Presentation to
Rocky Mountain Land Use Institute
Denver, Colorado
March 8, 2007

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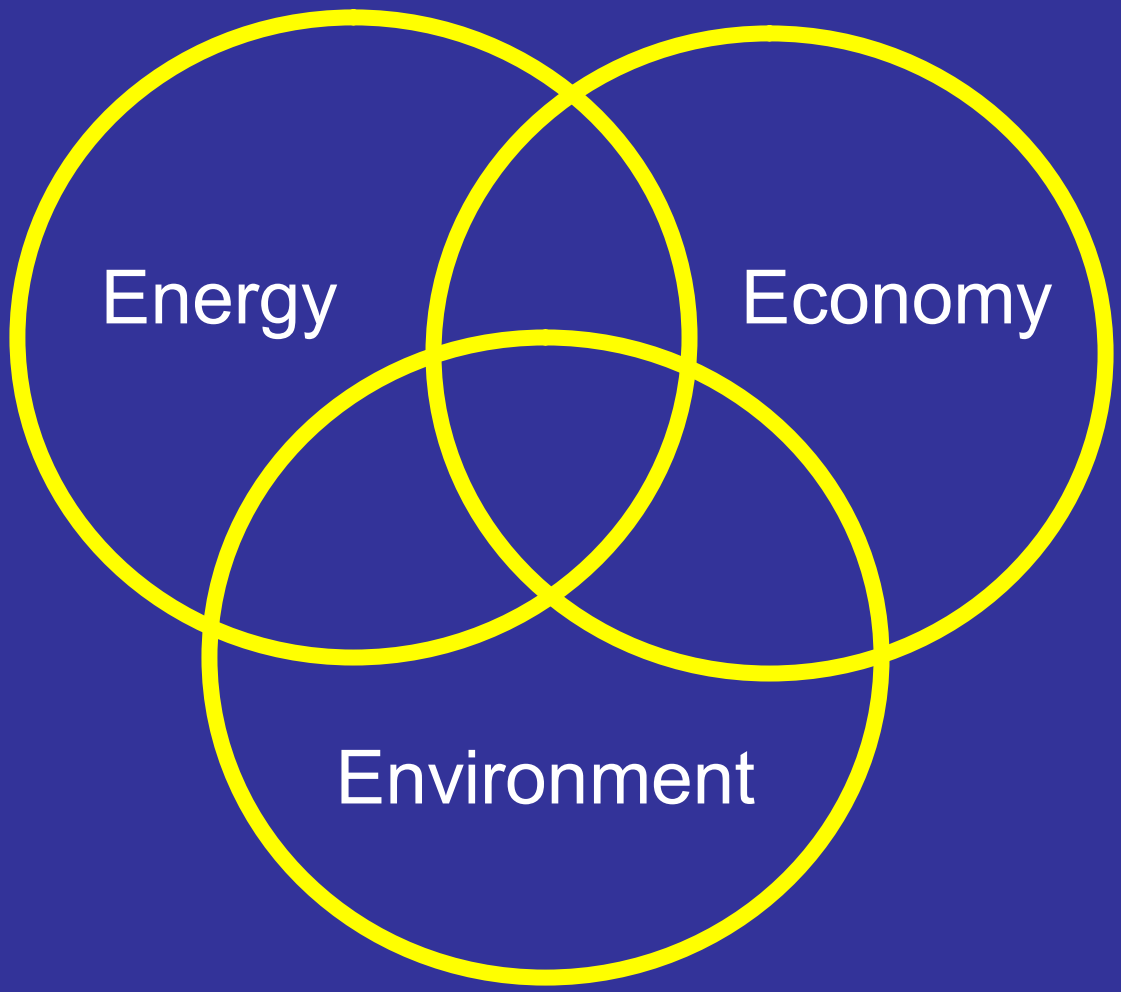

Energy
Economy
Environment

Energy Options

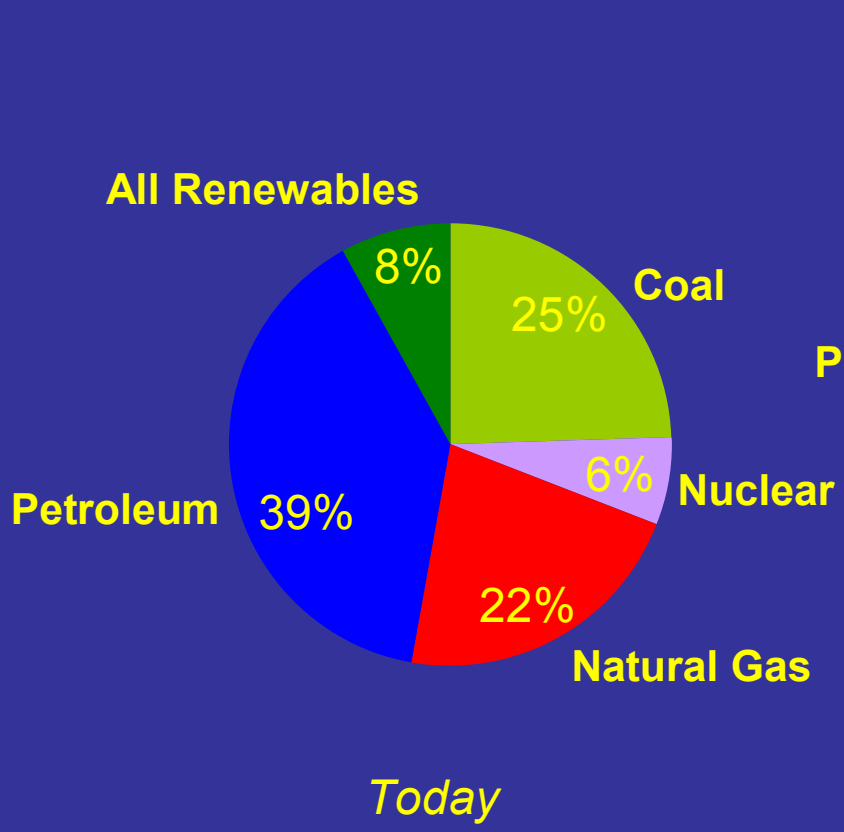
For each energy source-
We need to understand:

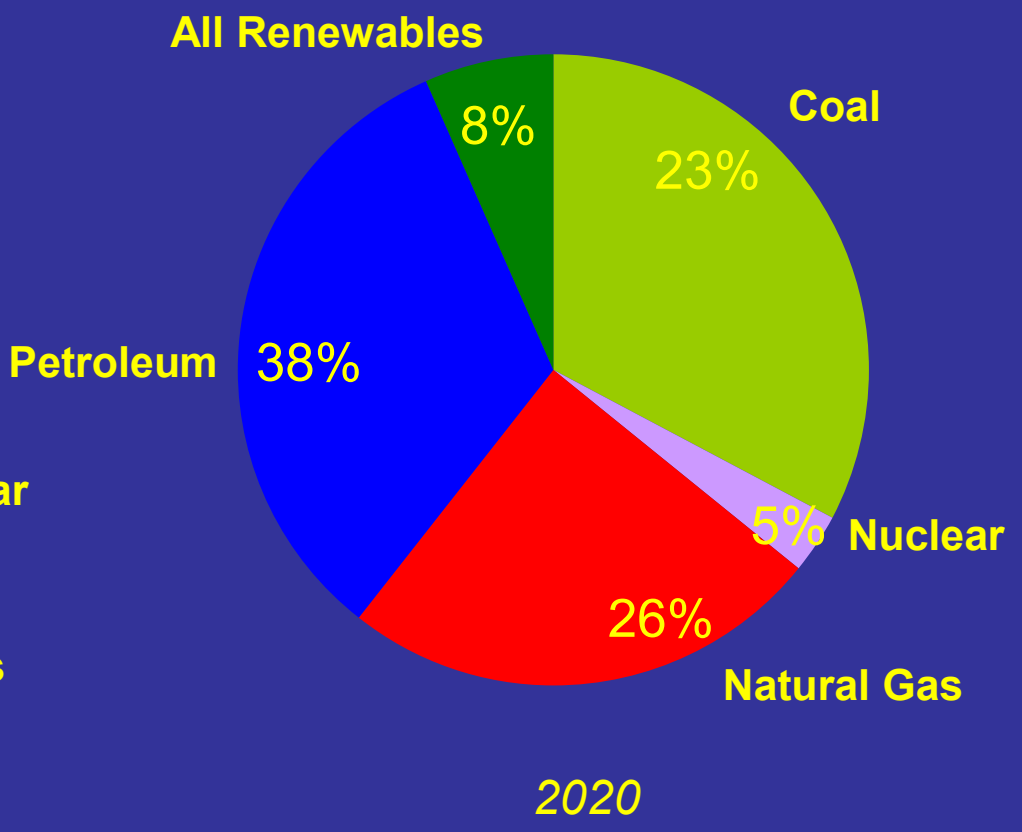
What is the resource base?
What are the economic costs?
What are the geopolitical consequences?
What are the environmental consequences?
What is the role of public policy to ensure a sustainable outcome?

What are the world's largest energy sources?

Oil	39%
Coal	25%
Natural Gas	22%
Nuclear	6%
Hydroelectric	4%
Renewables	2%

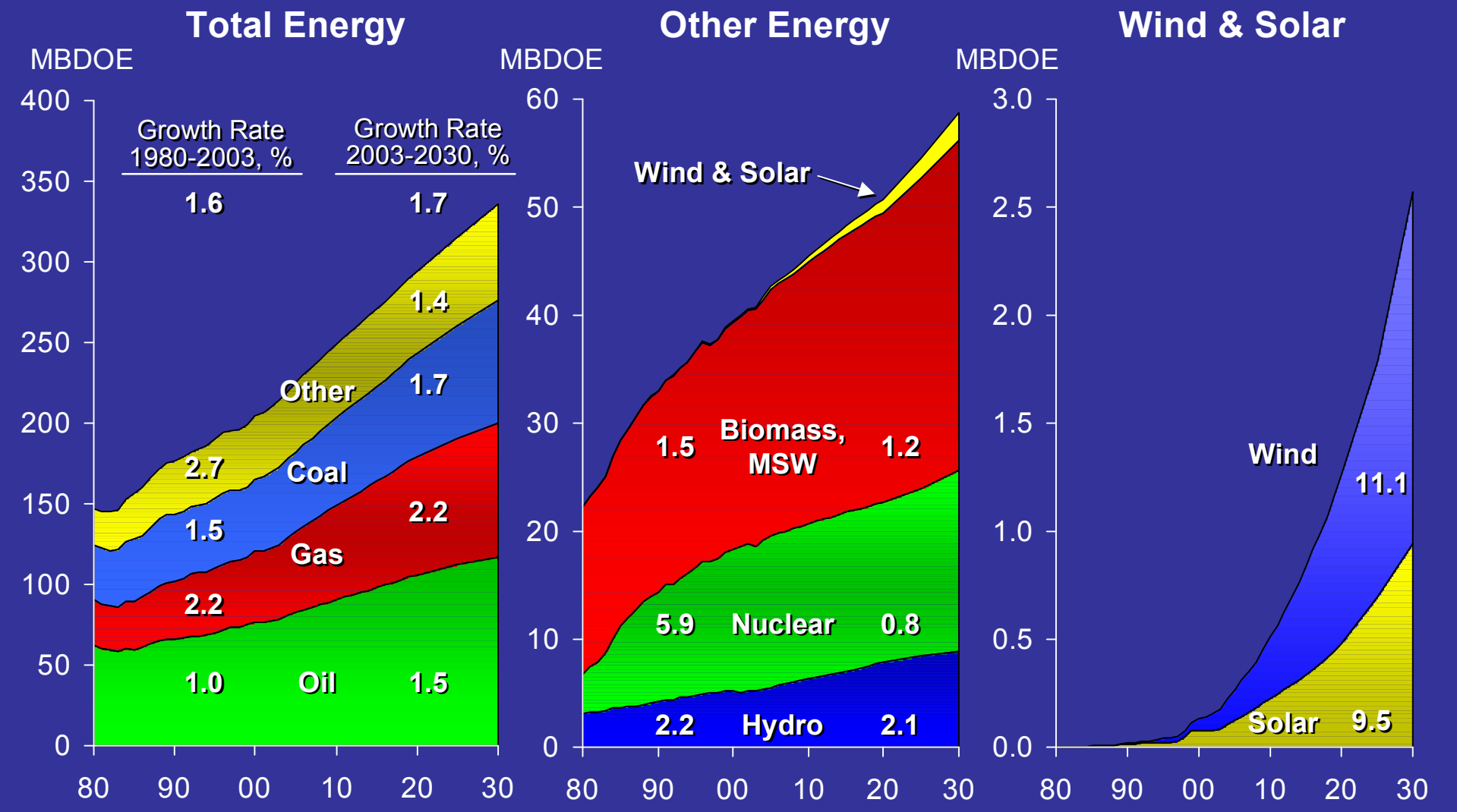
Worldwide Energy Consumption
Projected by Source - 2020



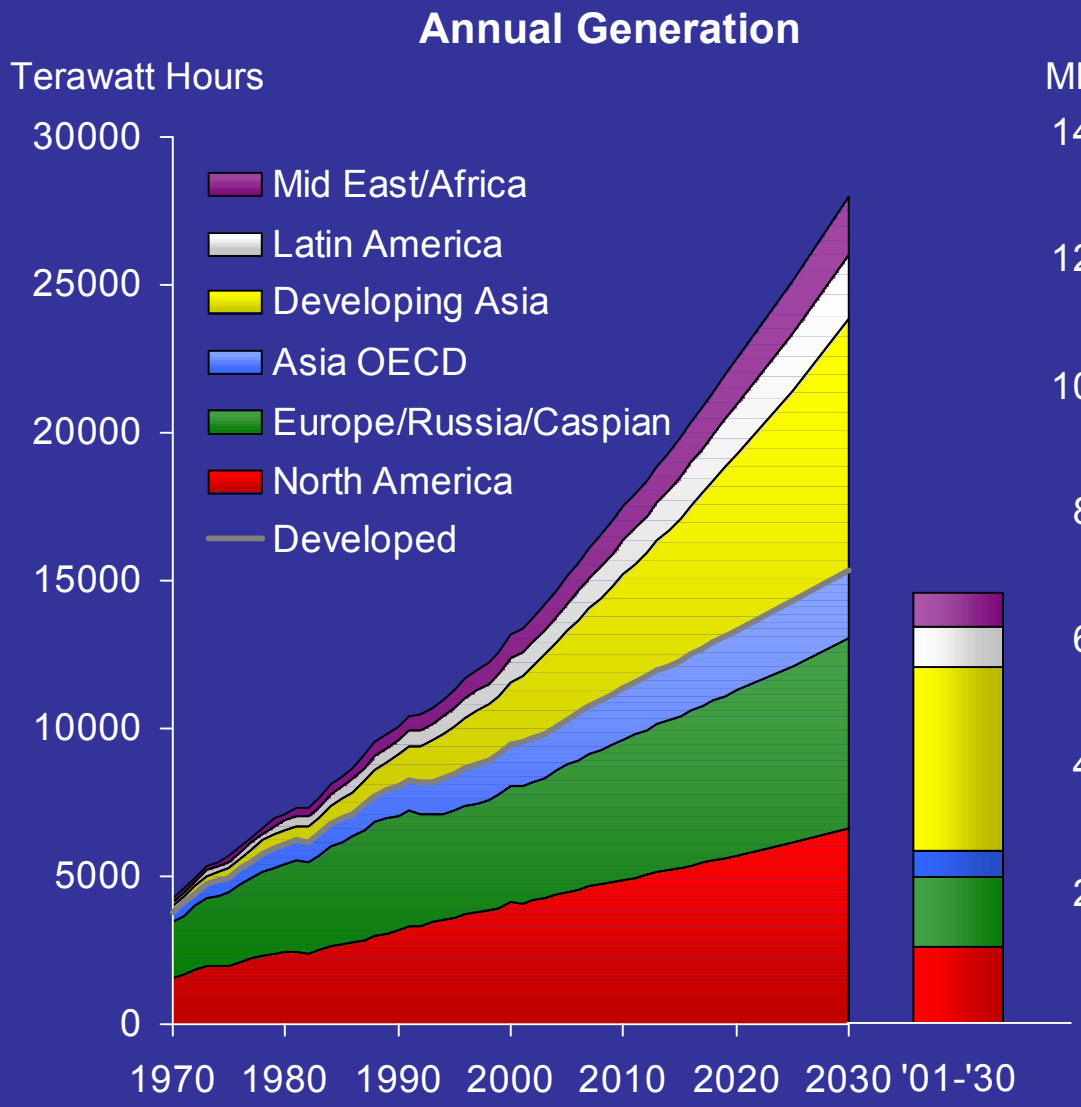


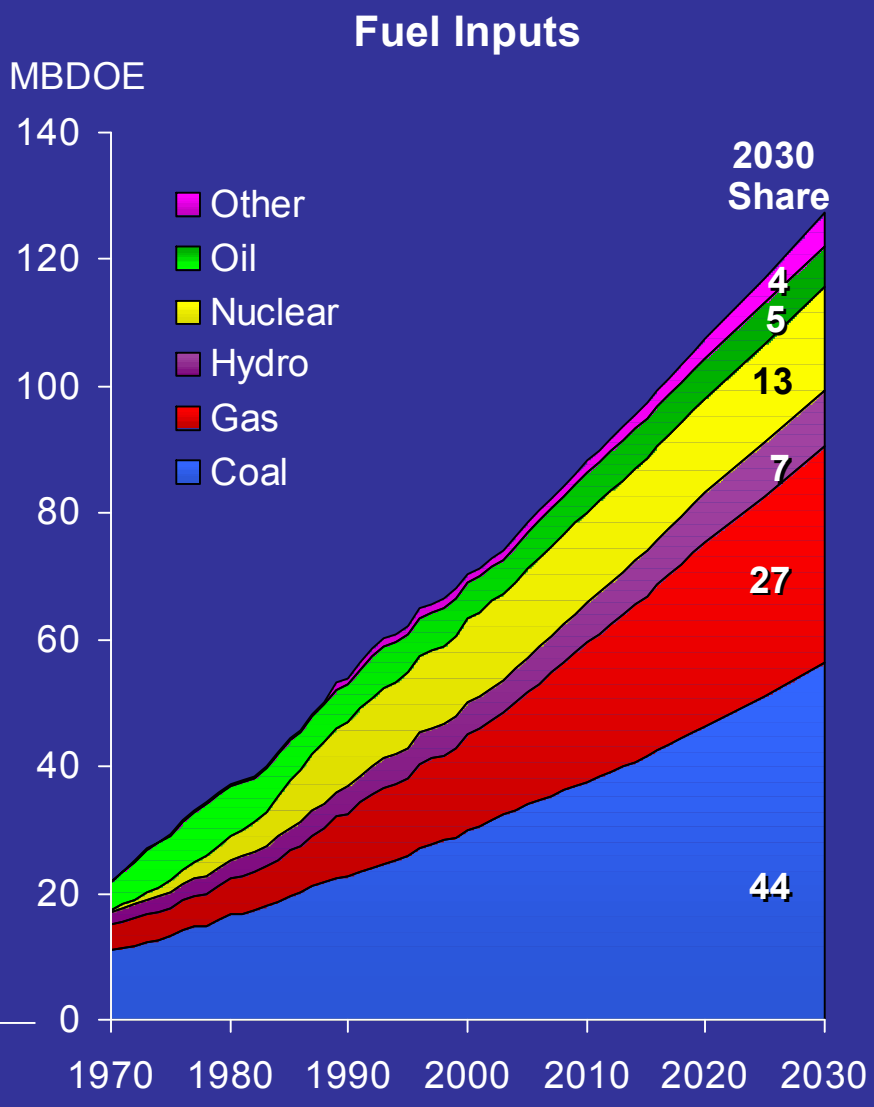
Source: Energy Information Administration, *International Energy Outlook 2000*, Table A2

Fossil and Nuclear Power Remain as World's Primary Energy Sources



Growing Electric Demand by World Region





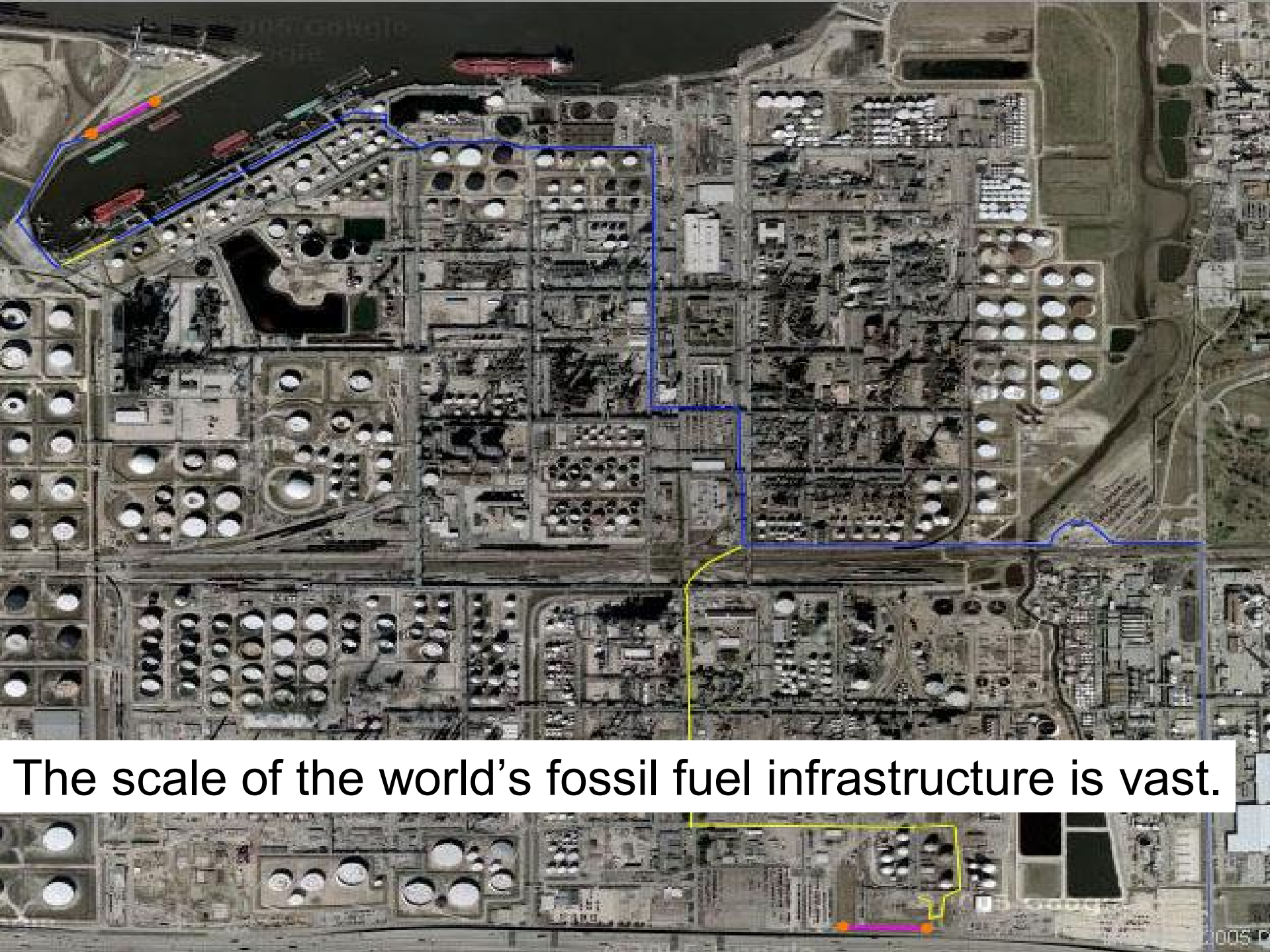
Source: UDI, IEA, EM Forecast

Petroleum

Remember these words:

Geopolitics

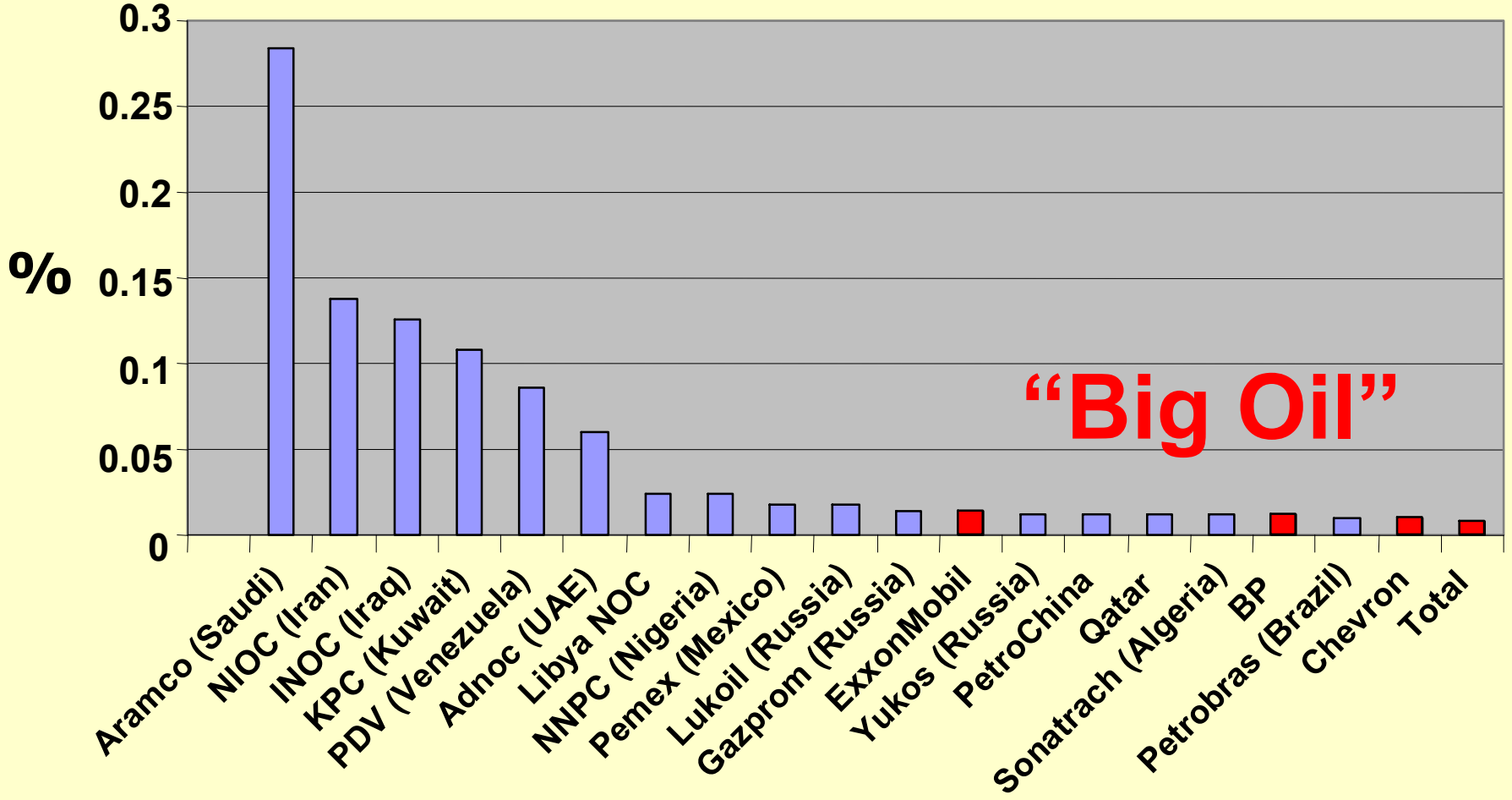
Depletion



The scale of the world’s fossil fuel infrastructure is vast.

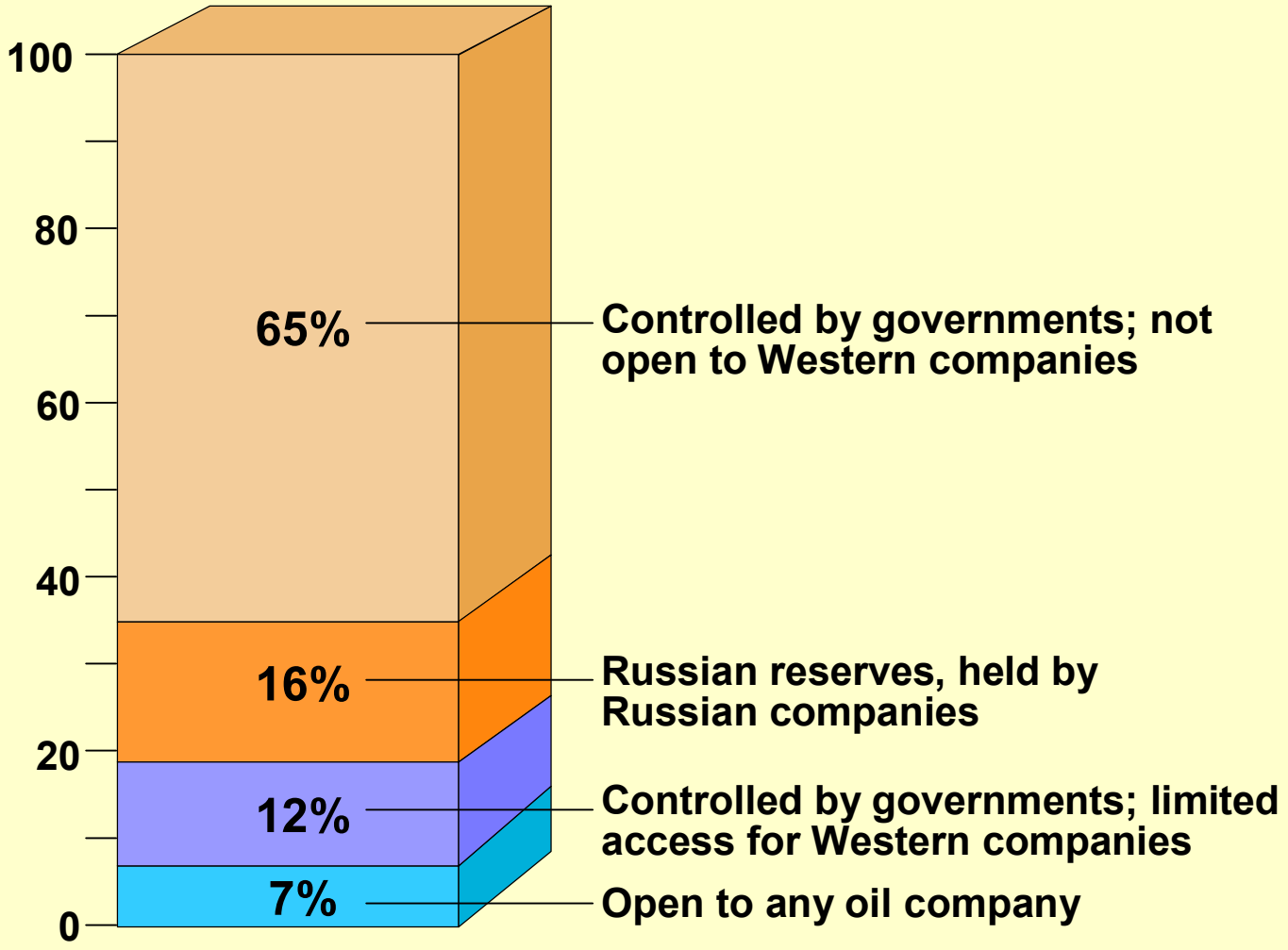
Energy is the largest, most capital-intensive industry in the world

Global Conventional Oil Reserves
(2004 %)



Source: Oil and Gas Journal, 2005

Access to World's Proved Oil and Natural Gas Reserves

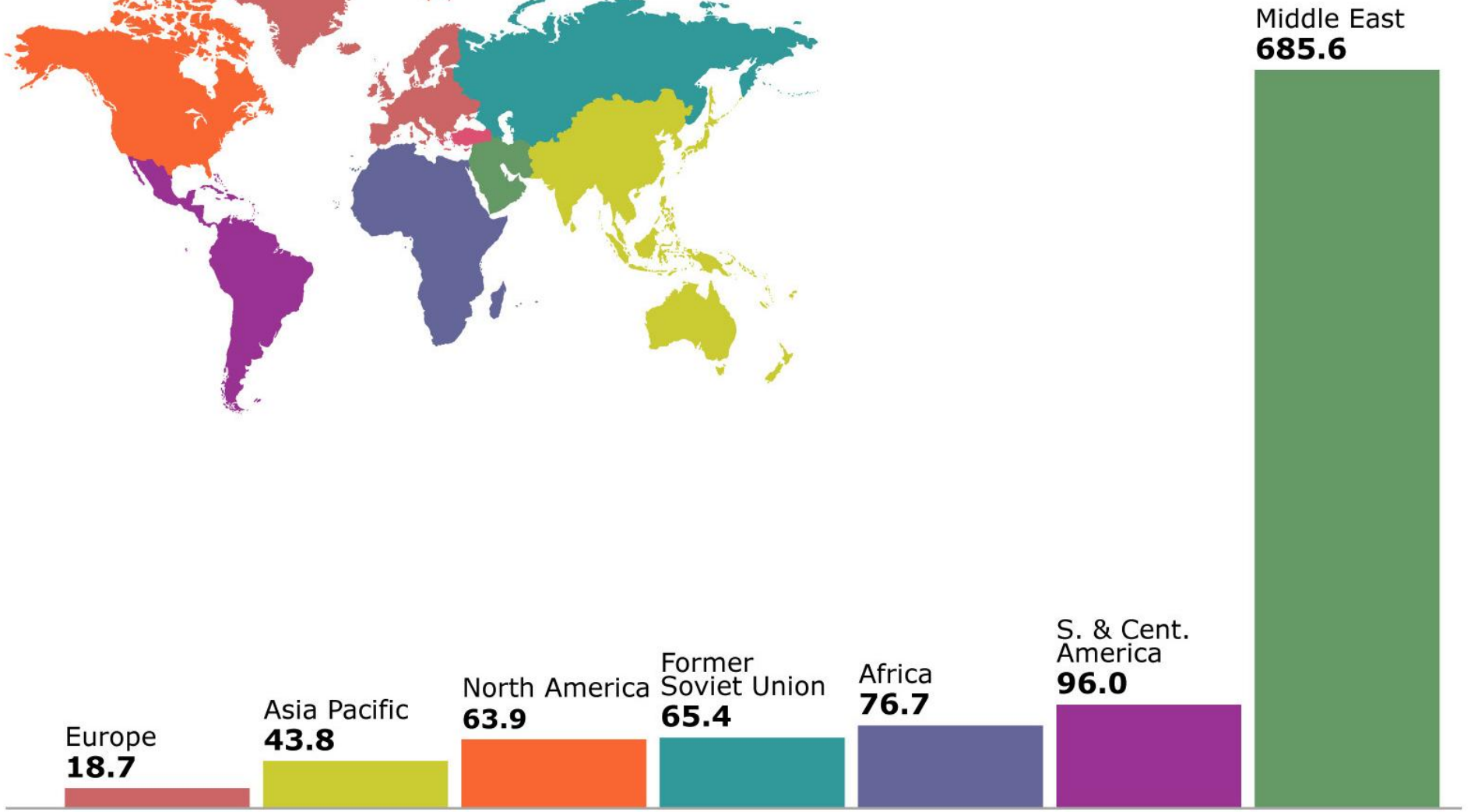


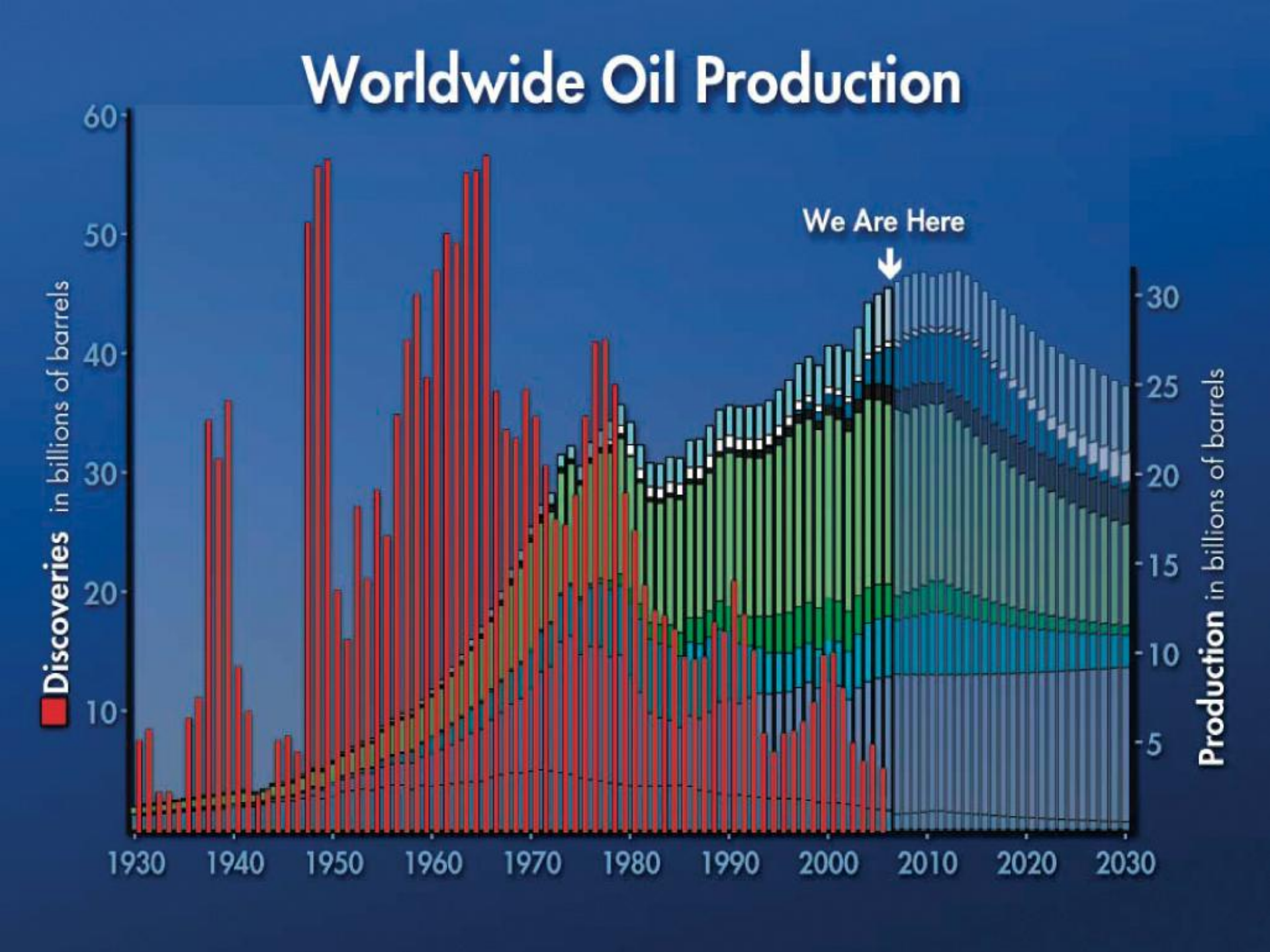
Source: PFC Energy research, based on BP's 2005 Statistical Review of World Energy
From Ball (2006)

QAd4882x

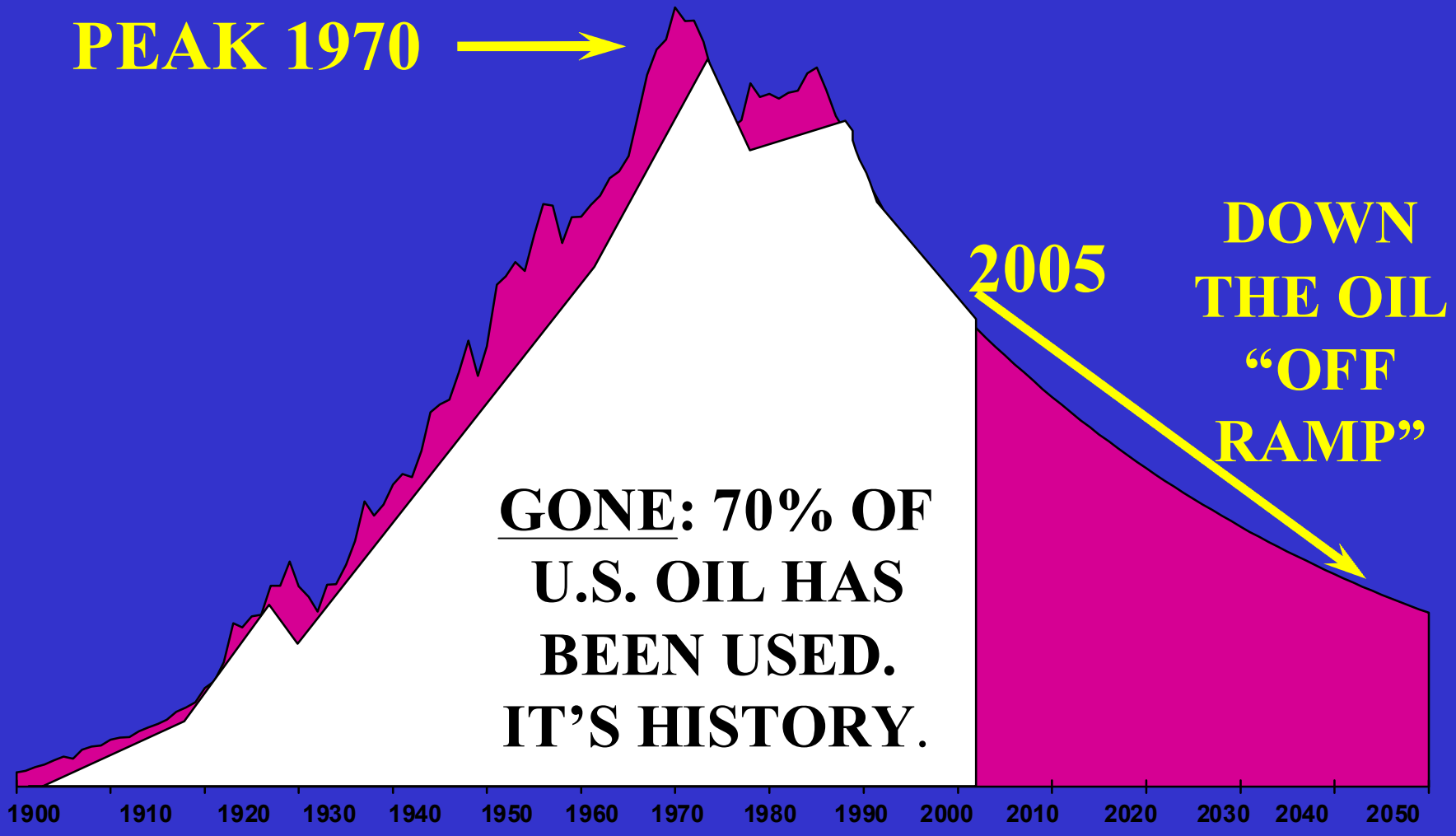
map of proved oil reserves at end 2001

Thousand million barrels




Worldwide Oil Production
We Are Here
Discoveries in billions of barrels
Production in billions of barrels
60
50
40
30
20
10
30
25
20
15
10
5
1930
1940
1950
1960
1970
1980
1990
2000
2010
2020
2030

U.S. OIL PRODUCTION 1900 TO 2050



US Oil- If you think of the original U.S. oil endowment as a six pack, four of the cans are empty. Two remain for all future generations of Americans.

When considering unconventional oil

- Oil shale ("Colorado has more fossil fuel than Saudi Arabia")
- Tar sands (Canada)
- Heavy oil (Venezuela)
- Coal to liquids (US, China, South Africa, etc.)

Consider:

Energy Return on Energy Investment?

Carbon dioxide?

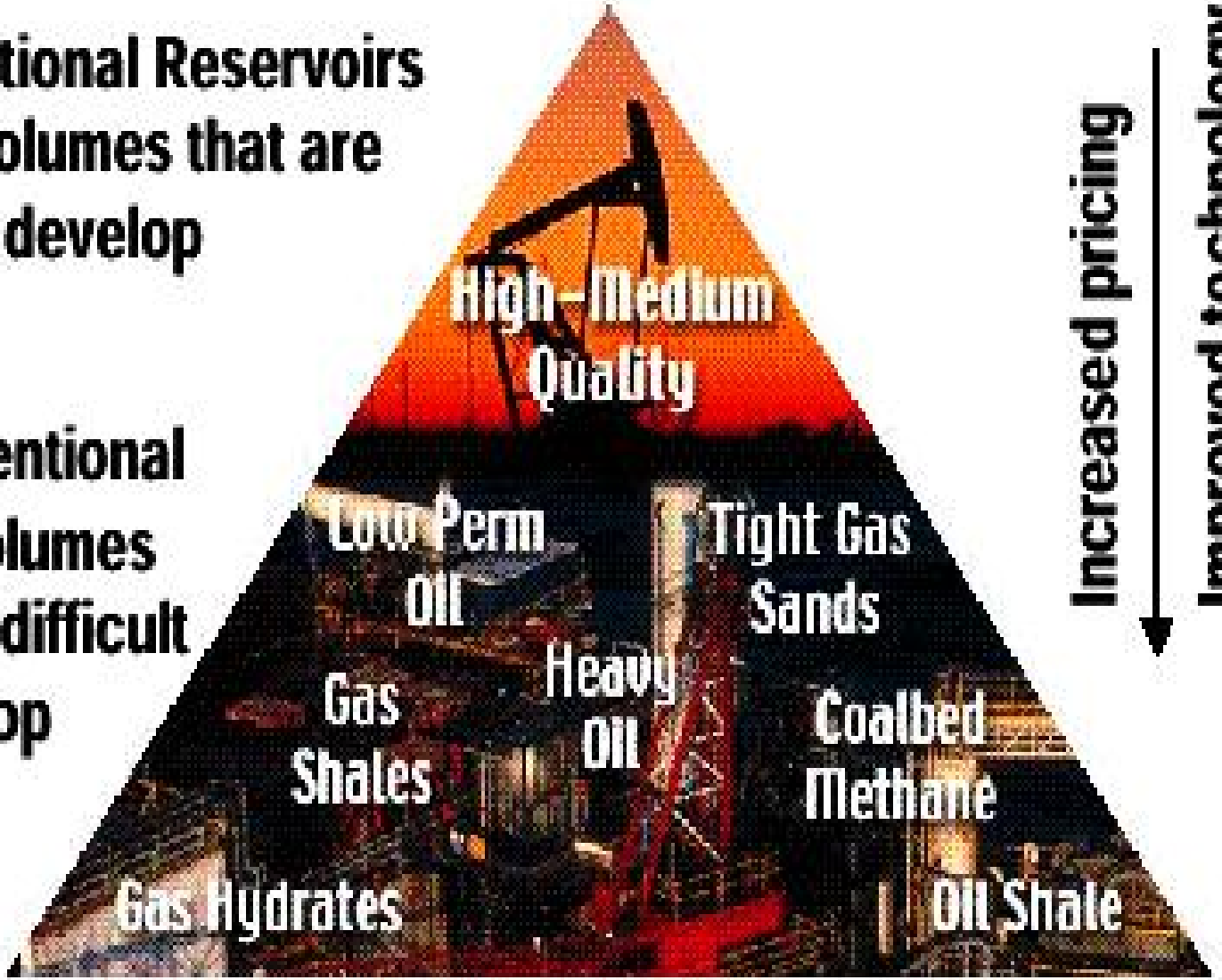
Capital required?

Environmental outcome?

Resource Triangle

Conventional Reservoirs
Small volumes that are easy to develop

Unconventional
Large volumes that are difficult to develop



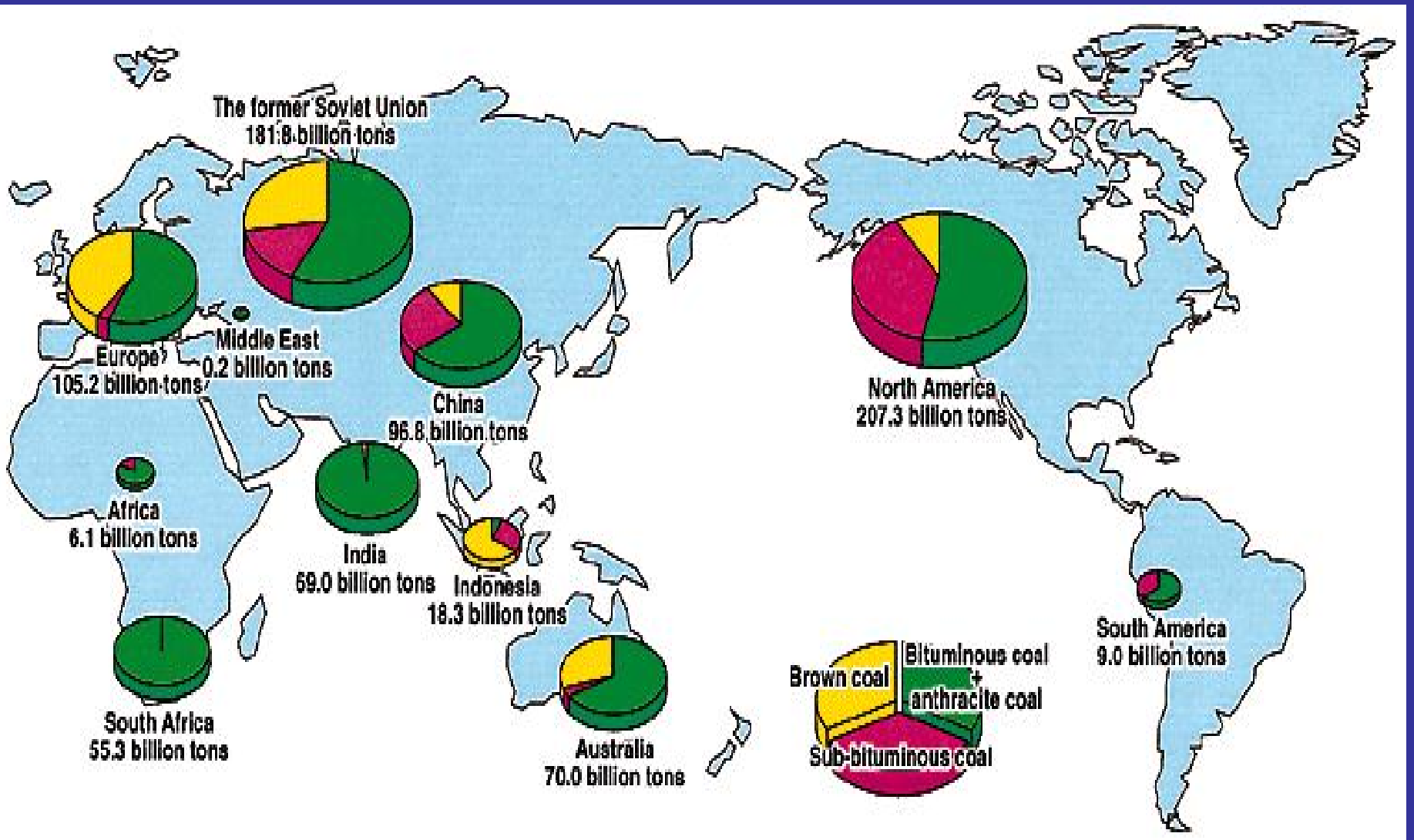
Tar Sands

Tar Sands

Tar Sands

Big “public education” campaign under way by corn growers in the US

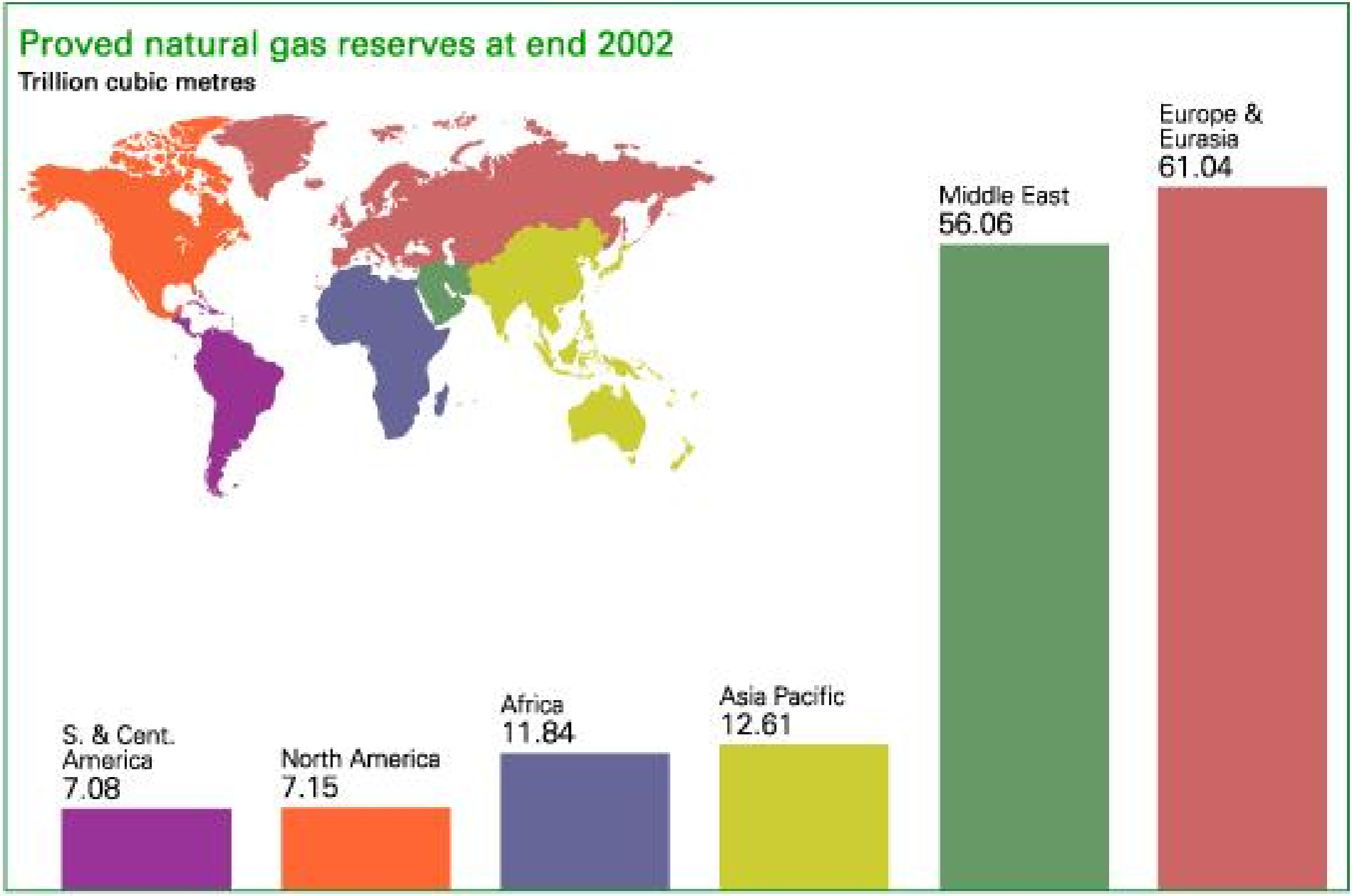
Coal provides 25% of the world's energy


The former Soviet Union
181.8 billion tons
Europe
105.2 billion tons
Middle East
0.2 billion tons
China
96.8 billion tons
North America
207.3 billion tons
Africa
6.1 billion tons
India
69.0 billion tons
Indonesia
18.3 billion tons
South America
9.0 billion tons
South Africa
55.3 billion tons
Australia
70.0 billion tons
Brown coal
Bituminous coal
+
anthracite coal
Sub-bituminous coal

We have 250 years of domestic coal!

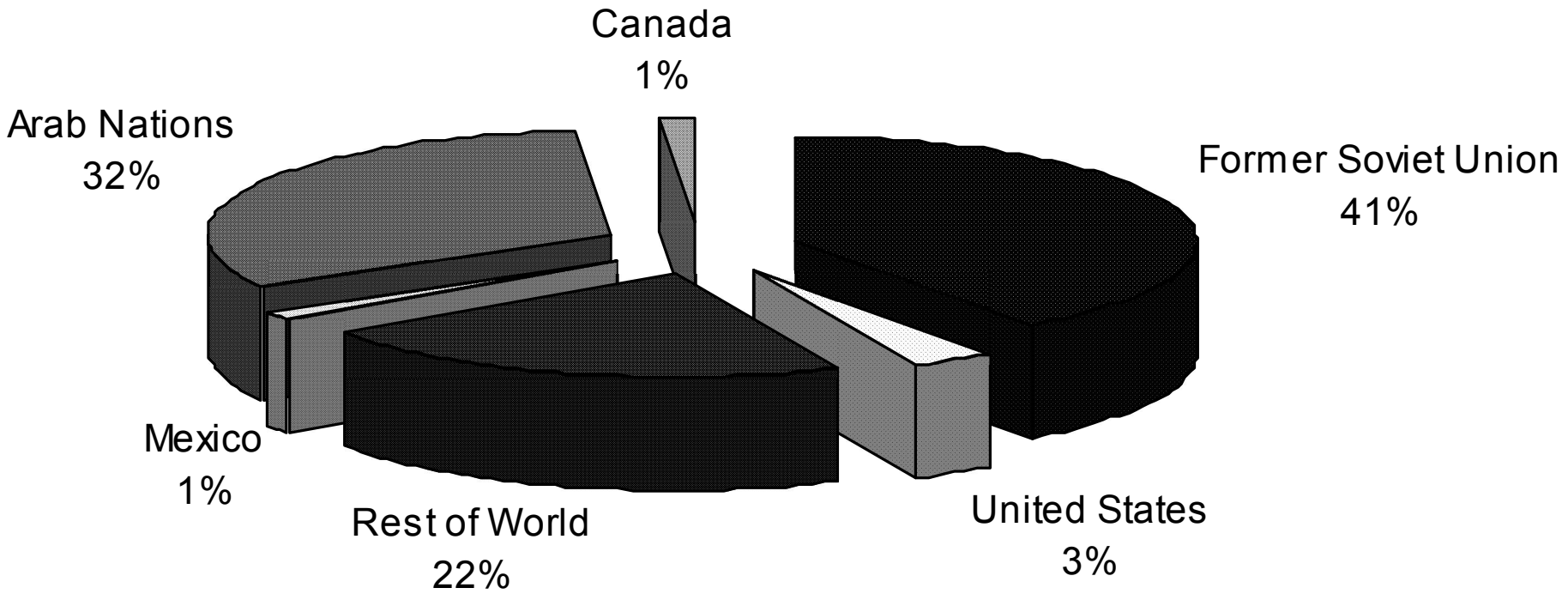
- And in the small print:
  - "At the current level of consumption."
- Oh….. Okay.
- So, it's more like 75 years, right?

Natural Gas supplies 22% of world energy



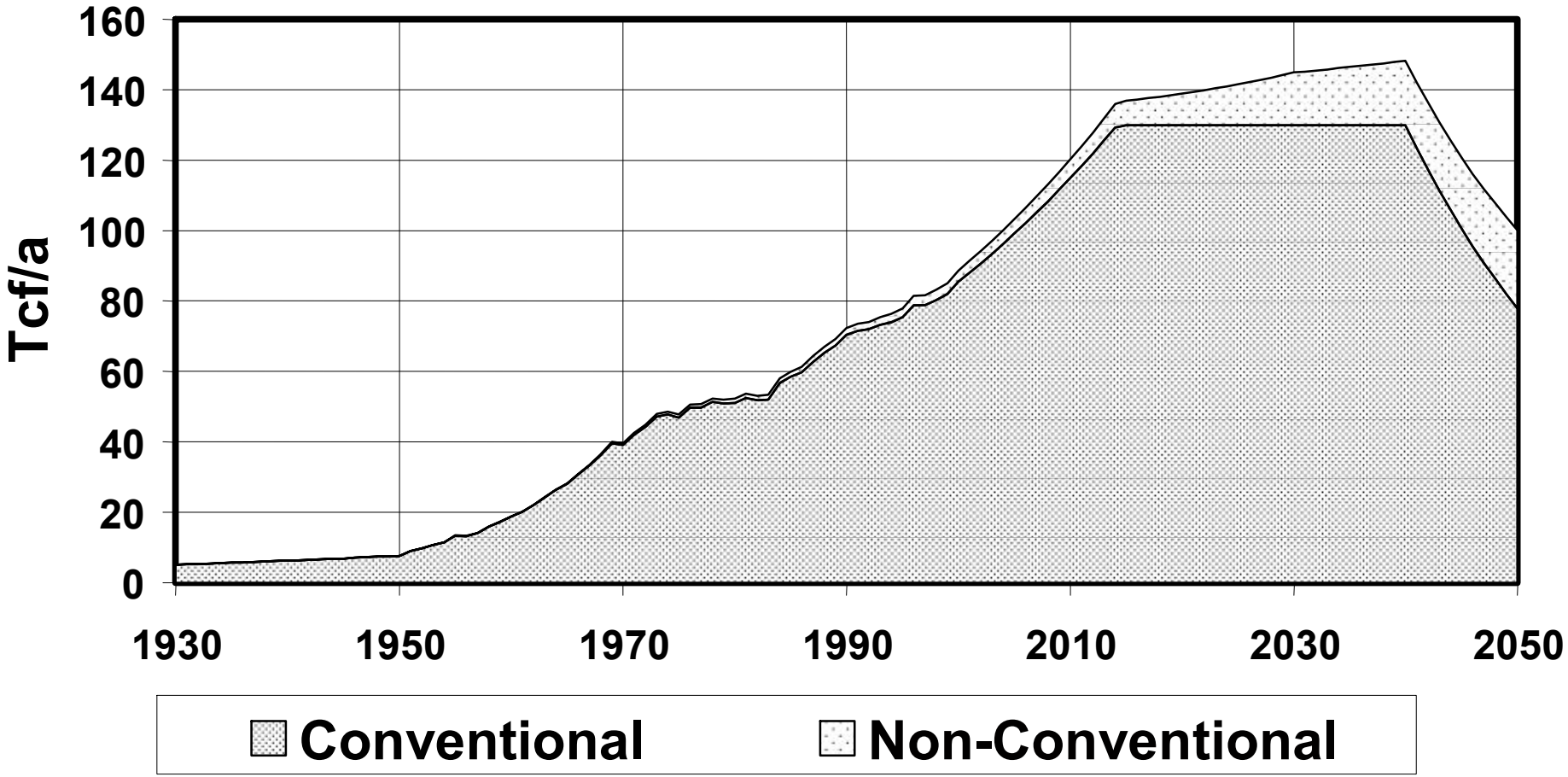
"The Rockies are the Saudi Arabia of Natural Gas"

Global Natural Gas Reserves



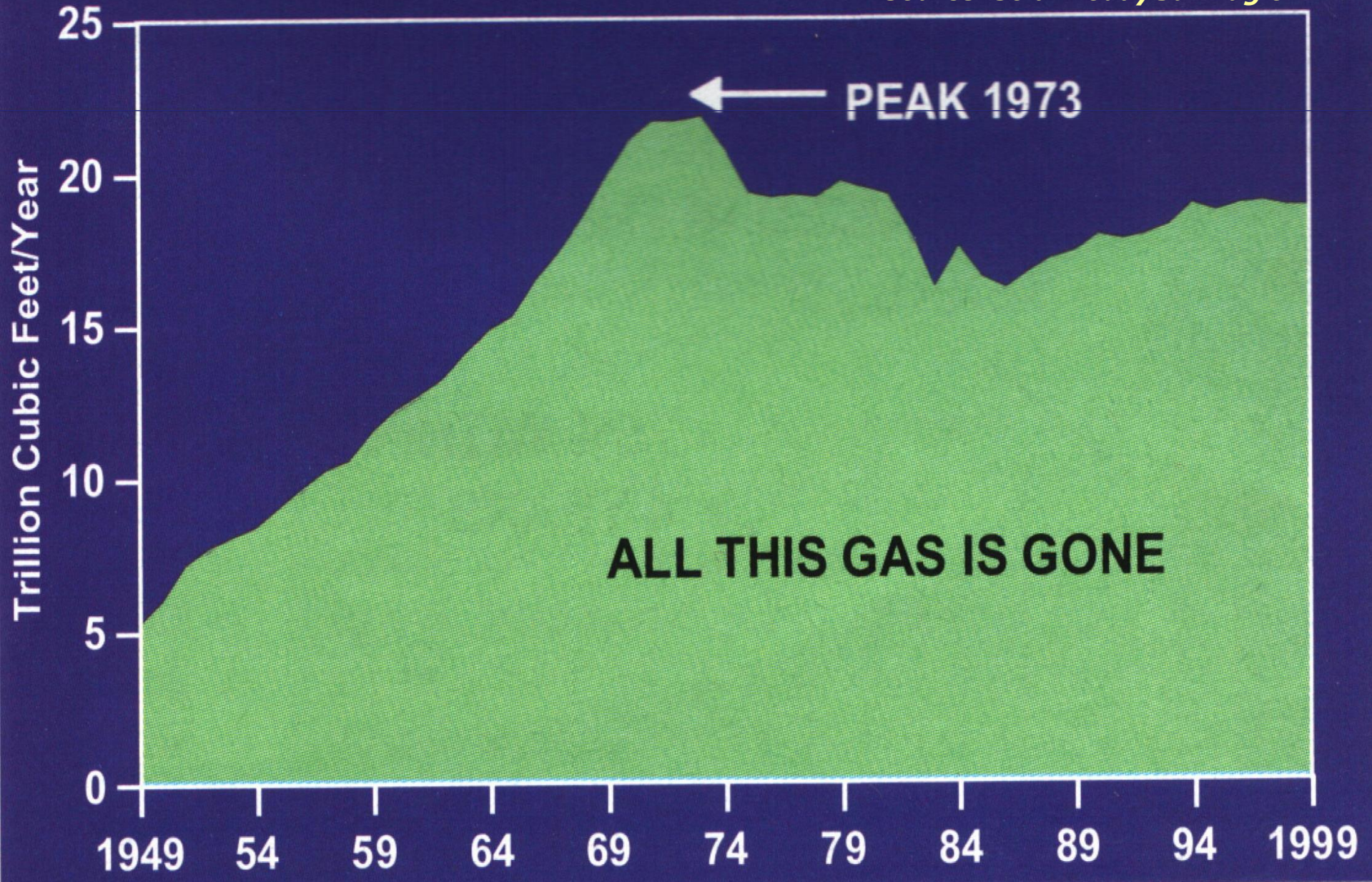
Source: Energy Information Administration, International Energy Outlook 1997

Global Natural Gas



U.S. NATURAL GAS PRODUCTION

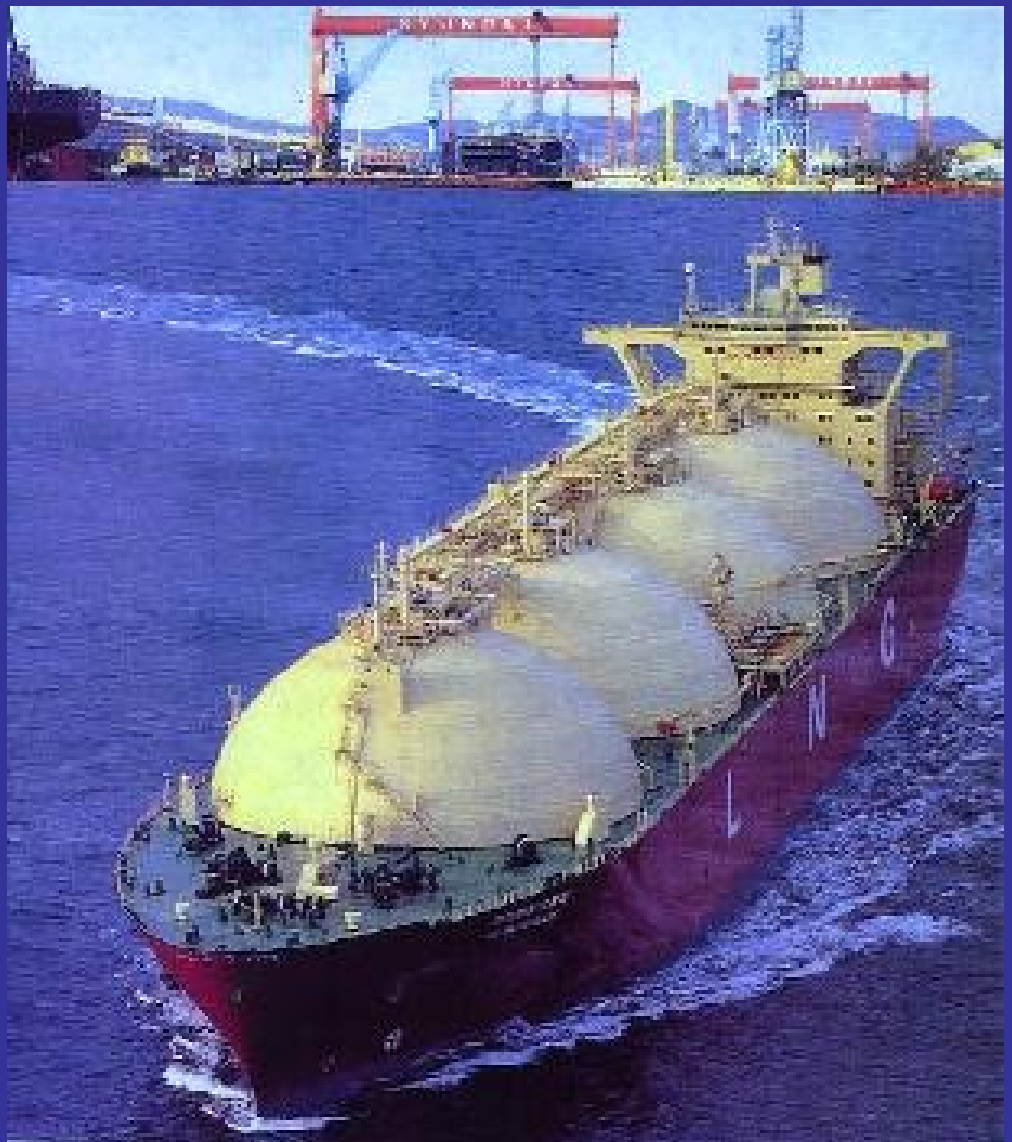
Source: Solar Today Jul-Aug 01



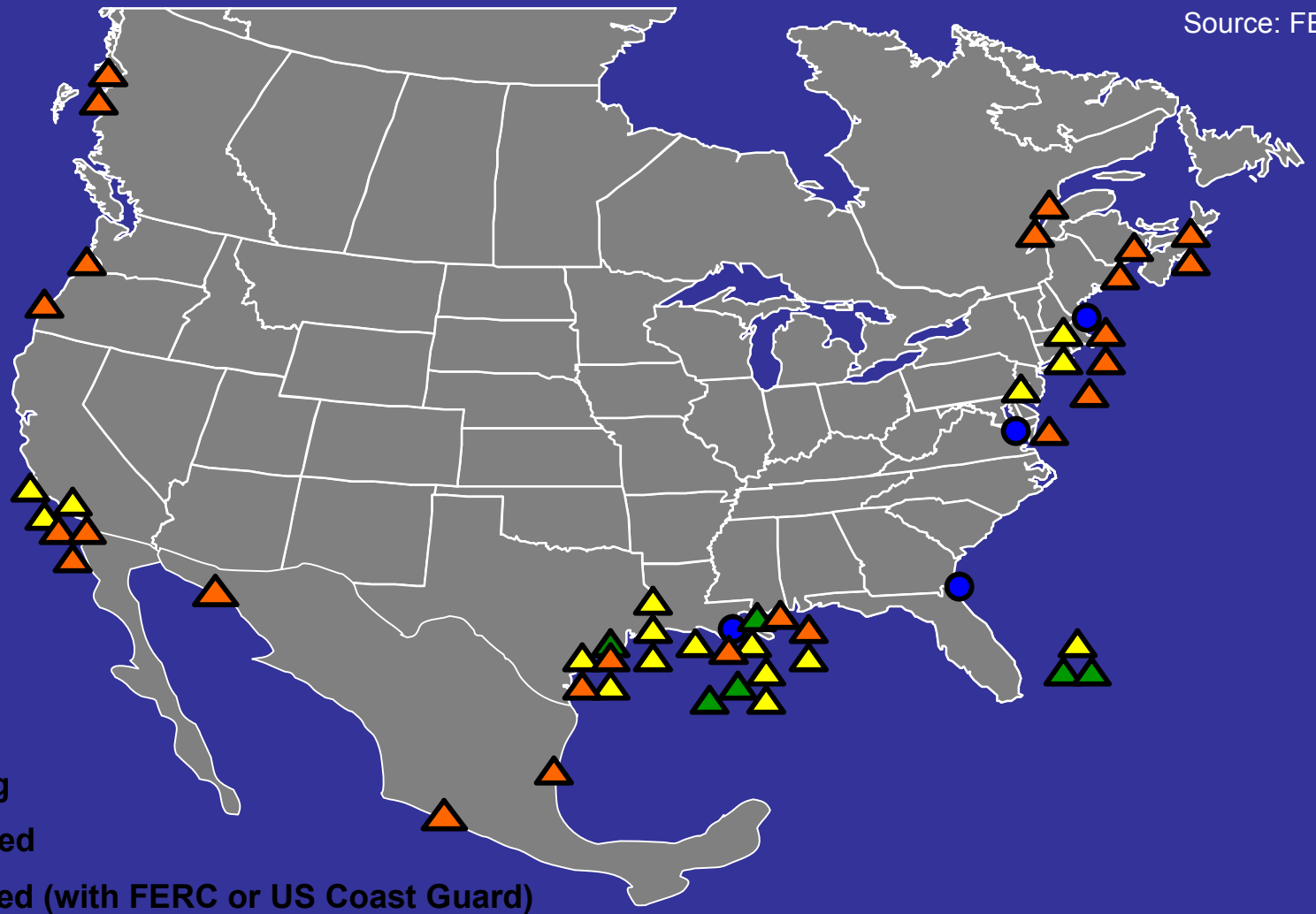
Qatar has more natural gas reserves than North America.

With proven reserves of 509 trillion cubic feet (Tcf), Qatar 's natural gas resources rank third in size behind Russia 's and Iran 's.

Import our gas from Russia and the Middle East? What choice do we have?

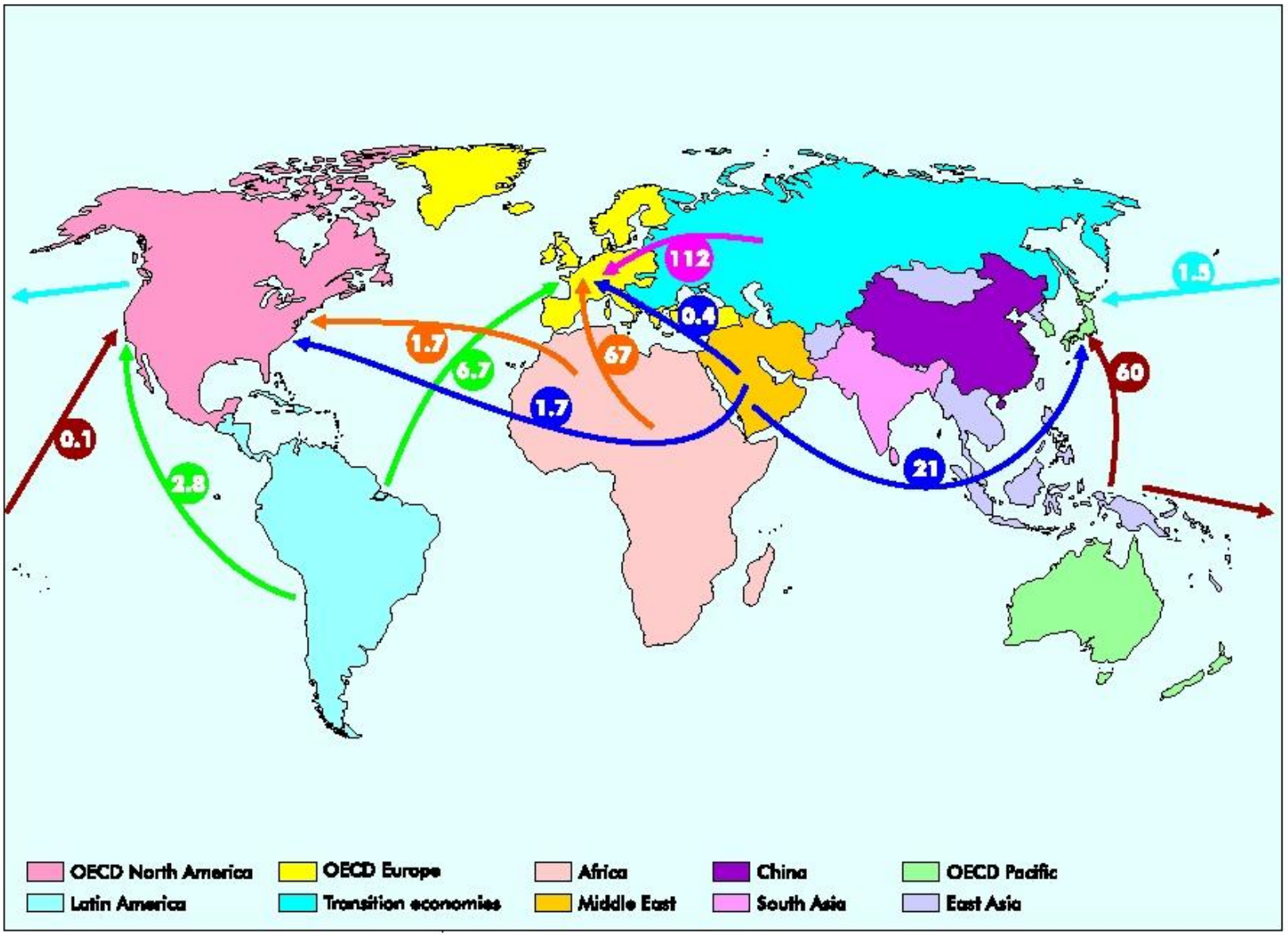


Proposed US Regasification Terminals



Gas resource and transport issues

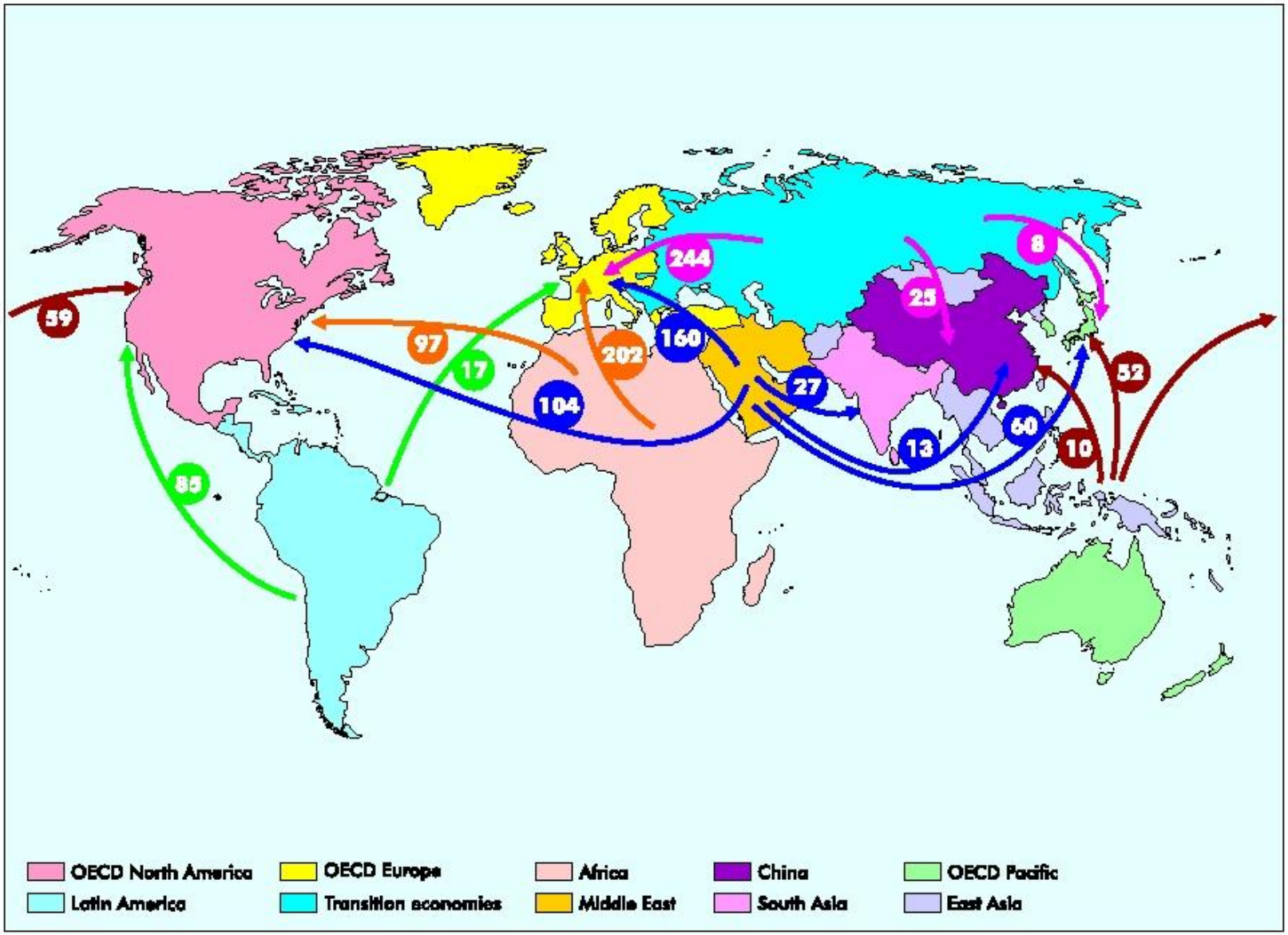
Figure 3.12: **Net Inter-regional Natural Gas Trade Flows, 2000** (bcm)



World Energy Outlook 2002, International Energy Agency

Gas resource and transport issues

Figure 3.13: **Net Inter-Regional Natural Gas Trade Flows, 2030** (bcm)



World Energy Outlook 2002, International Energy Agency

Hydroelectric

Hydroelectric plants provide 6% of the world's energy supply

Nuclear Fission

Nuclear fission provides 6% of the world's energy

Concerns

Accidents

Chernobyl, Three Mile Island

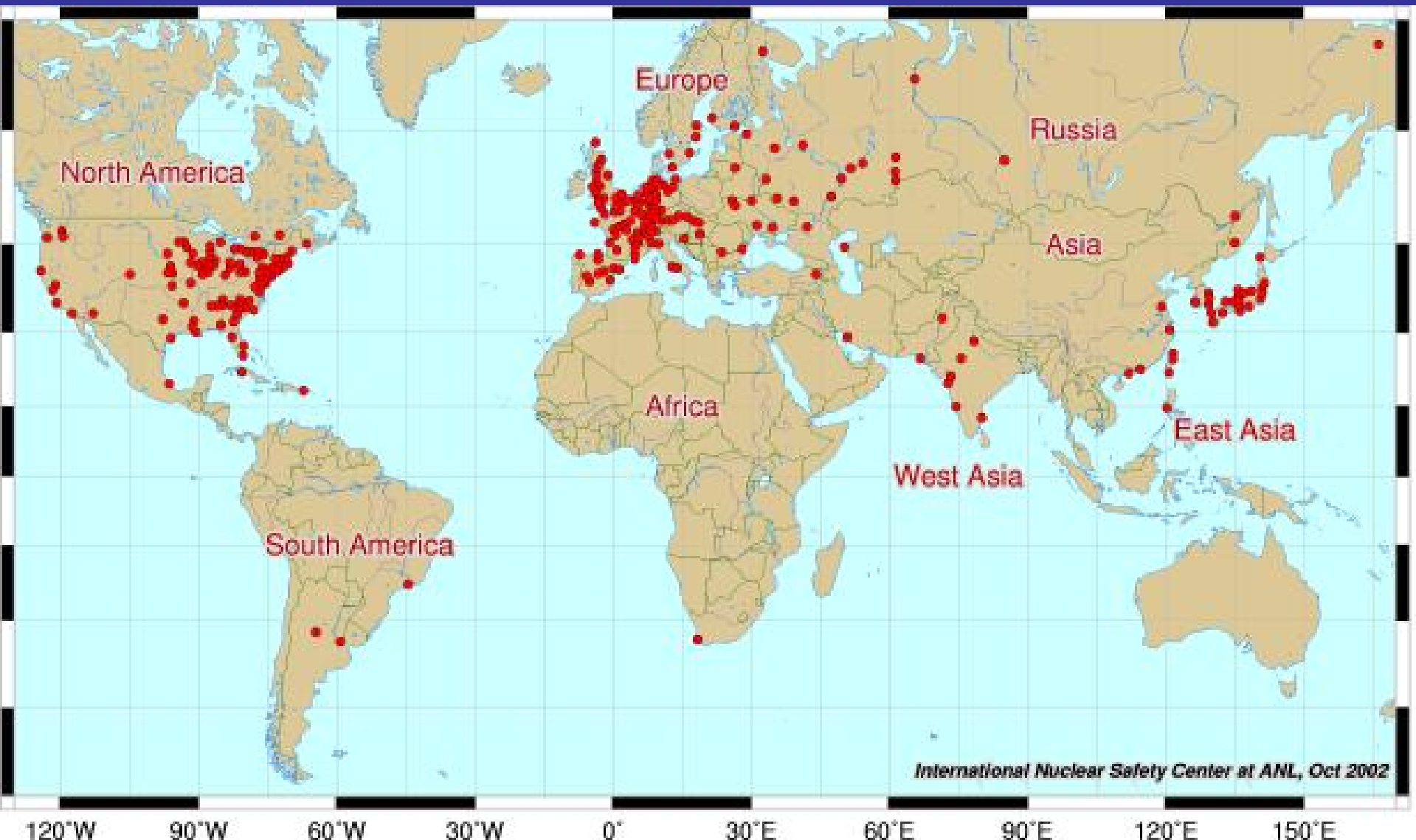
Diversion of nuclear fuel for nuclear weapons

North Korea, Iraq, Iran

Disposition of spent fuel

Yucca Mountain

Financial Cost


Europe
Russia
North America
Asia
Africa
East Asia
West Asia
South America
International Nuclear Safety Center at ANL, Oct 2002
120˚W
90˚W
60˚W
30˚W
0˚
30˚E
60˚E
90˚E
120˚E
150˚E

Major Uranium Producers

Australia, Canada, China, Kazakhstan, Namibia, Niger, Russia, Uzbekistan

Welcome to Peak Uranium

- World uranium production is expected to peak in the next 15 years.
- After that--- welcome to the plutonium economy.

Nuclear power has gone from:

- "too cheap to meter, " starting in the 1950s

to

- "too expensive to matter," since the 1980s

NOW:

Xcel Energy CEO Richard Kelly 2/24/07:

> "Comparing a new nuclear plant to Xcel's new Comanche unit near Pueblo, which will cost about $1 billion, a new nuclear plant could cost seven times that amount and take as many as a dozen years to complete."

Geothermal Power

Ocean Power Concept

Tidal Power Concept

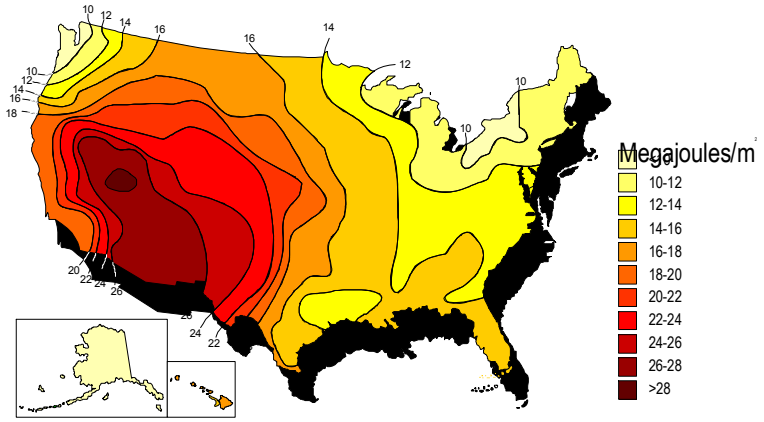
Energy Efficiency

Australia and California have recently introduced legislation to ban the incandescent light.

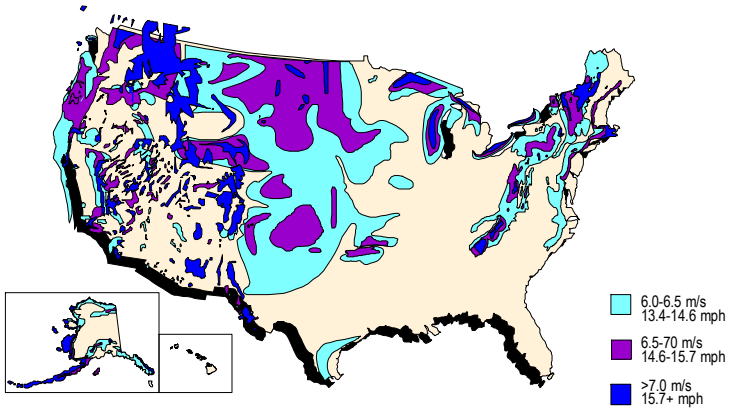
Renewable Energy

Renewable Energy Resources

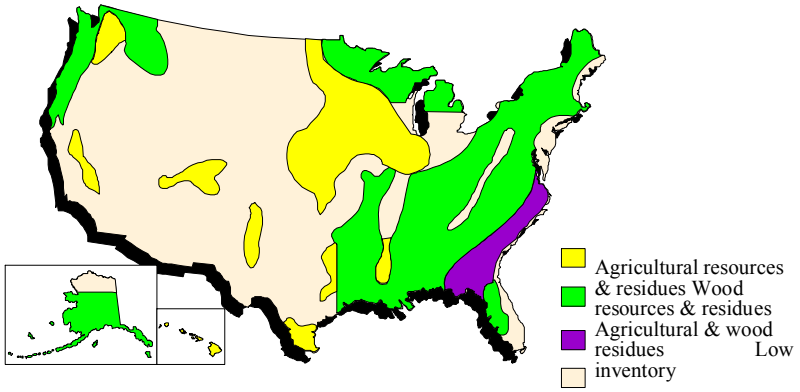
Solar



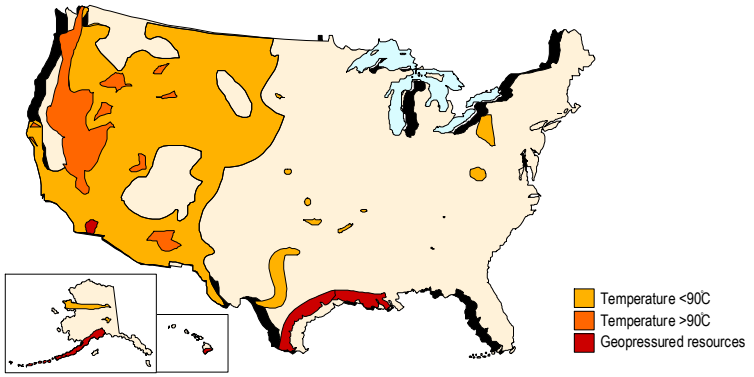
Wind



Biomass

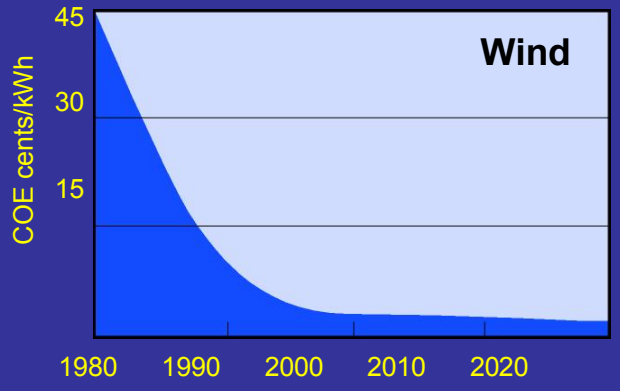


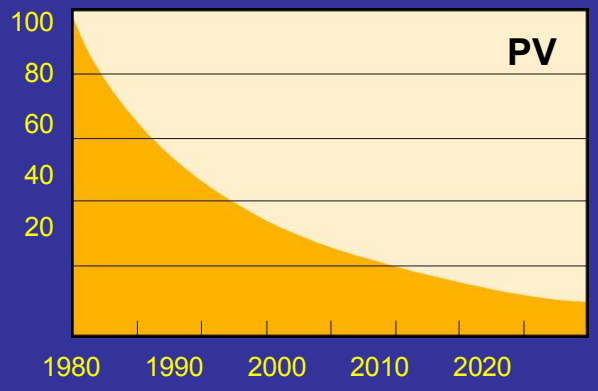
Geothermal

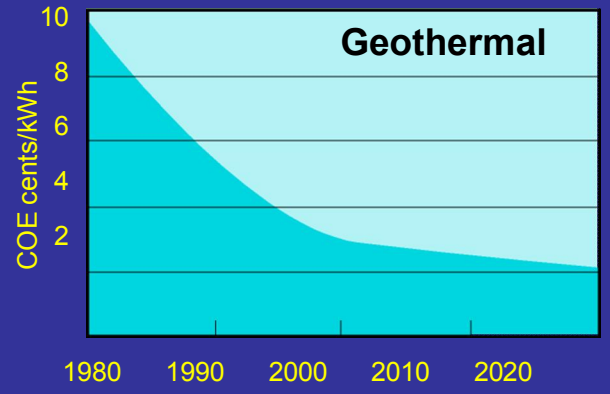


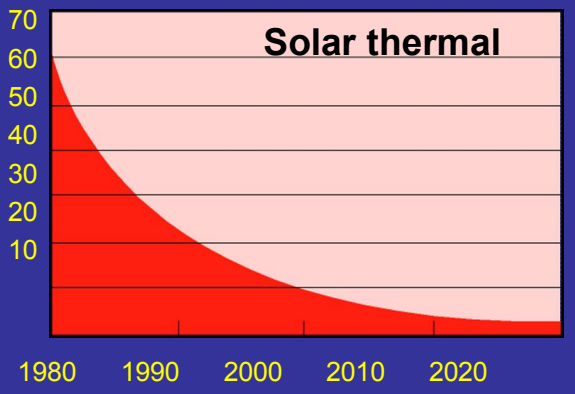
Renewable Energy Cost Trends

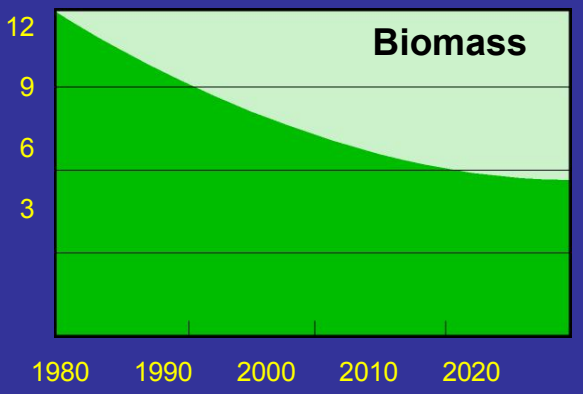
Levelized cents/kWh in constant $2000[1]











Source: NREL Energy Analysis Office
[1]See attached slides for background information.
Updated: June 2002

Cost of Wind Energy Trend

1979: 40 cents/kWh

2000:
4 - 6 cents/kWh

- Increased Turbine Size
- R&D Advances
- Manufacturing Improvements

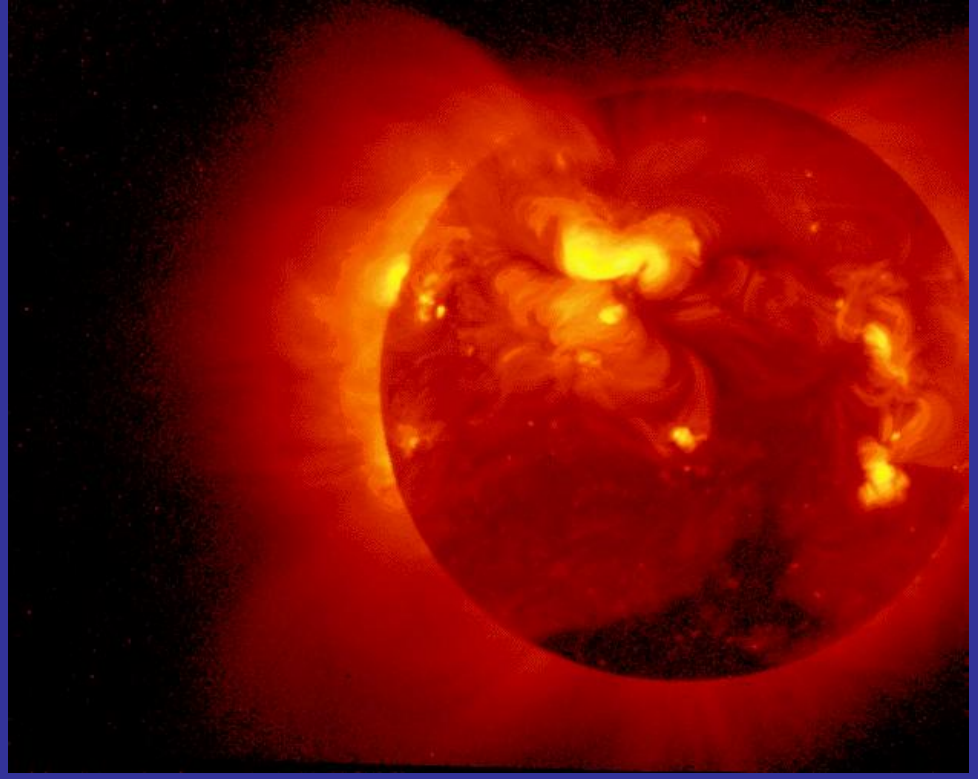
2004:
3 - 5 cents/kWh

NSP 107 MW Lake Benton wind farm
4 cents/kWh (unsubsidized)


Boeing 747-200
GE WindEnergy
3.6 MW
Prototype
Turbine in Spain

6 MW Wind Farm, Lolland, Denmark

Picture: Technical University



Each day, more energy falls to the earth from the sun's rays than the total amount of energy the planet's 6.3 billion inhabitants would consume in 27 years.

Concentrating Solar Power

In the Mohave Desert since 1995,
and within five years, likely coming to
the San Luis Valley

Photovoltaics: From Space to Earth

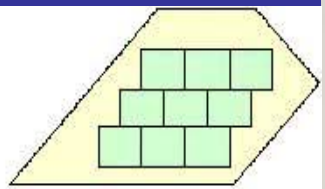
From $100/watt in 1970 to $4/watt today.
Needs to get to $1/watt
to get to the proverbial “tipping point.”

Look where they placed this 1.4 MW installation in Neustadt, Germany…….


Neatly tucked in next to a runway at a regional airport

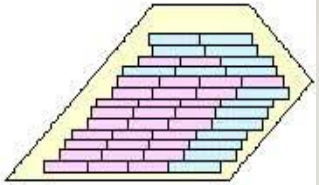

spheral solar pow
RV & CAMPING

Kyocera's roof mount type (for the Japanese market)
9 x 175 W modules = **1,575kW**

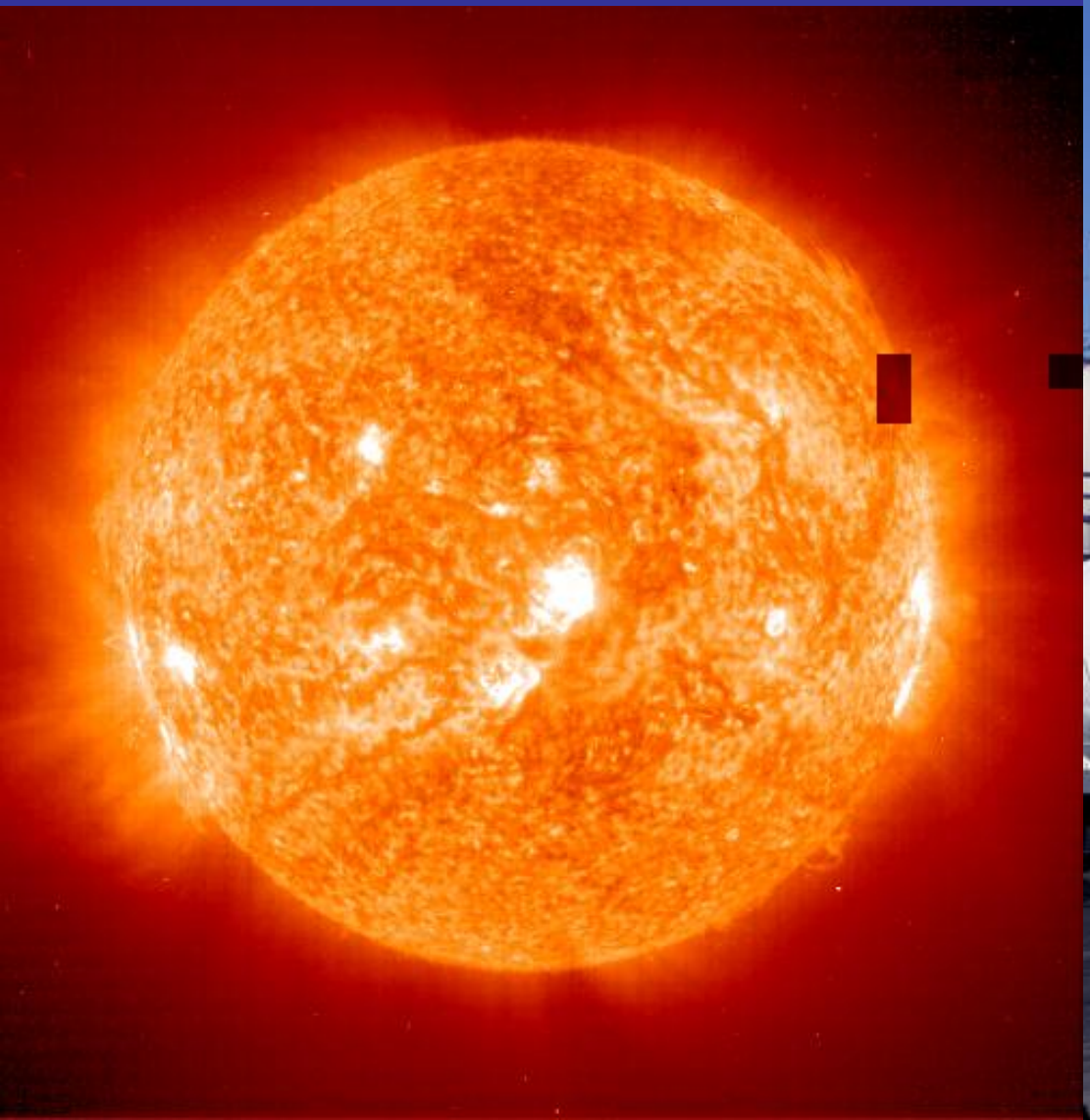


Up 28.0 percent

HEYBAN (for the Japanese market)
16 x 51 W modules, plus
30 x 40 W modules = **2,016kW**



The Renewable Hydrogen Economy



Intermittent Renewables

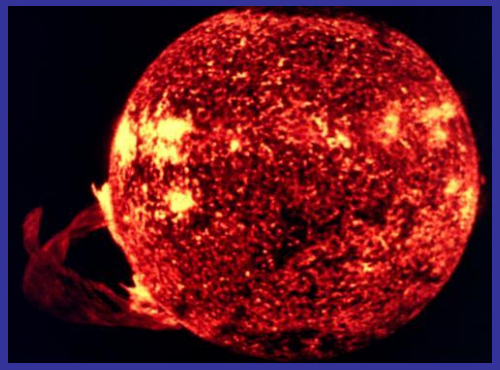
Constant Demand

Energy storage can mitigate intermittency

Any renewable based energy scheme must have integrated energy storage before it can become a viable, sustainable energy system.

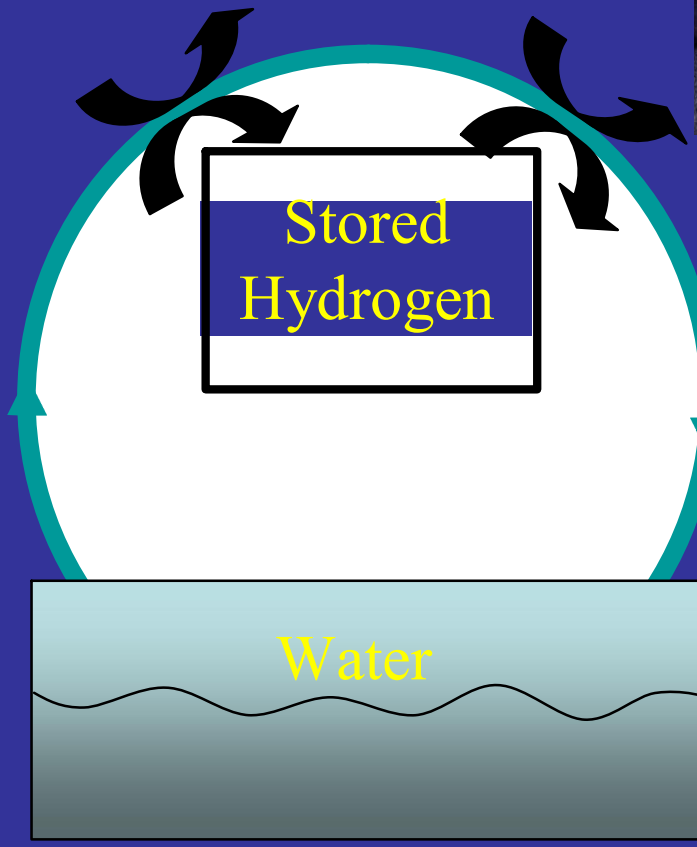
- Hydrogen
- Biofuels
- Batteries
- Pumped Hydro
- Compressed air
- Flywheels
- Superconductivity
- ….

Hydrogen Economy
Closed Energy Cycle



Inputs:

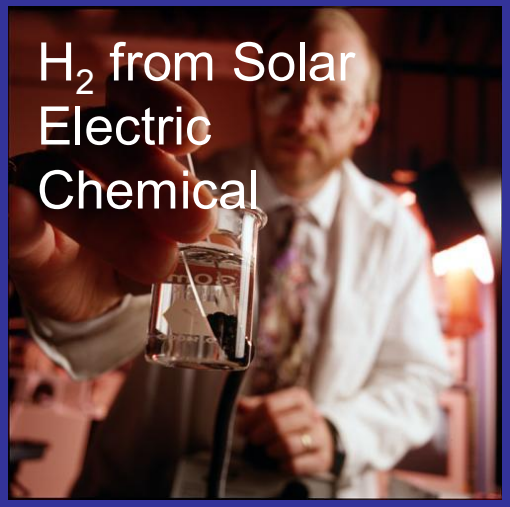
Solar Energy and Water

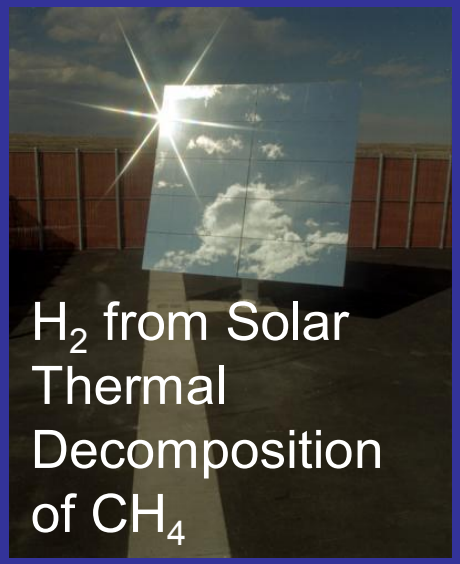


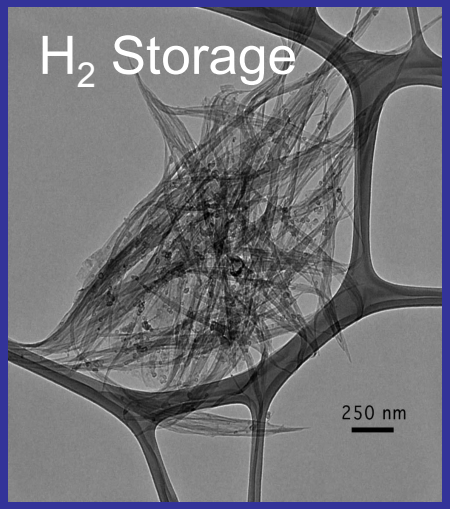
Outputs:

Electricity, Heat and Water

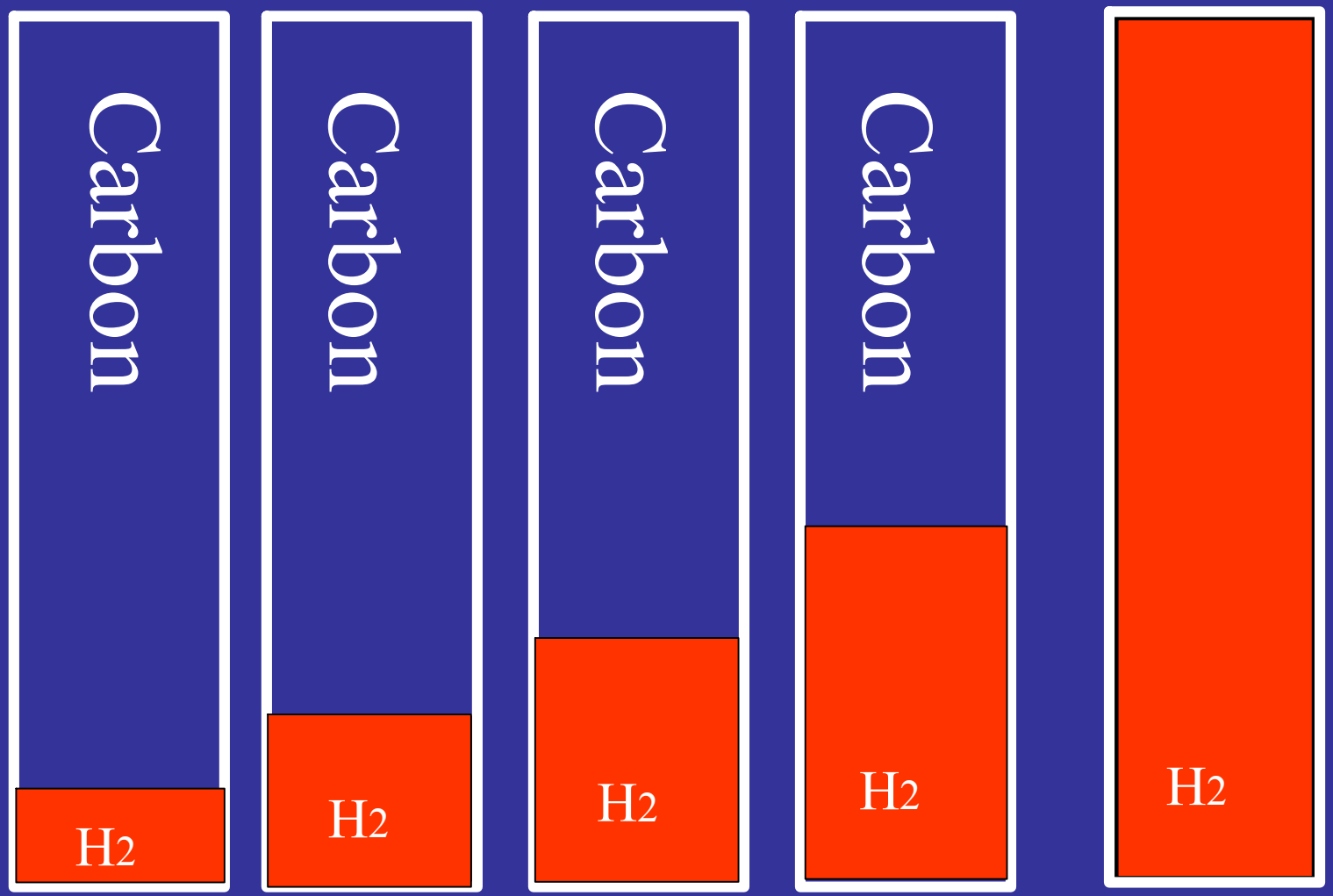
Renewable Hydrogen Production



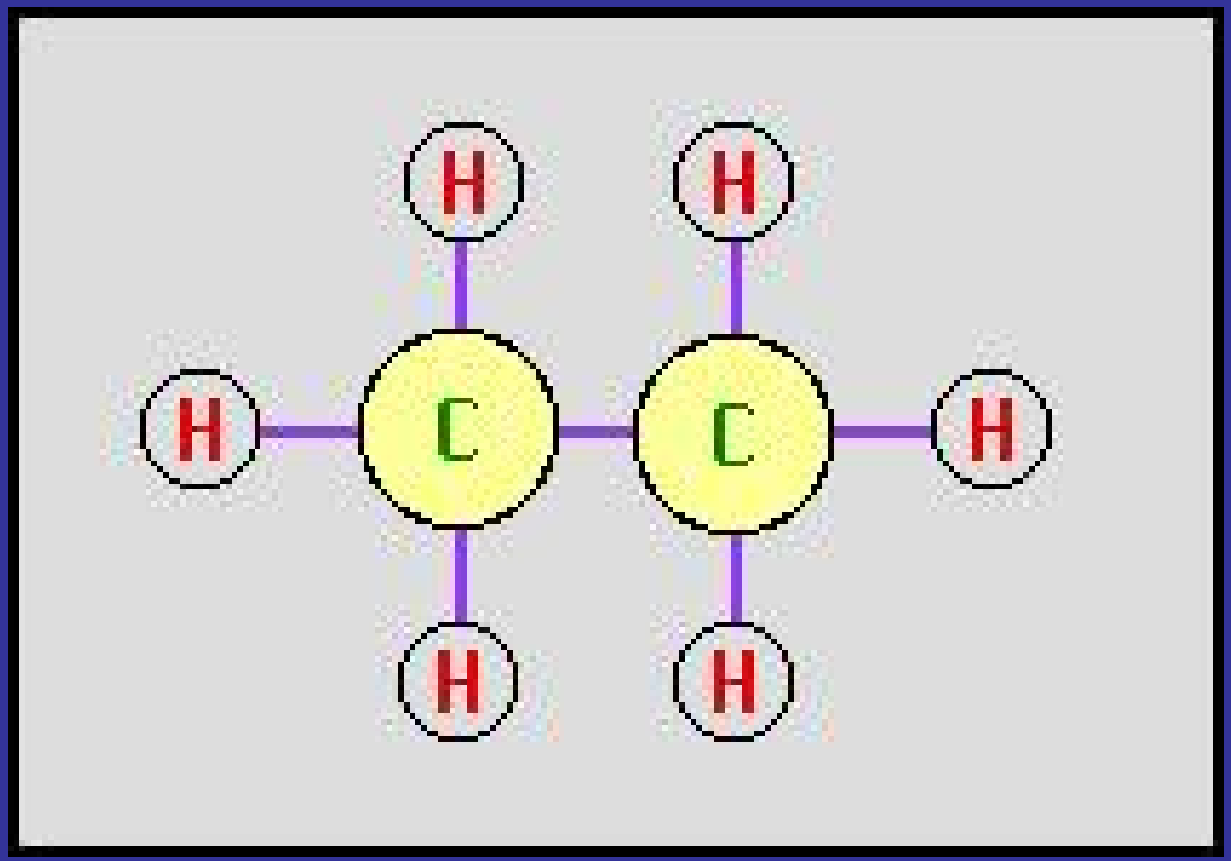




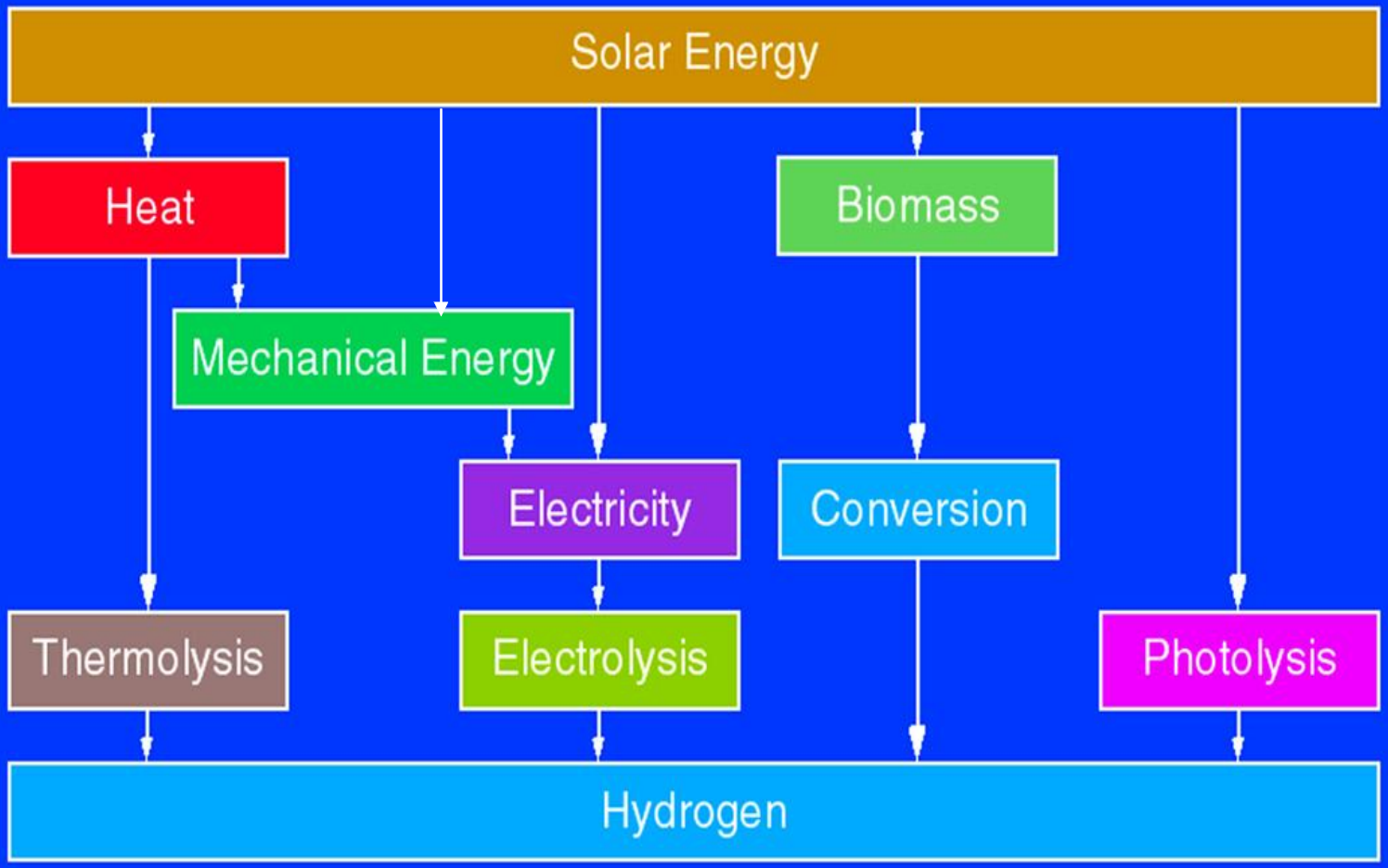
Illustrative Hydrogen Content of Fuels



Burn the hydrogen, not the carbon.



Sustainable Paths to Hydrogen

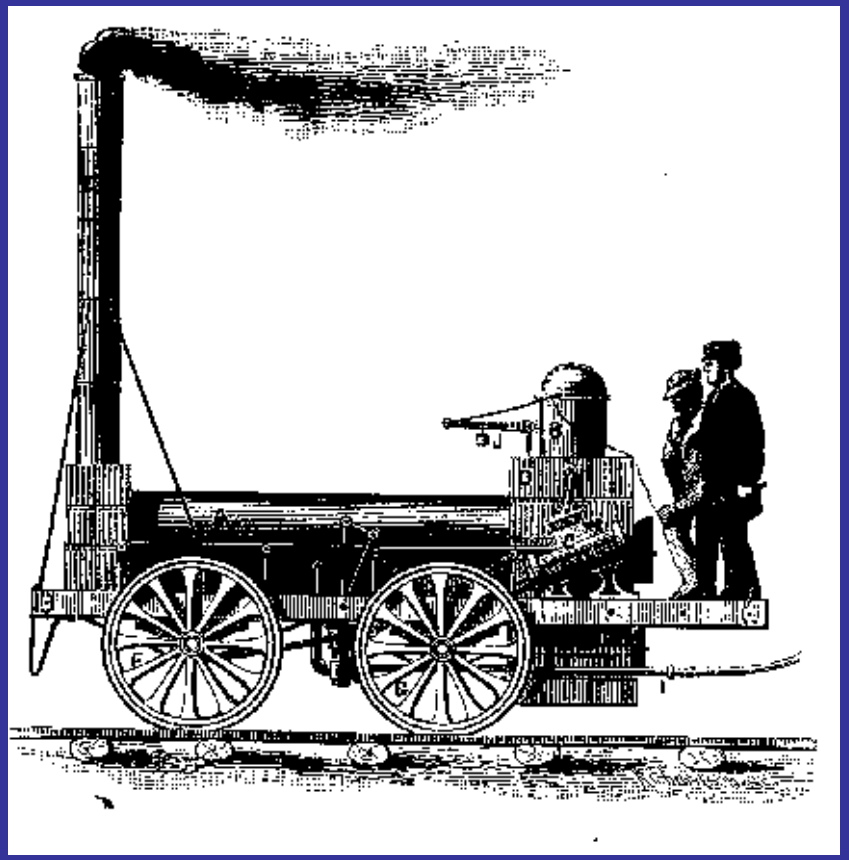


P158-A199106

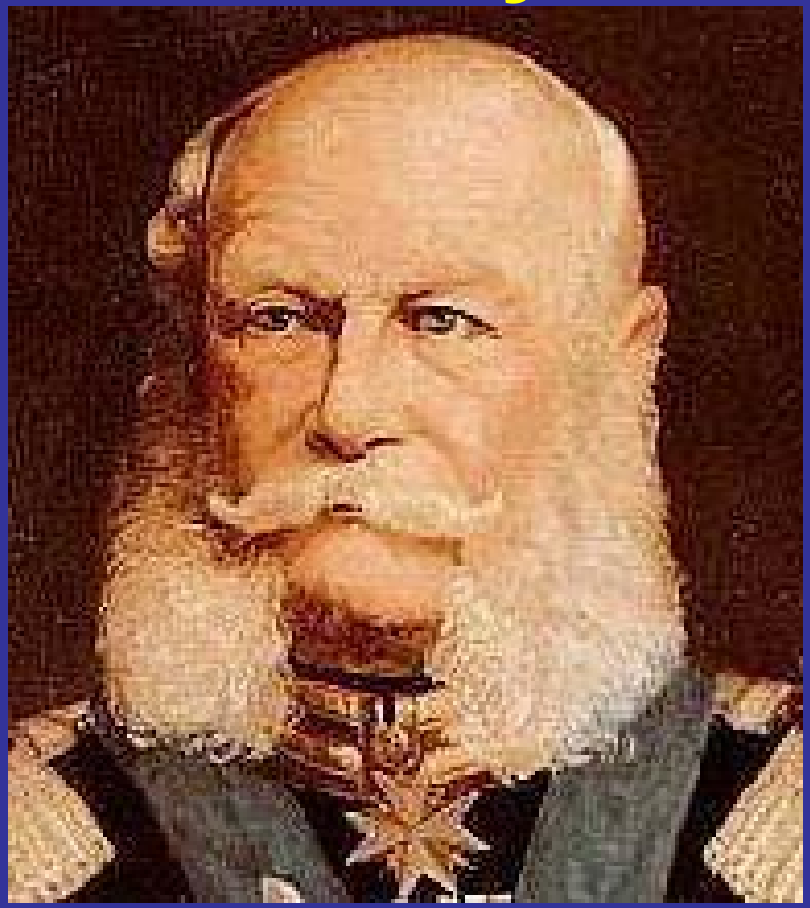
Can we meet the challenge?

1830: "Rail travel at high speeds is not possible because passengers, unable to breathe, would die of asphyxia."

– Dionysius Lardner, Professor of Natural Philosophy and Astronomy at University College, London, and author of "The Steam Engine Explained and Illustrated"



1864: "No one will pay good money to get from Berlin to Potsdam in one hour when he can ride his horse there in one day for free."



–Kaiser Wilhelm I of Prussia

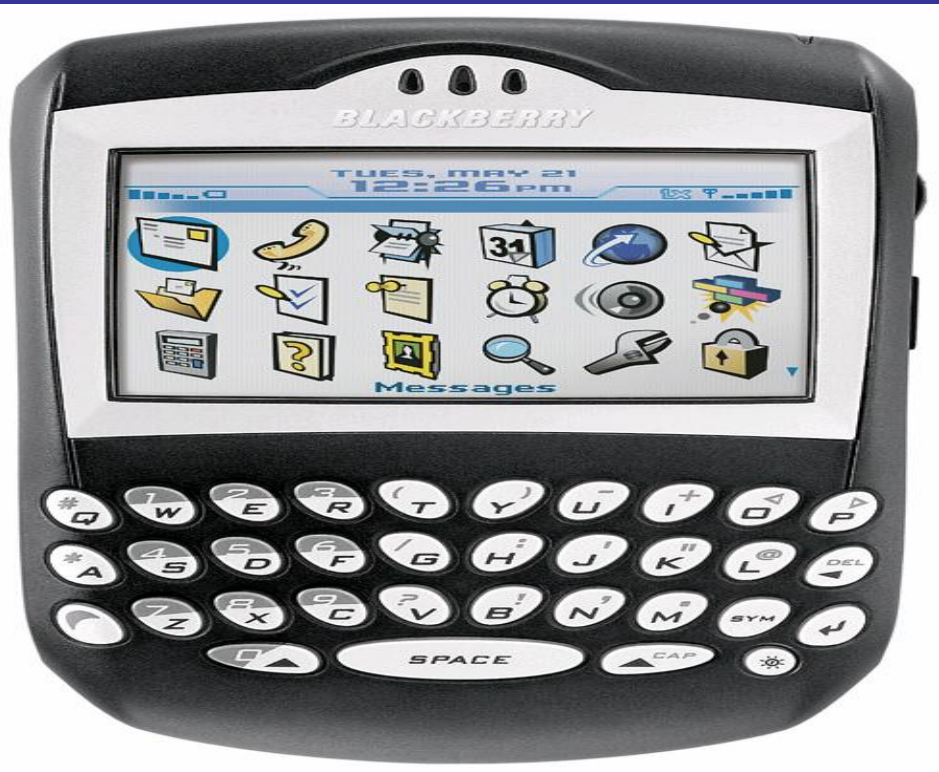
1933: "There will never be a bigger plane built."

– A Boeing engineer at the launch of the ten-seater Boeing 247

1977: “There is no reason anyone would want a computer in their home.”

– Ken Olson, president, chairman and founder of Digital Equipment Corp.

The Only Constant is Change



The calculator retailed for $400 when first introduced.

Things Change


iPod
Photos
Extras
Settings
Shuffle Songs
Backlight

Change is created through:

Leapfrog Technology

Honda Motor Enters Solar Cell Market

"We are serious about solar cells, and in the future will be making hydrogen with them," said Takeo Fukui, president and chief executive officer (CEO) of Honda Motor Co Ltd of Japan.

Plug in hybrid vehicle powered up by a green grid (dominated by wind power)

Breakthroughs are needed in advanced battery technology

Bill Gates at the World Altair Computer Convention, 1976.

The Founders of Apple Computer:

Steve Wozniak and Steve Jobs
in Jobs' garage - 1976

Google co-founders Larry Page and Sergey Brin


Google

Conclusion:

Crash Program Needed: Renewable Economy

The Apollo Project

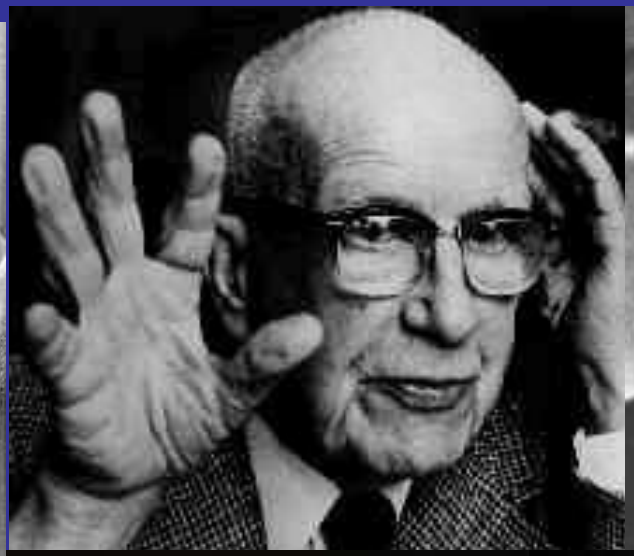
On July 20, 1969, the impossible dream came true. After 8 years, and $24,000,000,000, the Apollo XI landing craft made a perfect landing on the moon in the Sea of Tranquility.

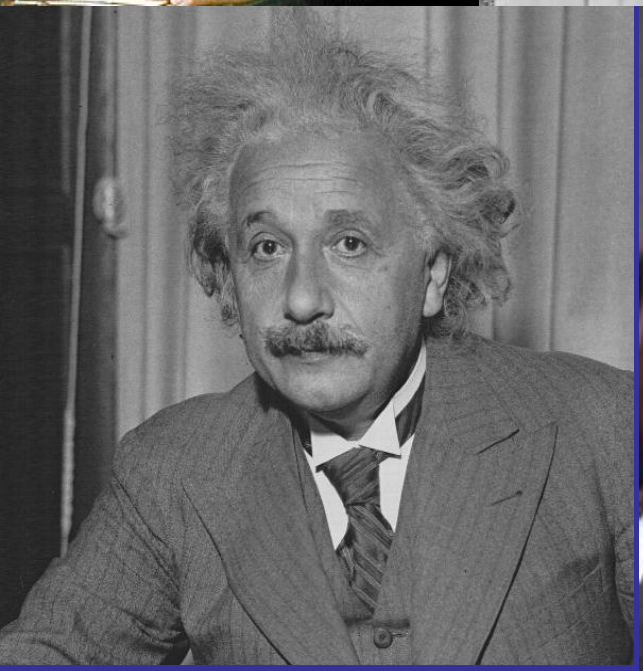
Kissinger: "Strategy, Mr. President. Strategy."

The Lessons of History….

- “We can no longer afford to ignore the reality that we have fixed resource boundaries, and that radical changes in our oil-based economy cannot be denied any longer. The era of cheap, abundant oil is over, and the sooner we accept this fact, the sooner we can get on with the task of developing alternative energy sources.”
  - Former Secretary of Defense William Cohen, December 22, 1973







It has been done before. We can do it now.

Thank you!