The Grand Energy Challenges: the Next Fifty Years and Beyond

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Tokyo, Japan

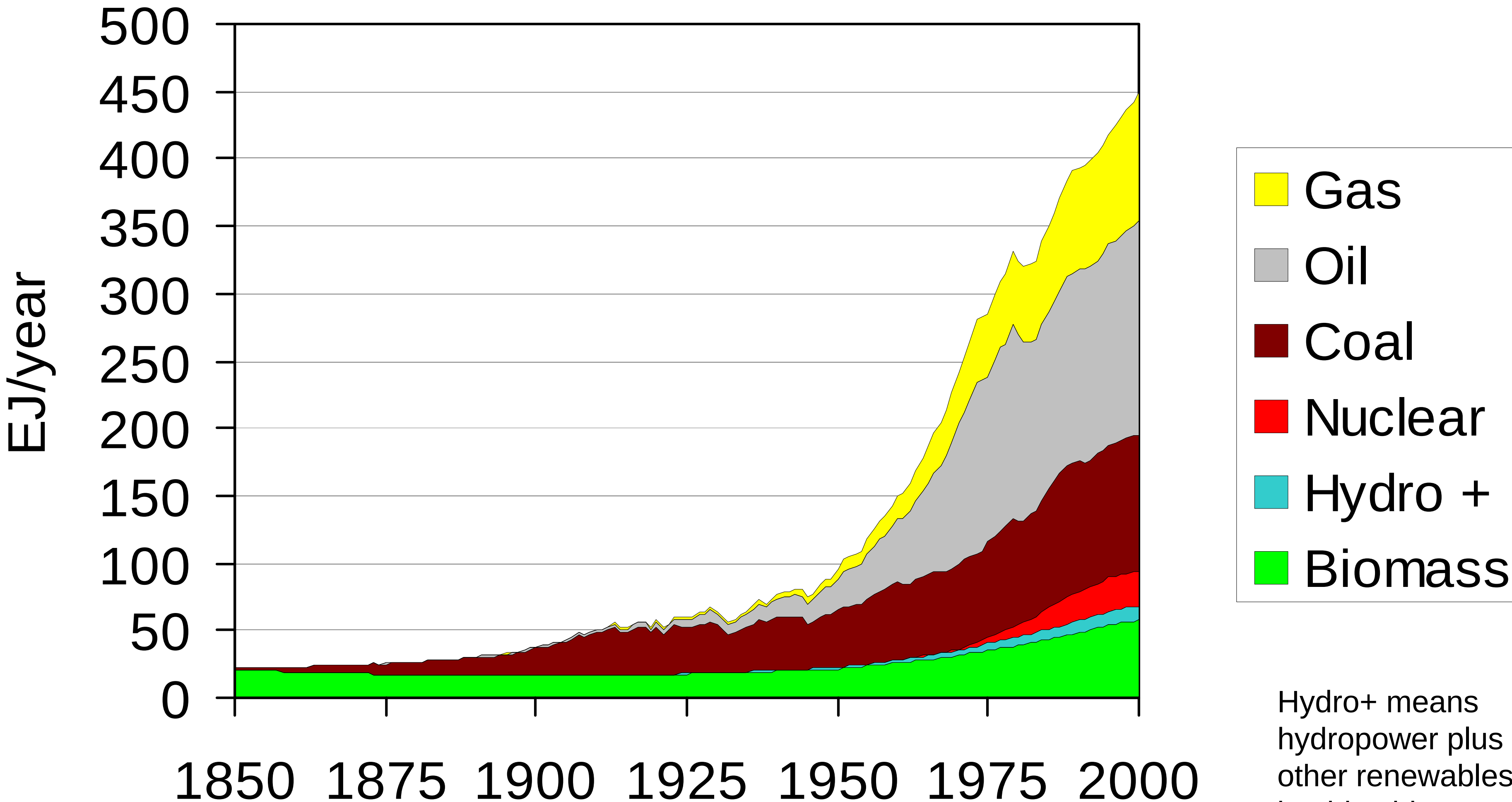
Grand Challenges

- Energy and energy services for poverty alleviation
- Liquid fuels for transportation
- Global climate change

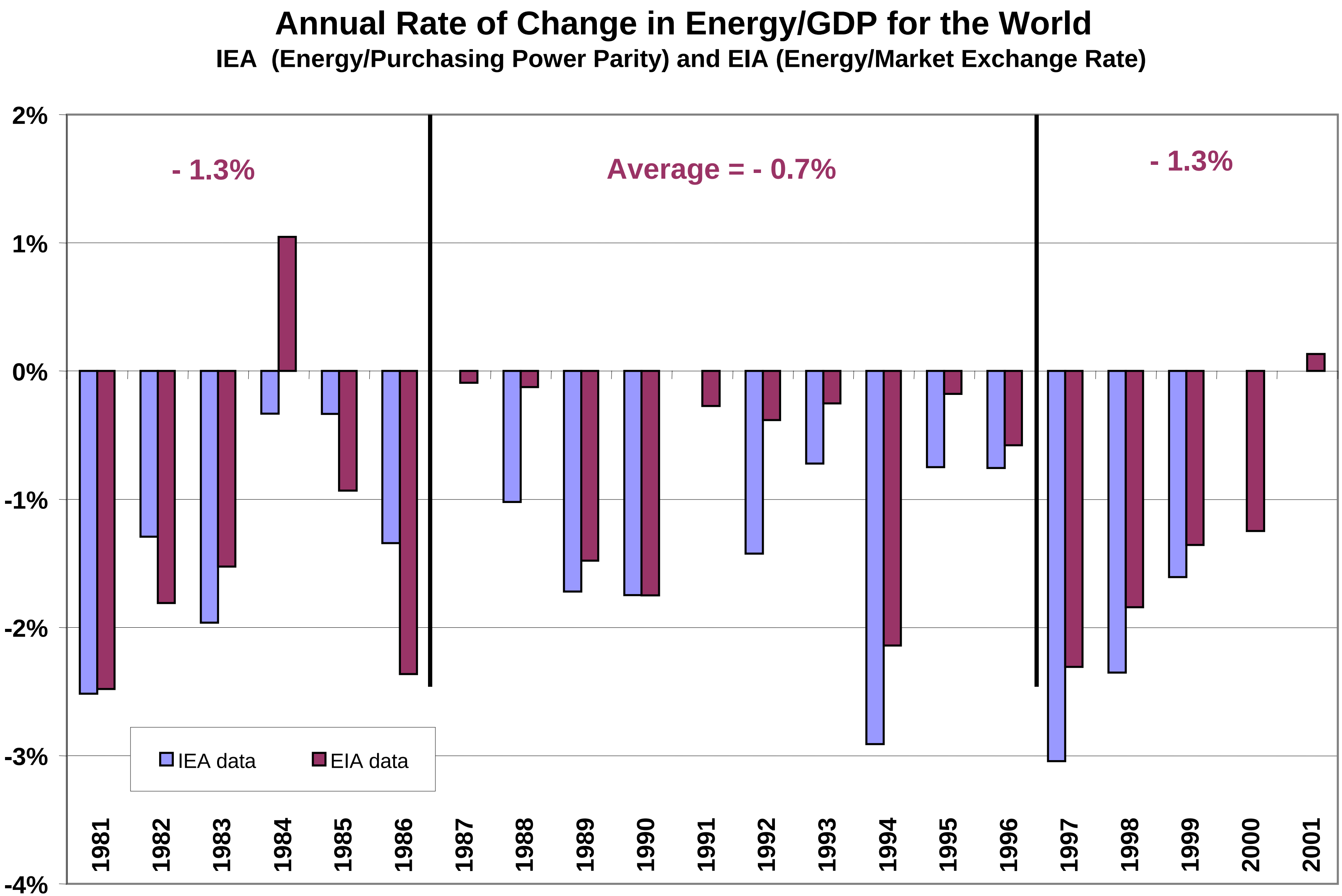
I. Historical Overview of Energy Supply and Demand

A Global View

World Energy Supply, 1850-2000

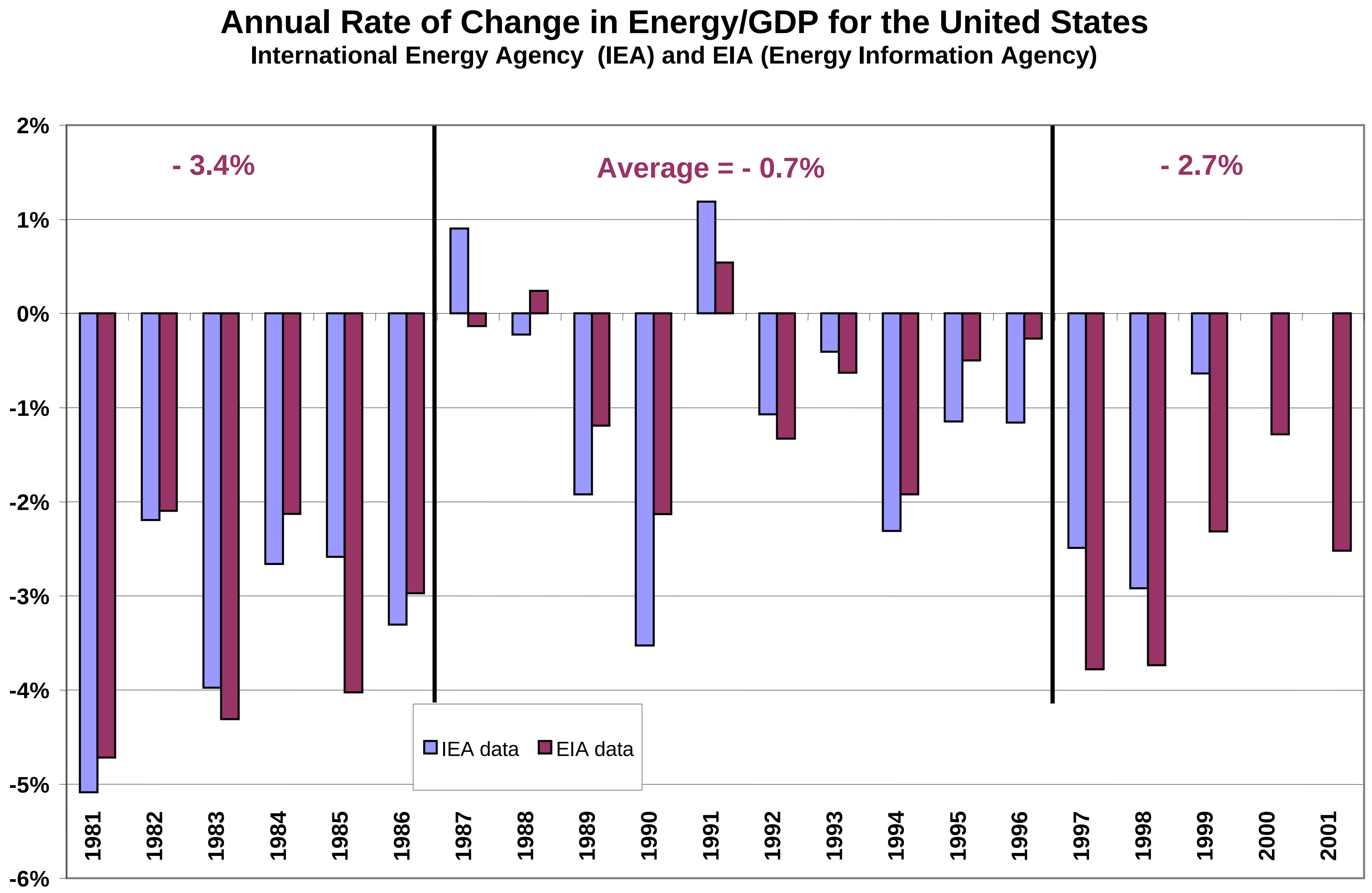


Hydro+ means hydropower plus other renewables besides biomass



note: Russia not included until 1992 in IEA data and 1993 in EIA data

Industrialized Countries



Annual Rate of Change in Energy/GDP for the United States
International Energy Agency (IEA) and EIA (Energy Information Agency)
- 3.4%
Average = - 0.7%
- 2.7%
2%
1%
0%
-1%
-2%
-3%
-4%
-5%
-6%
IEA data
EIA data
1981
1982
1983
1984
1985
1986
1987
1988
1989
1990
1991
1992
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1997
1998
1999
2000
2001

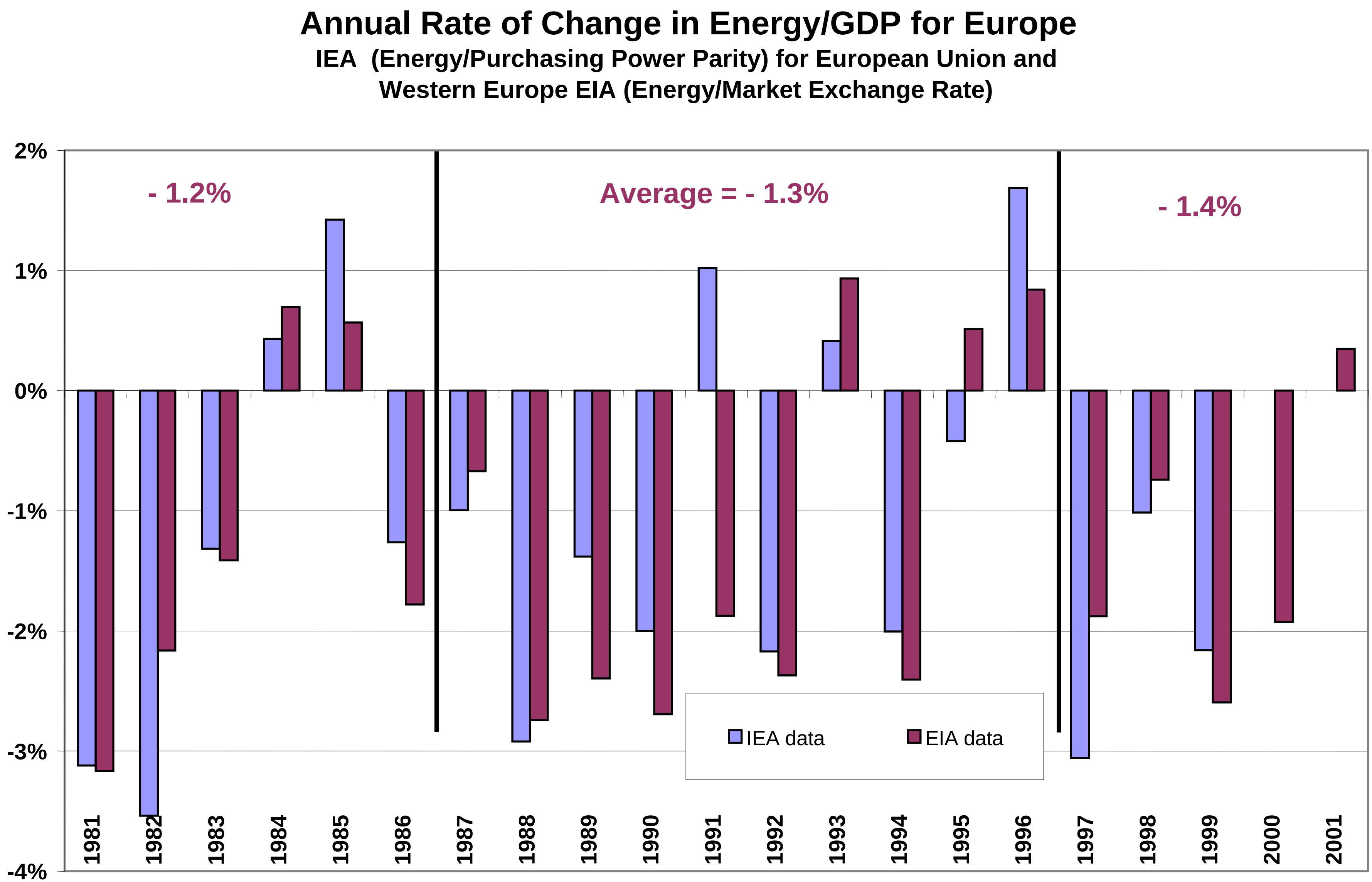
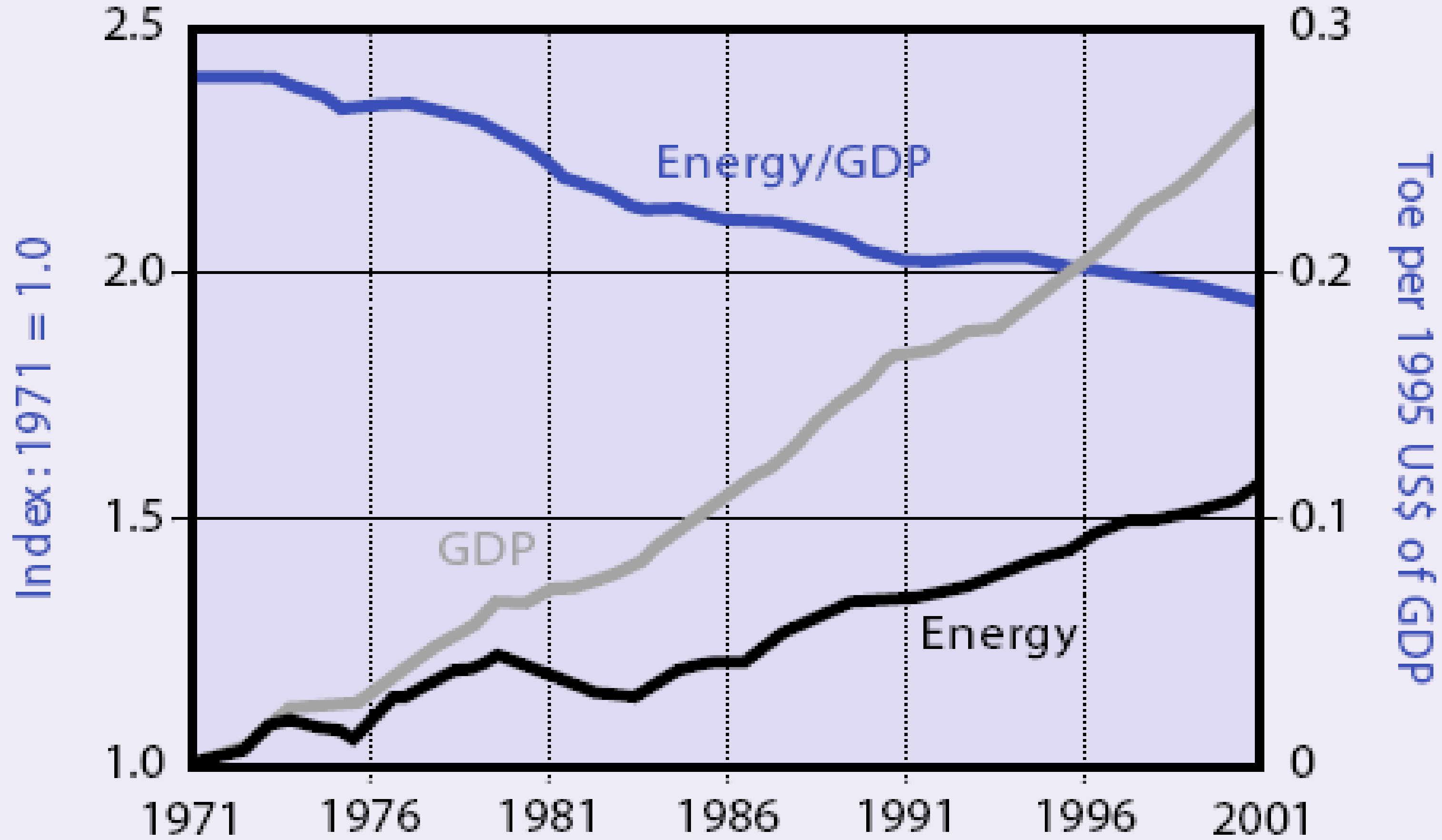

Annual Rate of Change in Energy/GDP for Europe
IEA (Energy/Purchasing Power Parity) for European Union and
Western Europe EIA (Energy/Market Exchange Rate)
2%
1%
0%
-1%
-2%
-3%
-4%
- 1.2%
Average = - 1.3%
- 1.4%
IEA data
EIA data
1981
1982
1983
1984
1985
1986
1987
1988
1989
1990
1991
1992
1993
1994
1995
1996
1997
1998
1999
2000
2001

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.

Grand Challenge: Can the industrialized world reduce use of energy* as well as carbon dioxide emissions while preserving economic vitality

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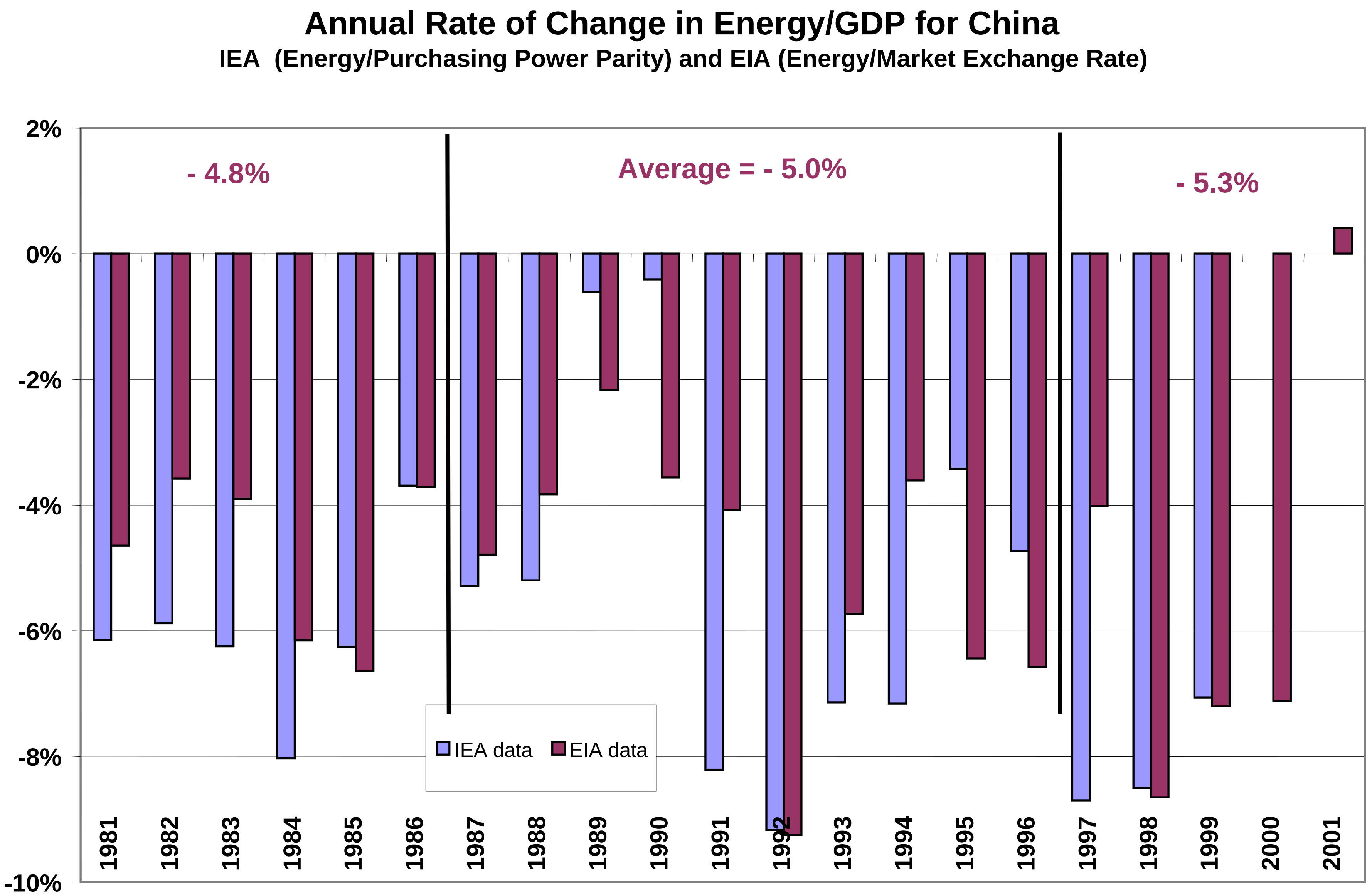
* Special concern about transportation fuels

Historical Overview

China



Annual Rate of Change in Energy/GDP for China
IEA (Energy/Purchasing Power Parity) and EIA (Energy/Market Exchange Rate)
2%
0%
-2%
-4%
-6%
-8%
-10%
- 4.8%
Average = - 5.0%
- 5.3%
IEA data
EIA data
1981
1982
1983
1984
1985
1986
1987
1988
1989
1990
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1992
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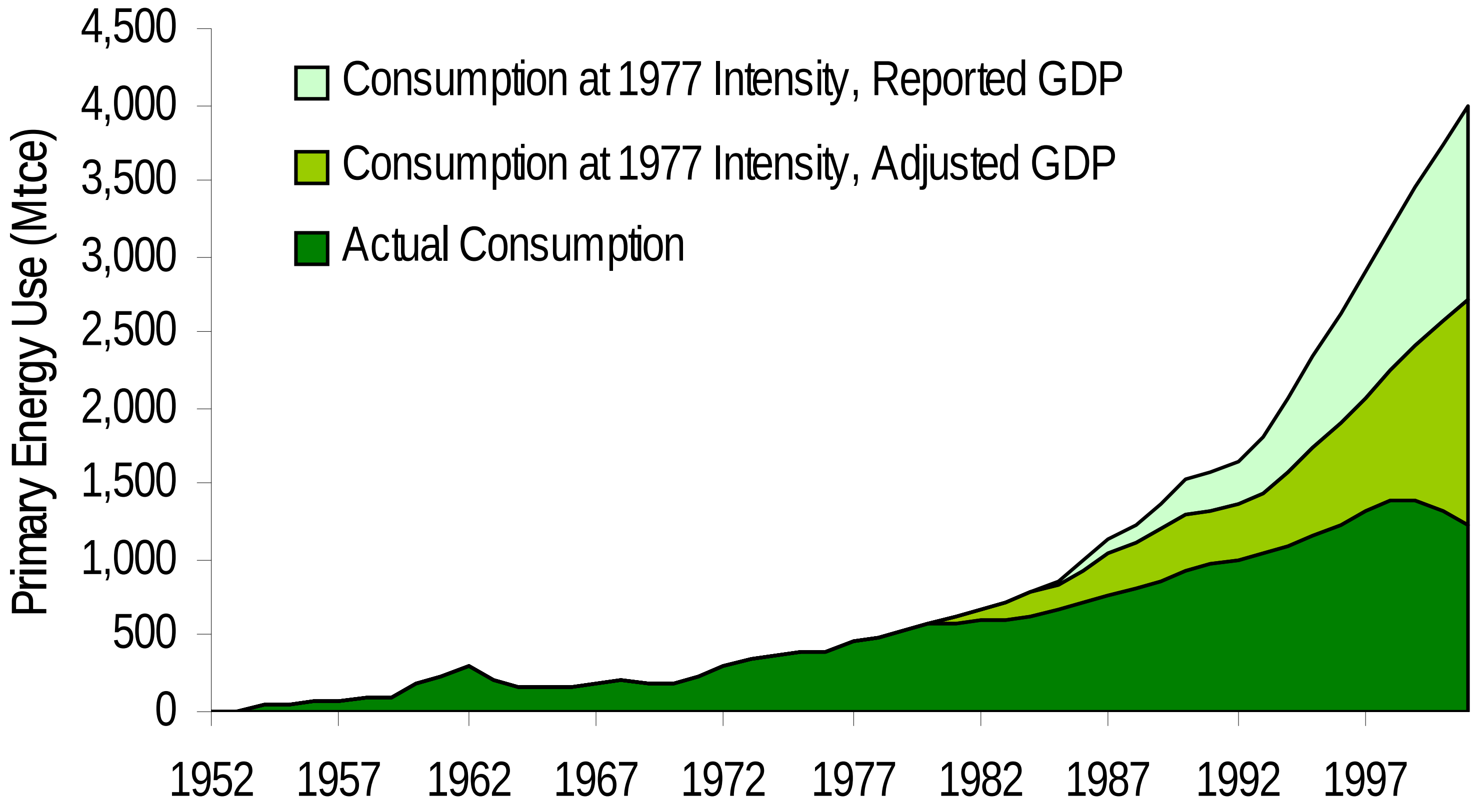
Investment in energy efficiency and other policies greatly reduced China's energy intensity (1980-2000)

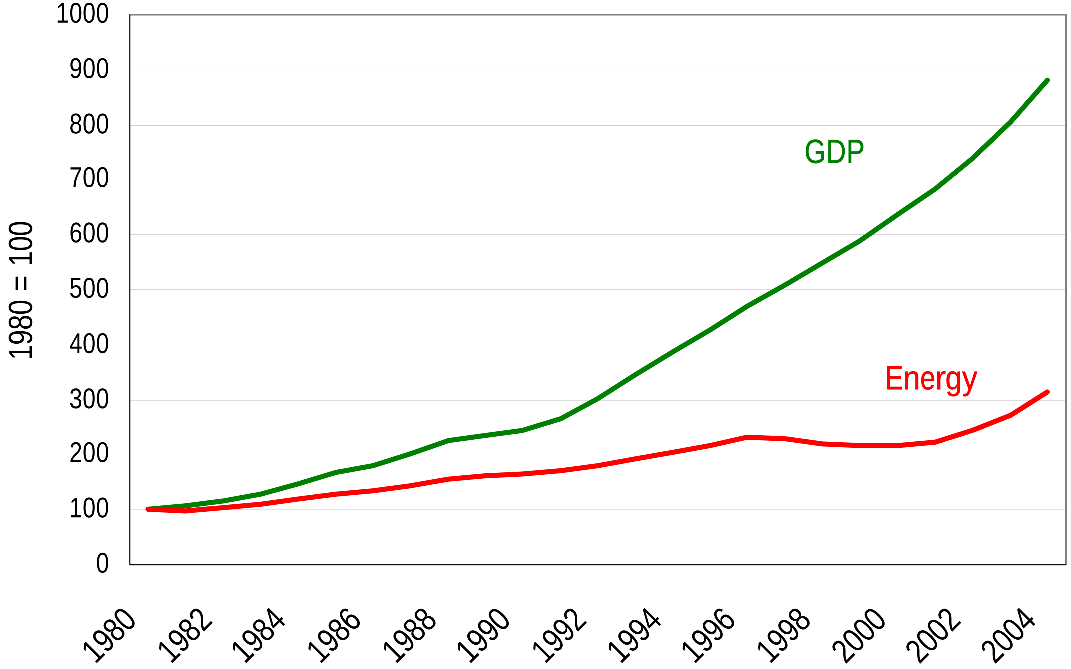


Energy Use, Actual and Projected at 1977 Intensity, 1952-1999

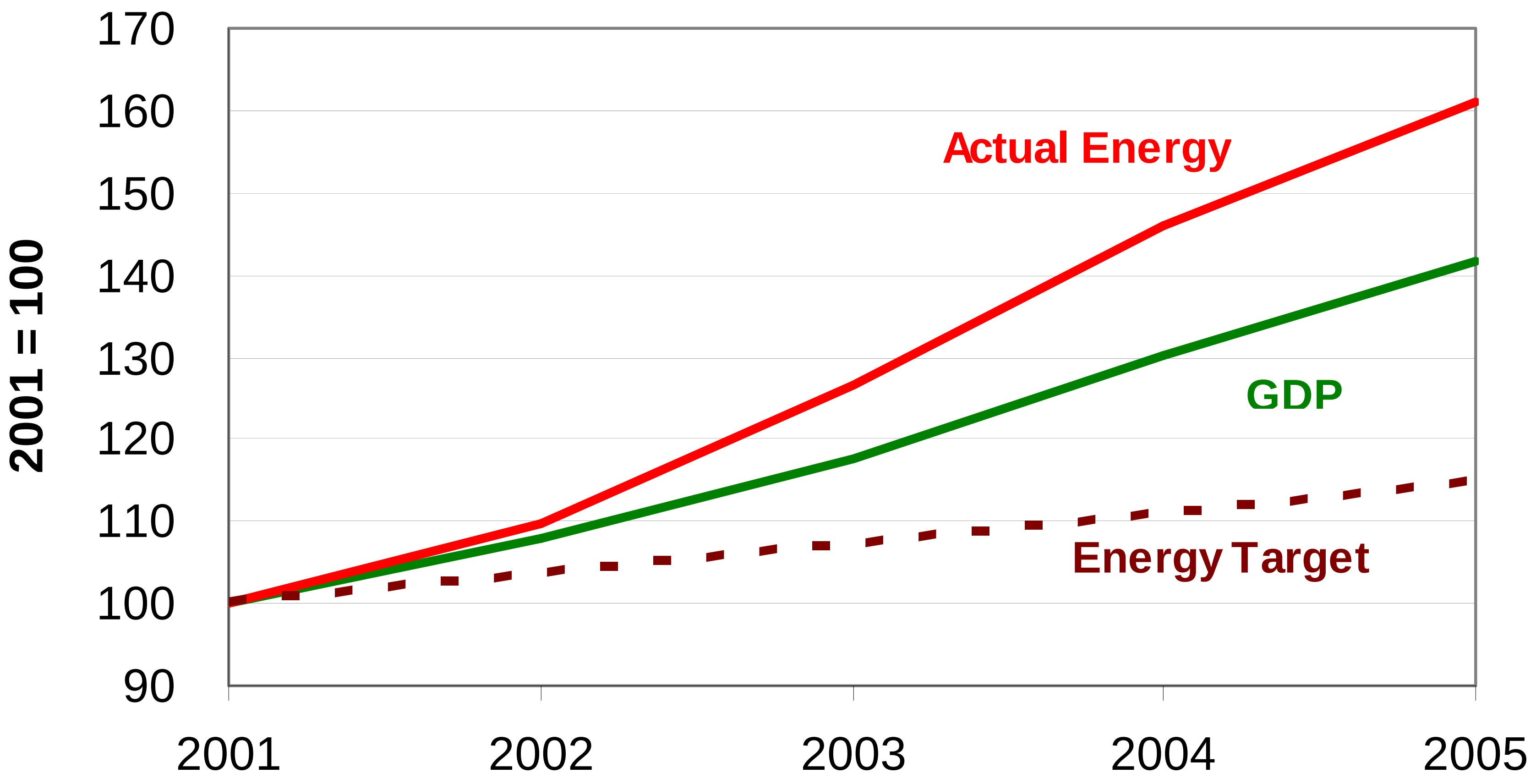
Source: NBS

Berkeley Lab

China has demonstrated that a rapidly developing nation can decouple energy and GDP growth with bold policies initiated in 1980



Since 2001, energy use has grown much faster than GDP, reversing patterns from 1980 to 2000



Source: NBS, China Statistical Yearbook, various years; China Statistical Abstract 2005; growth estimates extrapolated from mid-year production data for 2005.

China's government now recognizes the urgency of energy efficiency

- The reform period (1980-2000) showed that energy efficiency was essential to achieve economic goals *and that it could be achieved (Deng Xiaoping)*

- The current leadership recognizes the same imperative (*Plenary of the Communist Party, Nov, 2005)*
  - *Premier Wen Jiabao*: "Energy use per unit of GDP must be reduced by 20% from 2005 to 2010."

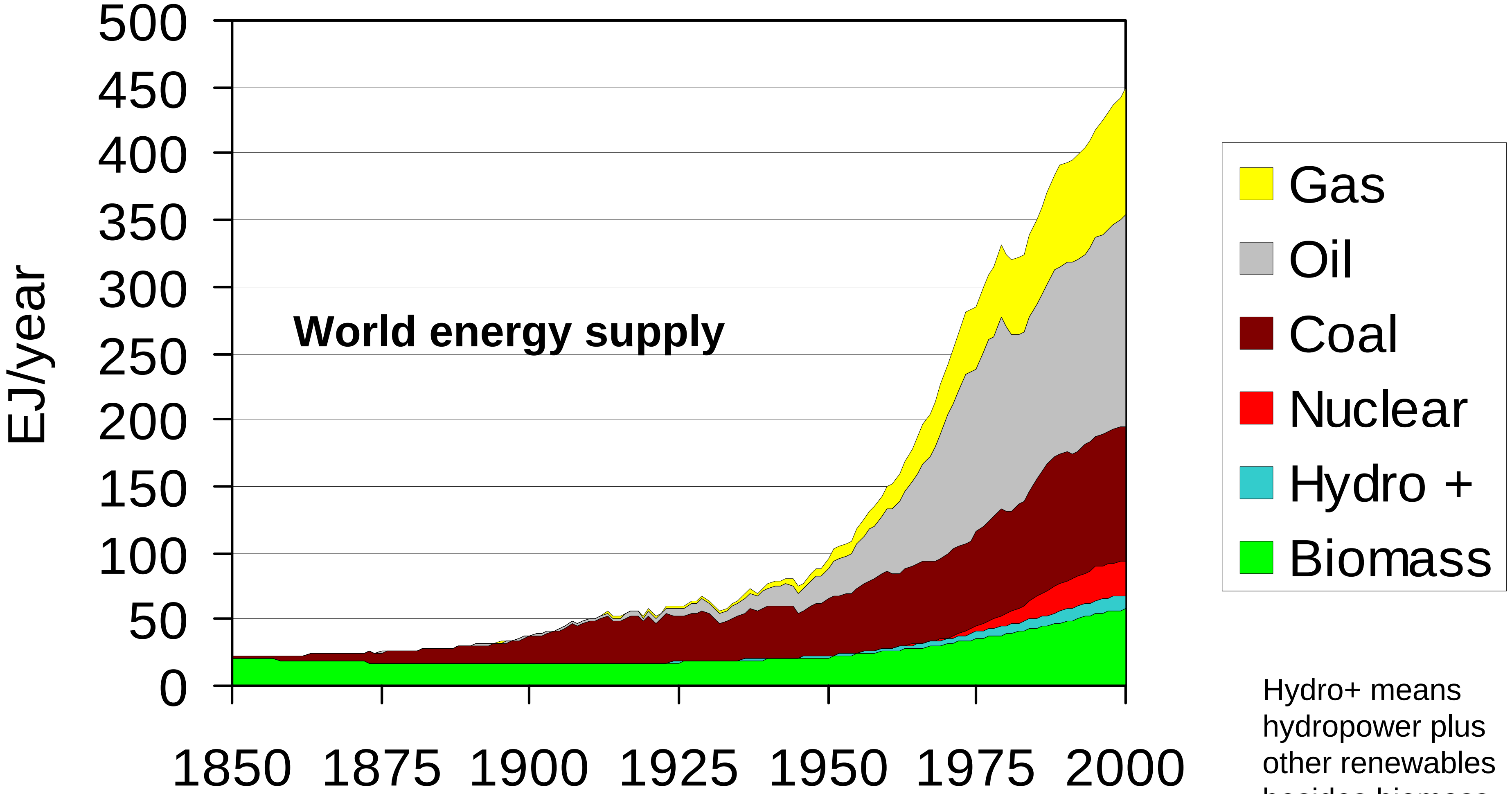
- Statement reiterated by the National Peoples Congress (March 2006), incorporated in 5-Year Plan; efforts to implement underway

Grand Challenge: Can the developing world (including China) follow the remarkable Chinese example of the 1980-2000 period, with reduced energy demand growth supporting poverty alleviation and social/economic development?

Or will the more recent period foreshadow the future

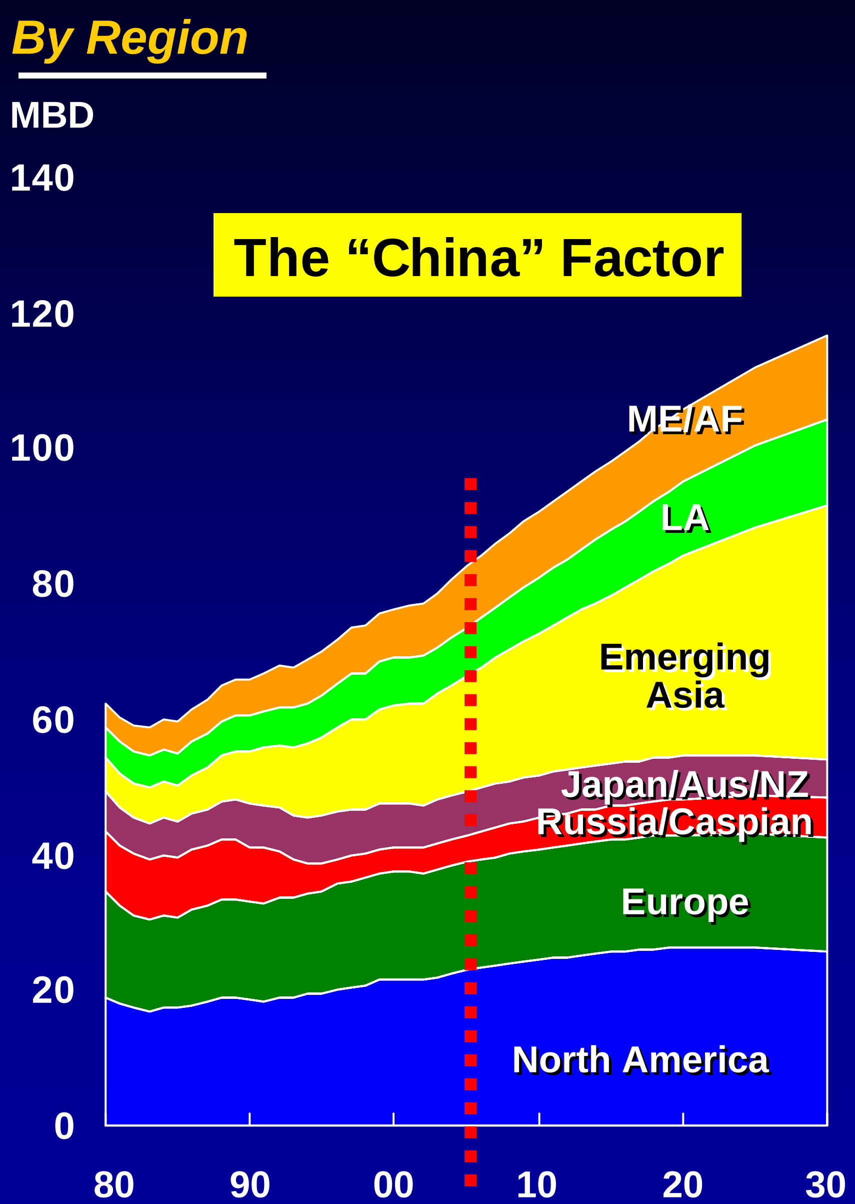
II. Transportation Fuels: the Oil Challenge

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



Hydro+ means hydropower plus other renewables besides biomass

World Oil Demand



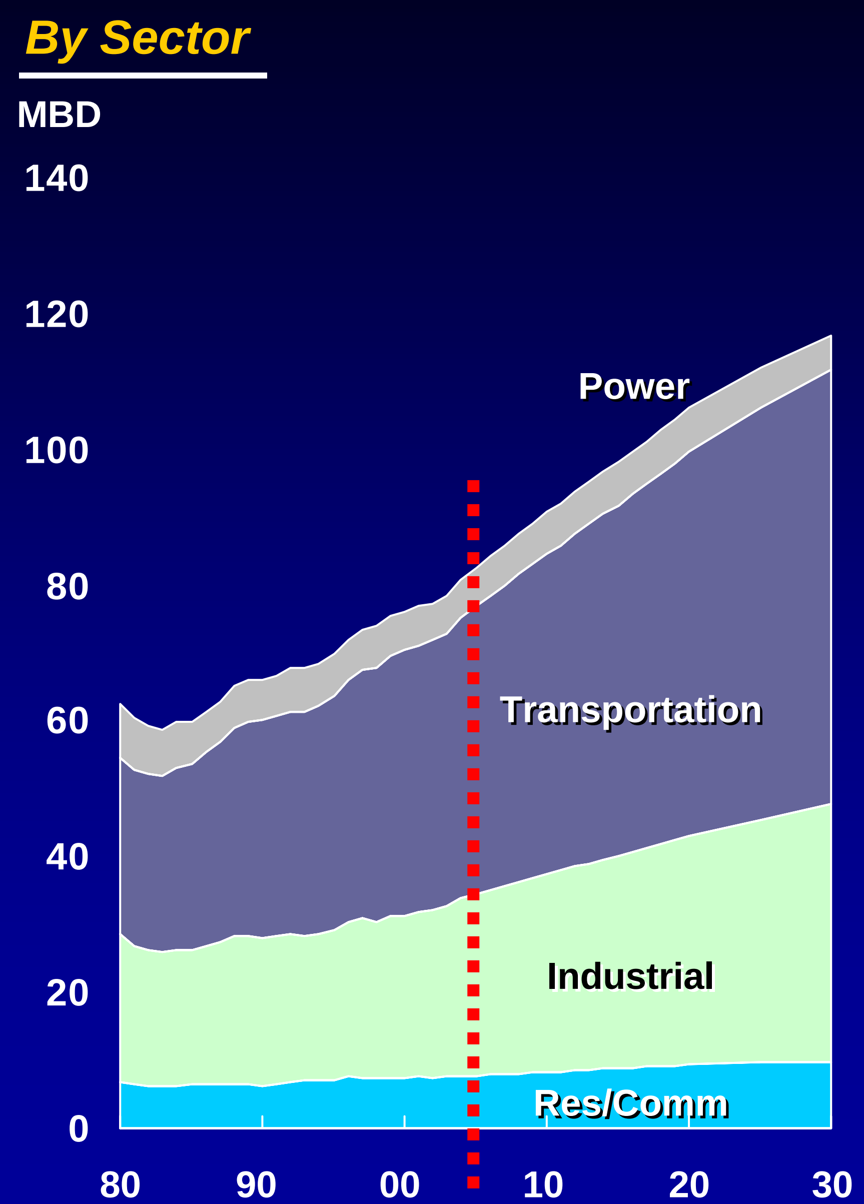
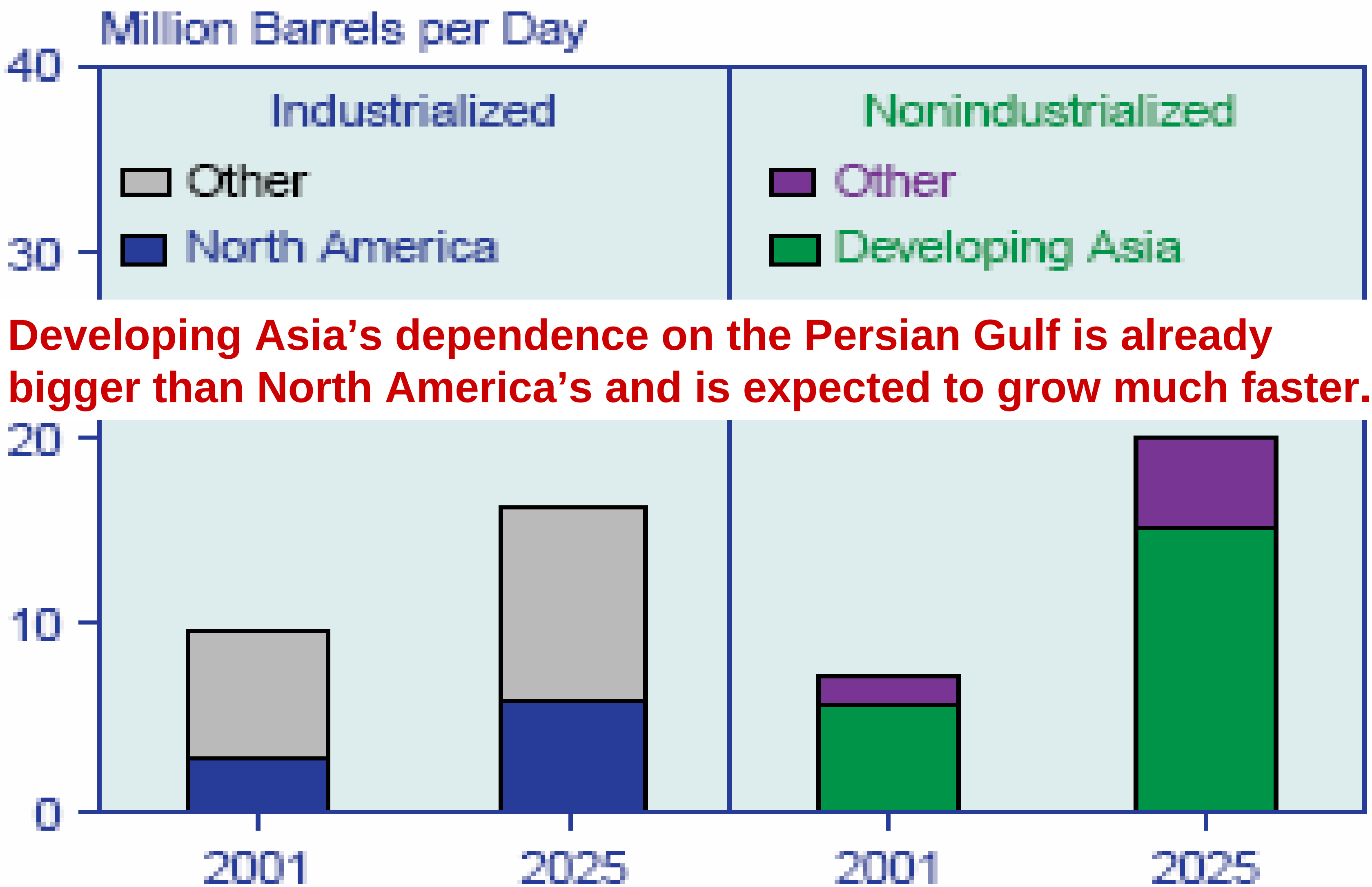


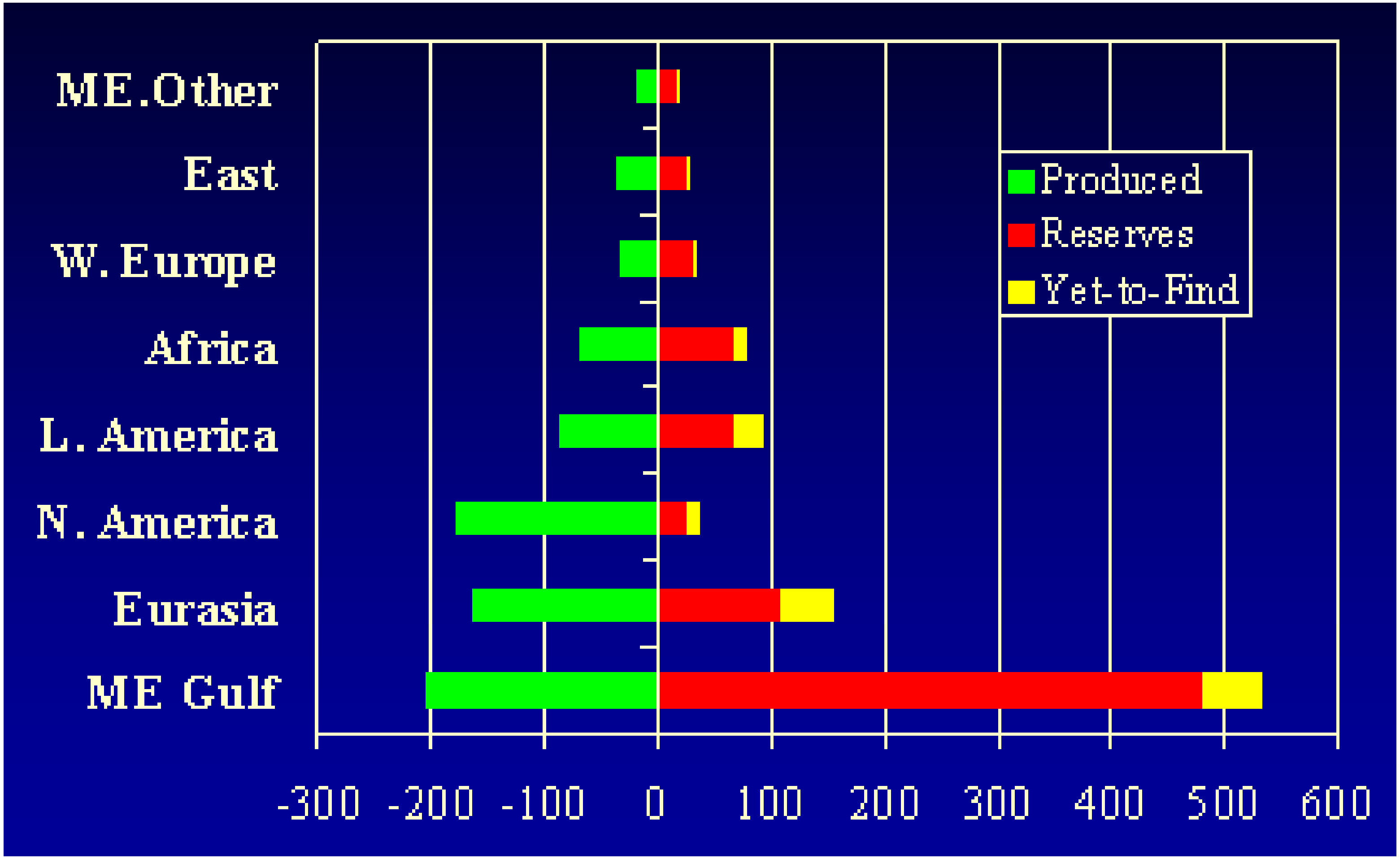
Figure 34. Imports of Persian Gulf Oil by Importing Region, 2001 and 2025



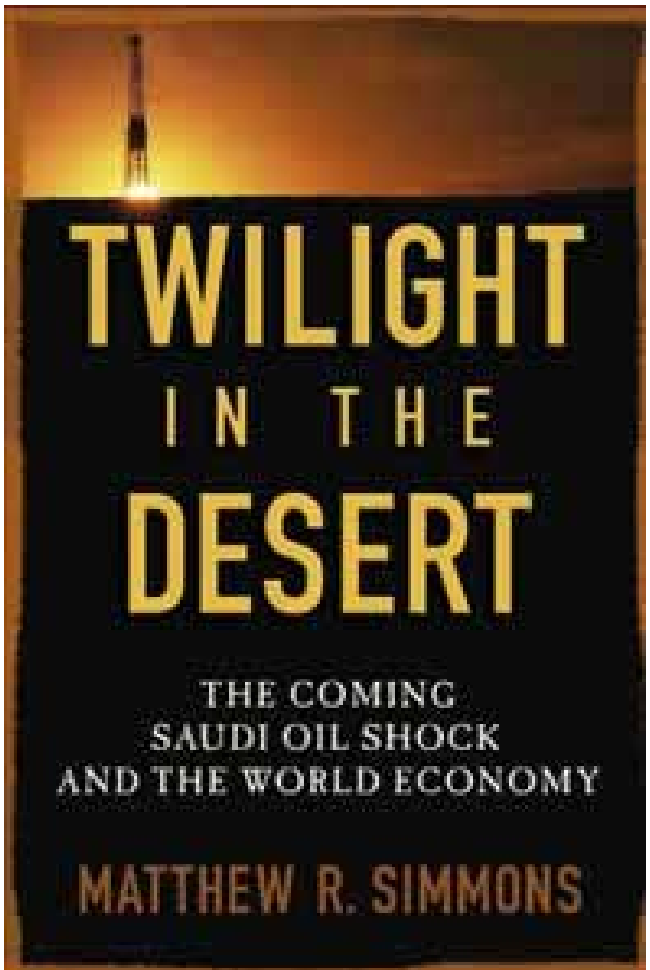
Developing Asia's dependence on the Persian Gulf is already bigger than North America's and is expected to grow much faster.

Source: EIA International Energy Outlook 2004, p 41

Where The Oil Is



Saudi Oil

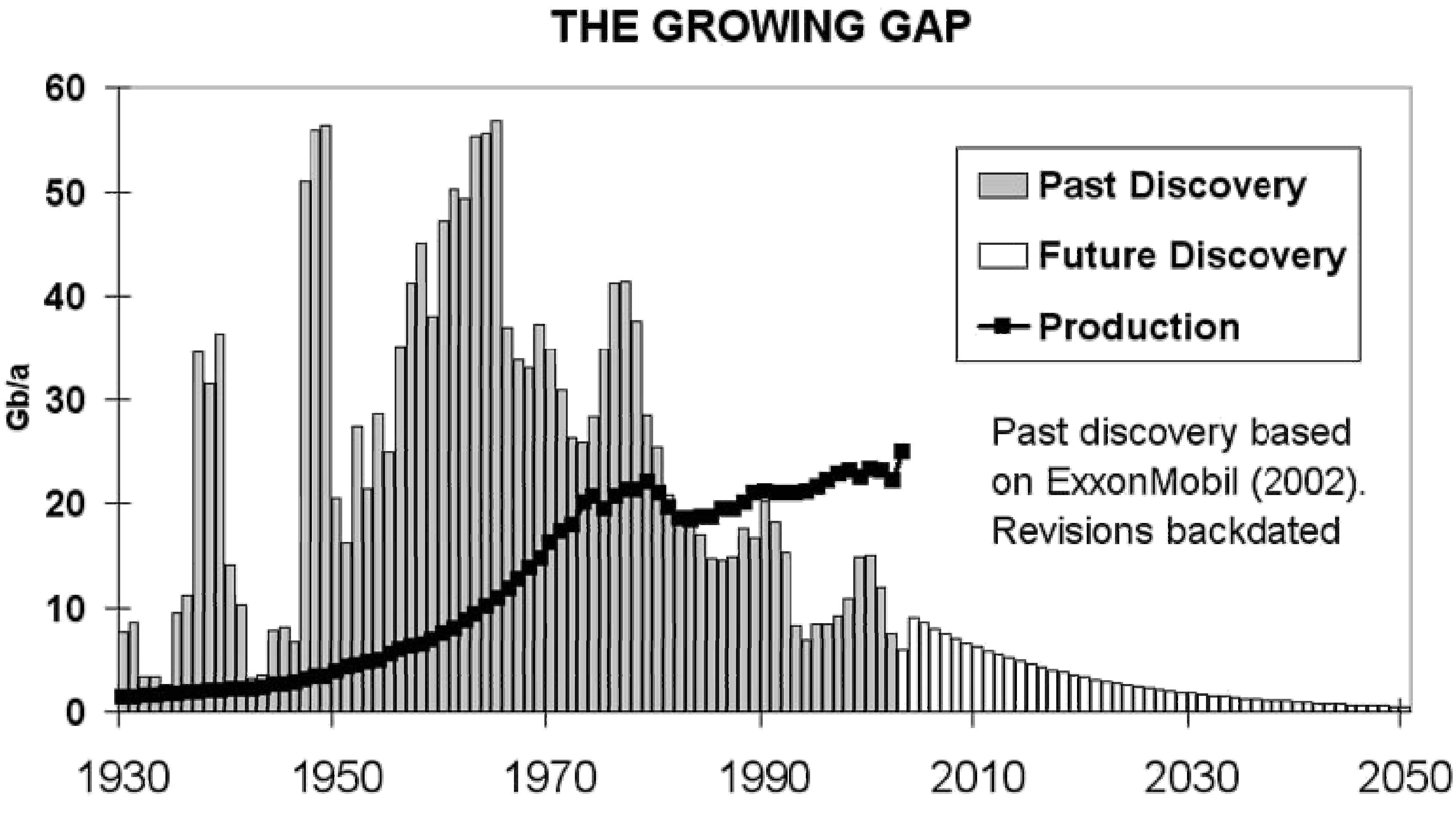


- One "super giant" field (Ghawar) contains 50% of all Saudi oil
- 4 other super giant oilfields make up an additional 40%
- And 3 others are another 8%
- All fields are between 40 and 60 years old
- All are reaching point of decline
- Half of "proven reserves" are questionable
- Remaining oil is increasingly difficult to produce.

Saudi Importance

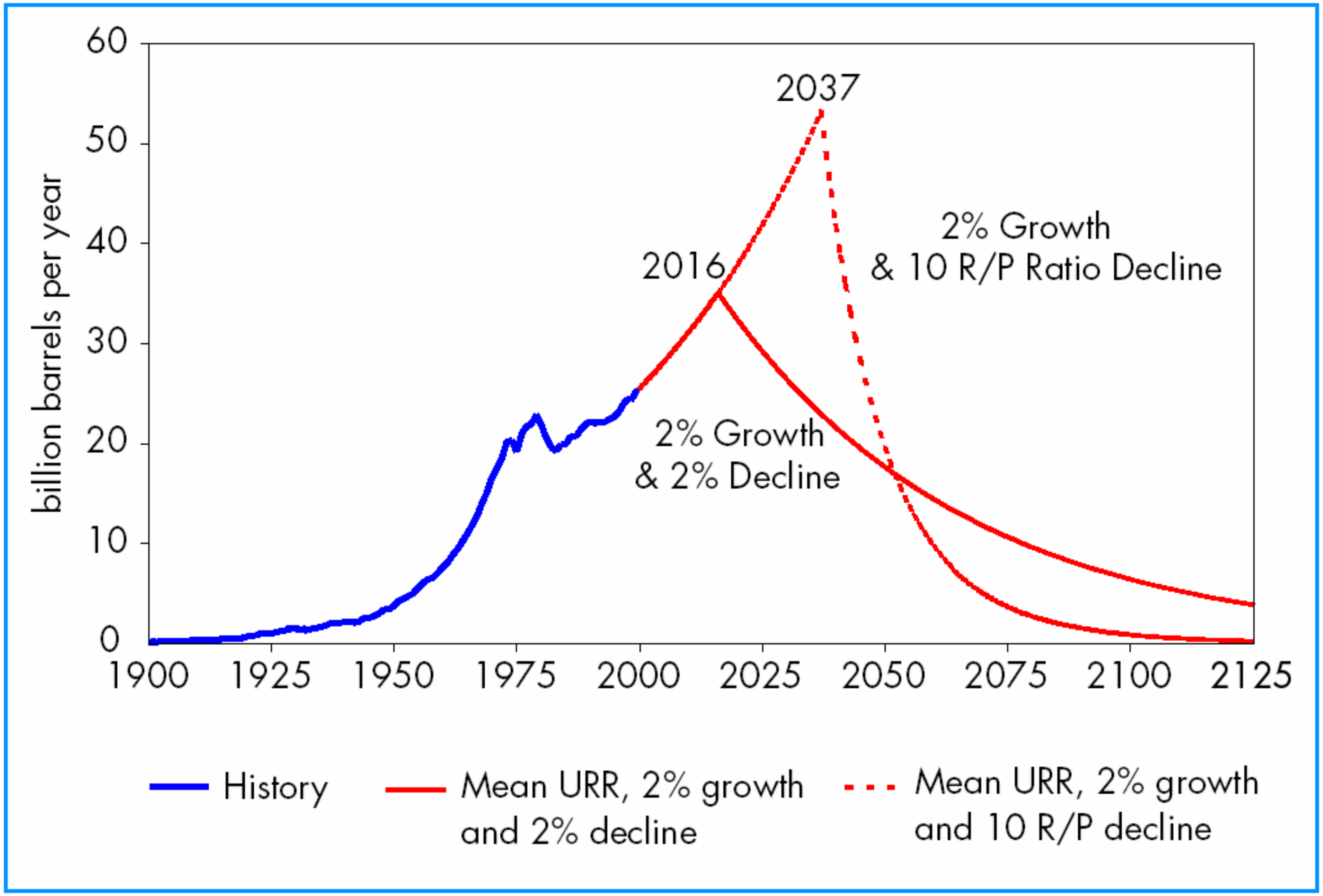
- Can produce about 10-12 Mbpd or about 12% of current world oil demand
- Has more than 22% of reported “proven” reserves worldwide
- Will become the sole arbiter of price when remainder of world oil peaks – this is coming soon

New Oil . . . ?



Source: Campbell, C.J. "Oil Depletion – The Heart of the Matter." Association for the Study of Peak Oil and Gas, October 2003. (http://www.hubbertpeak.com/campbell/TheHeartOfTheMatter.pdf)

USGS and DOE best estimates of global oil production

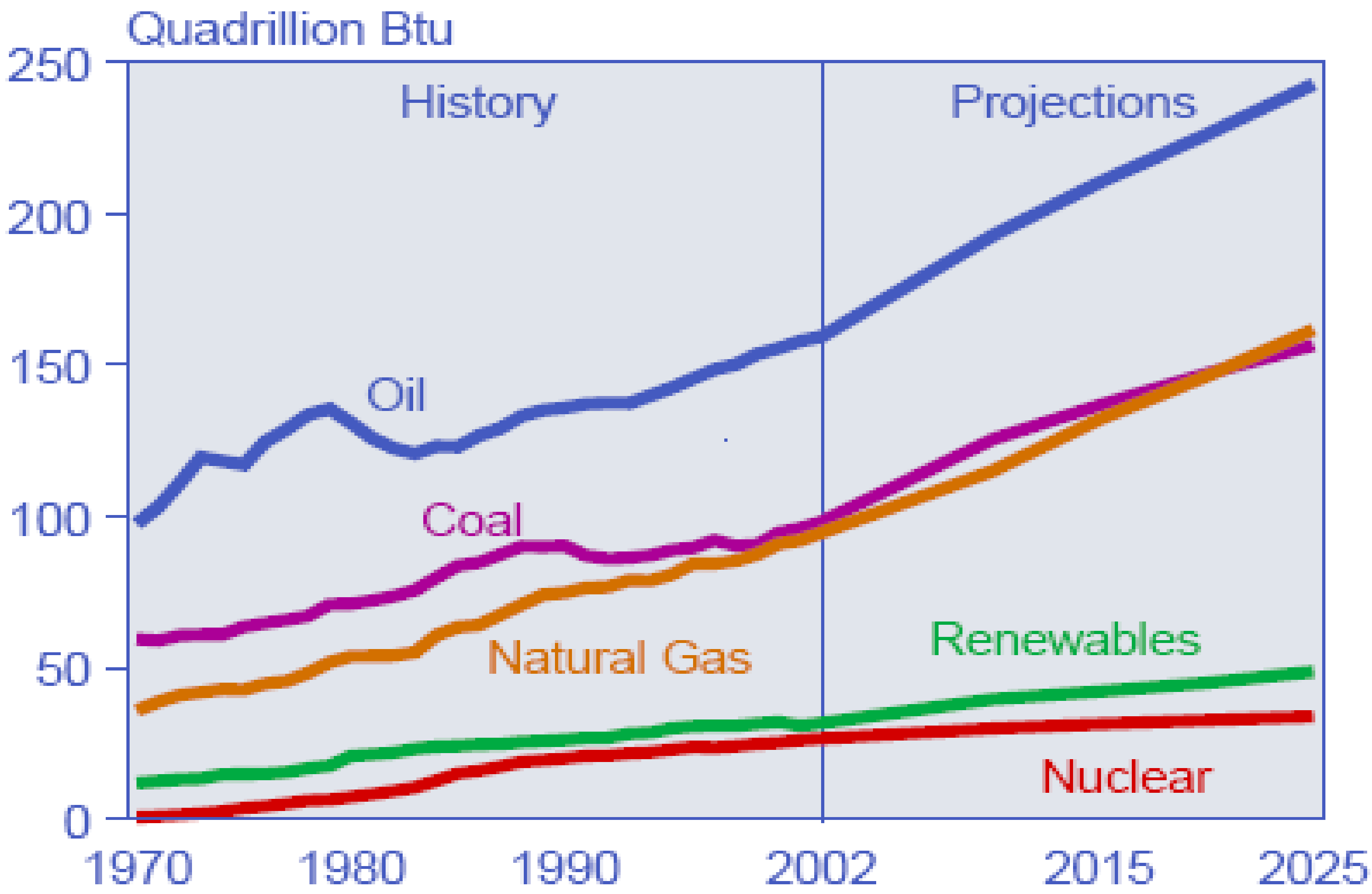


World Energy Outlook, 2001 by the International Energy Agency, Organization for Economic Co-operation and Development (OECD)

Predictions of Peaking of World Oil Production

- 2007-2009: Matthew Simmons, investment banker
- Before 2009: Ken Deffeyes, retired oil company geologist
- Before 2010: David Goodstein, Cal Tech physicist
- Around 2010: Colin Campbell, oil geologist
- 2016: U.S. EIA nominal case
- After 2020: Dan Yergin, CERA

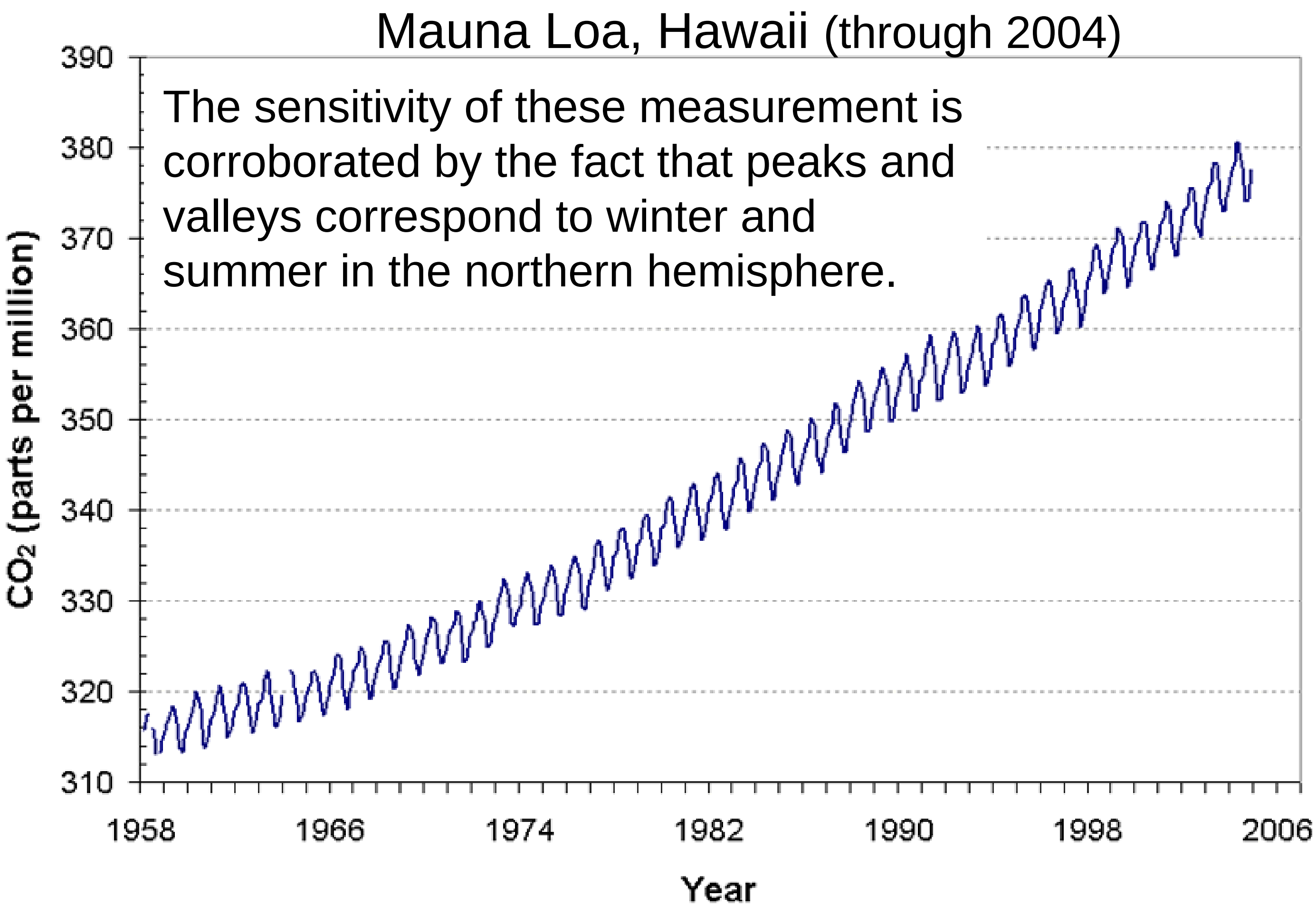
The dominance of oil and gas is projected to continue



Source: EIA 2005 International Energy Outlook

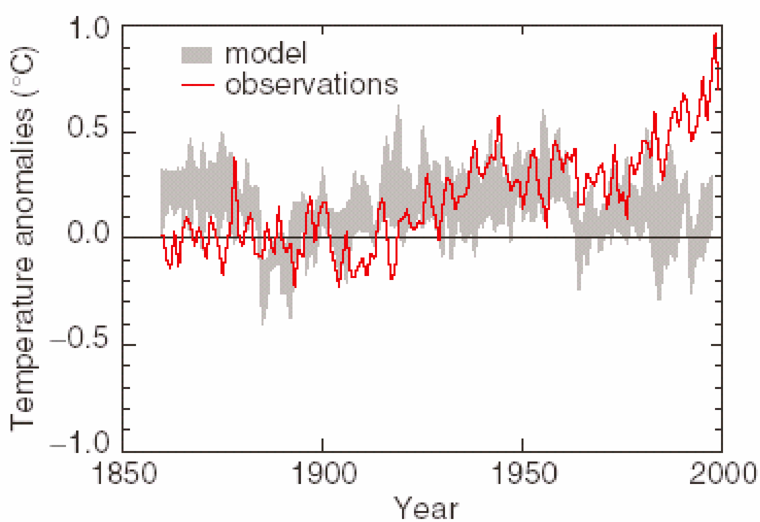
III. The Danger of Global Climate Change

The "Keeling Curve"

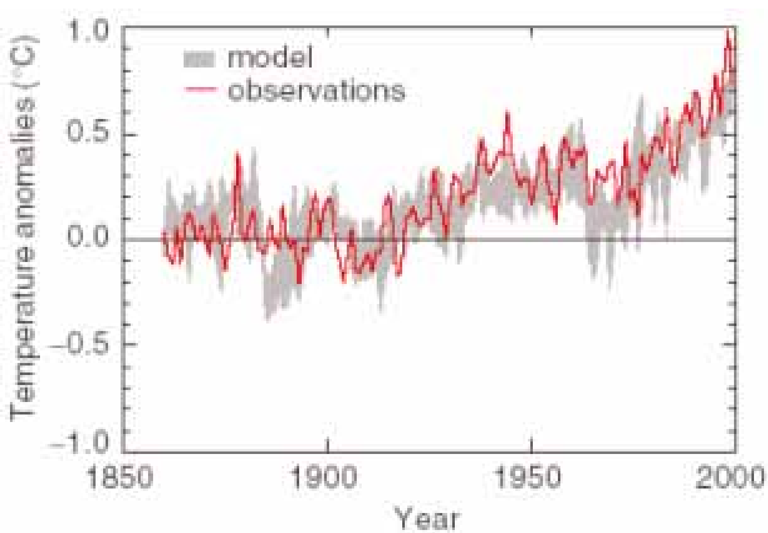


Source: Keeling, C.D. and T.P. Whorf, Carbon Dioxide Research Group, Scripps Institution of Oceanography, University of California, La Jolla, CA (http://cdiac.esd.ornl.gov/ftp/trends/co2/maunaloa.co2.)

Temperature rise due to human emission of greenhouse gases



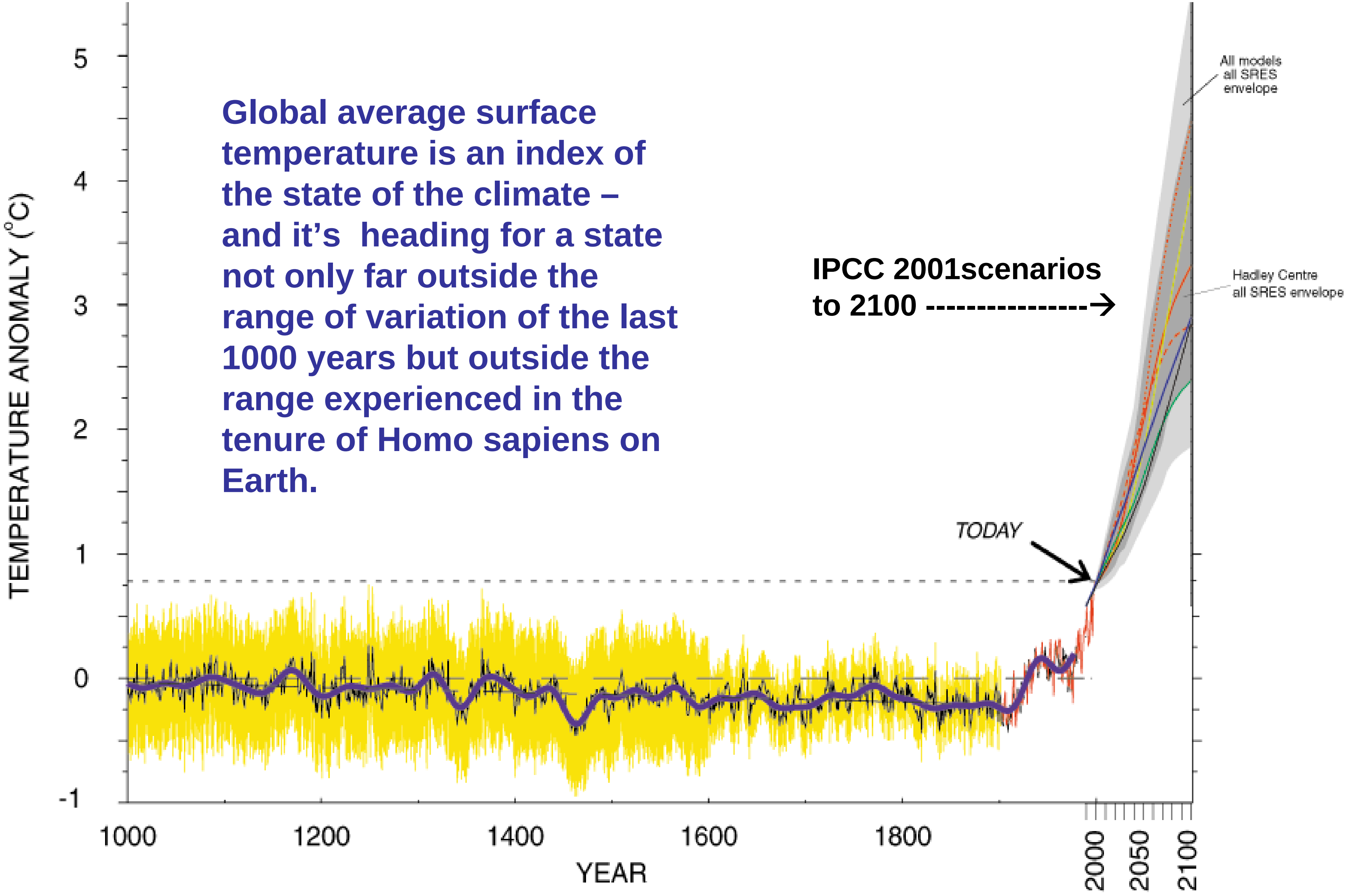
Climate change due to natural causes (solar variations, volcanoes, etc.)



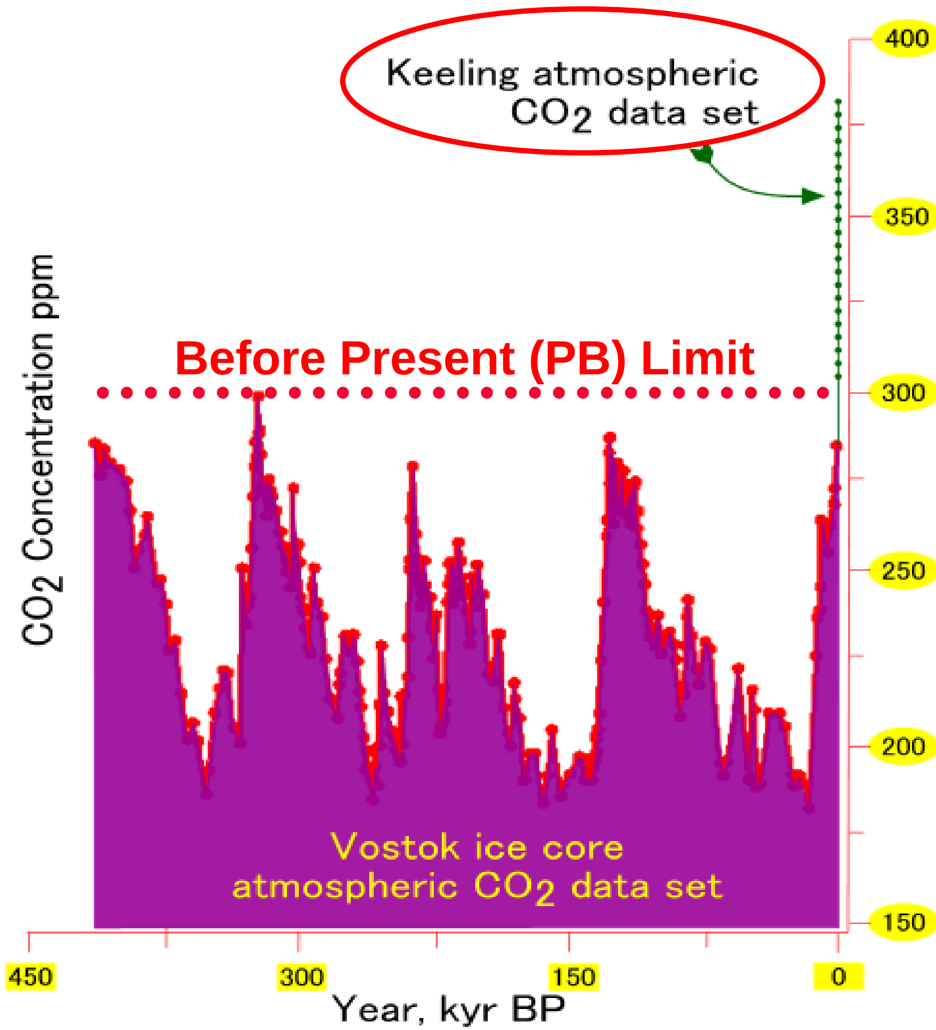
Climate change due to natural causes and human generated greenhouse gases

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

Global average surface temperature is an index of the state of the climate – and it's heading for a state not only far outside the range of variation of the last 1000 years but outside the range experienced in the tenure of Homo sapiens on Earth.



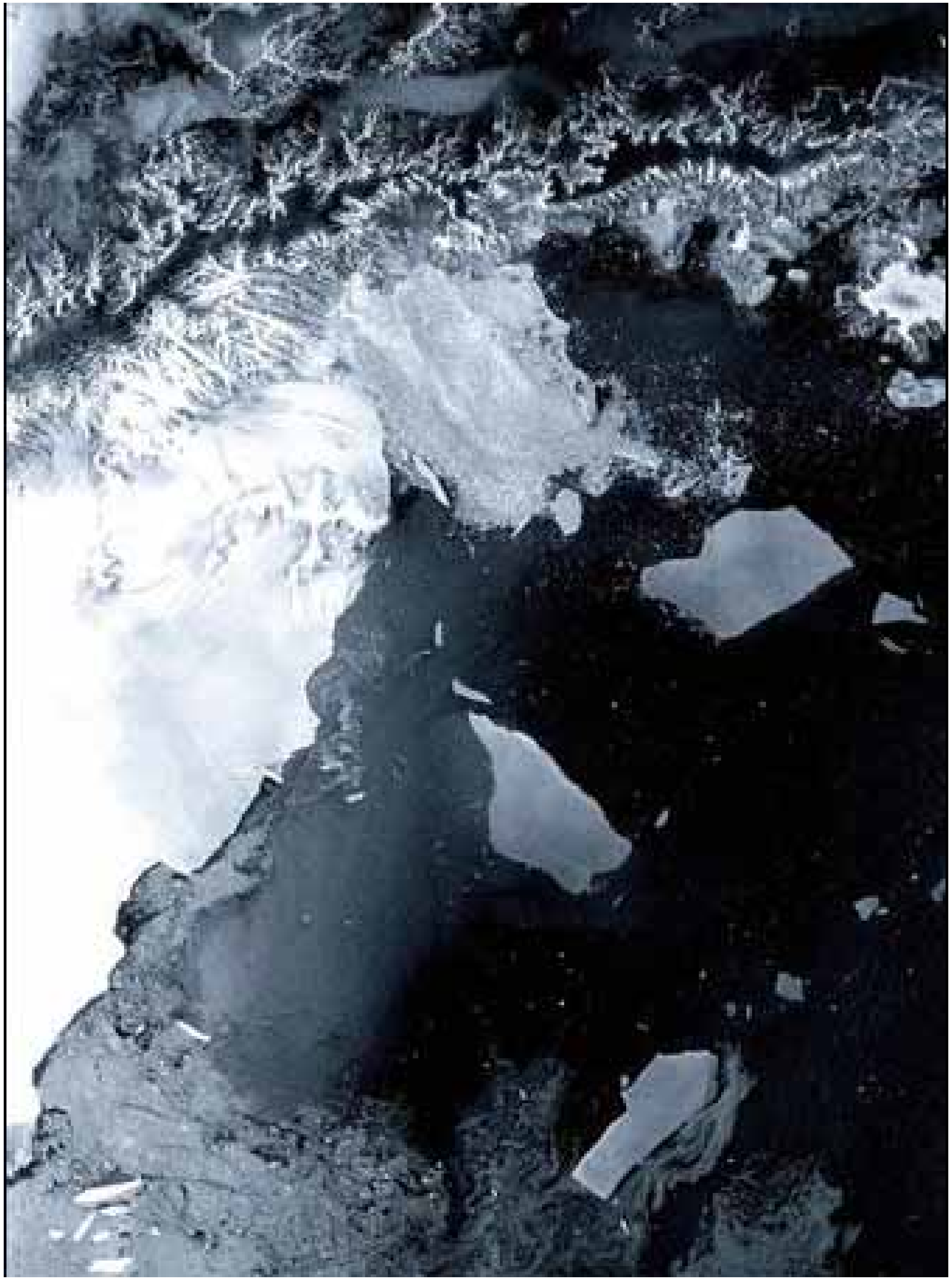
400,000+ Years of Data!



- **<u>Eons of data</u>** – well correlated to global temperature change
- What will it take to tip the balance?
  - **<u>550 ppm</u>** – very scary
  - **<u>+2 ºC</u>** – equally scary
- **<u>Amplification</u>** is entirely possible

Evidence of Global Warming Is Mounting

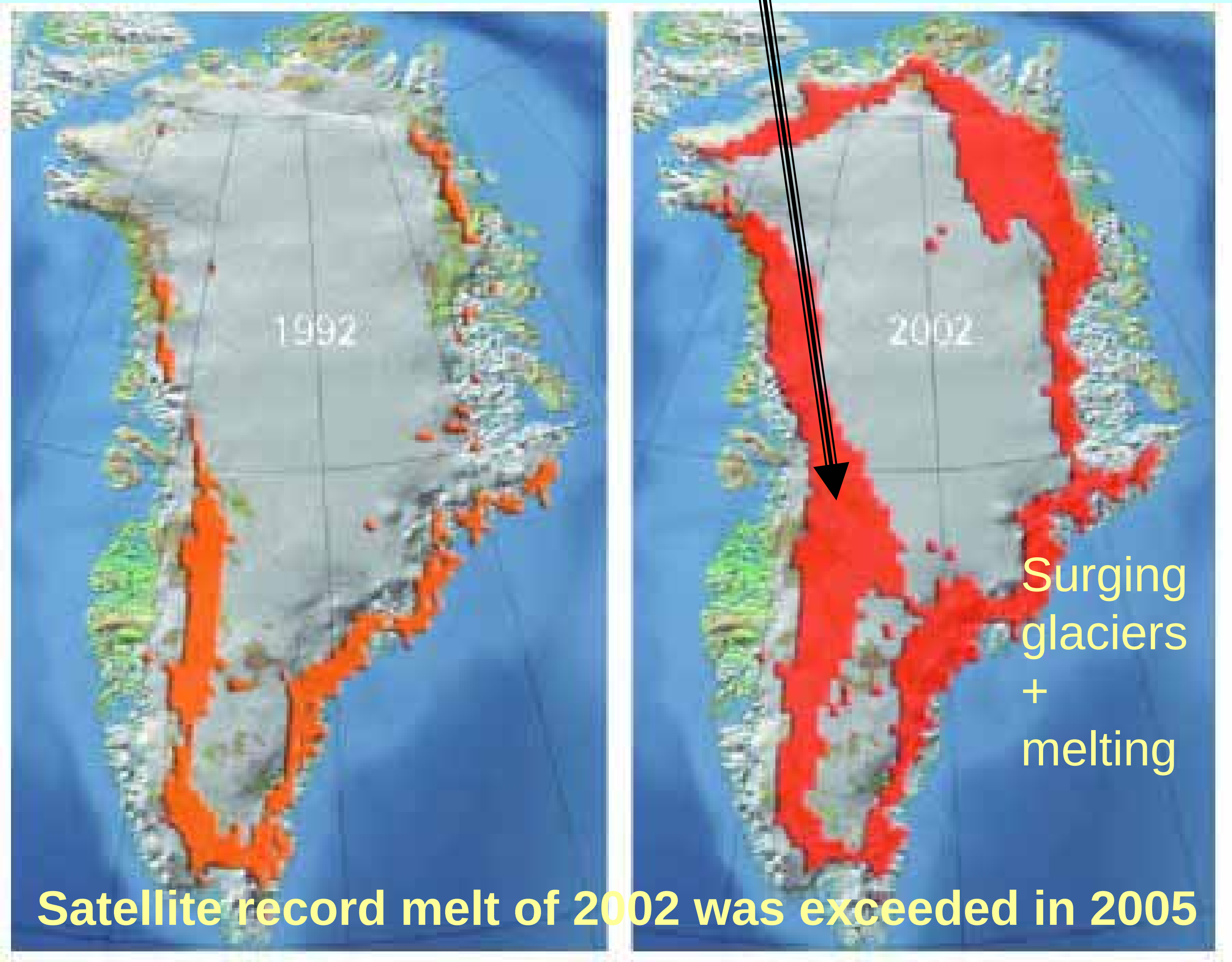
- Greenhouse gases building up rapidly in the atmosphere; CO_2 ~35% higher and CH_4 ~170% higher than pre-industrial levels
- Average temperature increase of 0.6^{o}C in past century; temperature rise accelerating
- More extreme weather events—drought, flooding, hurricanes
- Arctic, Antarctic and Greenland ice melt
- Ocean acidification
- Less snow and changes in rainfall in the West— impacts on agriculture, water supply, wildfires, etc.



Larson B
ice shelf
break-up,

Antarctica,
2002

Greenland Ice Sheet: 70m thinning in 5 years



Unstable Glaciers

Surface melt on Greenland ice sheet descending into moulin, a vertical shaft carrying the water to base of ice sheet.

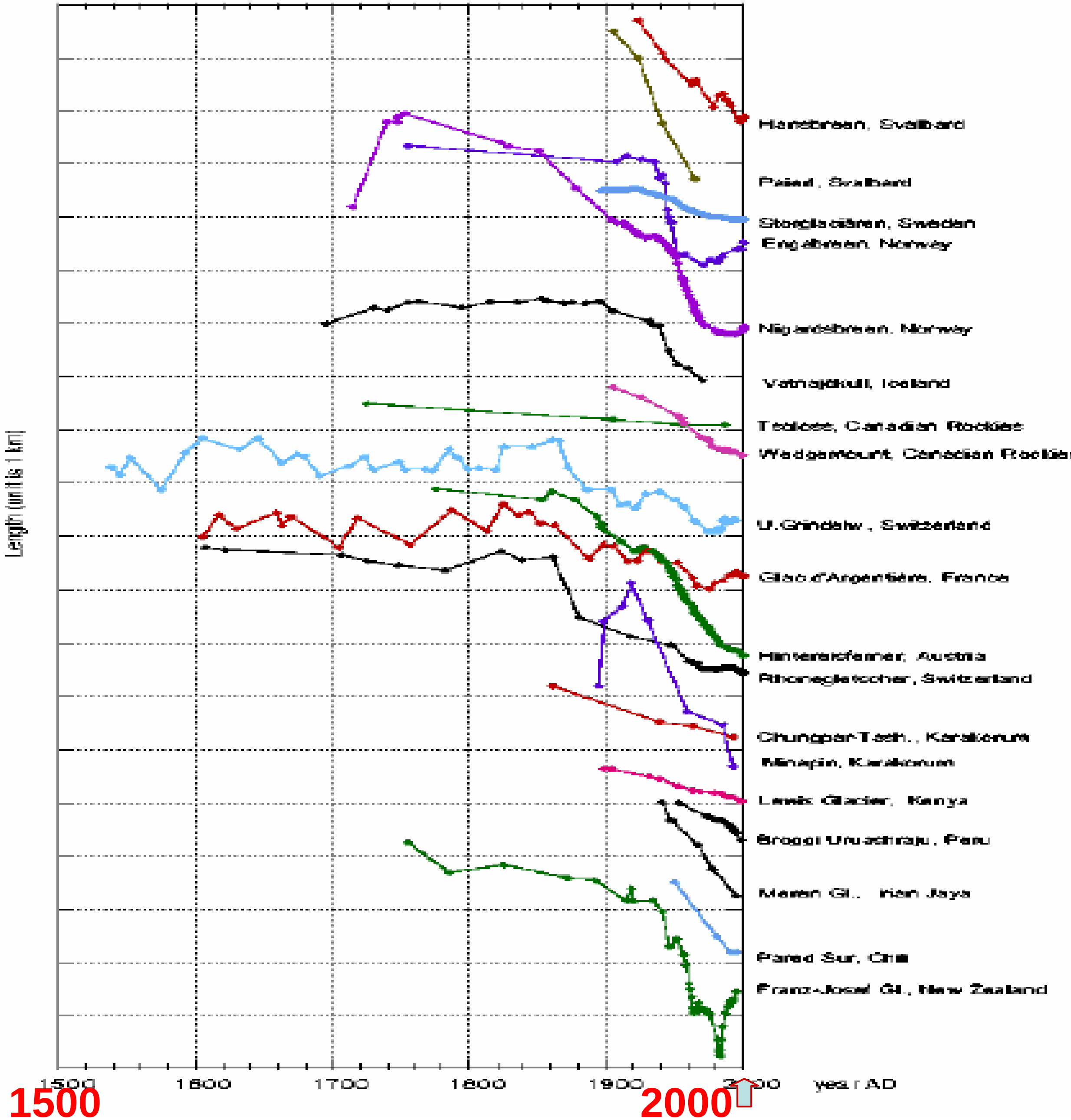
Source: Roger Braithwaite

Jakobshavn Ice Stream in Greenland

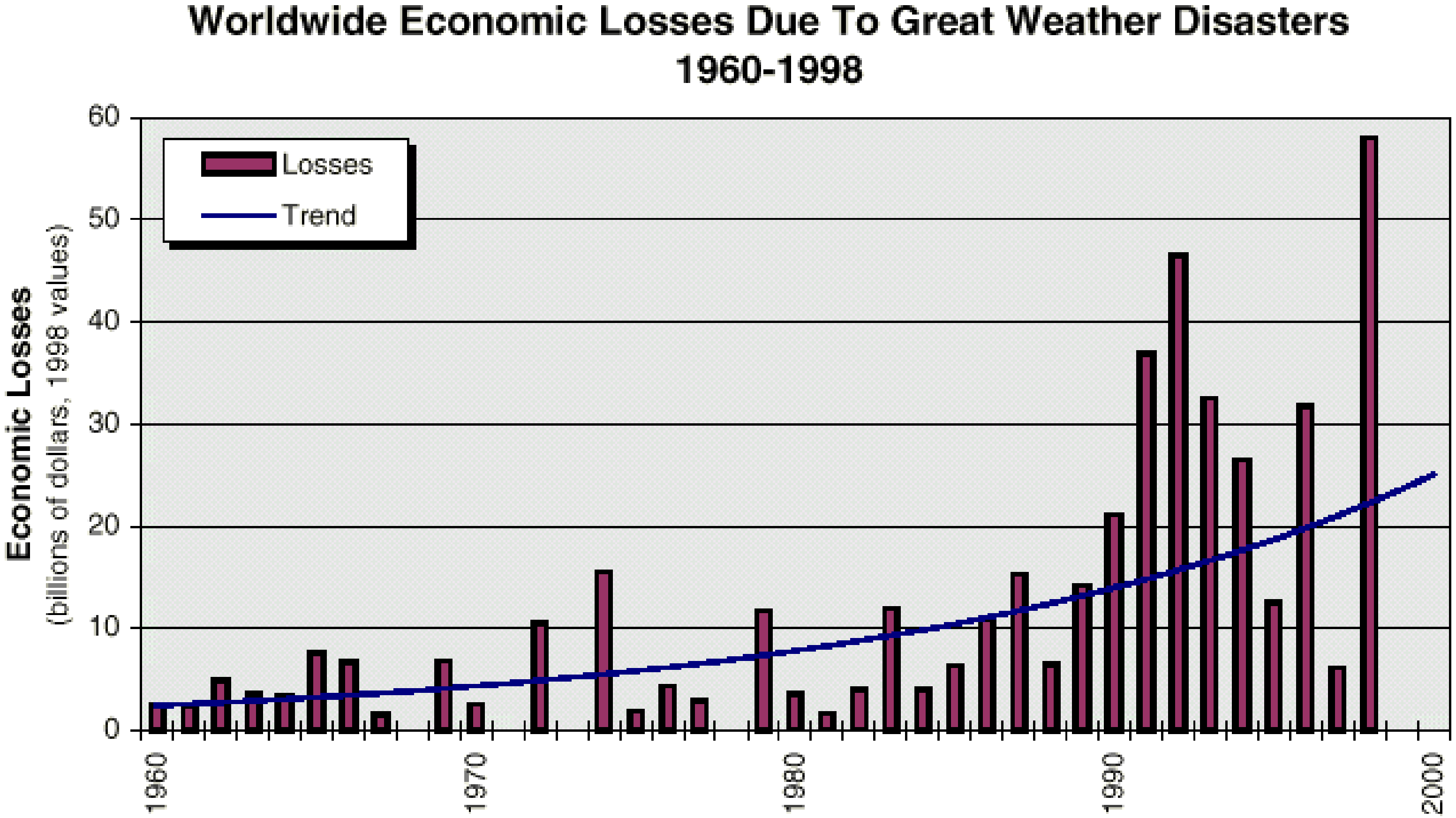
Discharge from major Greenland ice streams is accelerating markedly.

Source: Prof. Konrad Steffen, Univ. of Colorado

Changes
In Glacier
Areas, 1500
-2000

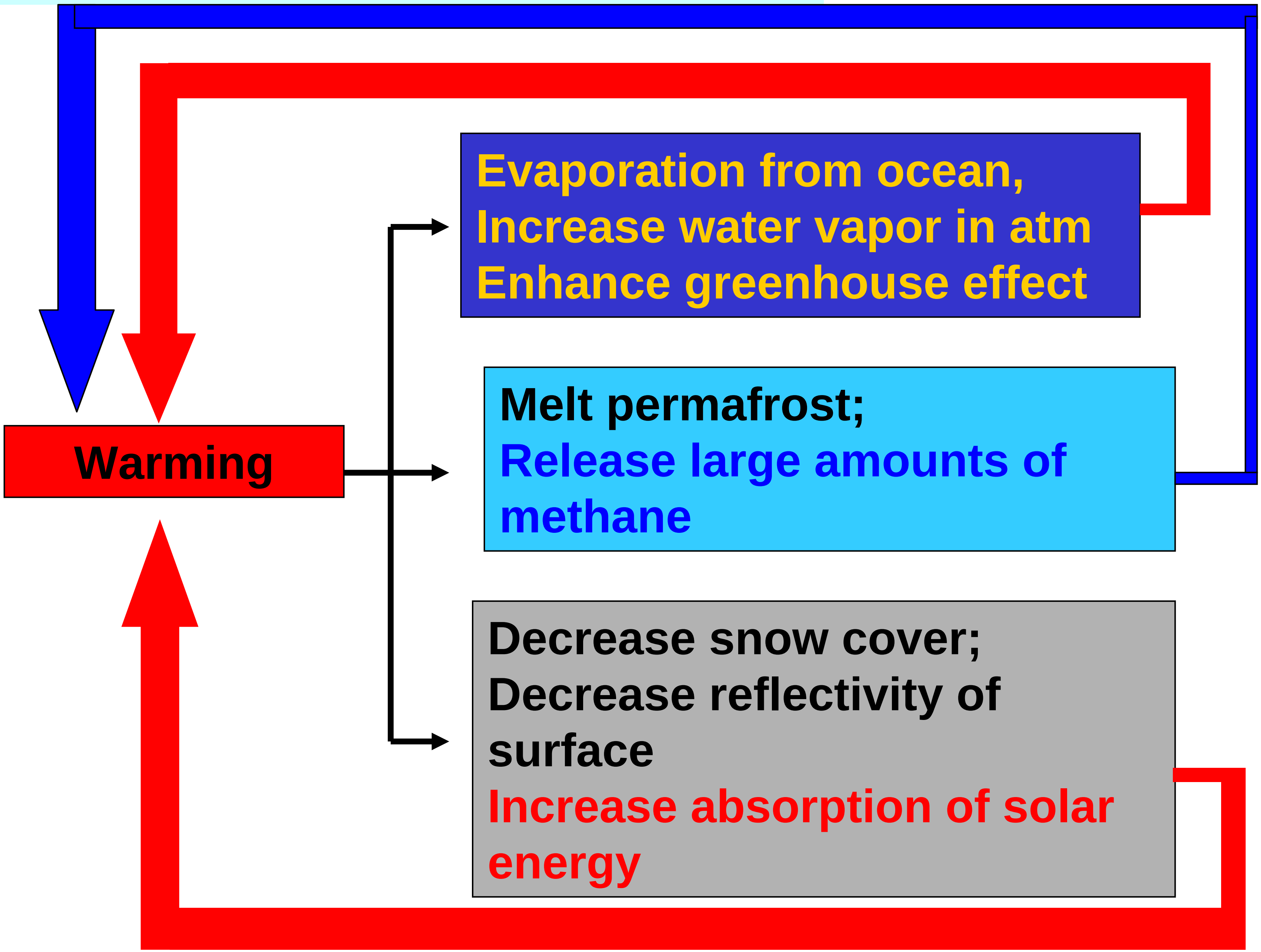


Watching Their Losses



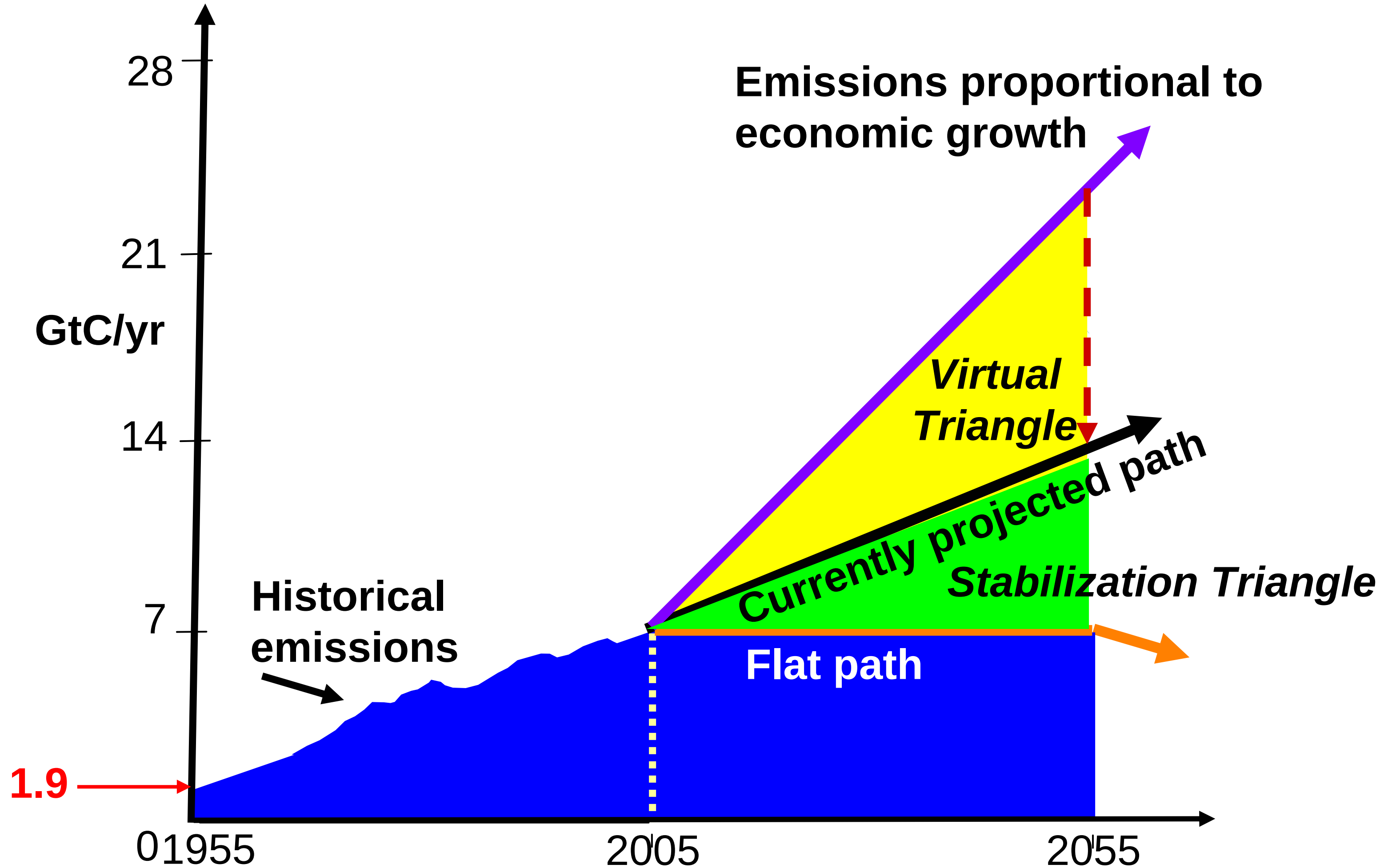
© Munich Re, 1999

Climate Feedbacks



What can be done to reduce CO_2 emissions?

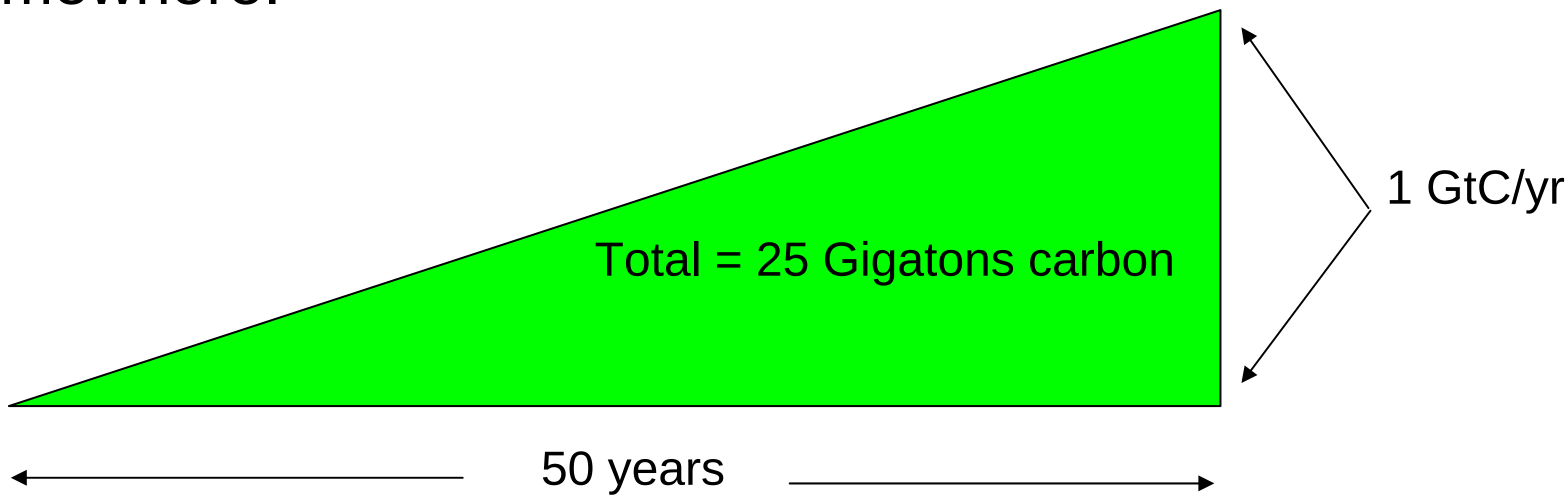
The Virtual Triangle: Large Carbon Savings Are Already in the Baseline



Models differ widely in their estimates of contributions to the virtual triangle from structural shifts (toward services), energy efficiency, and carbon-free energy.

What is a "Wedge"?

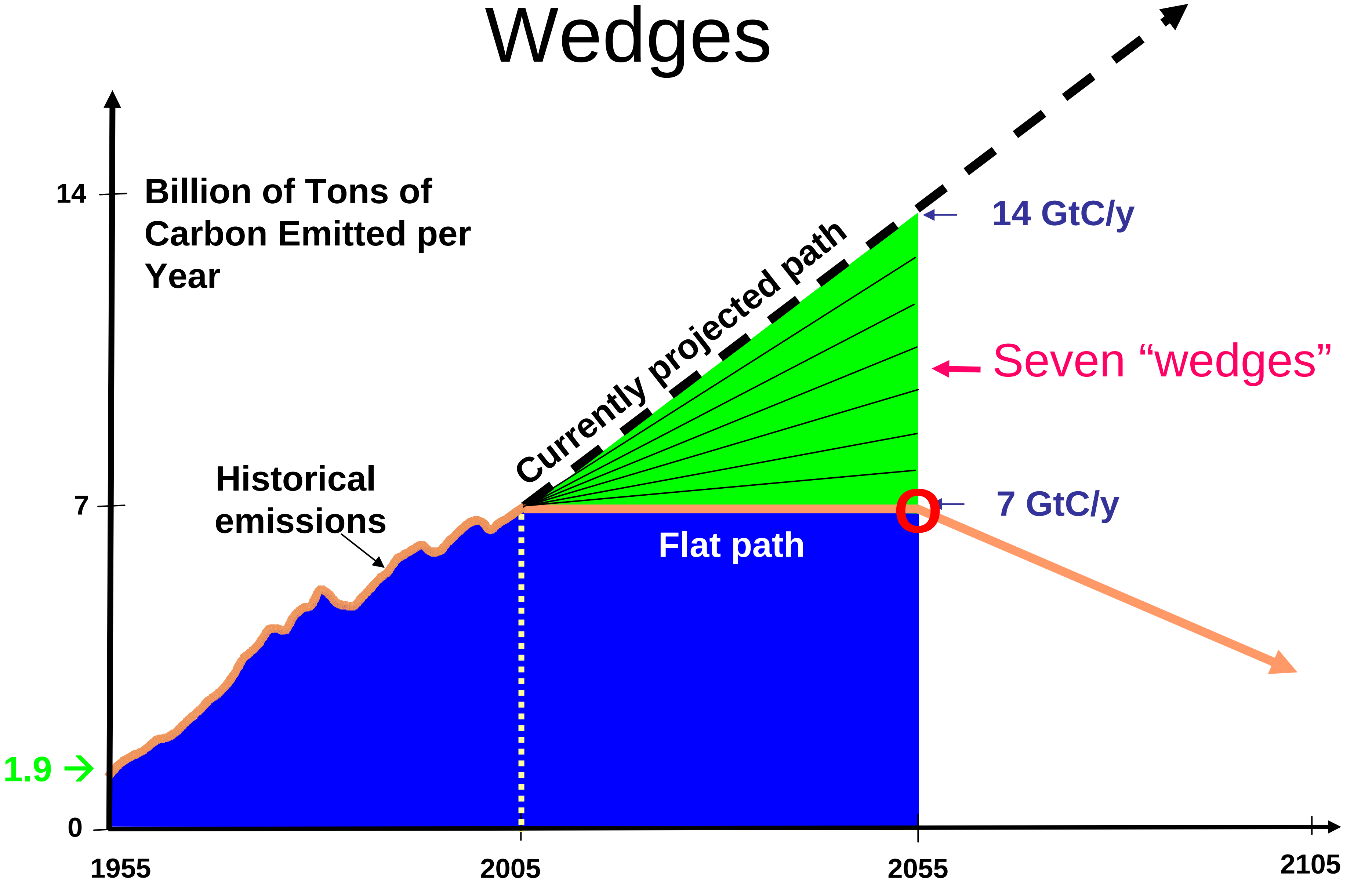
A "wedge" is a strategy to reduce carbon emissions that grows in 50 years from zero to 1.0 GtC/yr (~65 EJ/yr). The strategy has already been commercialized at scale somewhere.



Cumulatively, a wedge redirects the flow of 25 GtC in its first 50 years. This is 2.5 trillion dollars at $100/tC.

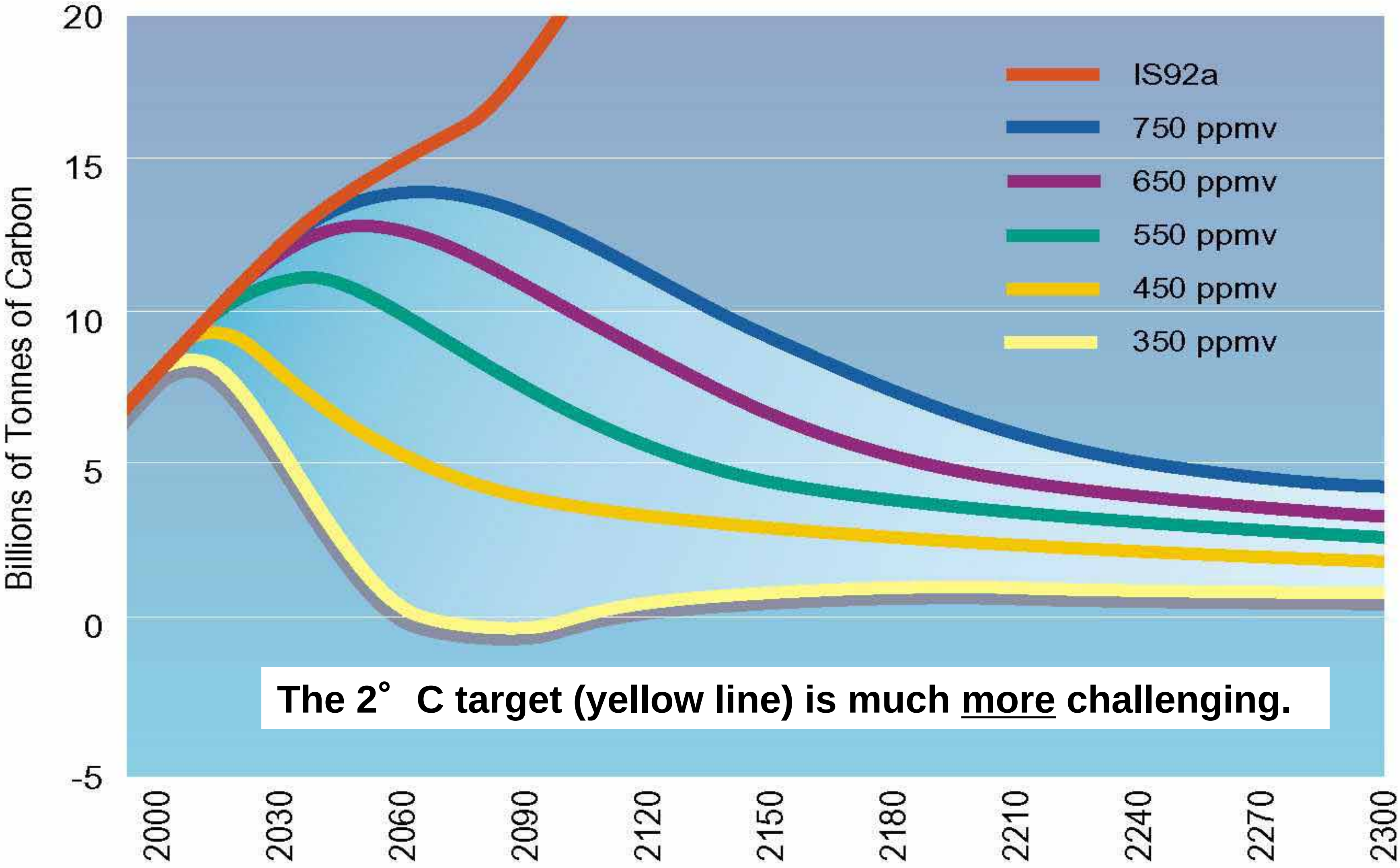
A "solution" to the CO_2 problem requires 7 wedges by 2055.

Wedges



14
7
0
Billion of Tons of Carbon Emitted per Year
Historical emissions
Currently projected path
14 GtC/y
Seven "wedges"
7 GtC/y
O
Flat path
1.9
1955
2005
2055
2105

Emissions Trajectories Consistent With Various Atmospheric CO_2 Concentration Ceilings



Example Wedges

At the power plant, CO_2 heads for the sky, the electrons head for buildings!

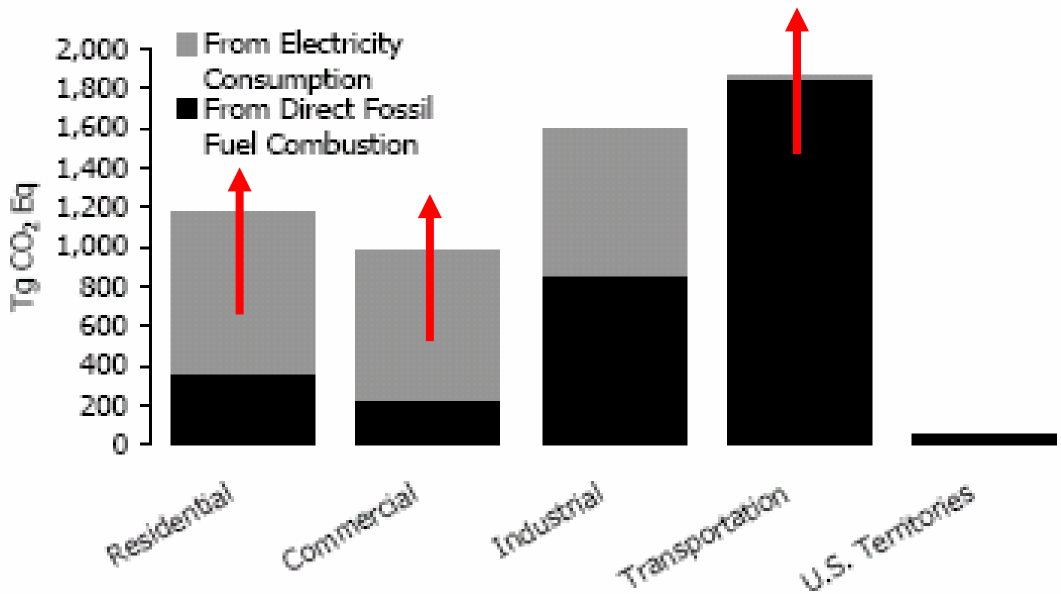


Figure 2-9: 2004 End-Use Sector Emissions of CO_2 from Fossil Fuel Combustion

1) Electricity in buildings, and 2) fossil fuel from all forms of transport are the components of CO_2 emissions that rise in a post-industrial society.

They are the two top places to look for wedges.

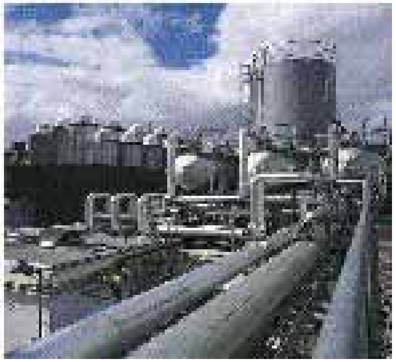
Source: U.S. EPA

Efficient Use of Electricity

motors

lighting

cogeneration



Effort needed by 2055 for 1 wedge:

.

25% reduction in expected 2055 electricity use in commercial and residential buildings

Efficient Use of Fuel

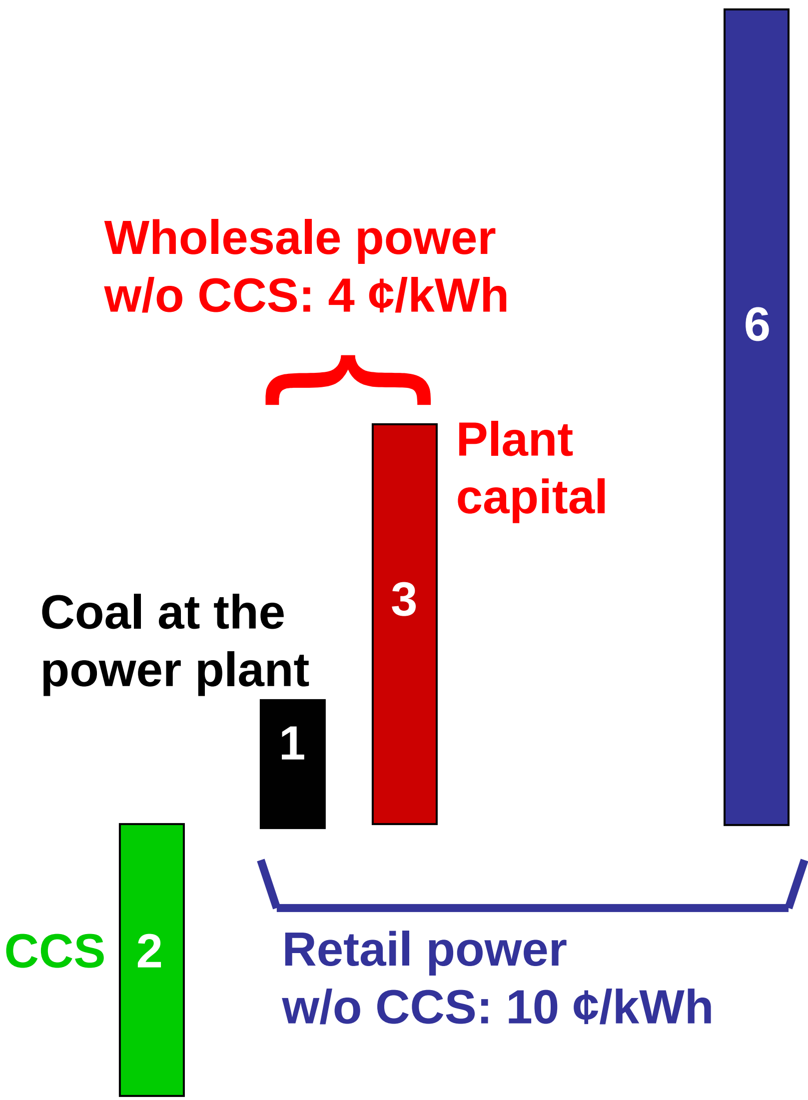
Effort needed by 2055 for 1 wedge:

2 billion cars driven 10,000 miles/yr at 25.5 km/l (60 mpg) instead of 12.25 km/l (30 mpg) ***or***

1 billion cars driven, at 30 mpg, 5,000 instead of 10,000 miles/yr.

A car at 12.25 (30 mpg), 10,000 miles/yr, emits 1 tC/yr.

$100/tC ≈ 2¢/kWh induces CCS. Three views.



If the added cost of capturing CO2 and generating electricity with coal-gasification is 2¢/kWh ($100/tC), then this:

triples the price of delivered coal;

adds 50% to the busbar price of electricity from coal;

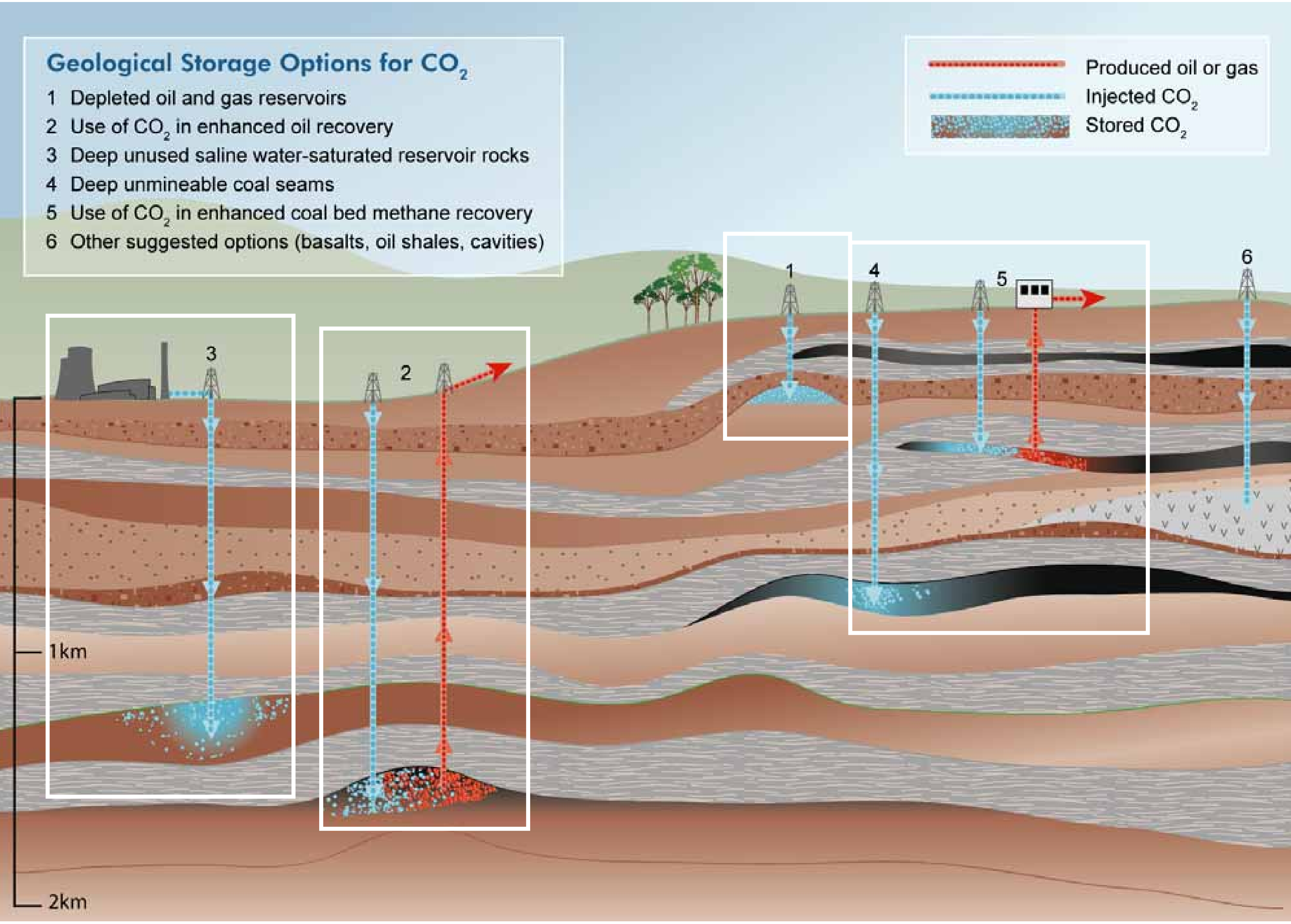
adds 20% to the household price of electricity from coal.

The Long Term

Even if 7 or more wedges could be achieved by 2055 with existing resources and technology (an unlikely prospect), new carbon-neutral energy sources will be required. Transformation of energy supply is very slow, so much increased emphasis on R,D, &D is needed today.

Potential supply-side solutions to the Energy Problem

- Coal, tar sands, shale oil, …
- Fusion
- Fission
- Wind
- Solar photocells
- Bio-mass


Geological Storage Options for CO_2
1 Depleted oil and gas reservoirs
2 Use of CO_2 in enhanced oil recovery
3 Deep unused saline water-saturated reservoir rocks
4 Deep unmineable coal seams
5 Use of CO_2 in enhanced coal bed methane recovery
6 Other suggested options (basalts, oil shales, cavities)
Produced oil or gas
Injected CO_2
Stored CO_2
1
2
3
4
5
6
1km
2km

Carbon capture and storage costs

Power plant system	Natural Gas Combined Cycle (US$/kWh)	Pulverized Coal (US$/kWh)	Integrated Gasification Combined Cycle (US$/kWh)
Without capture (reference plant)	0.03 - 0.05	0.04 - 0.05	0.04 - 0.06
With capture and geological storage	0.04 - 0.08	0.06 - 0.10	0.05 - 0.09

“To achieve such an economic potential, several hundreds to thousands of CO_2 capture systems would need to be installed over the coming century, each capturing some 1 - 5 $MtCO_2$ per year. The actual use of CCS … is likely to be lower due to factors such as environmental impacts, risks of leakage, and the lack of a clear legal framework or public acceptance”.

IPCC Special Report on Carbon dioxide Capture and Storage

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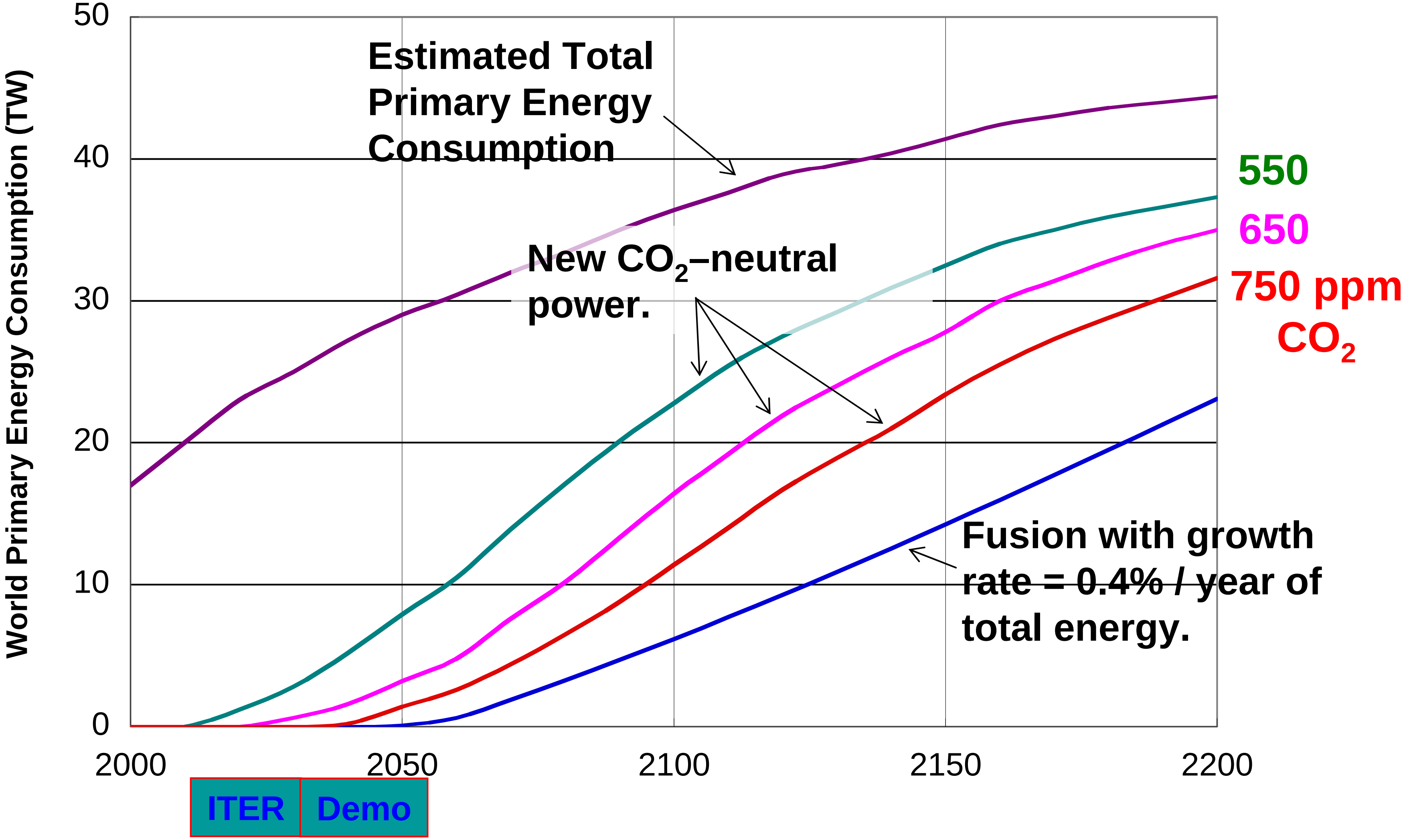
Fusion will not major contributor for most if not all of the 21st century



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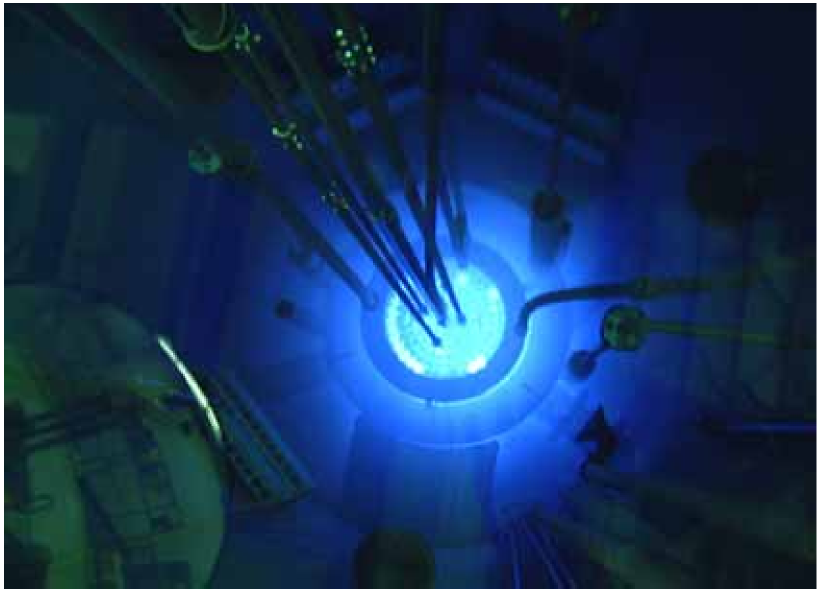
Nuclear Fission



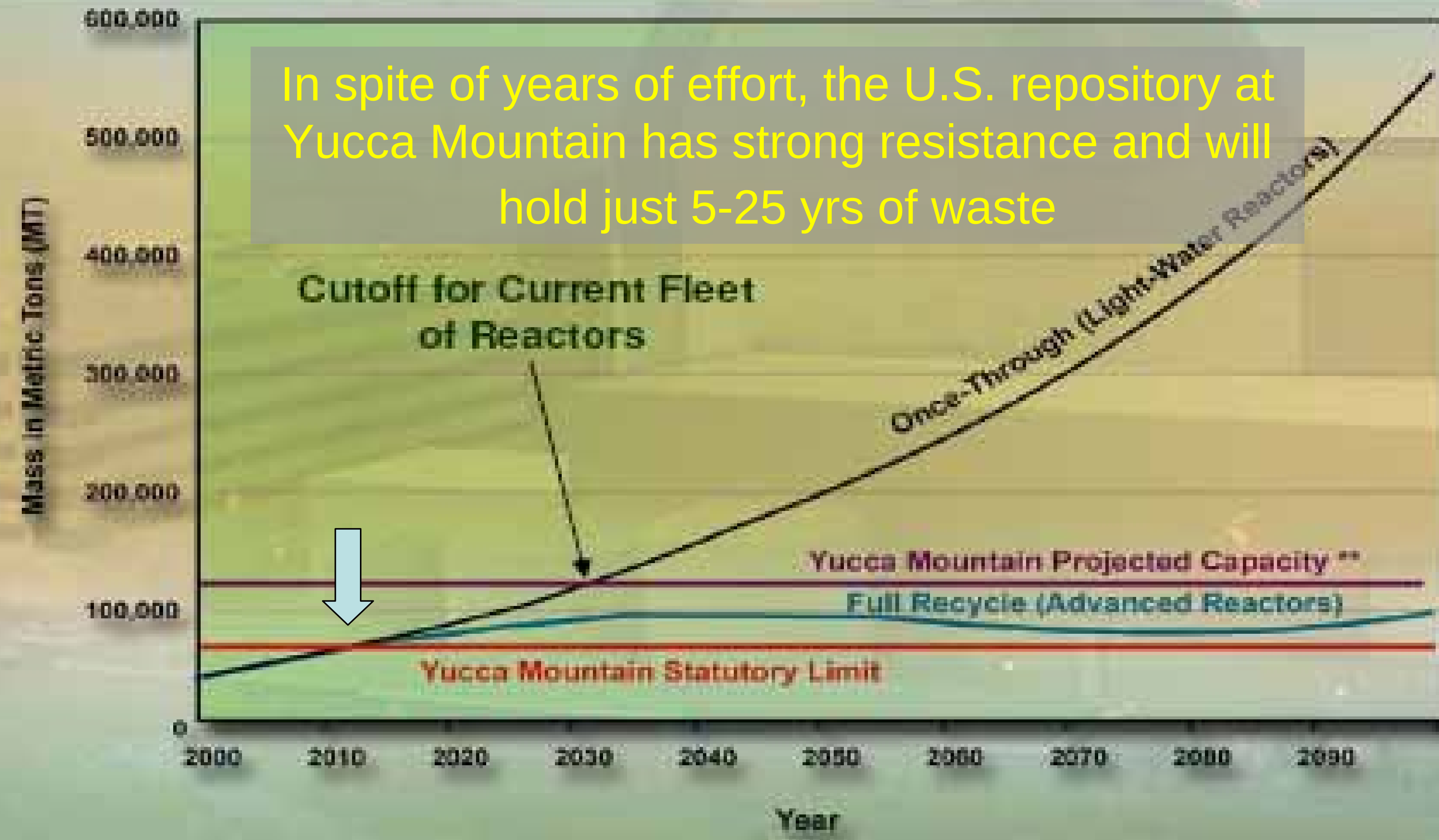
Nuclear fission has the technical and economic potential to have the greatest impact on CO_2 emissions today. . . *but there are key issues that need to be addressed*

Nuclear power issues define research agenda

- To extend resources and reduce waste repositories (100-fold), breeder reactors are needed to convert U-238
- In the U.S., the immediate concern (for once-through fuel cycle) is geological repository design and licensing: no place to store waste
- Transition to closed fuel cycle requires three technologies
  - processing/recycle for LWR legacy fuel
  - breeder reactors for actinide consumption
  - processing/recycle for breeder reactor spent fuel
- Proliferation-resistant nuclear fuel cycle

Even with successful research, the issue of public acceptance of nuclear power in such countries as the United States is problematic

In spite of years of effort, the U.S. repository at Yucca Mountain has strong resistance and will hold just 5-25 yrs of waste



*Assumes continued electricity growth, with nuclear energy maintaining 20 percent market share.

**U.S. Department of Energy, 2002, *Final Environmental Impact Statement for a Geologic Repository for the Disposal of Spent Nuclear Fuel and High-Level Radioactive Waste at Yucca Mountain, Nye County, Nevada*, DOE/EIS-0250, Washington, D.C., February.

Potential supply-side solutions to the Energy Problem

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- Fission
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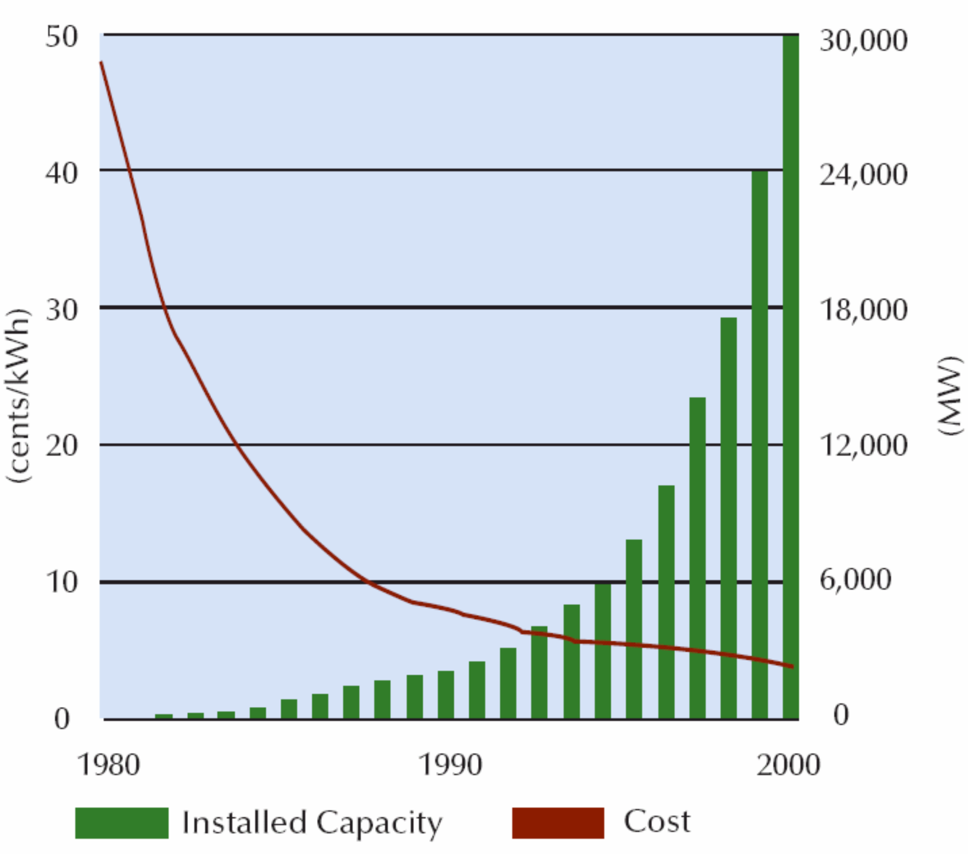
Tax incentives and rebates were essential to stimulate continued development of power generation from wind



Is it possible to develop a new class of durable solar cells with high efficiency at 1/10th the cost of silicon?

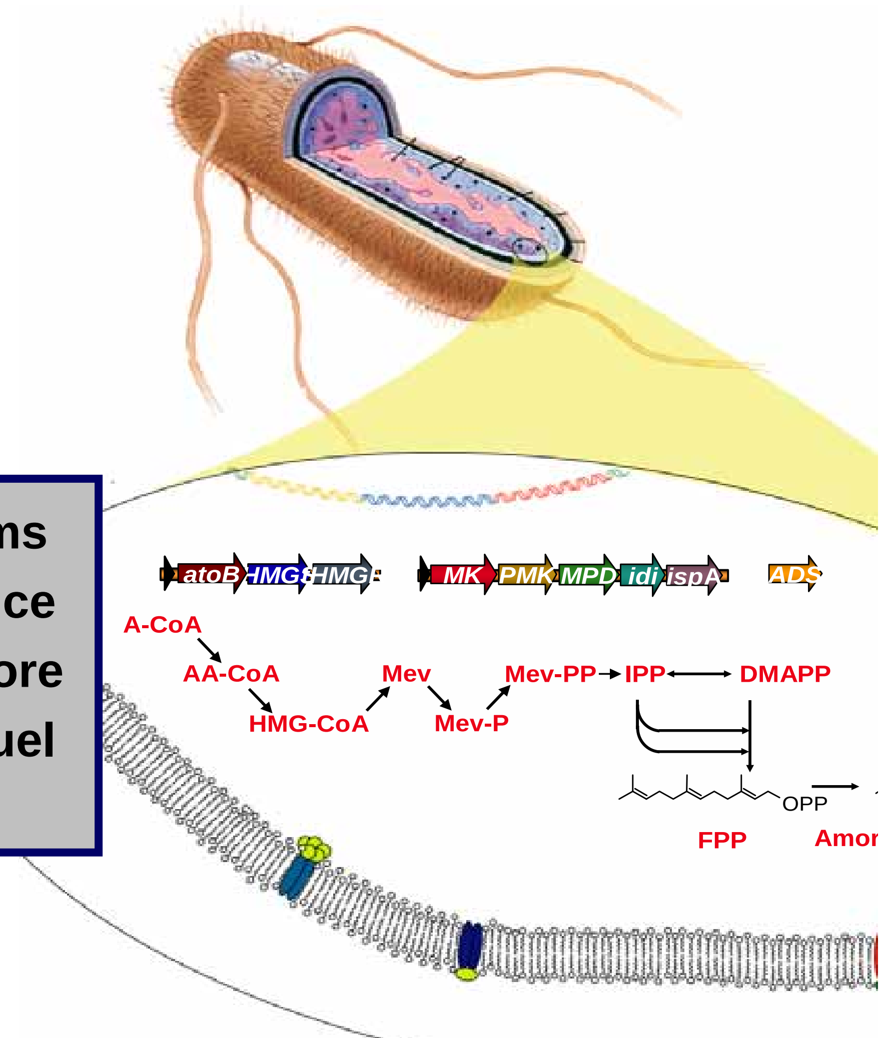
Potential supply-side solutions to the Energy Problem

- Coal, tar sands, shale oil, …
- Fusion
- Fission
- Wind
- Solar photocells
- Bio-mass

Photosynthesis: Nature has found a way to convert sunlight, CO_2, water and nutrients into chemical energy

Synthetic Biology: Production of artemisinin in bacteria to produce low-cost malaria medicine: with support from Bill Gates, project is successful

Can synthetic organisms be engineered to produce ethanol, methanol or more suitable hydrocarbon fuel biomass?



Conclusions

- We need aggressive energy efficiency policy, cost-effective measures*, and R&D
- And more energy efficiency
- And more . . . .
- We need to open markets and strongly emphasize all cost-effective,* carbon neutral energy supply technologies (at present, wind and nuclear)
  - R&D on storage for wind; on waste/non-proliferation for nuclear
- We need to greatly accelerate R&D on carbon neutral energy technologies
  - We need to pursue R&D in all technologies with promise: my view is that the greatest opportunities are in genetically engineered energy crops, advanced nuclear fuel cycles, photovoltaics and carbon capture and storage

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* With a carbon tax designed to reflect the costs of CO_2 emissions or to achieve specific reductions

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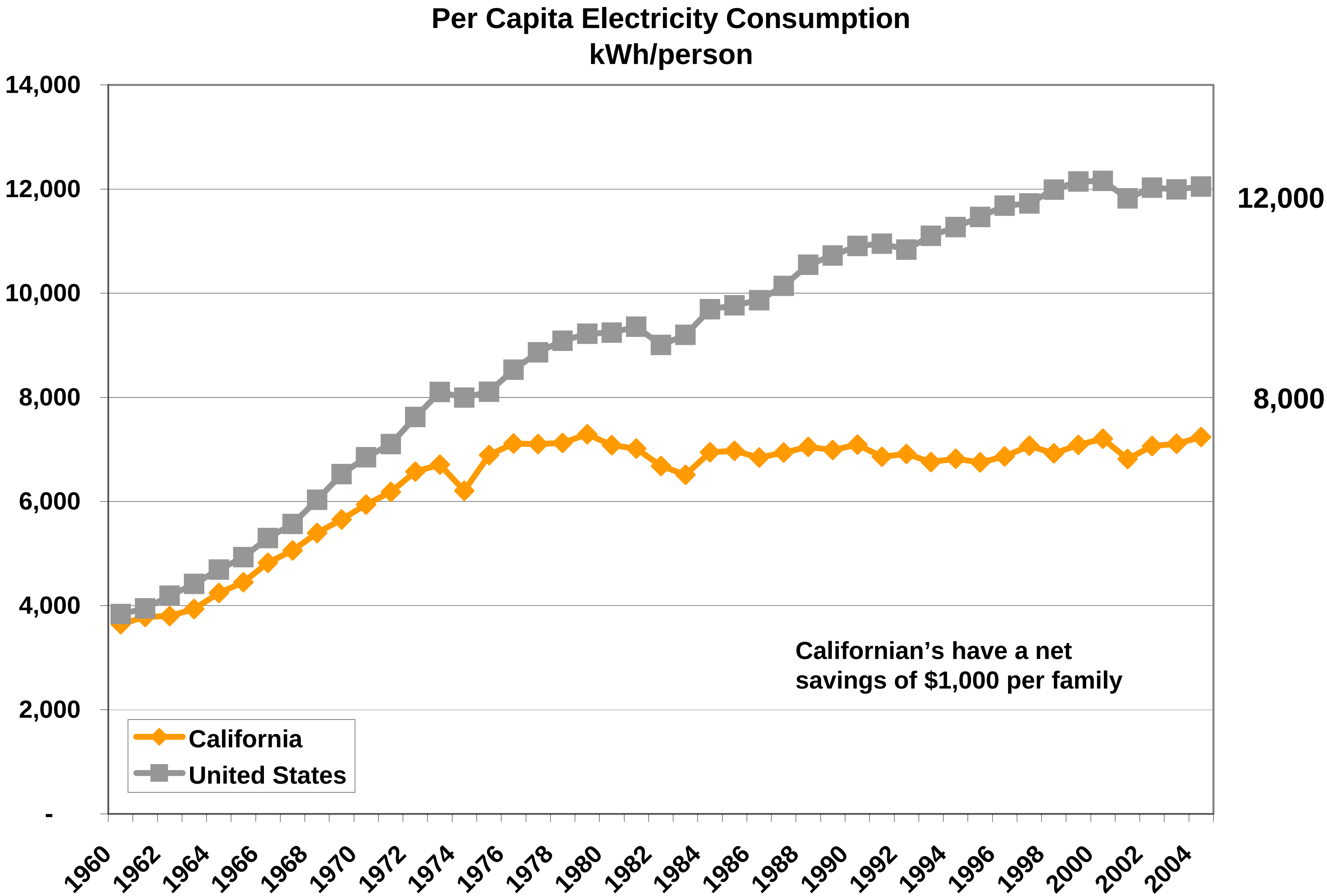
The End

Well, almost

Supplement:

The California Story



Source: http://www.eia.doe.gov/emeu/states/sep_use/total/csv/use_csv

Annual Energy Savings from Efficiency Programs and Standards