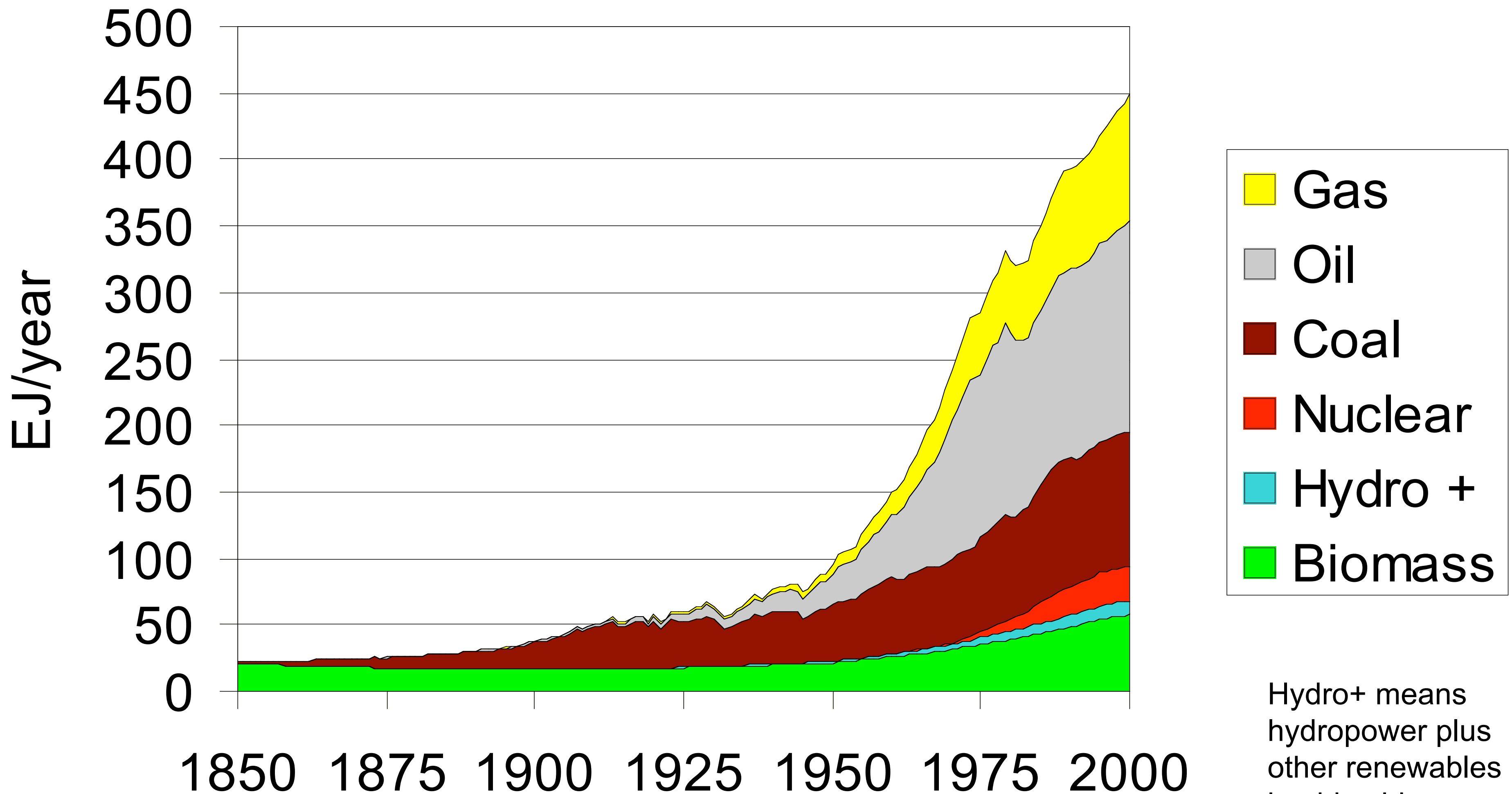
1. reduce oil demand & limit imports without incurring excessive economic or environmental costs
2. improve urban air quality while meeting growing demand for automobiles
3. use abundant coal resources without intolerable impacts on regional air quality & acid rain
4. expand the use of nuclear energy while reducing accident & proliferation risks
5. achieve & sustain economic prosperity worldwide while controlling the risks from global climate change

The two biggest challenges

- Reducing the economic vulnerability arising from oil & gas dependence overall -- and the balance-of-payments and foreign-policy liabilities arising from oil & gas imports -- despite growing demand from the transport sector for liquid fuel and from homes, industry, & electric utilities for gas.
- Providing the affordable energy services needed to create & sustain prosperity without unmanageable disruption of global climate by greenhouse gases from fossil-fuel use.

Magnitude of the challenges: oil & gas

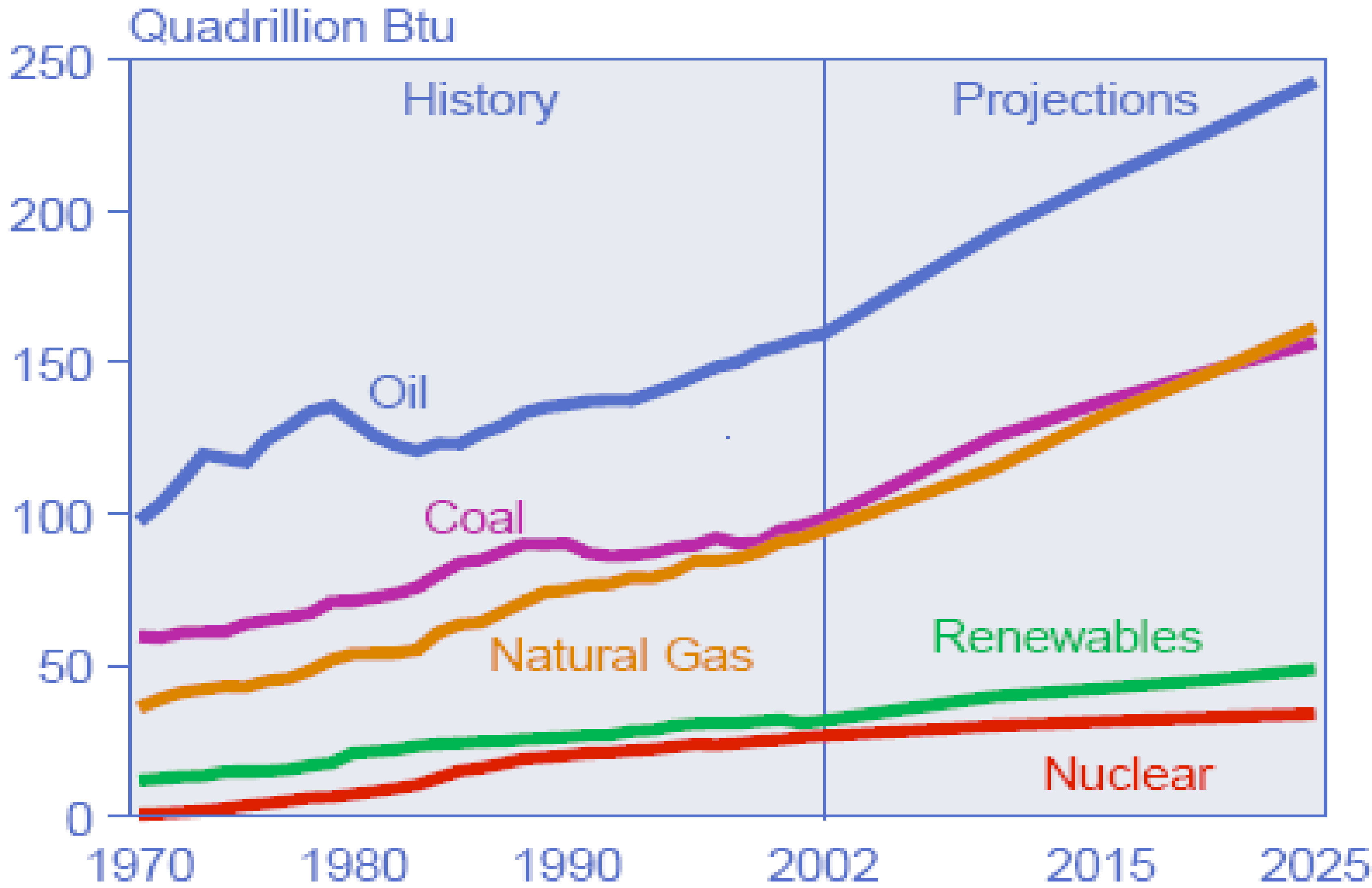
World primary energy supply, 1850-2000



Hydro+ means hydropower plus other renewables besides biomass

The world energy system is increasingly dominated by oil & gas.

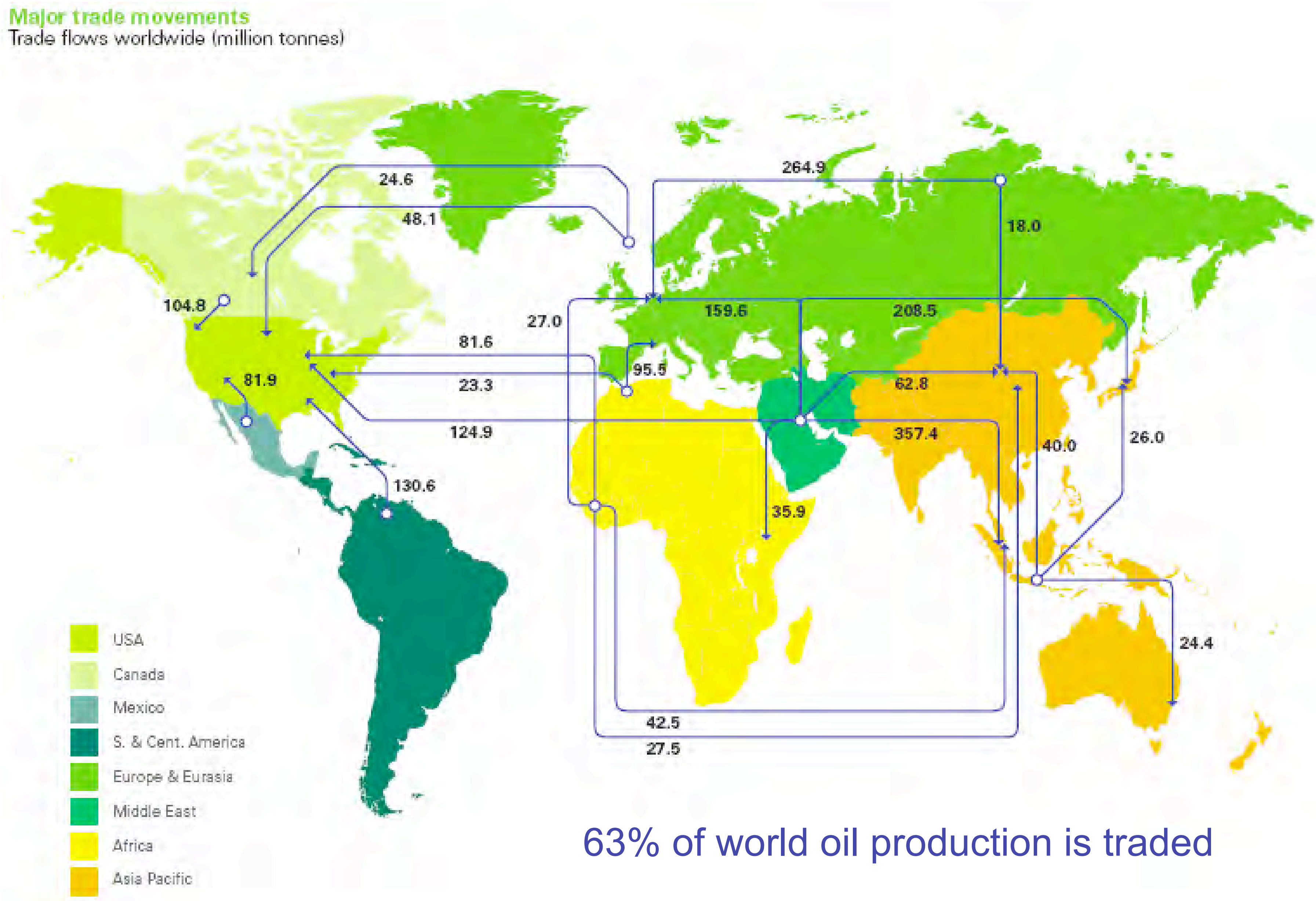
The dominance of oil and gas is projected to continue, threatened only by coal



Source: EIA 2005 International Energy Outlook

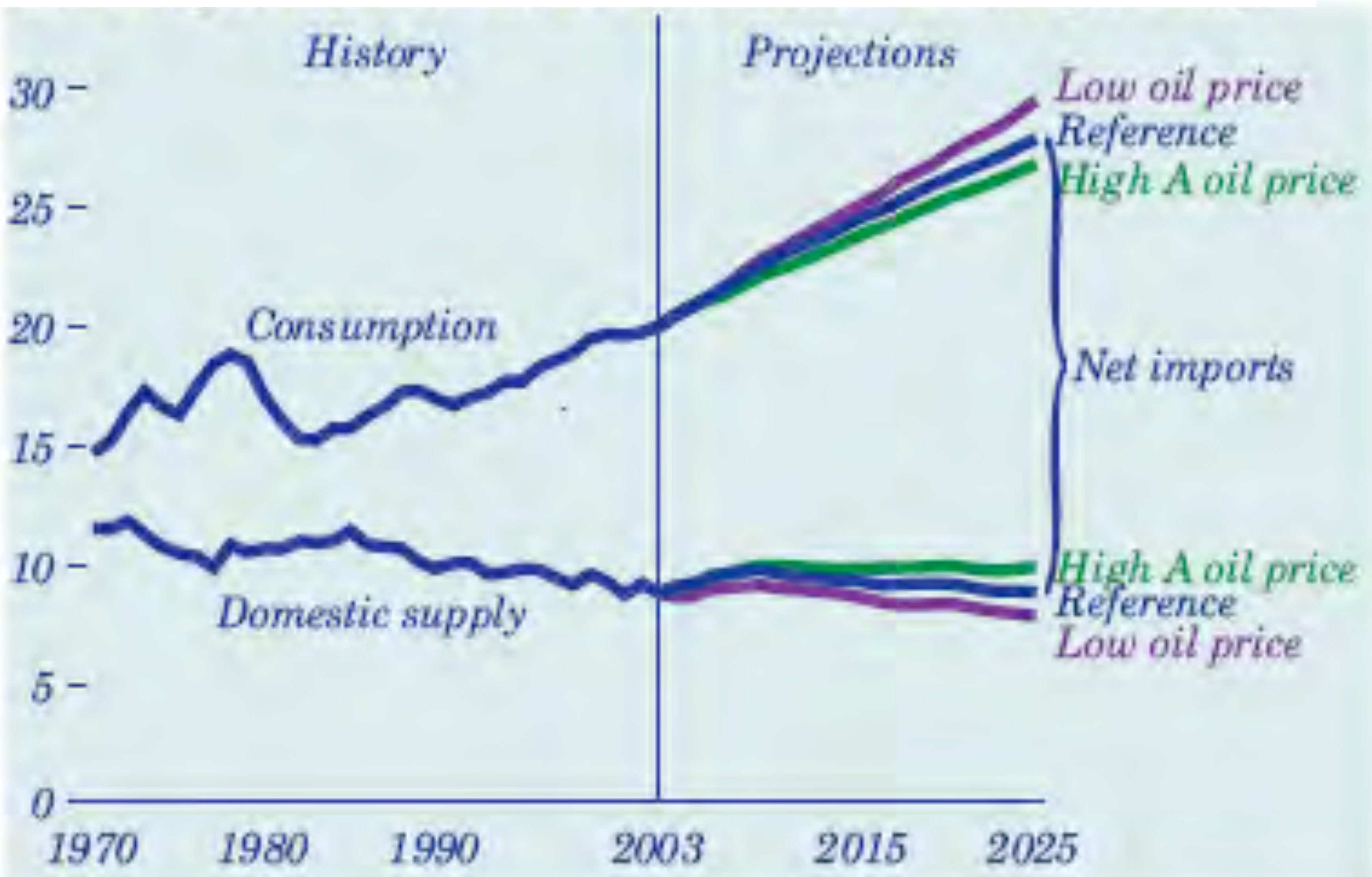
World oil trade flows, 2004

Source: BP 2005



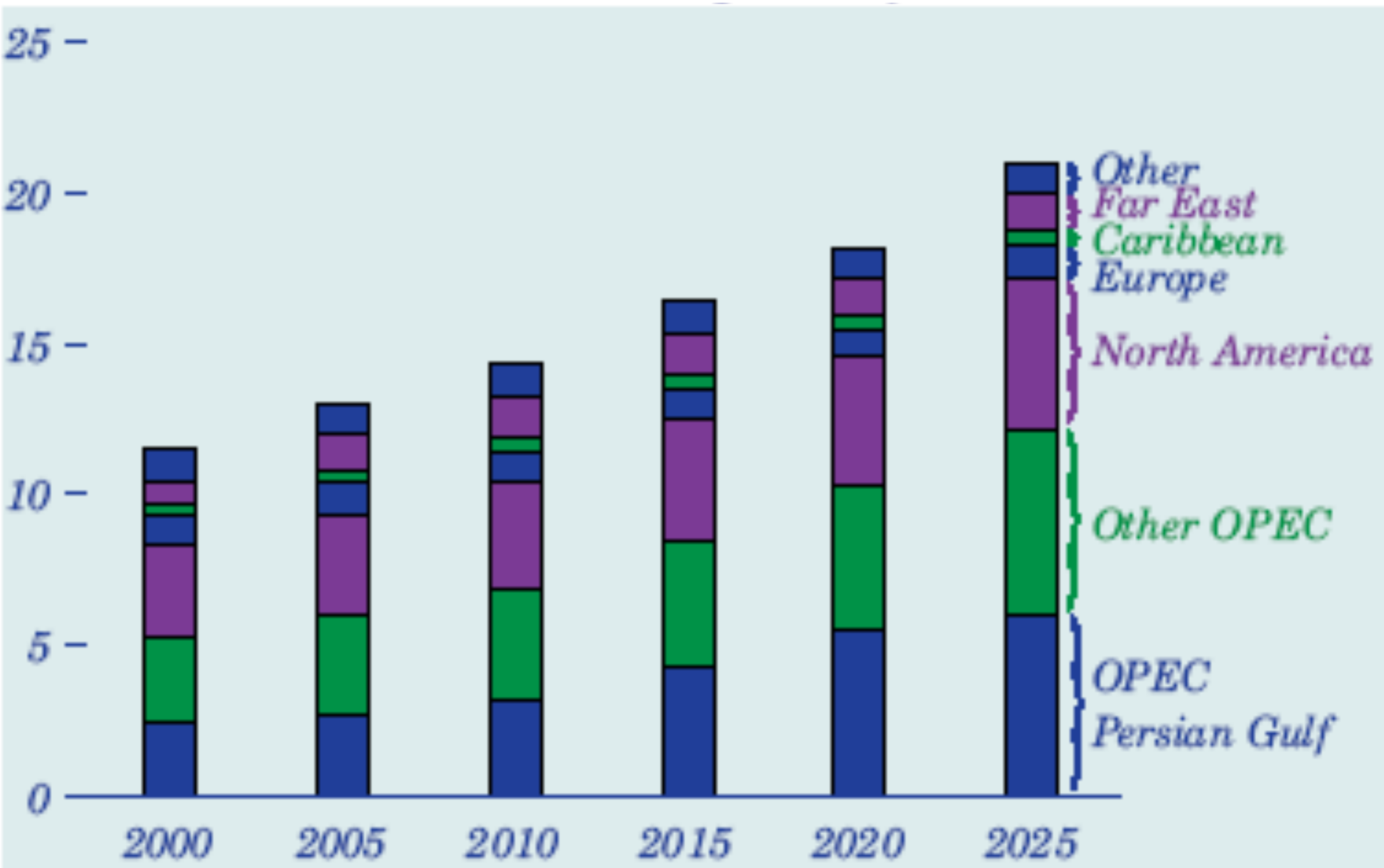
63% of world oil production is traded

The soaring oil-import dependence of the United States



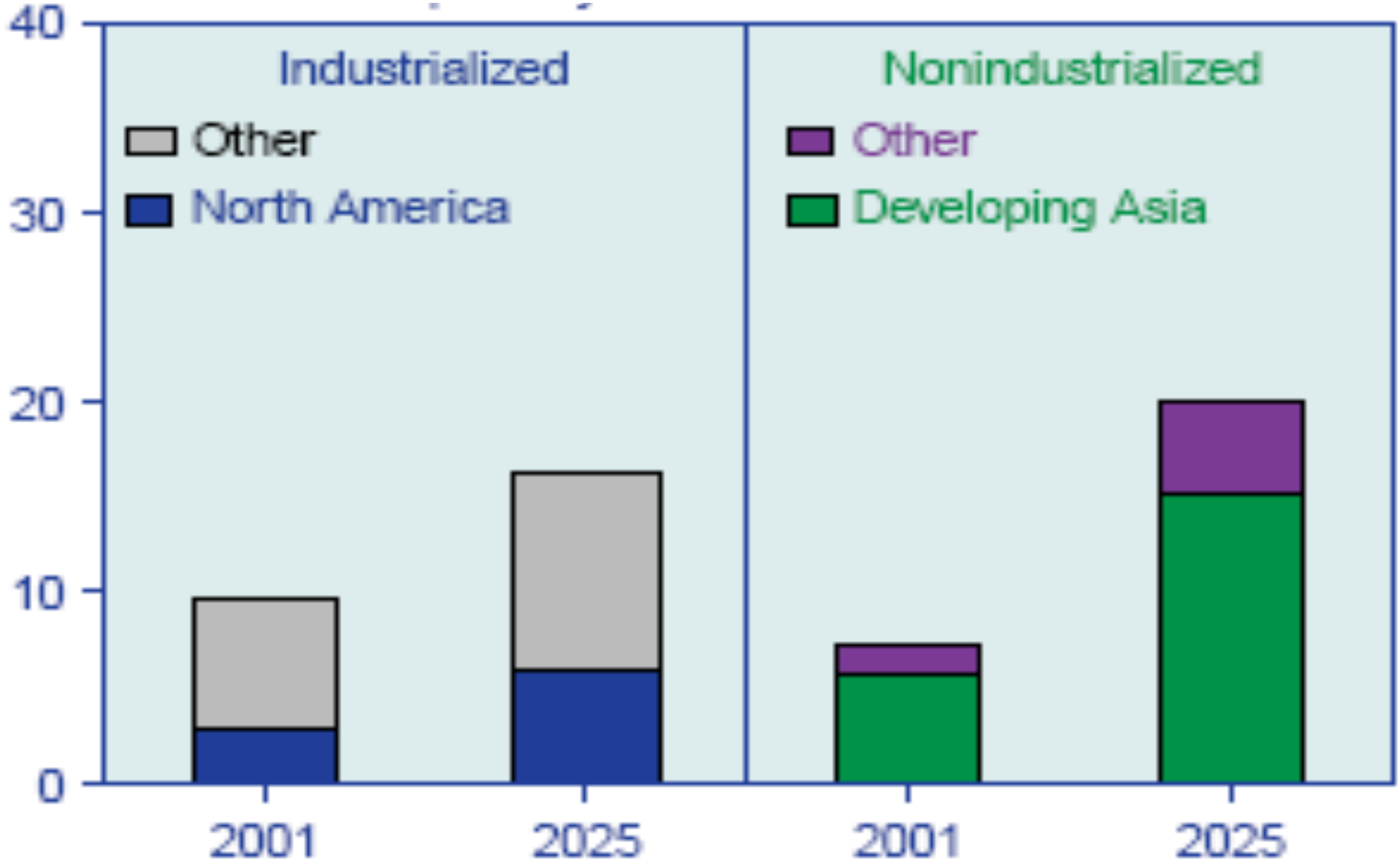
Source: EIA, Annual Energy Outlook 2005, p 101

U.S. oil imports are destined to come increasingly from the Persian Gulf



Source: EIA Annual Energy Outlook 2005, p 74

Developing Asia's dependence on the Persian Gulf is already bigger than North America's and is expected to grow much faster.

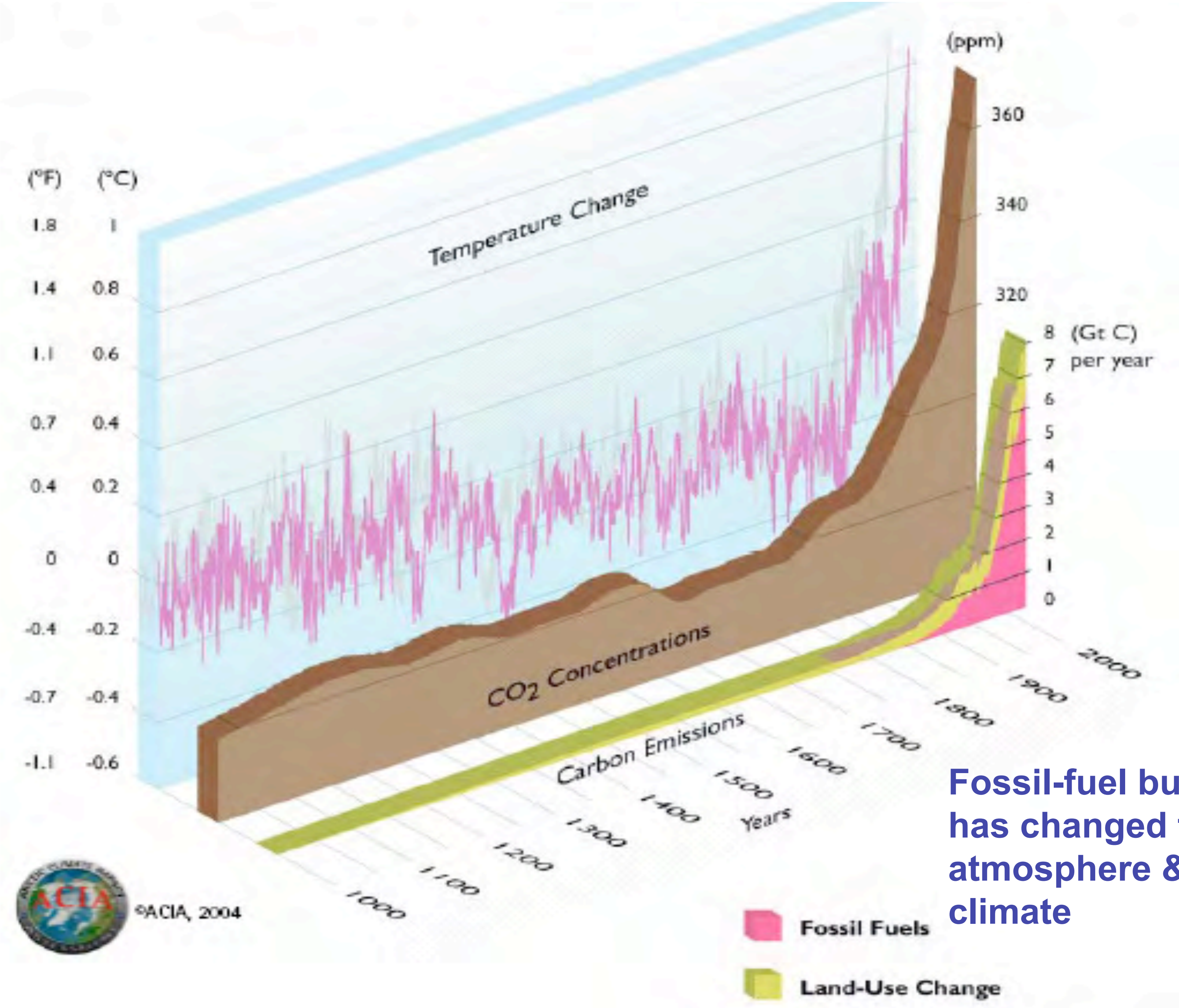


Source: EIA International Energy Outlook 2004, p 41

Magnitude of the challenges: What climate change puts at risk

- productivity of farms, forests, & fisheries
- prevalence of oppressive heat &humidity
- geography of disease
- damages from storms, floods, droughts, wildfires
- property losses from sea-level rise
- expenditures on engineered environments
- distribution & abundance of species

1000 years of global C emissions, CO_2 concentrations, and temperature



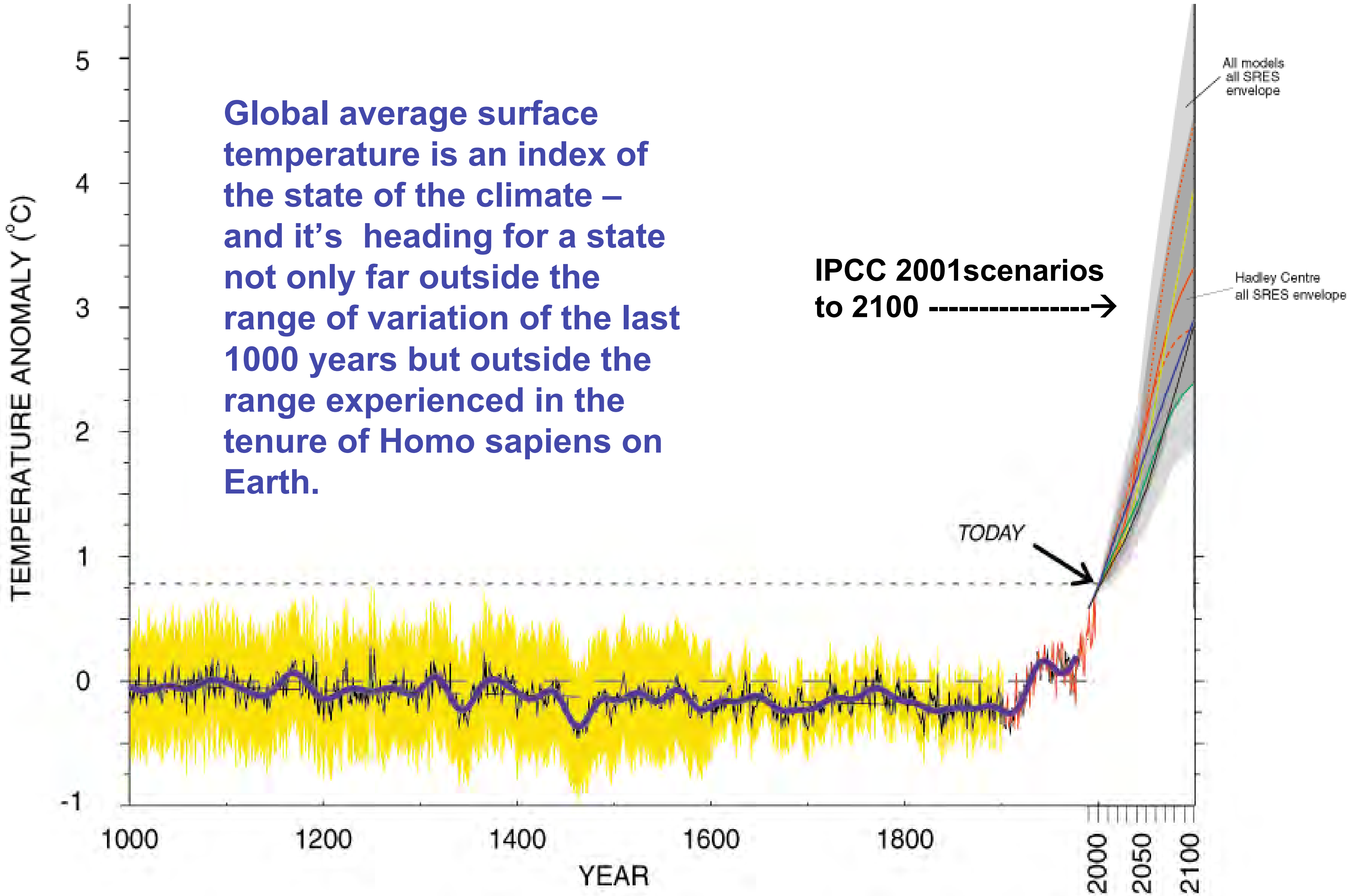
Fossil-fuel burning has changed the atmosphere & the climate

What are we headed for?

A "middle of the road" IPCC scenario (global)

	2000	2050	2100
	-------	-------	-------
Population, billions	6.1	9.8	11
Economy, trillion 2000$	45	170	450
Energy, exajoules	450	1100	1800
C in CO_2, gigatons	6.4	14.3	20.8

1000 years of Earth temperature history…and 100 years of projection



How much deflection from BAU is needed?

- The climate-policy aim negotiated in the process of formulating the UN Framework Convention on Climate Change was…

  …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 consensus as to what this level is.

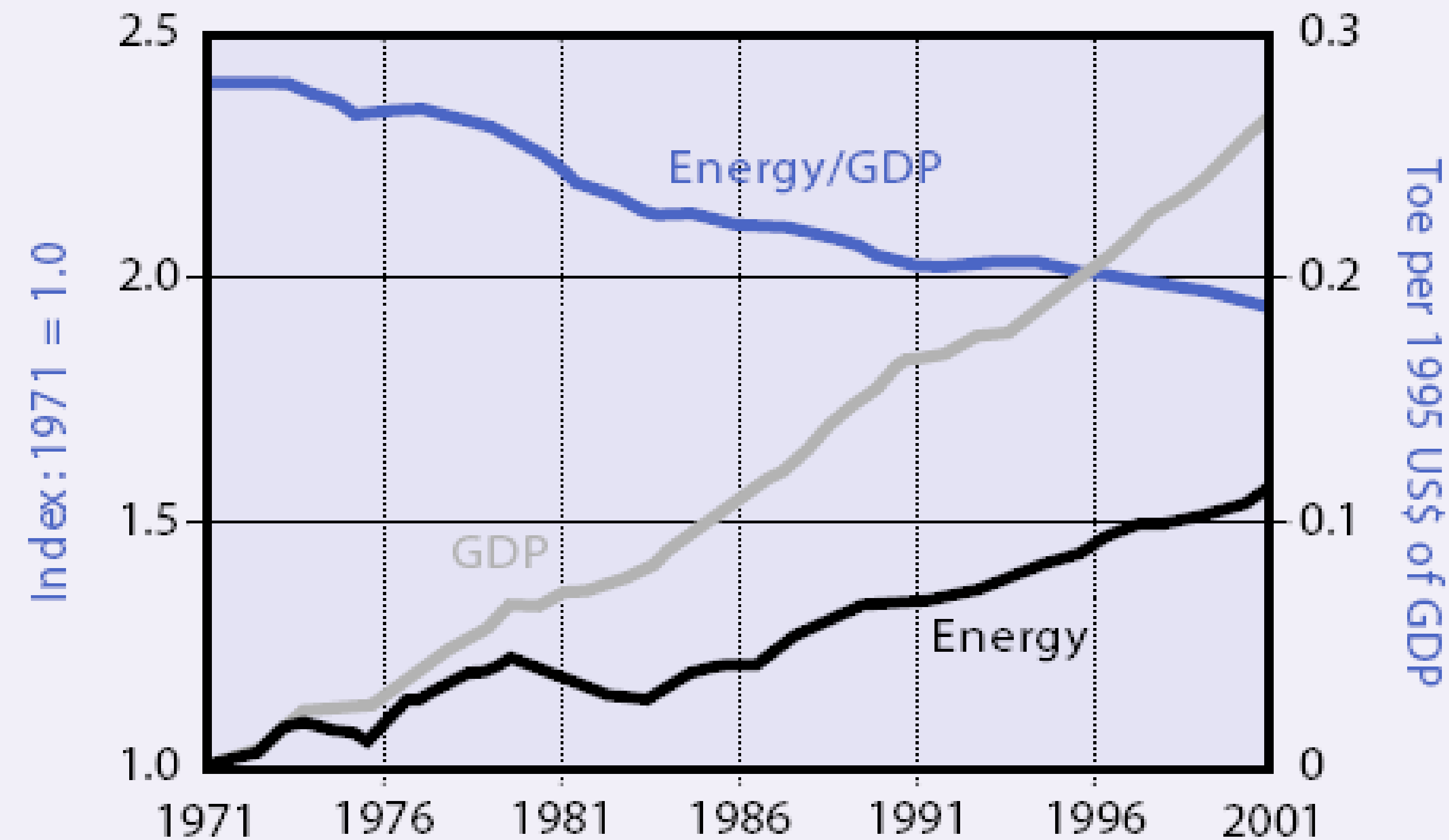
How much deflection? (continued)

- Still no consensus, but…

  Significant impacts in terms of floods, droughts, wildfires, species, and melting ice are already evident at ~0.8°C above pre-industrial T_{avg}, and current GHG concentrations commit us to ~0.6°C more.

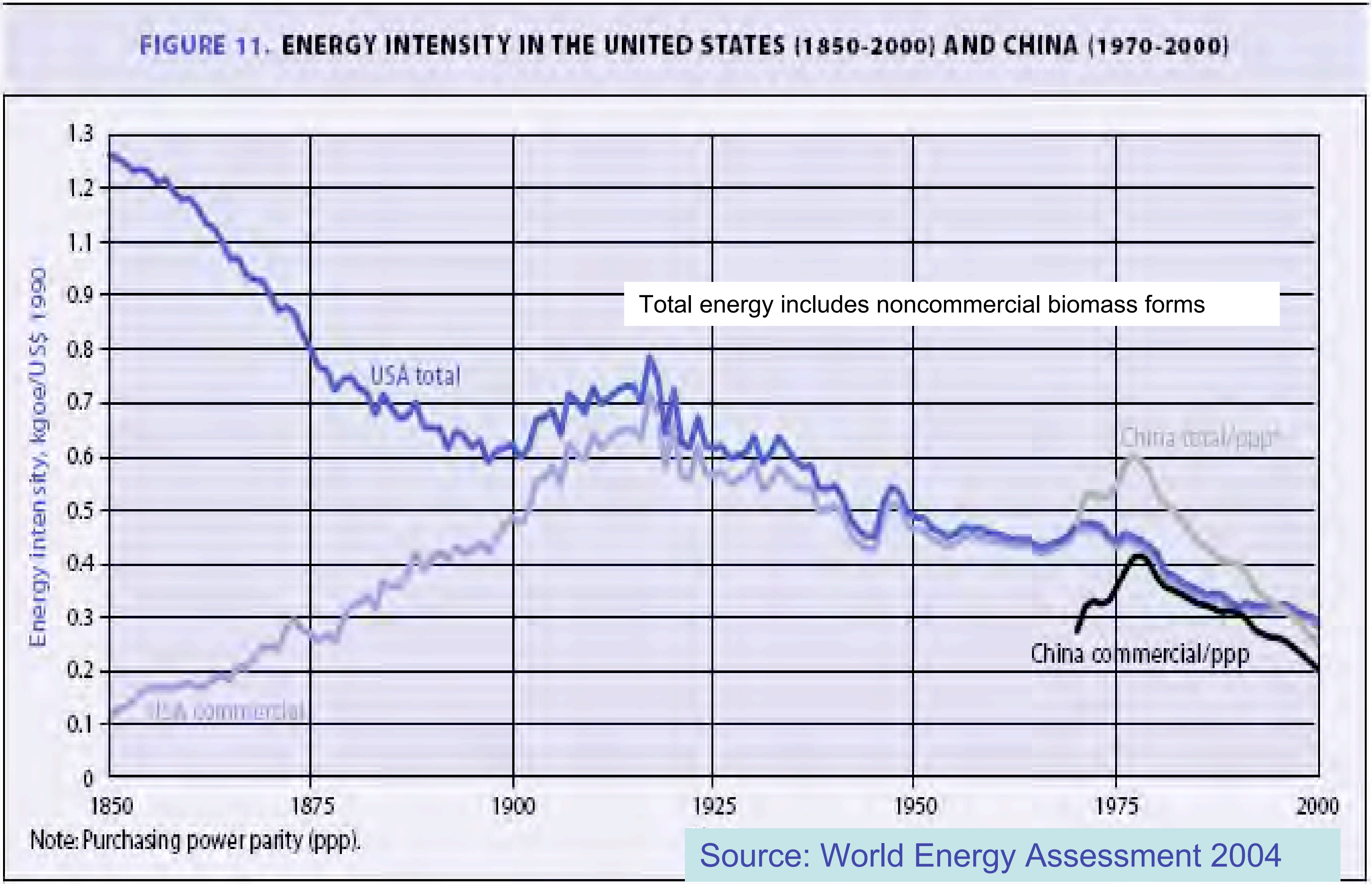
- It's increasingly clear that…
  - ΔT_{avg} ~ 1.5°C could mean end of coral reefs & polar bears
  - ΔT_{avg} ~ 2°C could mean catastrophic melting of Greenland & Antarctic ice
  - ΔT_{avg} ~ 2.5°C could sharply reduce crop yields worldwide
- This means stopping at a doubling of pre-industrial CO_2 (550 ppmv, corresponding to ~3°C and once thought a reasonable target by many) is <u>not good enough</u>.

FIGURE 10. GDP AND PRIMARY ENERGY USE IN OECD COUNTRIES, 1971-2001



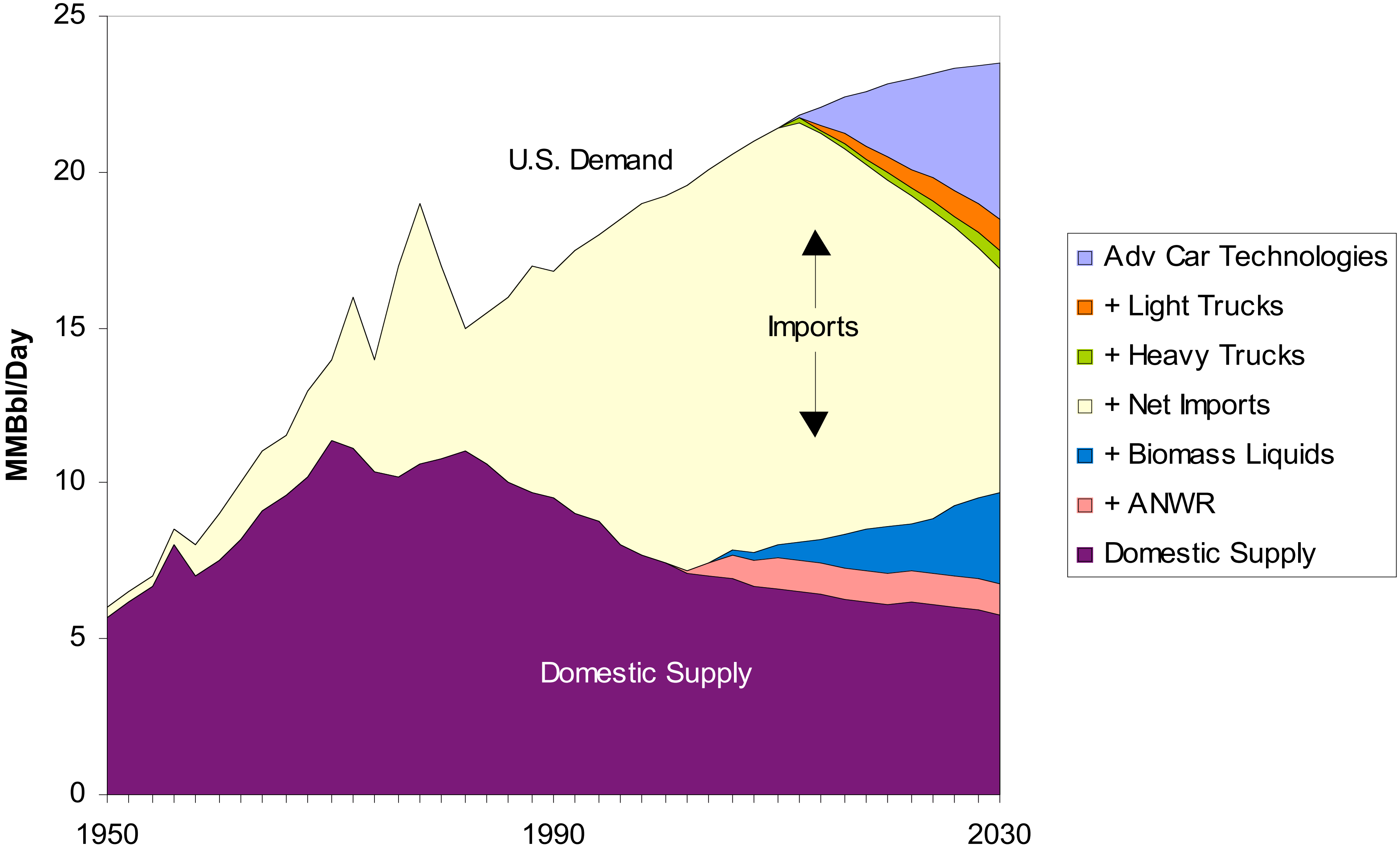
Source: World Energy Assessment 2004

The amount of energy needed per dollar of real GDP has been falling.



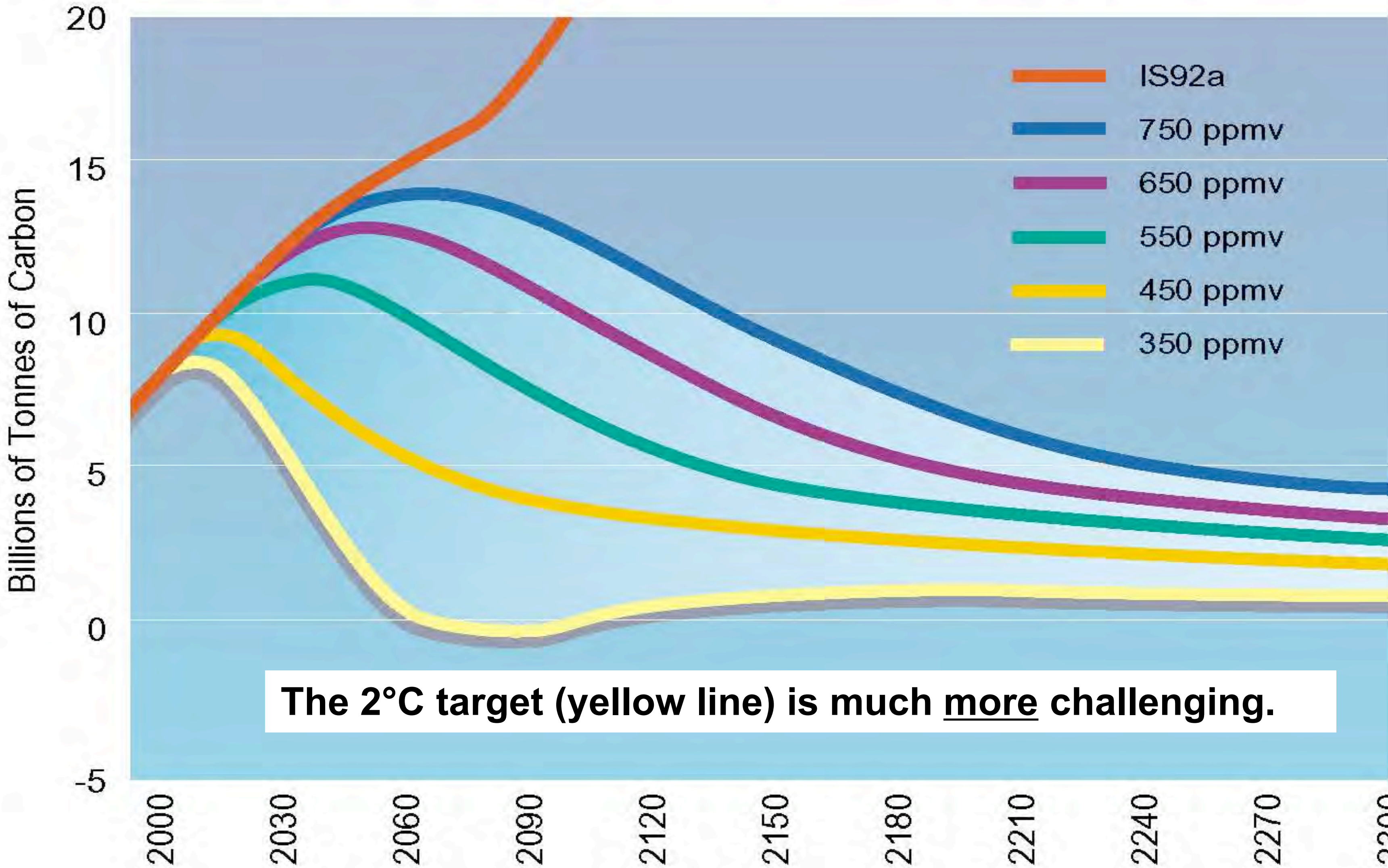
Energy intensity of GDP is declining in developing countries as well as in industrialized ones.

How much more do we need to do?
U.S. oil futures



PCAST 1997, DOE 2003

Emissions Trajectories Consistent With Various Atmospheric CO_2 Concentration Ceilings



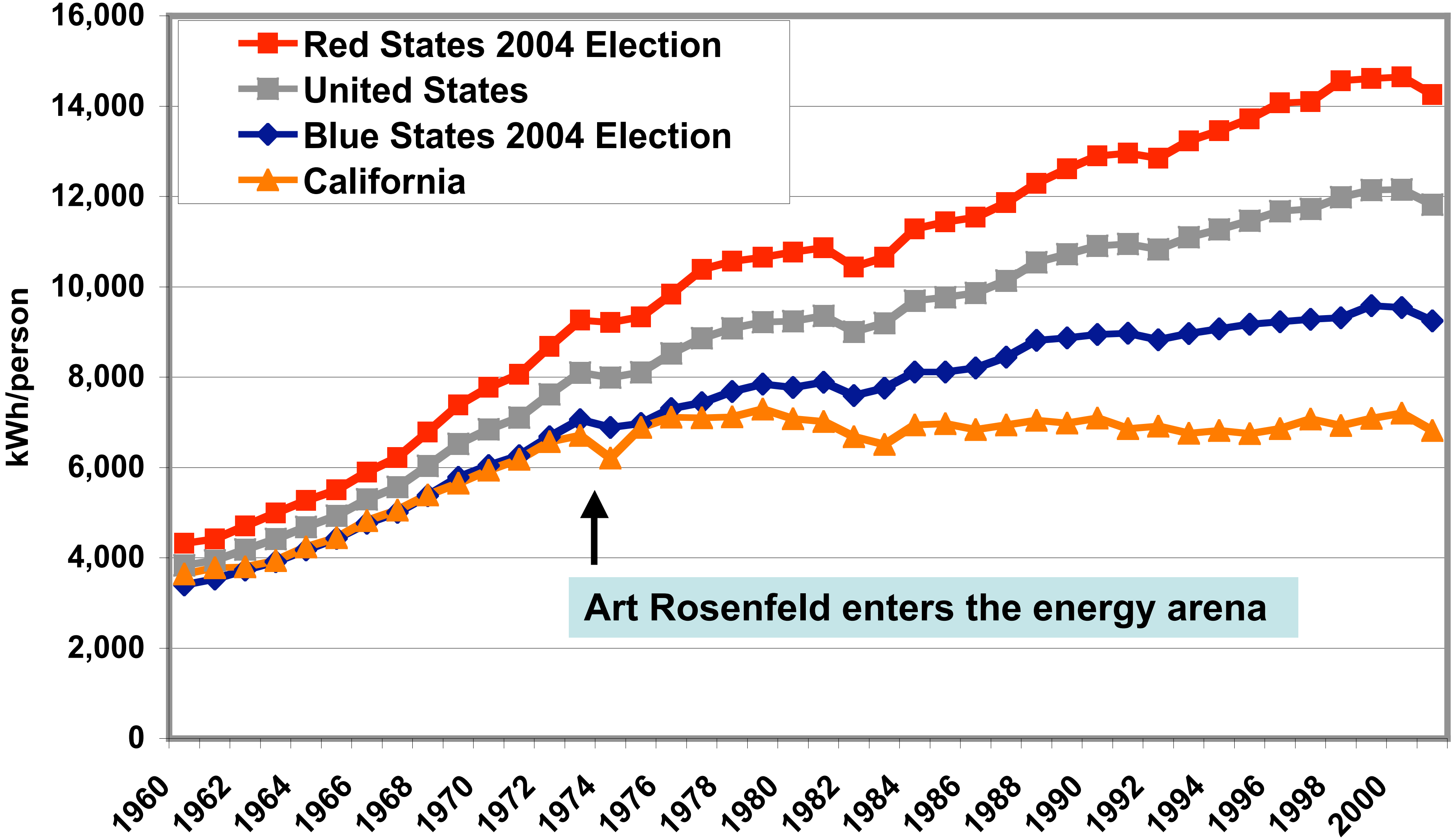
Thought experiment: How much carbon-free energy needed to stabilize CO_2 at 550 ppm_v?

Carbon-free energy in 2000 (from renewables and nuclear energy) ≈ 100 exajoules/year. (Fossil fuels ≈ 350 EJ/yr)

With BAU economic growth, future needs for C-free energy (renewables, nuclear, & advanced fossil with CO2 sequestration) depend on rate of improvement of energy efficiency as follows:

C-free energy (exajoules) in	2050	2100
	------	-------
E/GDP falls 1%/yr (BAU)	600	1500
E/GDP falls 1.5%/yr	350	800
E/GCP falls 2.0%/yr	180	350

U.S. & California energy use: the Rosenfeld effect



Conclusions

- Sharply increasing the rate of improvement of energy efficiency is the indispensable cornerstone of the needed nationwide and worldwide program to address the oil-dependence and climate-change challenges.
- California has shown the way (and Art Rosenfeld showed California the way).
- We need to clone him.
- If we can’t clone him, imitating him will have to do.
- In the United States, we need to turn more red states to blue.