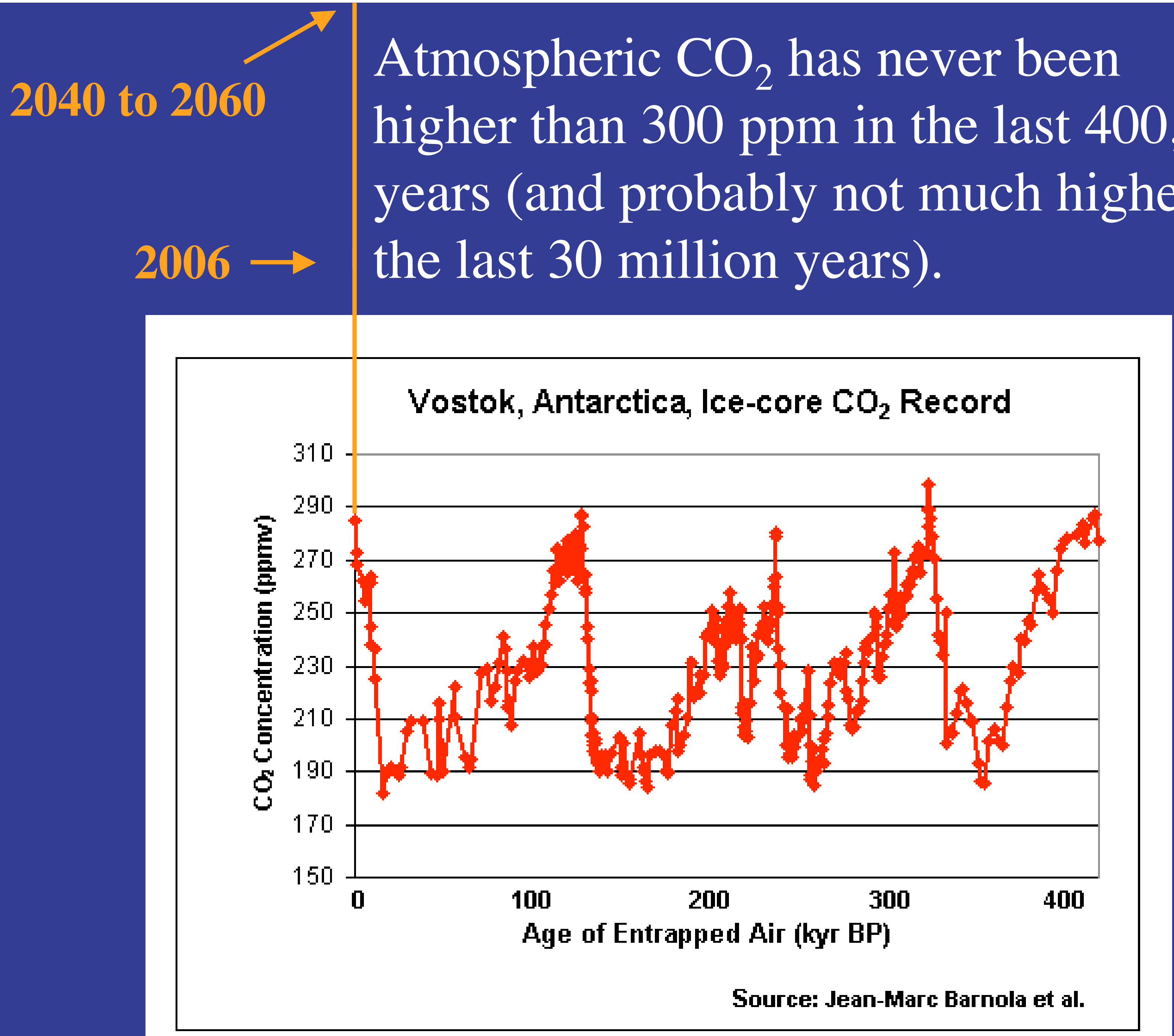
Energy Goals

security

economy

environment

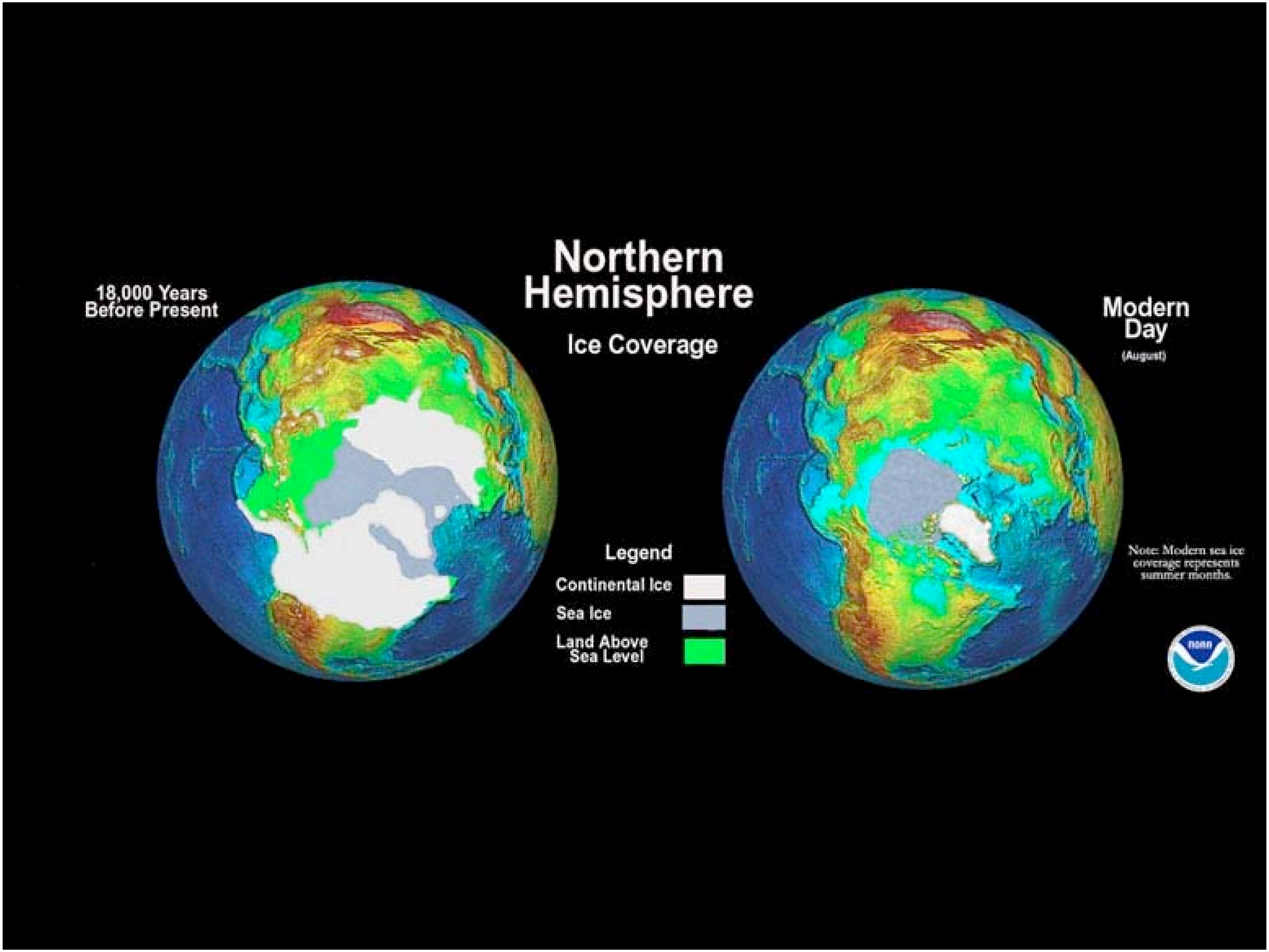
Atmospheric CO_2 has never been higher than 300 ppm in the last 400,000 years (and probably not much higher in the last 30 million years).



EOCENE (55 to 36 million years ago): The last time in Earth history when atmospheric CO_2 was above 500 ppm.

The Eocene climate was warm, even at high latitudes:

- -palm trees flourished in Wyoming
- -crocodiles lived in the Arctic
- -Antarctica was a pine forest
- -deep ocean temperature was 12°C (today it is ~2°C)
- -sea level was at least 100 meters higher than today


Northern
Hemisphere
Ice Coverage
18,000 Years
Before Present
Modern
Day
(August)
Legend
Continental Ice
Sea Ice
Land Above
Sea Level
Note: Modern sea ice
coverage represents
summer months.

We are performing an experiment *at a planetary scale* that hasn't been done for millions of years.

No one knows exactly what is going to happen.

There will be surprises....

droughts

heat waves

failure of water supplies

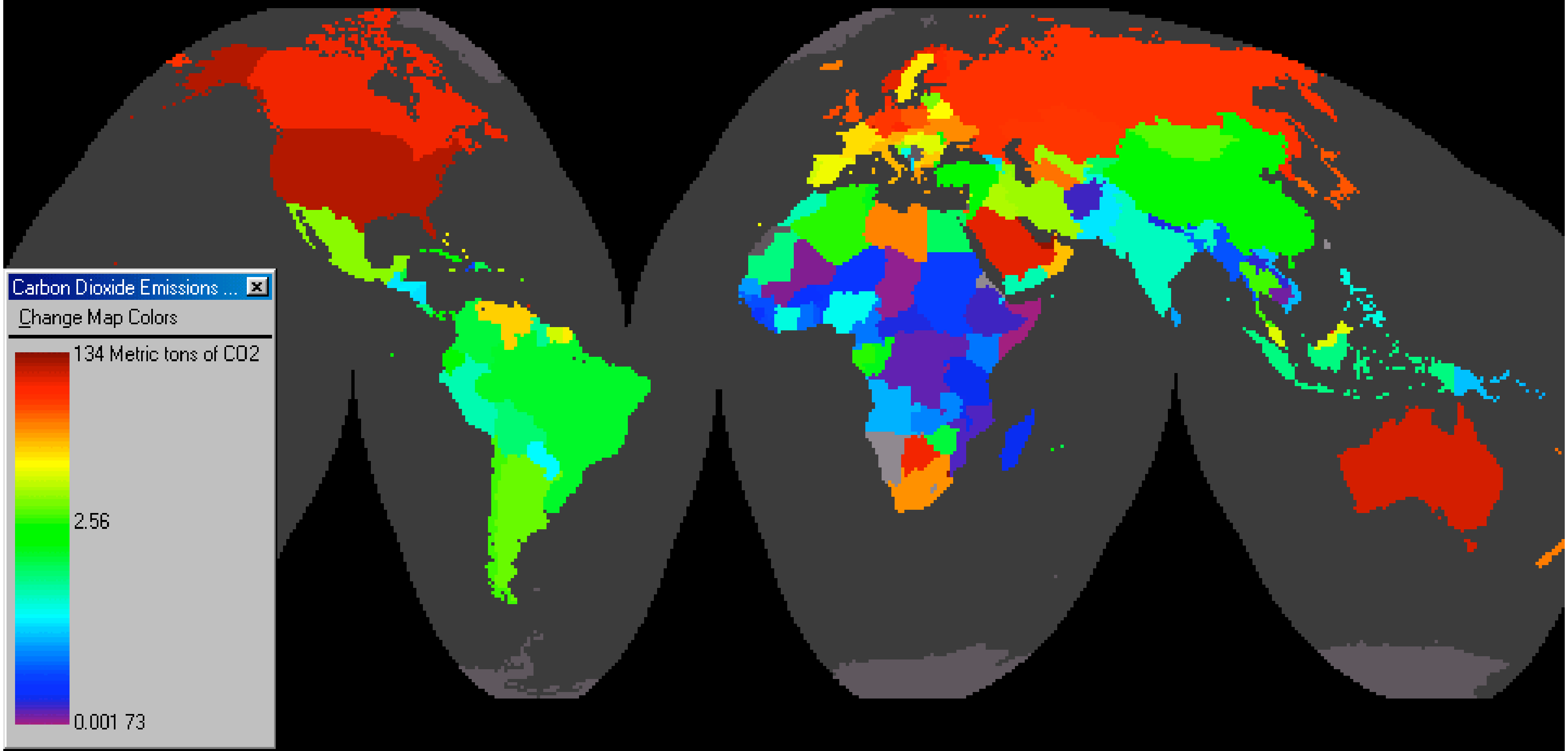
melting of ice sheets

What is the solution? How do we keep CO_2 below a dangerous level?

- What level is dangerous?
- We must act quickly because of long lifetime of CO_2 in the atmosphere *and* the long lifetime of energy capital investments, particularly in China and other rapidly developing countries.
- efficiency
- non-fossil fuel energy
  solar, wind, nuclear, biomass, hydroelectric
- carbon capture and storage

We need a plan…

Per capita carbon dioxide emissions, 1996



Source: Annual CO2 Emissions, 1751-1996 (March 1999), Carbon dioxide emissions data come from Carbon Dioxide Information Analysis Center (CDIAC), Environmental Sciences Division, Oak Ridge National Laboratory, "Global, Regional, and National Annual CO2-Emissions from Fossil-Fuel Burning, Hydraulic Cement Production, and Gas Flaring: 1751-1996," NDP-030 (an Internet-accessible numerical database, available at http://cdiac.esd.ornl.gov/ftp/ndp030/)(Oak Ridge,Tennessee, March 1999). Population data come from The United Nations (U.N.) Population Division, Annual Populations 1950--2050 (The 1998 Revision), on diskette (U.N., New York, 1999).

Energy from oil and gas:

- supply is unlikely to meet growth in demand
- security concerns (funding our enemies)
- inherent price instability

Energy from coal:

•very abundant (several centuries of reserves)

•highest carbon emissions per unit of energy

Energy from the atom:

- more expensive than coal
- waste disposal?
- proliferation of weapons technology
- obstacles to investment

Energy from wind:

- economically competitive with fossil fuel,
- unreliable so it requires enormous excess capacity
- storage?

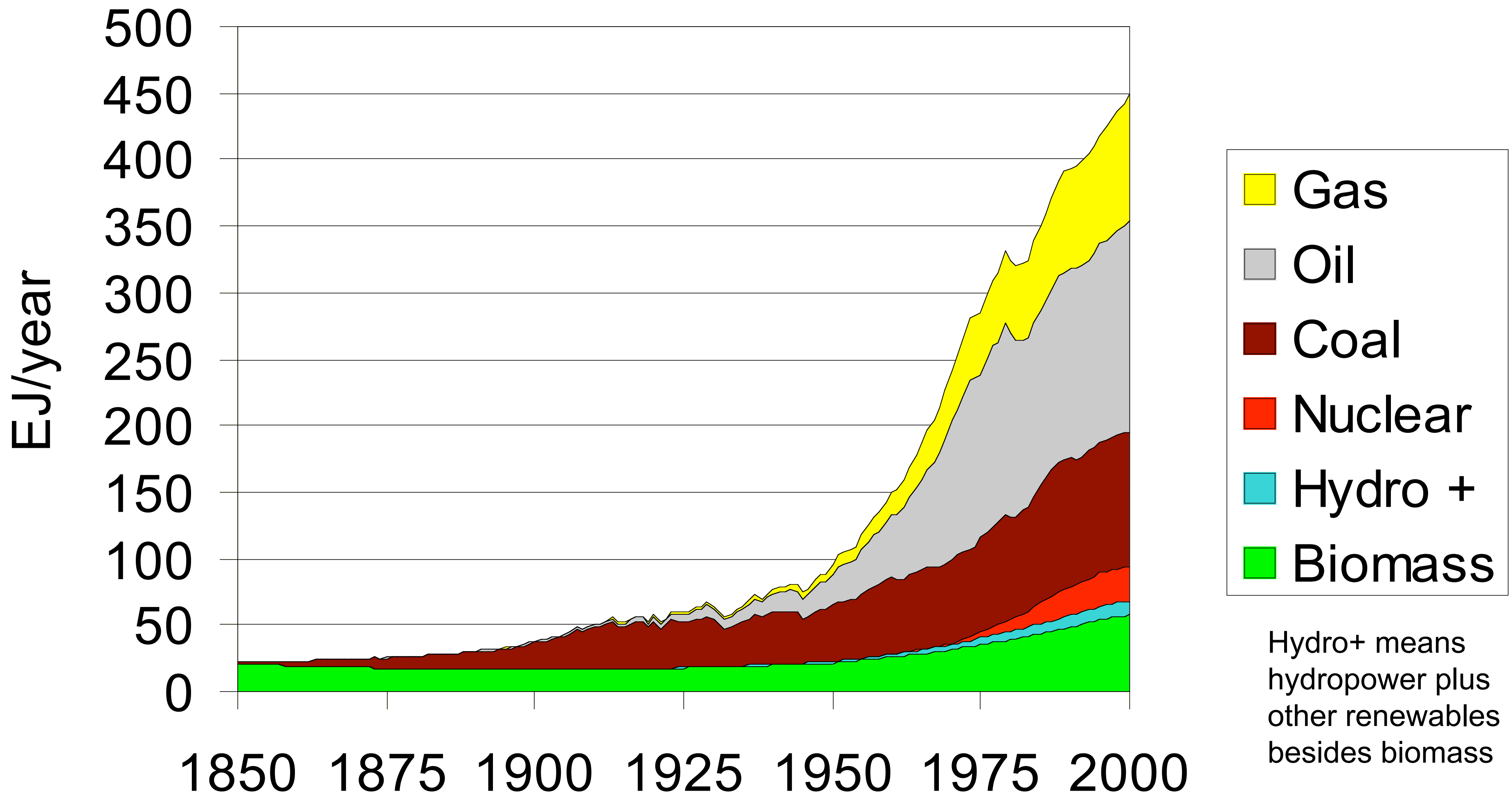
Energy from the sun:

- very expensive
- cannot be used everywhere
- storage?

Energy from agriculture:

- much more expensive than cheap oil
- may be a good option for developing world in the tropics
- politically attractive in the U.S.

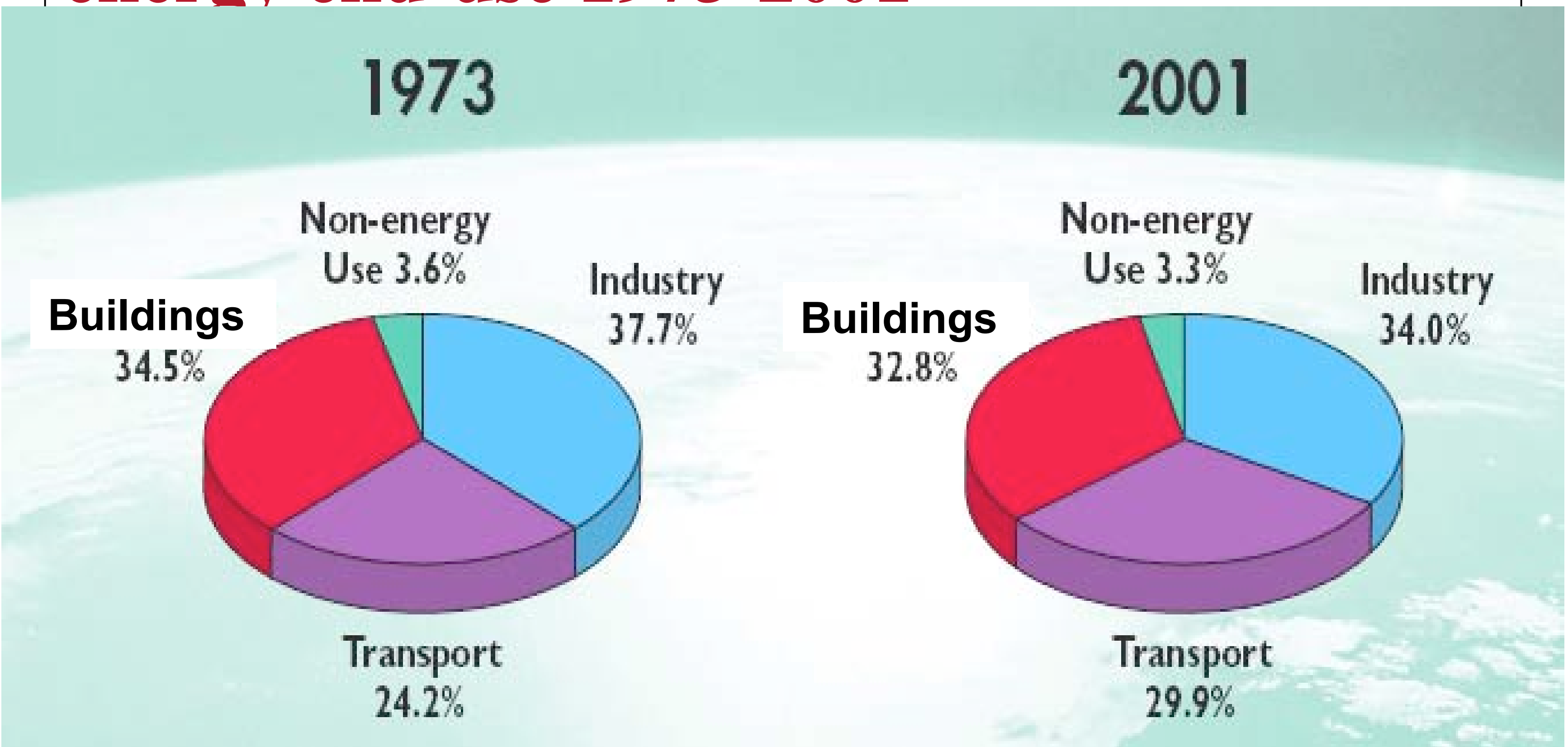
History of world supply of primary energy



Hydro+ means hydropower plus other renewables besides biomass

Energy supply grew 20-fold between 1850 and 2000. Fossil fuels supplied 80% of the world's energy in 2000.

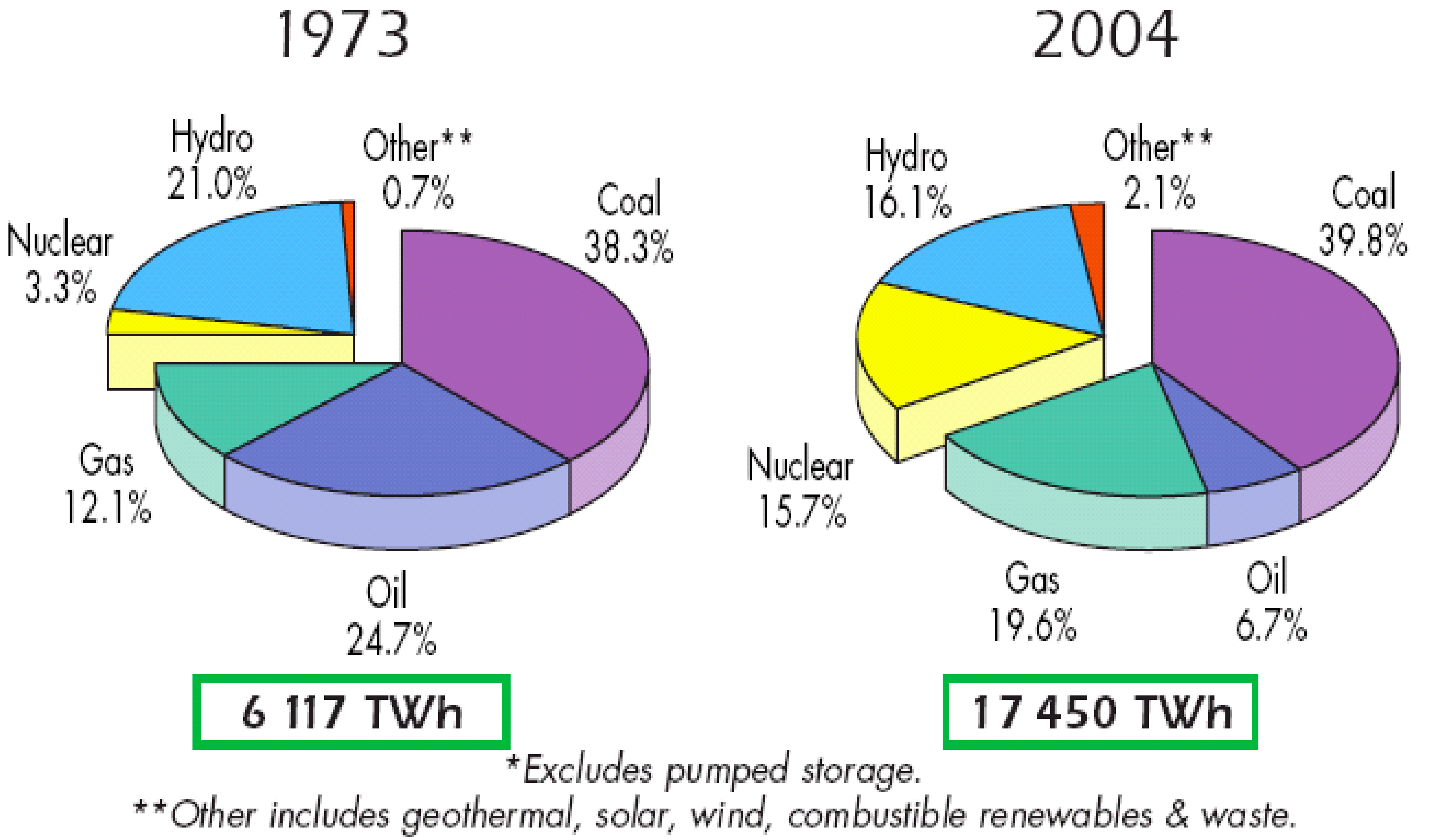
What does the energy do? Trends in energy end-use 1973-2001



Transport's share is growing; shares of other uses are shrinking.

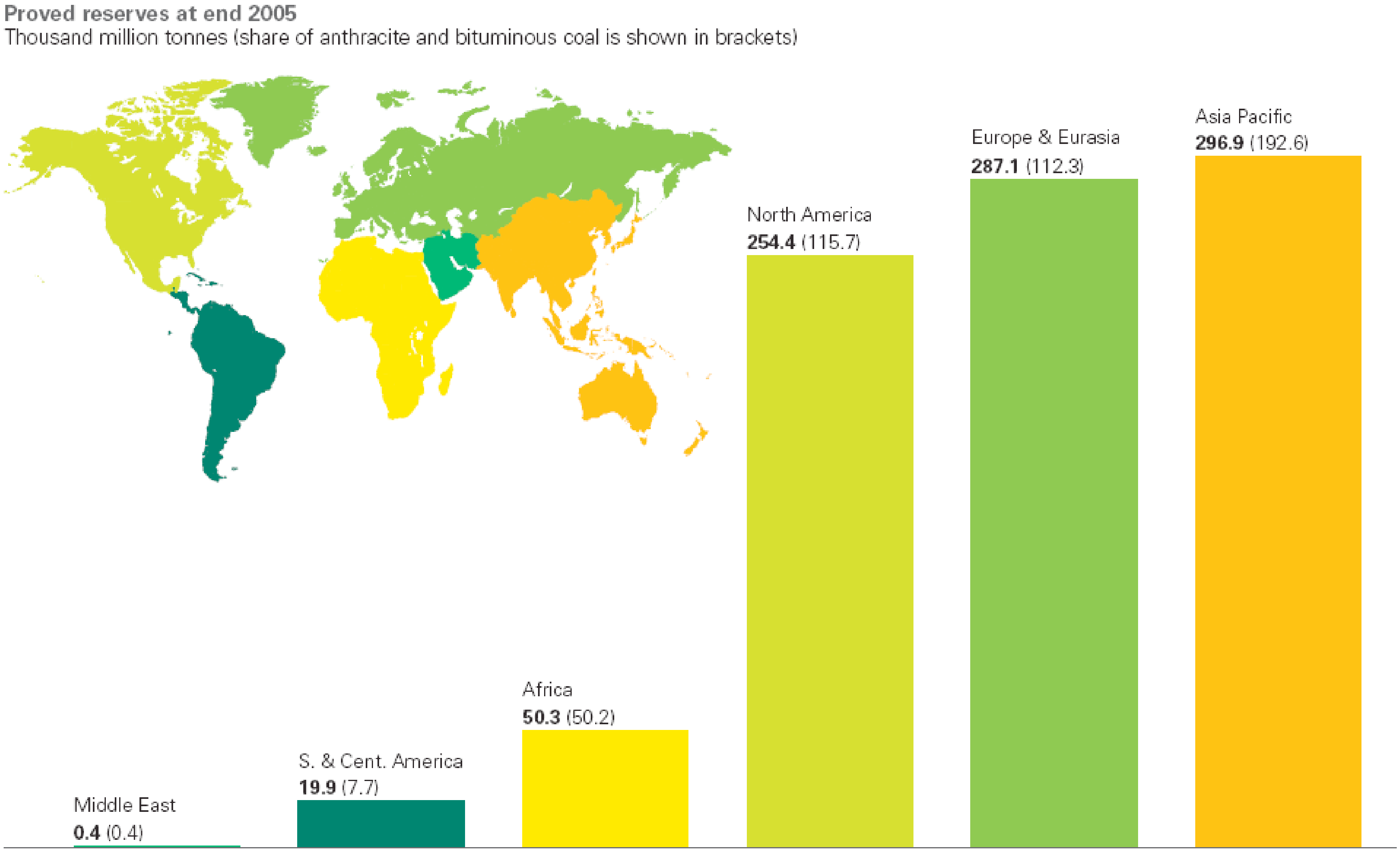
International Energy Agency 2005

About 1/3 of primary energy supply is used to generate electricity

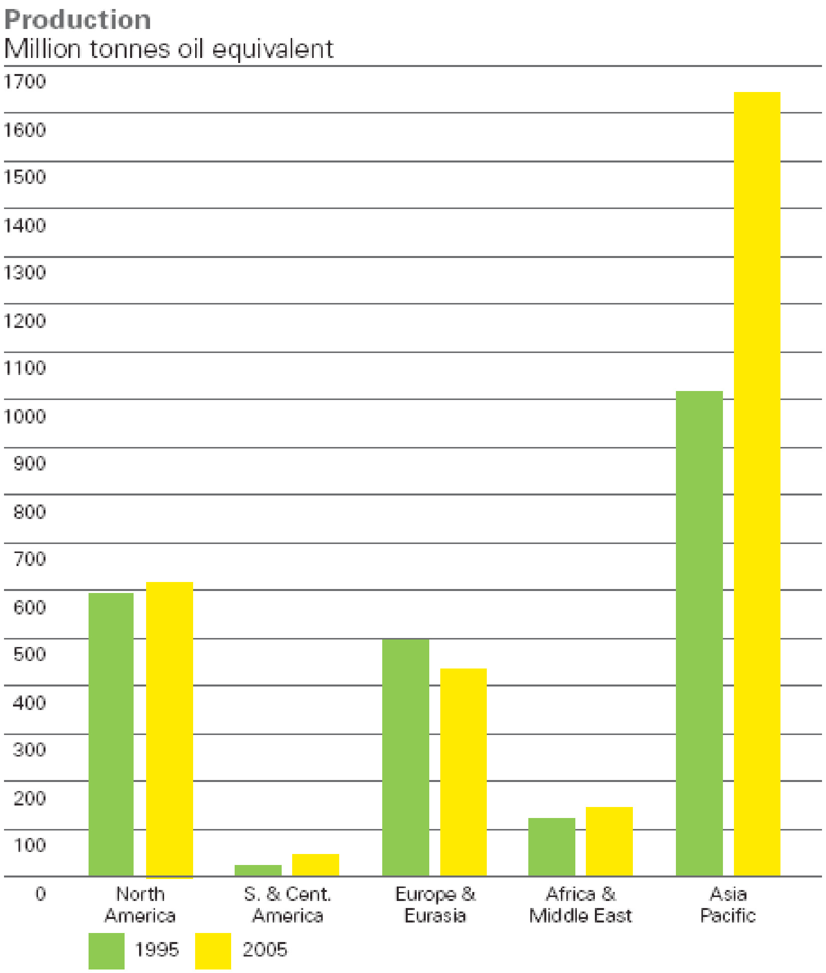


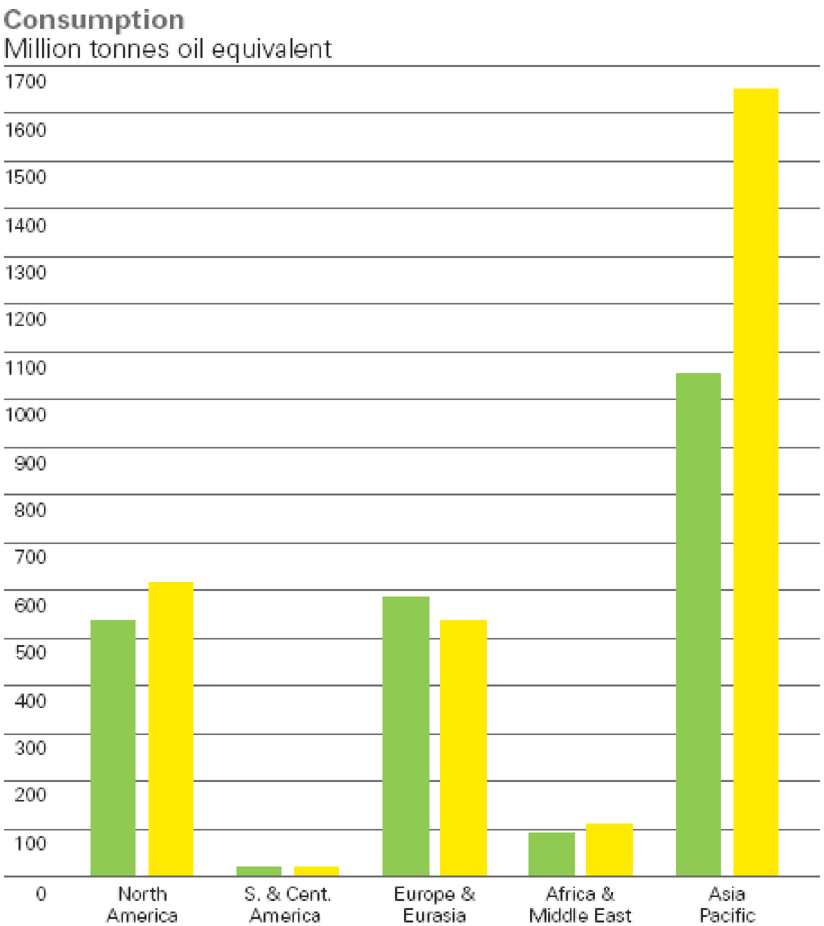
Shares of nuclear, natural gas, & coal growing, those of oil & hydro shrinking. USA gets 50% of its electricity from coal, China gets 80% from coal.

Proved coal reserves at end 2005



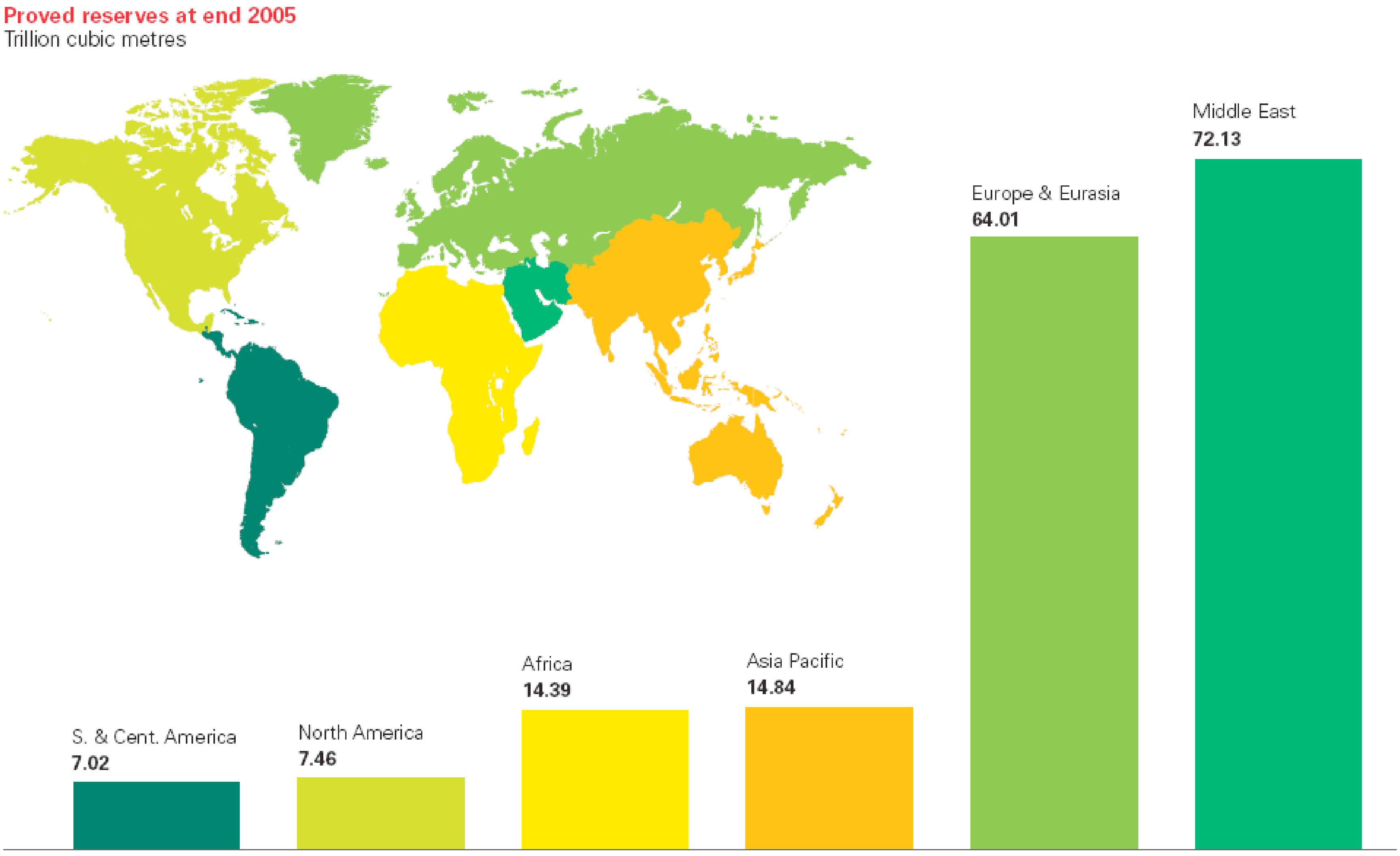
Coal production - Coal consumption



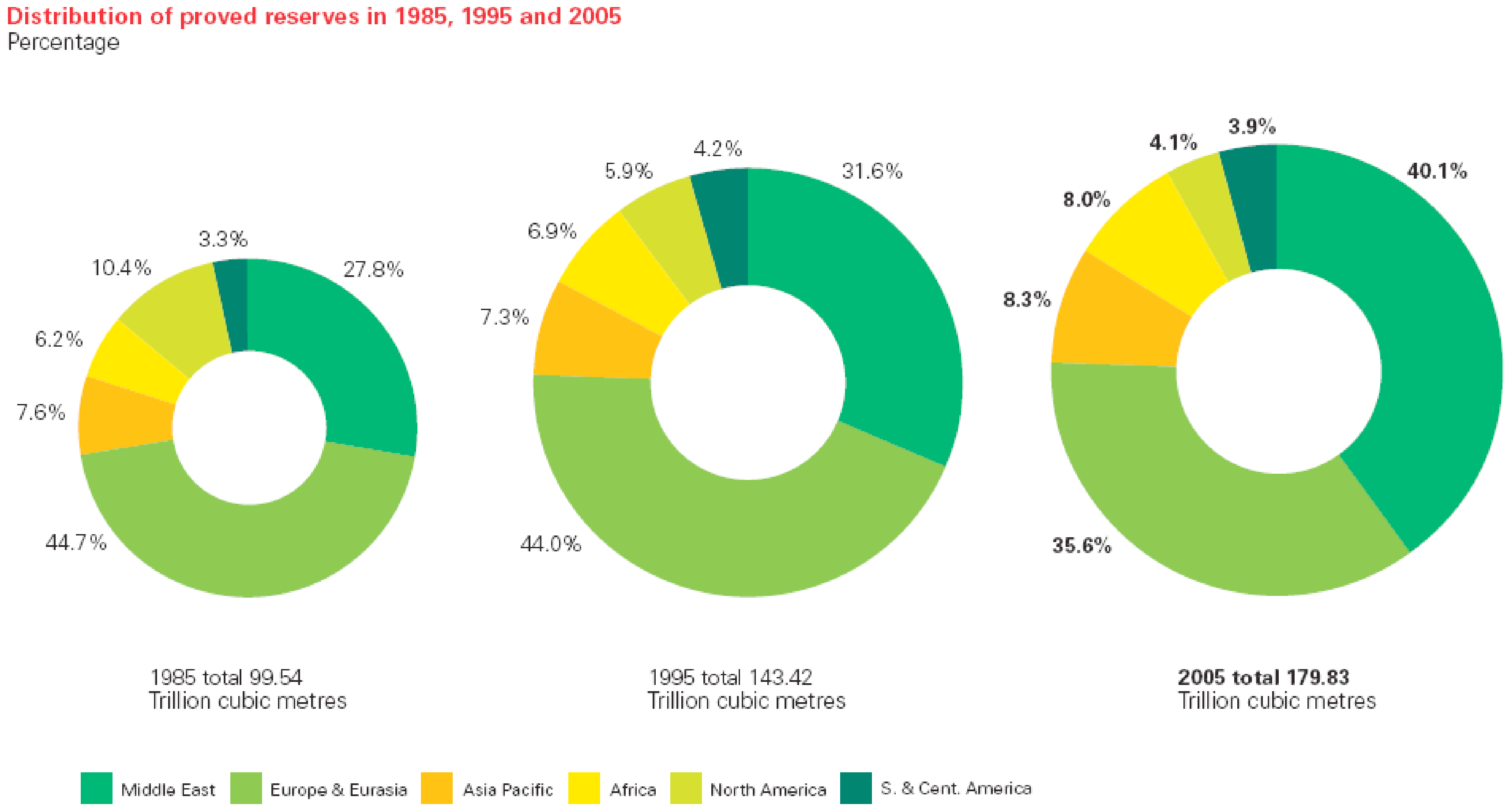


Coal was again the world's fastest-growing fuel and global consumption growth was twice the 10-year average. Growth was concentrated in China, the largest coal consumer, which accounted for 80% of global growth. Growth in the USA was also relatively strong.

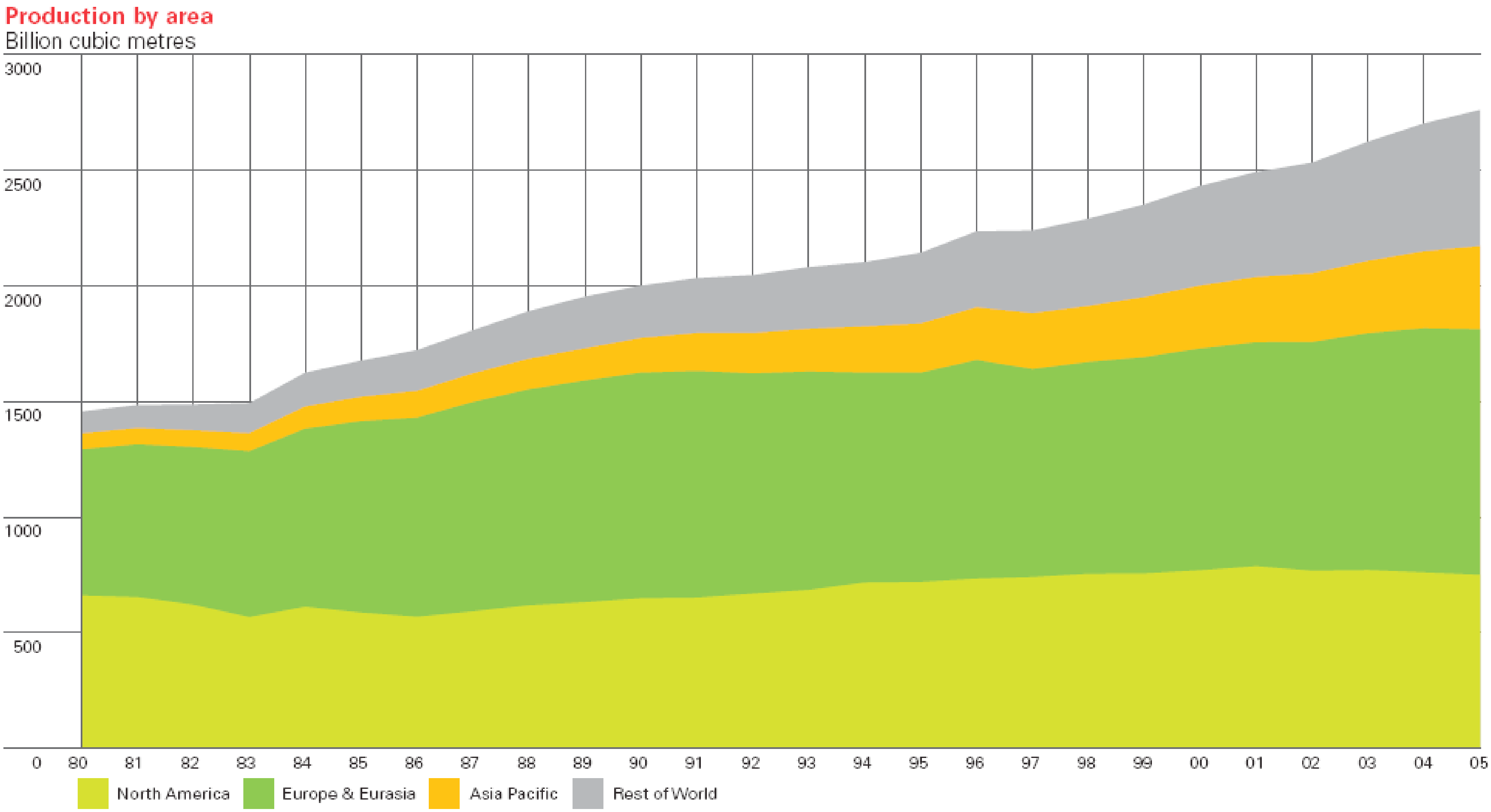
Proved natural gas reserves at



Distribution of proved (natural

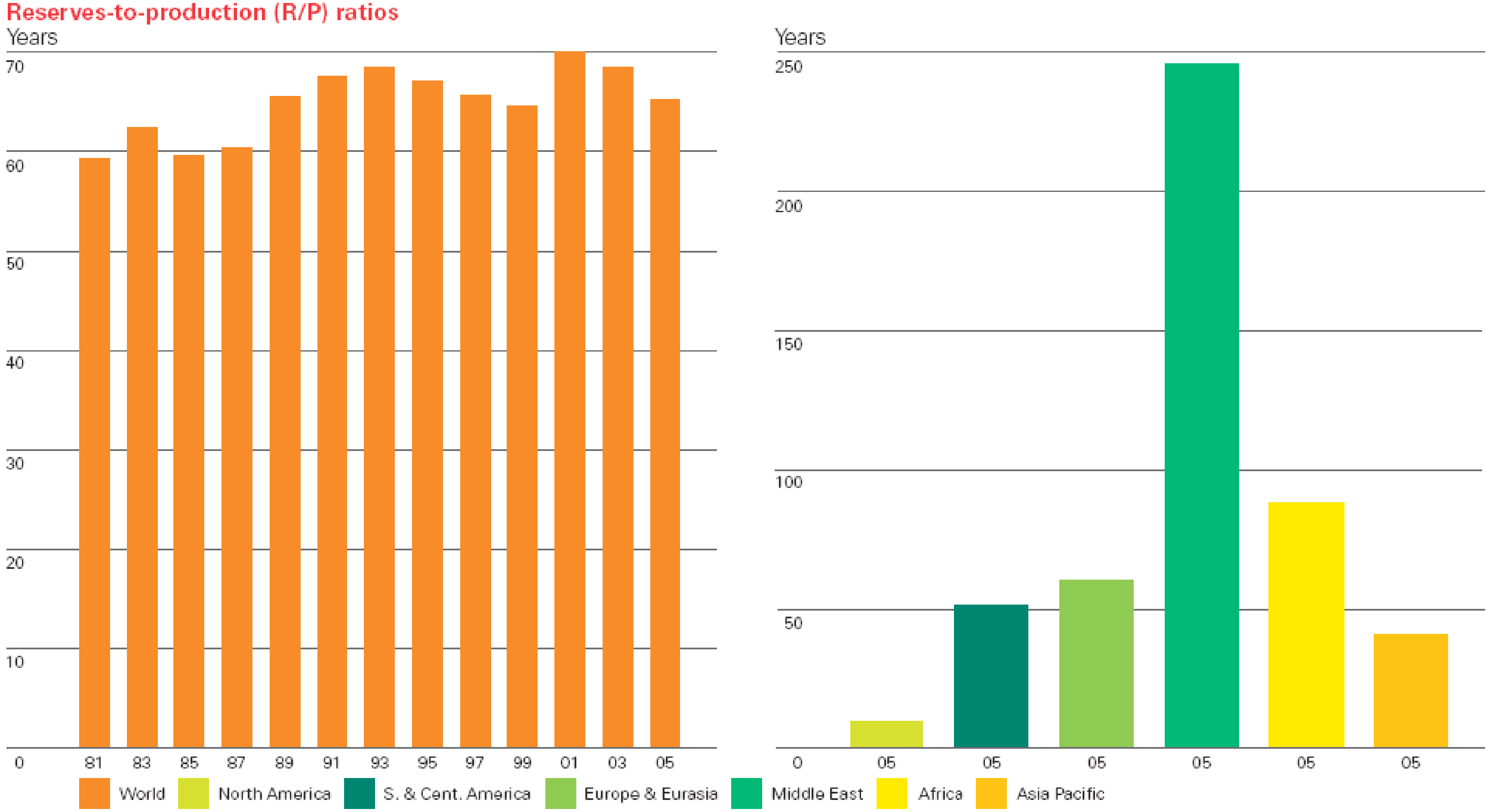


Natural gas production by area



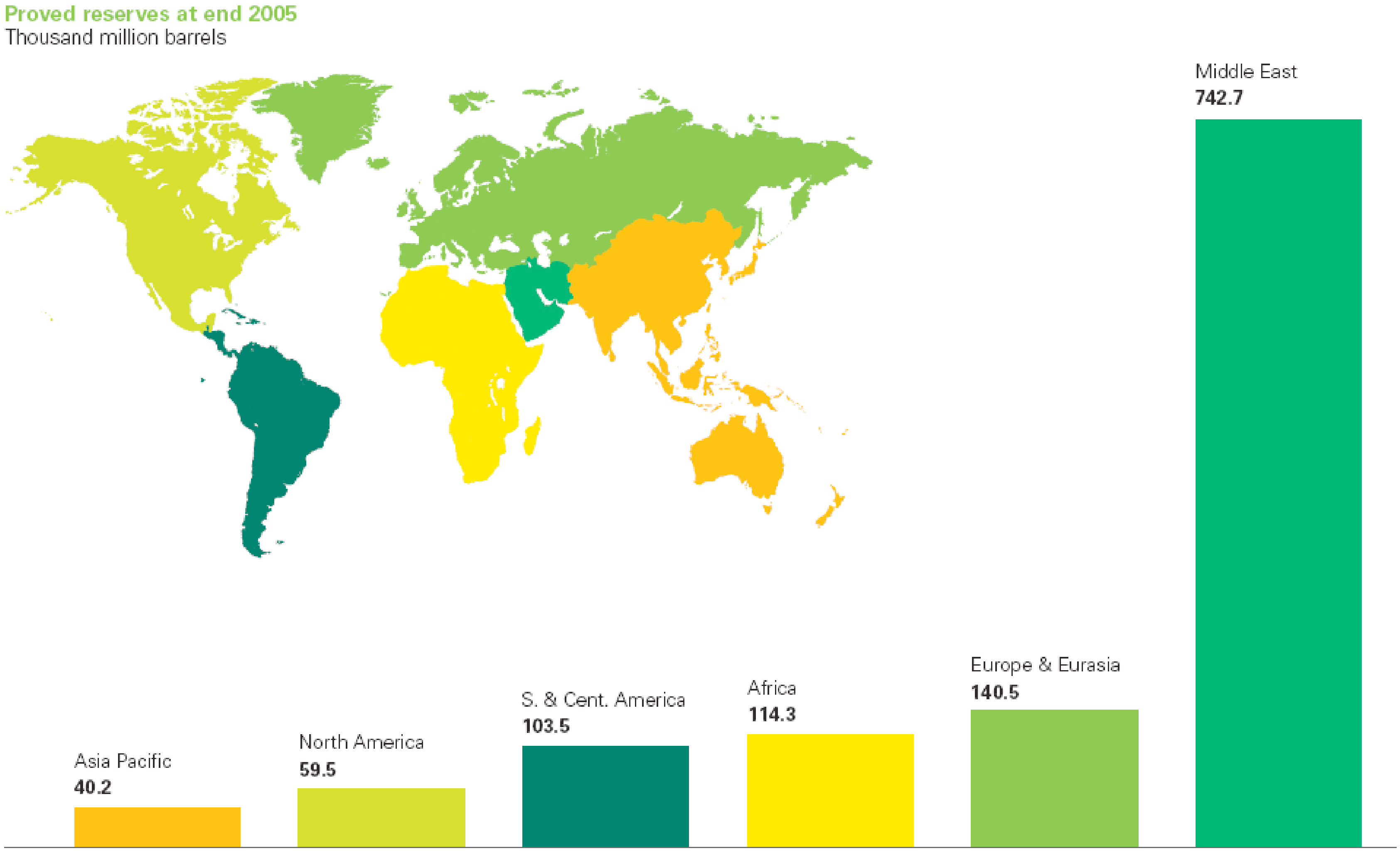
Natural gas production growth was close to the 10-year average. Output declined in North America, primarily owing to hurricane-related disruptions. China recorded the world's largest volume growth. Egyptian production increased 29% as LNG exports commenced.

Natural gas reserves-to-production (R/P) ratios

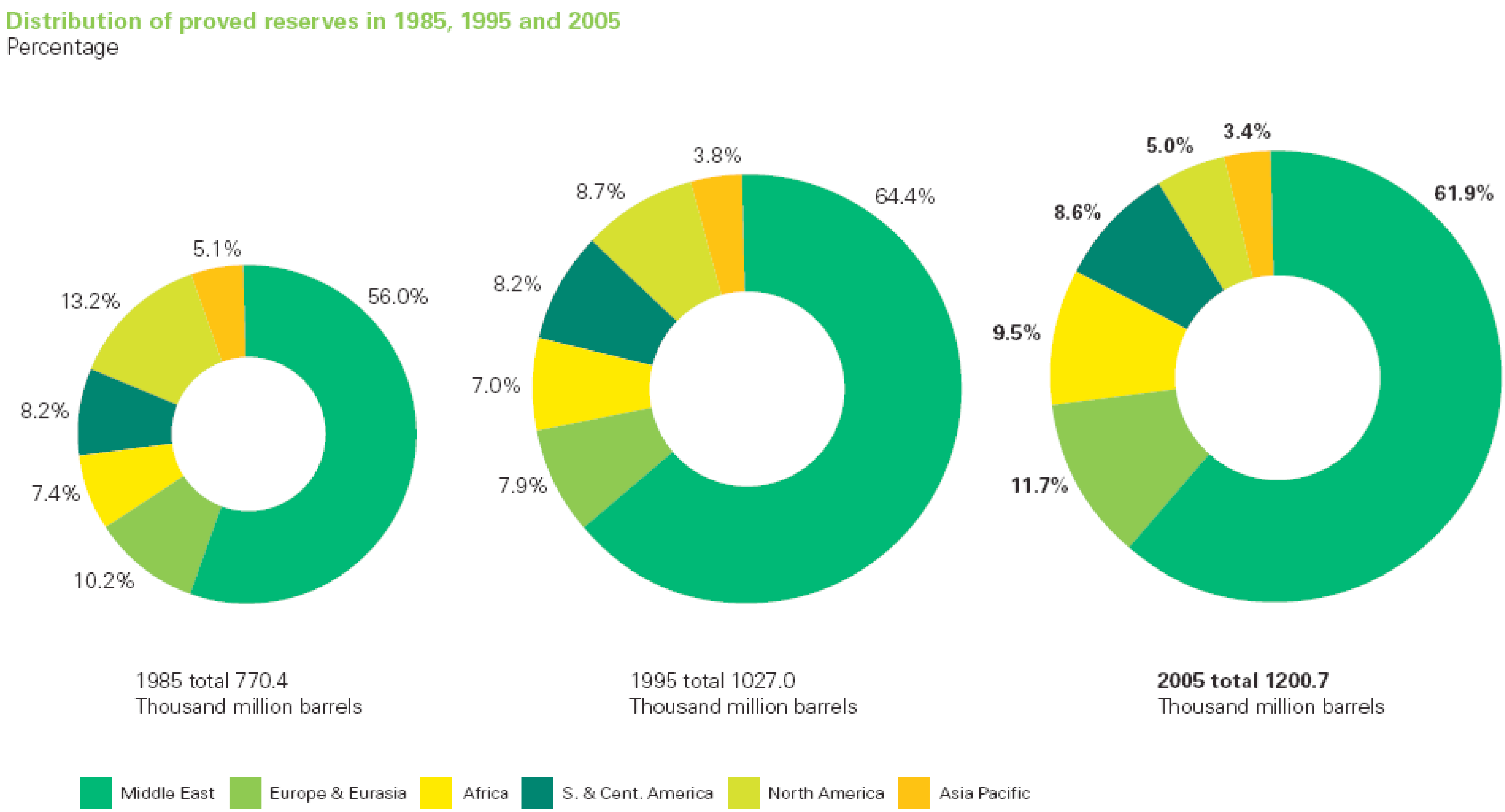


The world's gas R/P ratio fell to 65.1 years in 2005, but remained well above the oil R/P ratio. Reserves were 25% higher than the 1995 level; production was 29% higher.

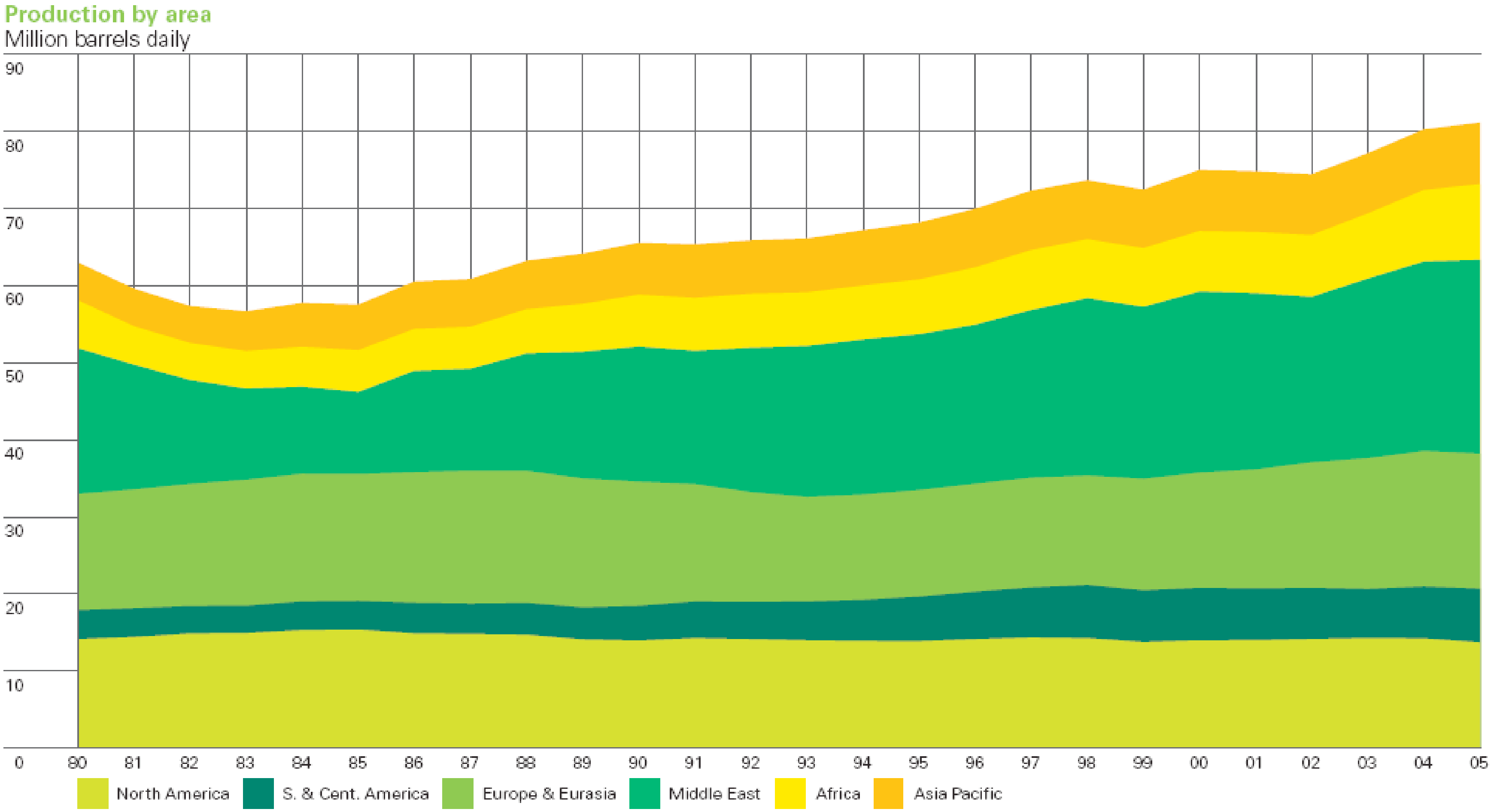
Proved oil reserves at end 2005



Distribution of proved (oil) reserves 1985, 1995, 2005

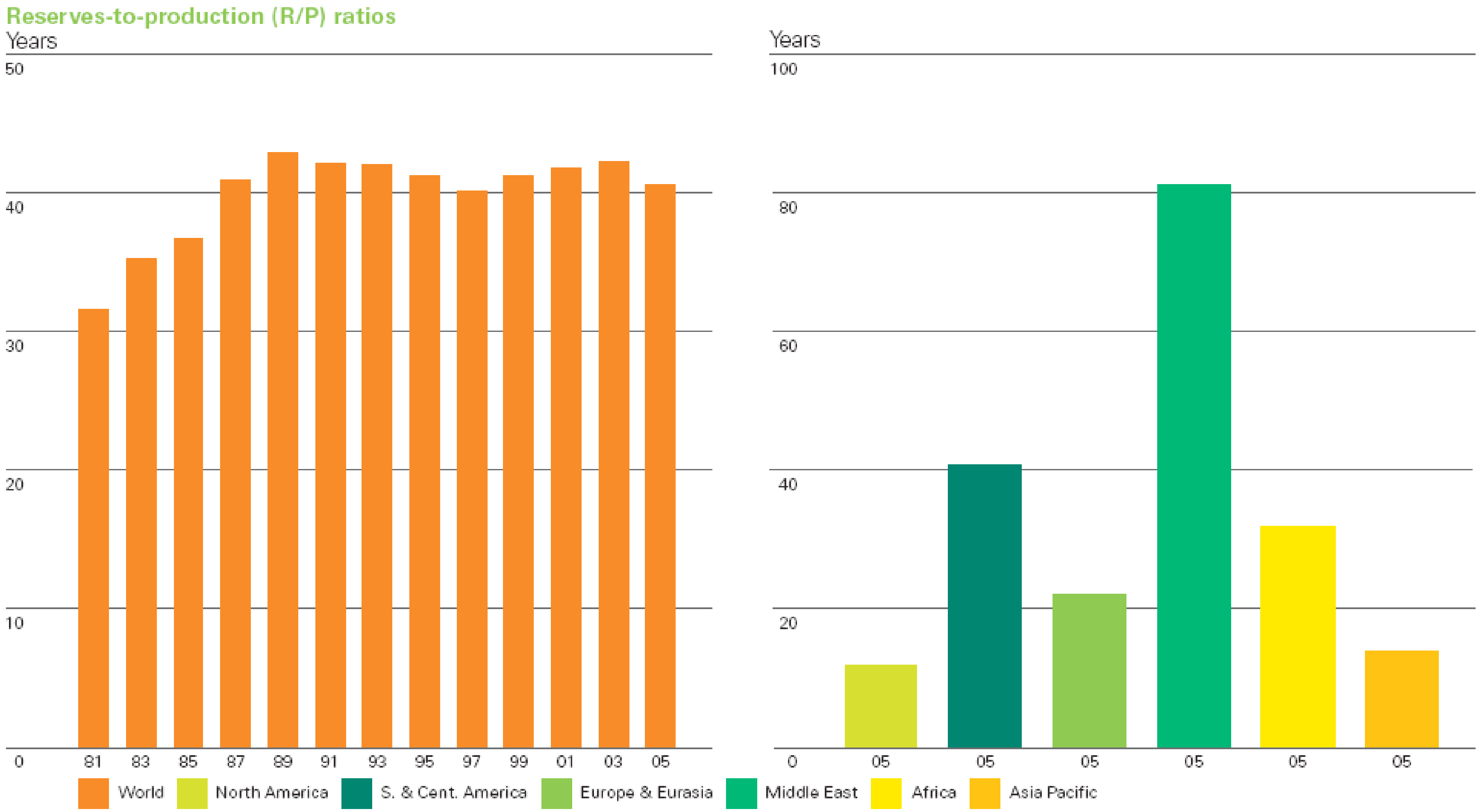


Oil production by area

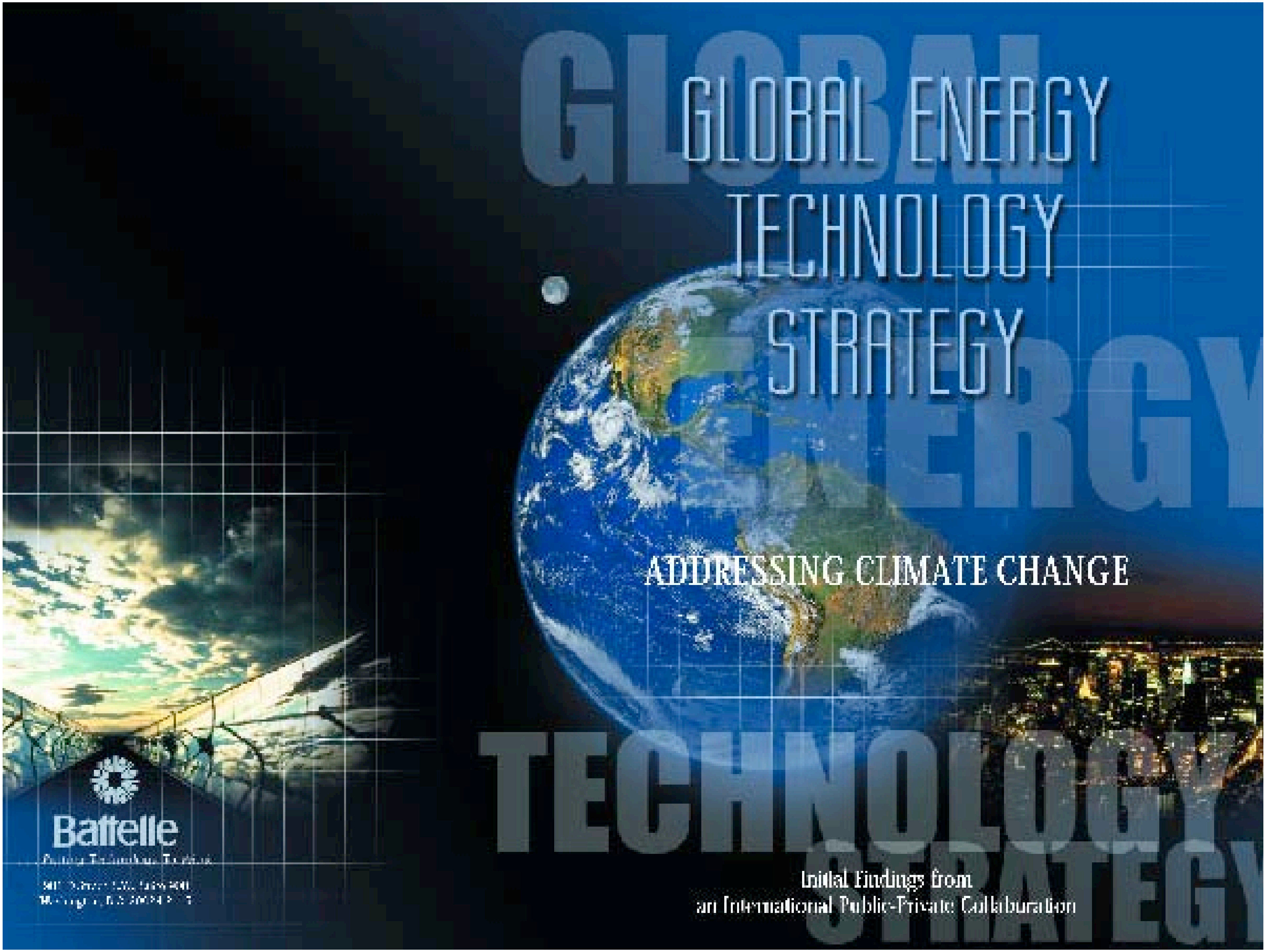


Oil production rose by 900,000b/d in 2005. OPEC accounted for virtually all the net increase. Russian production growth slowed. Growth in Angola, Brazil and China helped offset declines in Norway and the UK. US output also declined, in part owing to hurricane-related outages.

Oil reserves-to-production (R/P) ratios



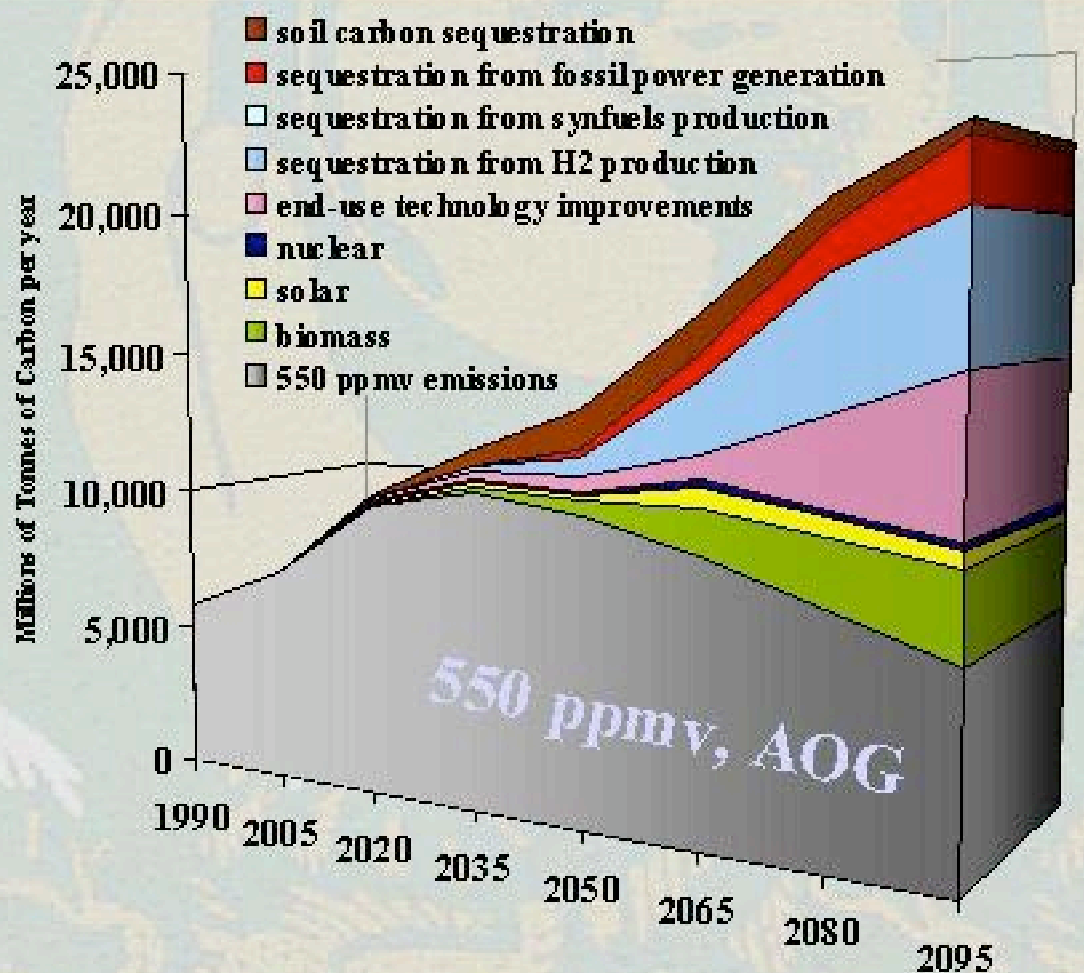
The world's oil R/P ratio declined slightly in 2005 to 40.6 years from 40.7 in 2004, although reserves continued to increase. Iran and Russia accounted for most of the increase. Reserves were 17% higher than the 1995 level; production was 19% higher.



GLOBAL ENERGY TECHNOLOGY STRATEGY
ADDRESSING CLIMATE CHANGE
TECHNOLOGY
Initial Findings from
an International Public-Private Collaboration
Battelle

Modeling A Carbon Technology System :

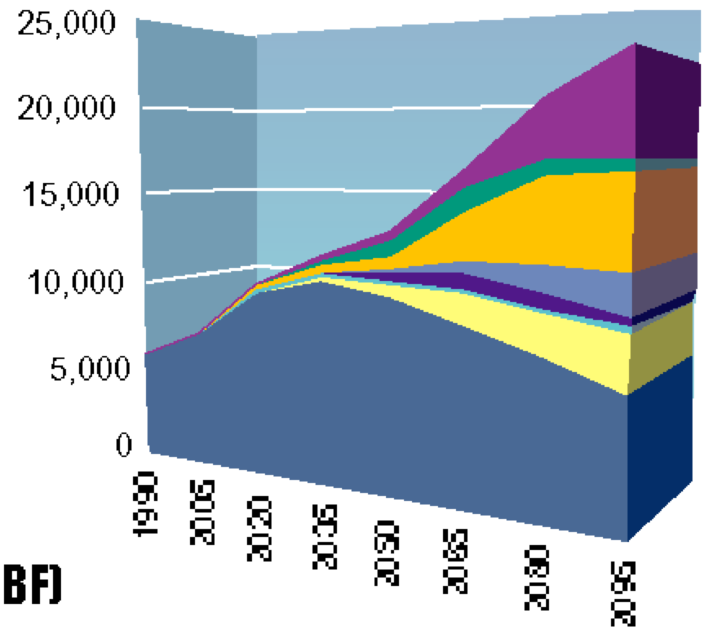
The Results



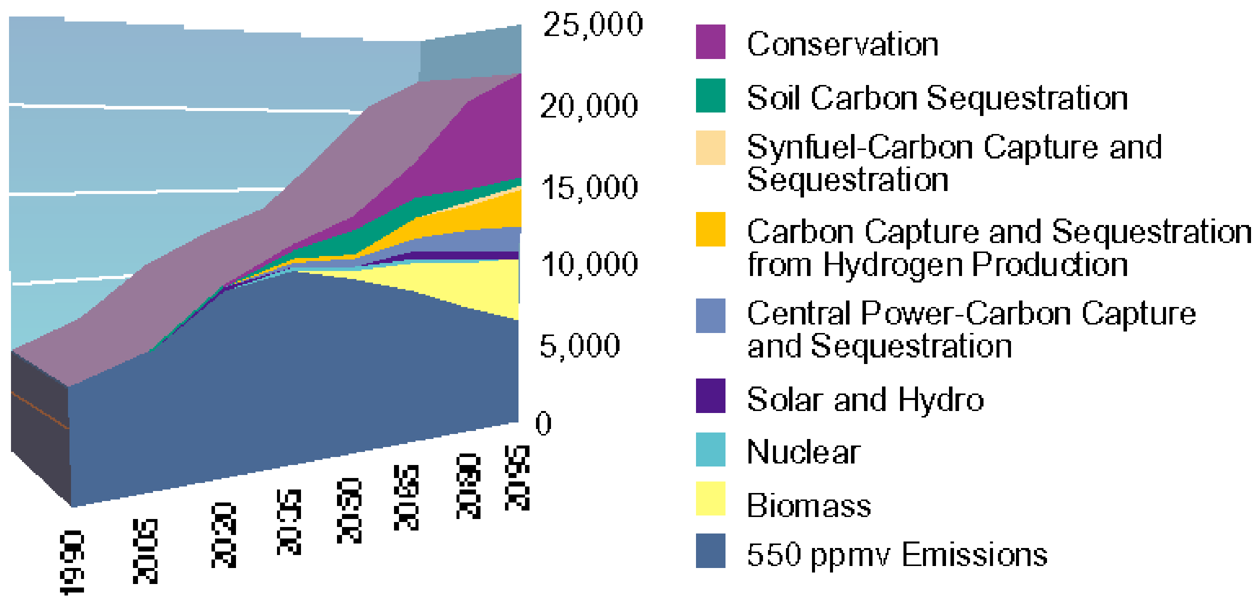
Technologies that Could Fill the Gap Under Different Energy Resource Futures

Shown in Million Tonnes of Carbon

Abundant Oil and Gas (AOG)

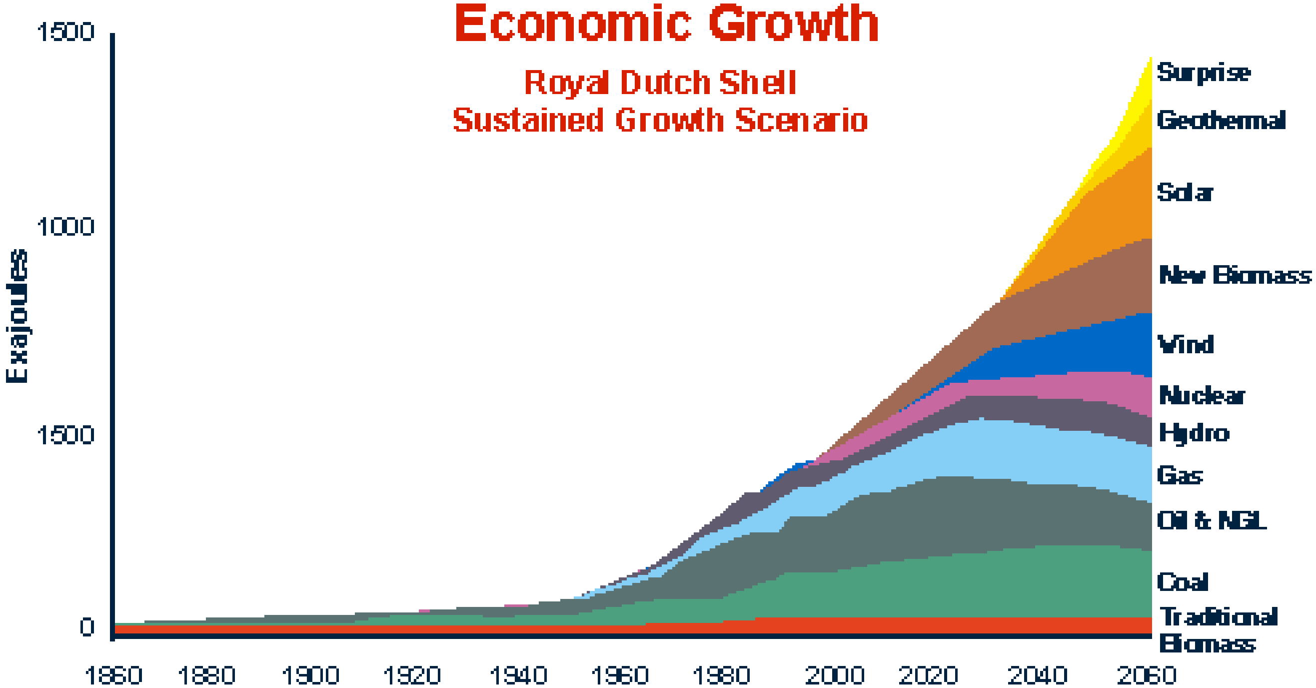


Coal Bridge to the Future (CBF)

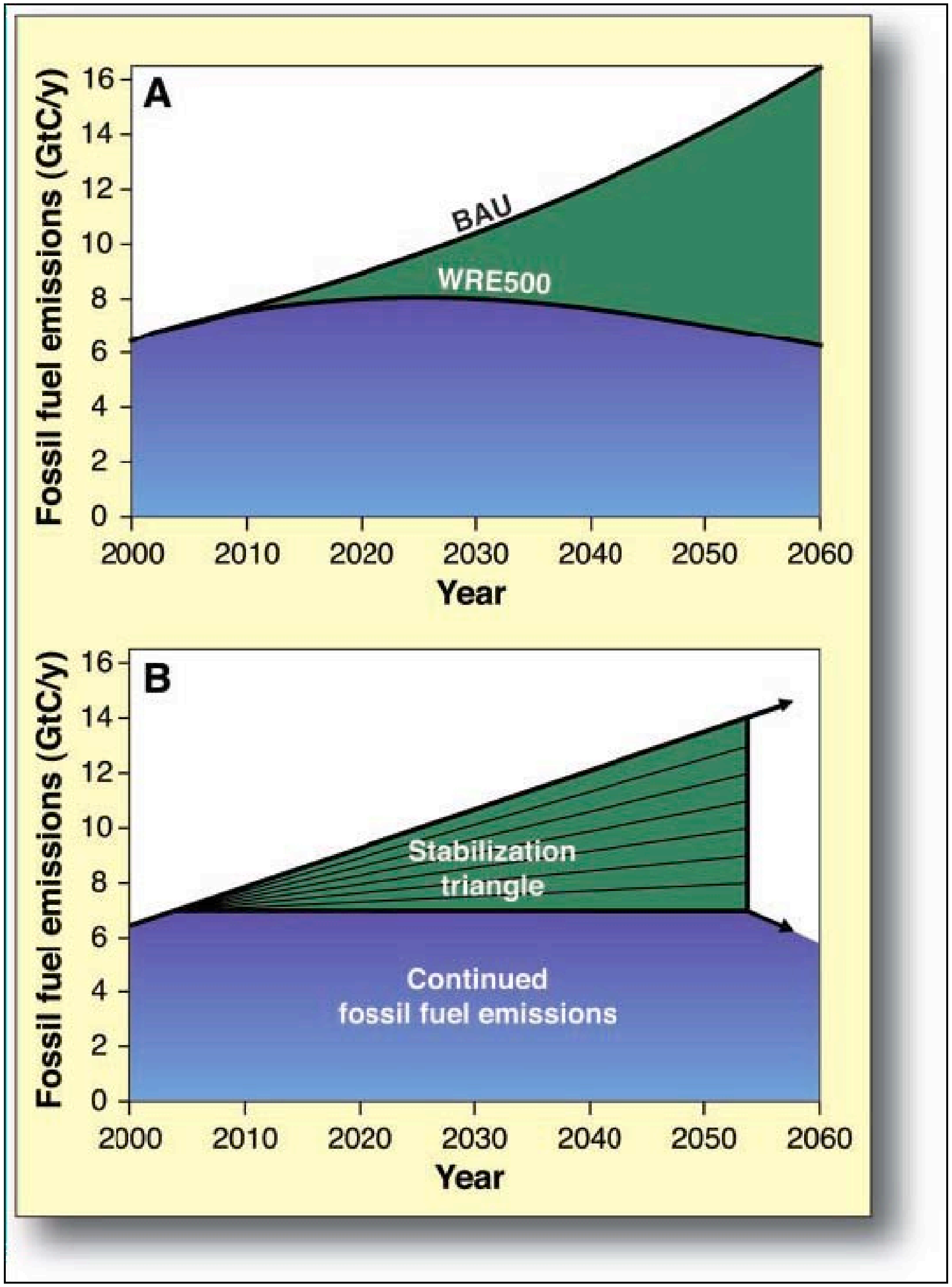


Economic Growth

Royal Dutch Shell
Sustained Growth Scenario

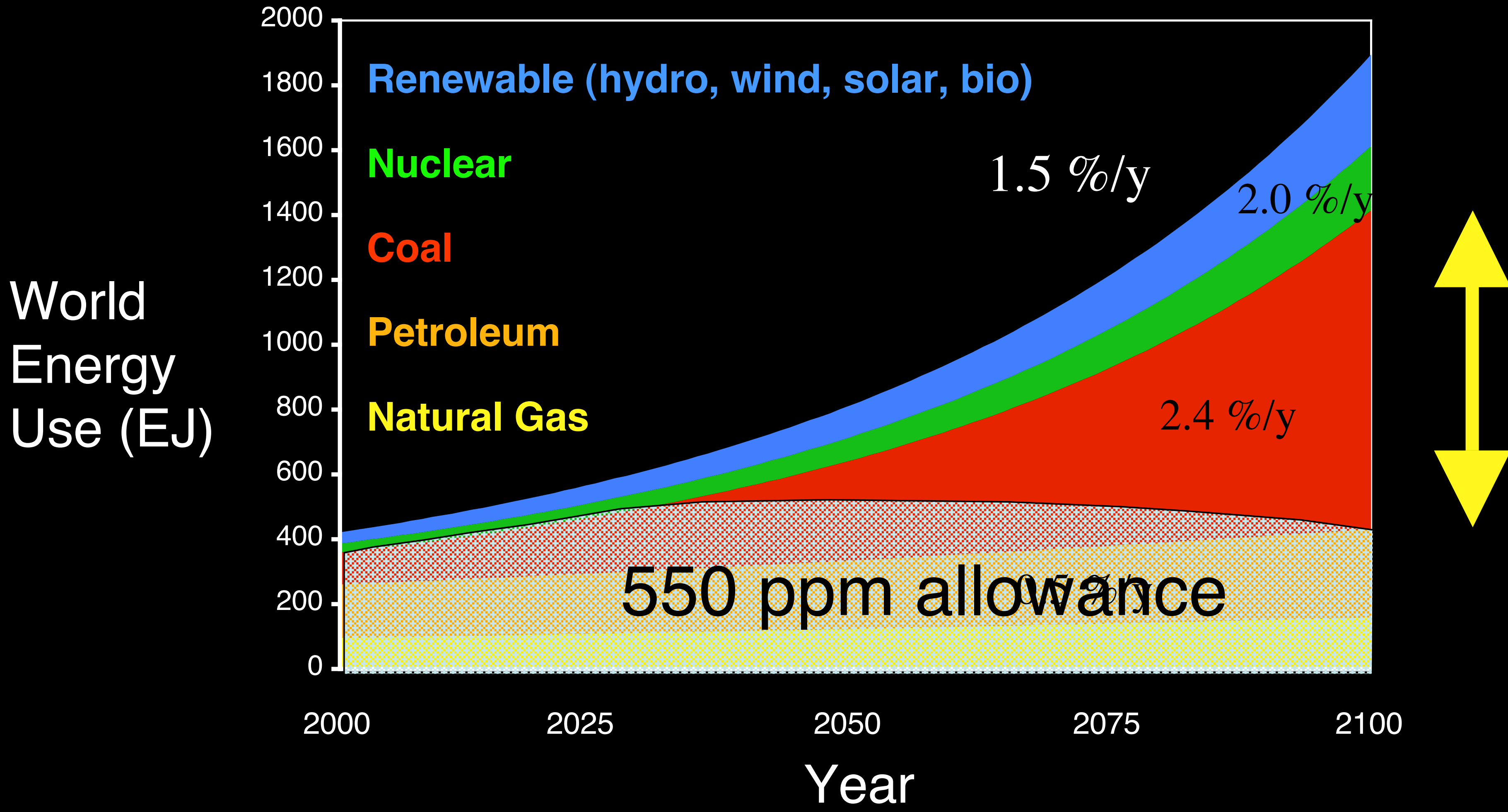


Source: Shell



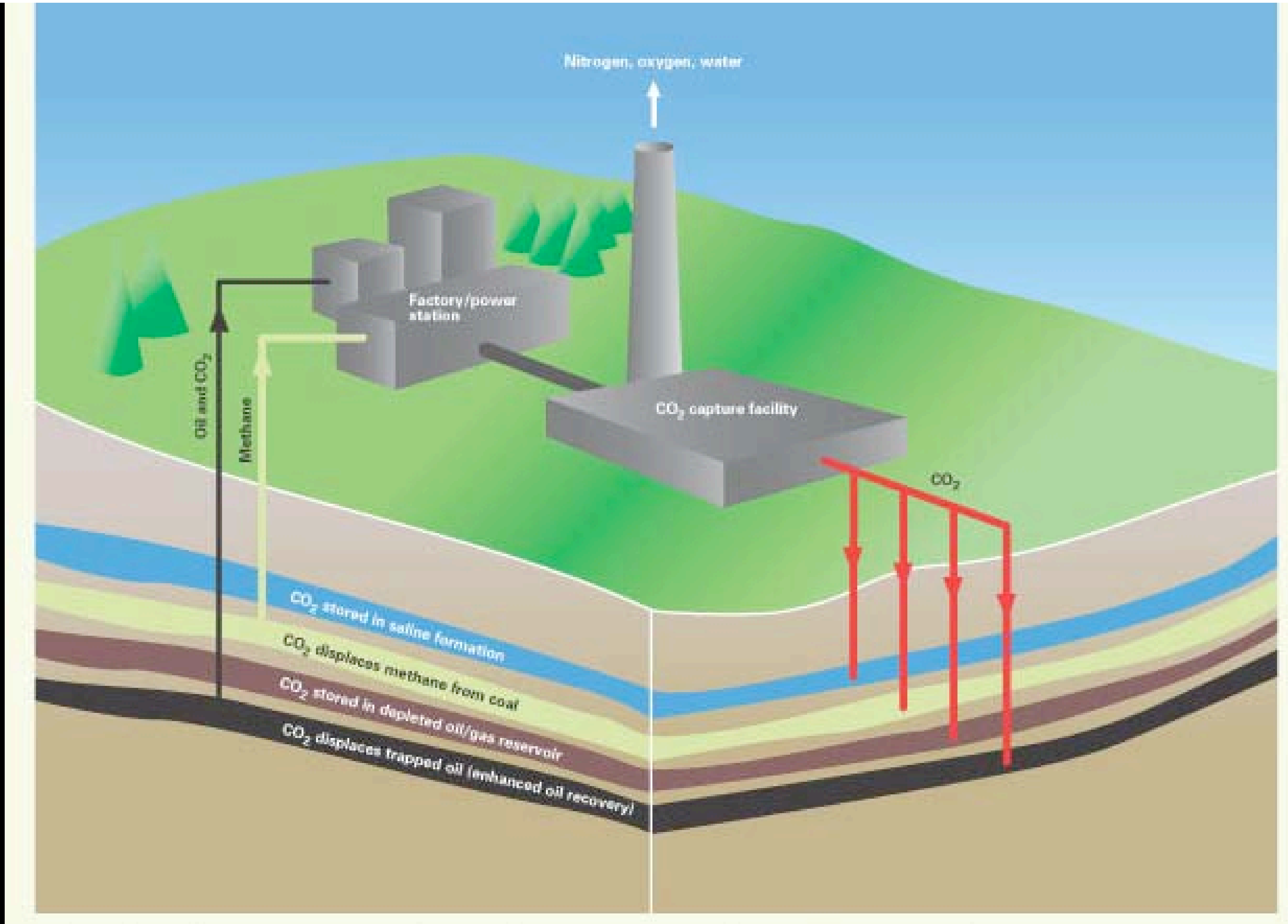
Pacala and Socolow,
Science (2004)

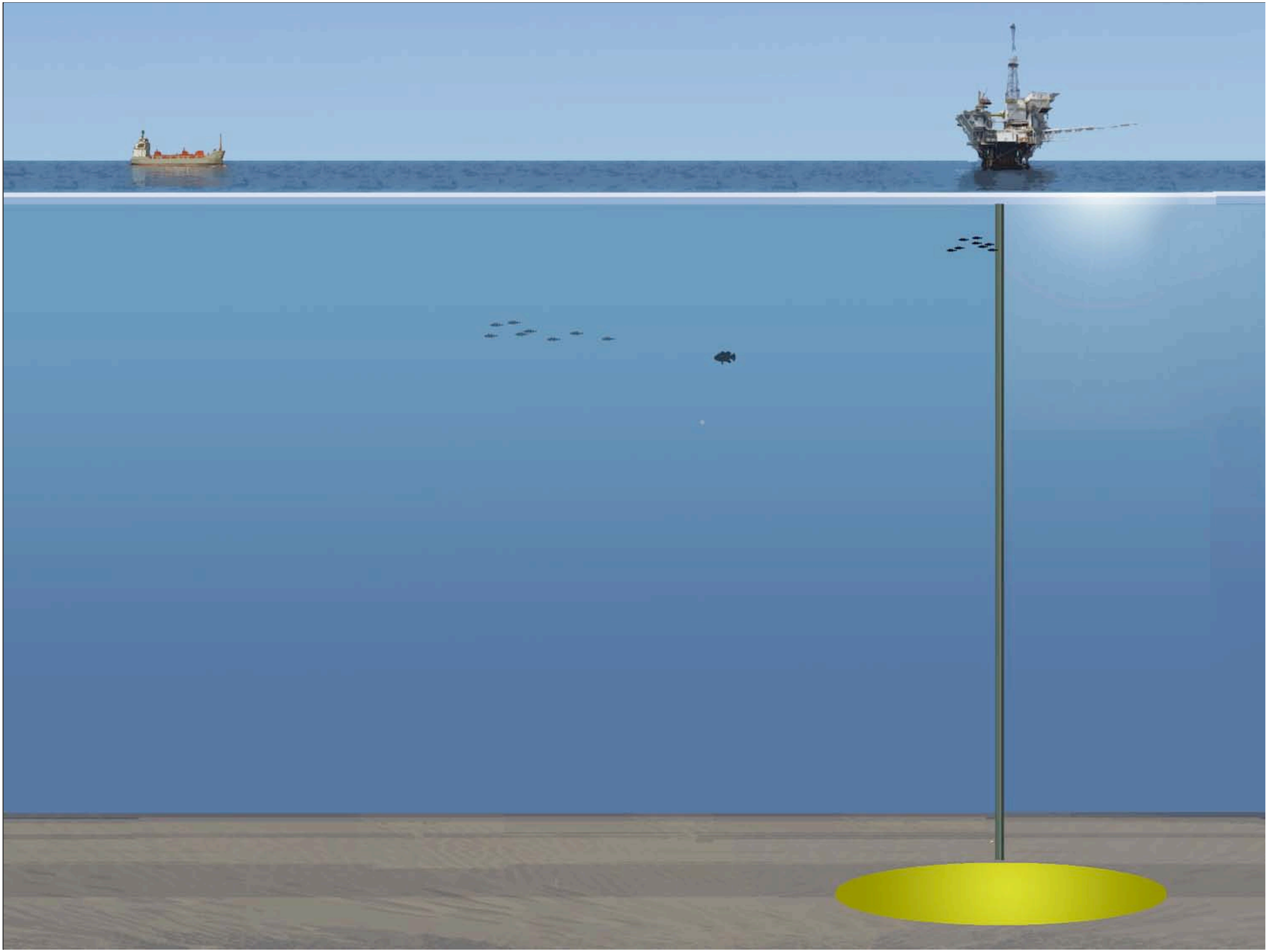
Stabilization Wedges:
Solving the Climate Problem
for the Next 50 Years with
Current Technologies



By the end of the century, we need to replace billion tons per year of conventional coal use with carbon-free technology if we want to keep atmospheric CO_2 under 550 ppm. How will we do it?

Better efficiency? More renewables/nuclear? Carbon sequestration?


Nitrogen, oxygen, water
Factory/power station
CO2 capture facility
CO2
Oil and CO2
Methane
CO2 stored in saline formation
CO2 displaces methane from coal
CO2 stored in depleted oil/gas reservoir
CO2 displaces trapped oil (enhanced oil recovery)



security economy environment

impact of new technologies:

biofuels

CTL-GTL

LNG

plug-in hybrids

- When serious action on climate change happens, it is likely to happen very quickly.

- It is not a question of whether we will use oil, coal and gas, but rather *how* will we use them.

- Advanced technologies including carbon capture and storage will be required.

- Renewable energy is essential for the 22nd century. For this century, it will share the stage with efficiency efforts and carbon sequestration.

- Replacing our energy infrastructure over 30 years is expensive, but not ridiculously expensive. (i.e., hundreds of billions per year, not trillions)

What are some of the institutional, technological, or economic obstacles to innovation and transformation in the energy system?

What are some of the breakthrough developments in each of these areas that could rapidly catalyze change?

What are the policies at national, state, and local levels that would most affect innovation and transformation?