Will there be enough energy for all in the 21st Century?

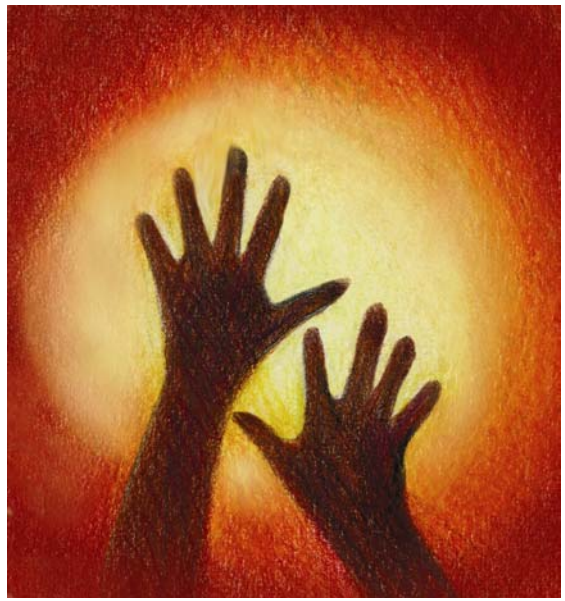
Rajan Gupta

Theoretical Division

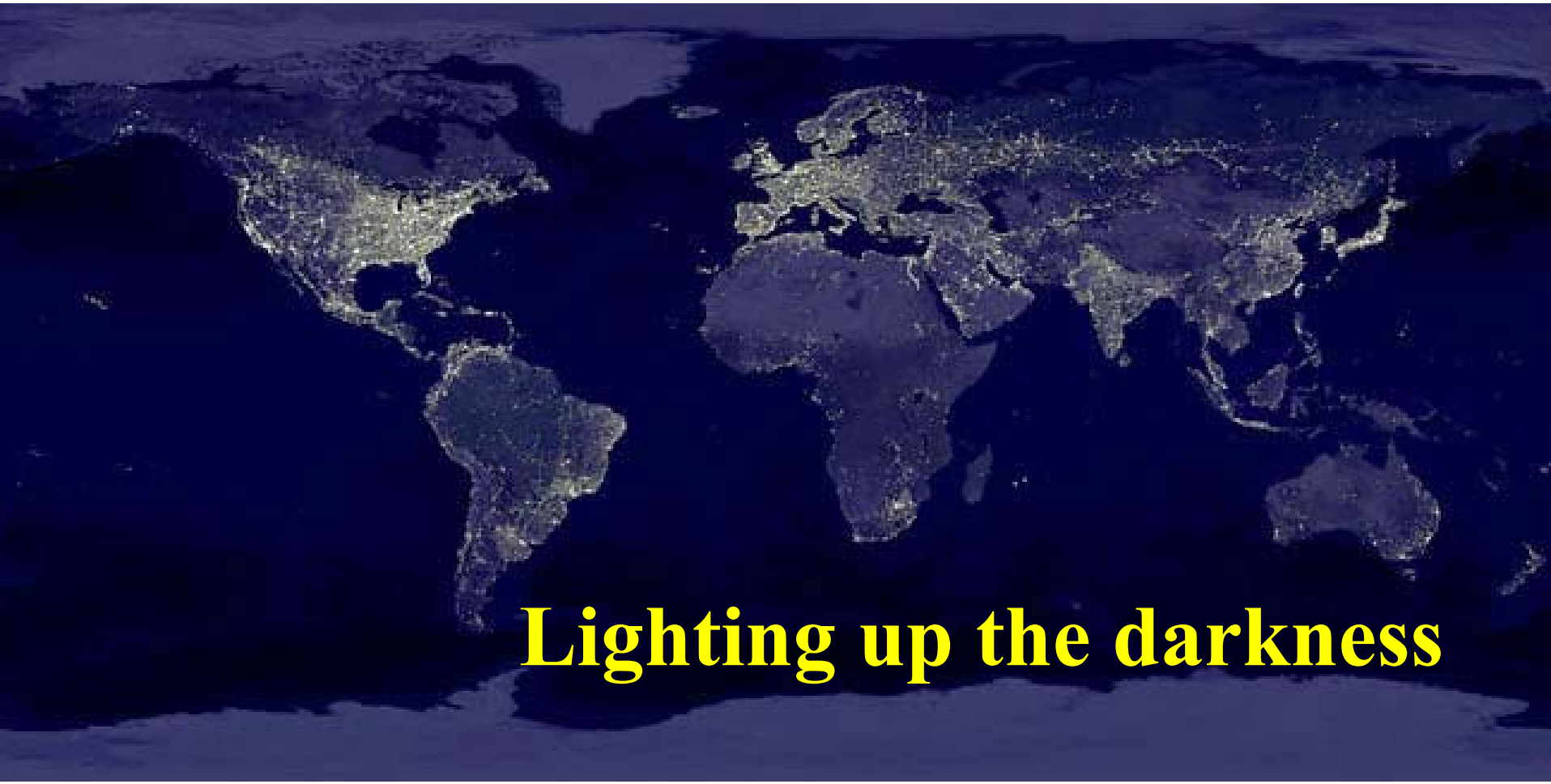
Los Alamos National Laboratory

Rajan@lanl.gov

http://t8web.lanl.gov/people/rajan/



3 billion people live on less than $2 per day

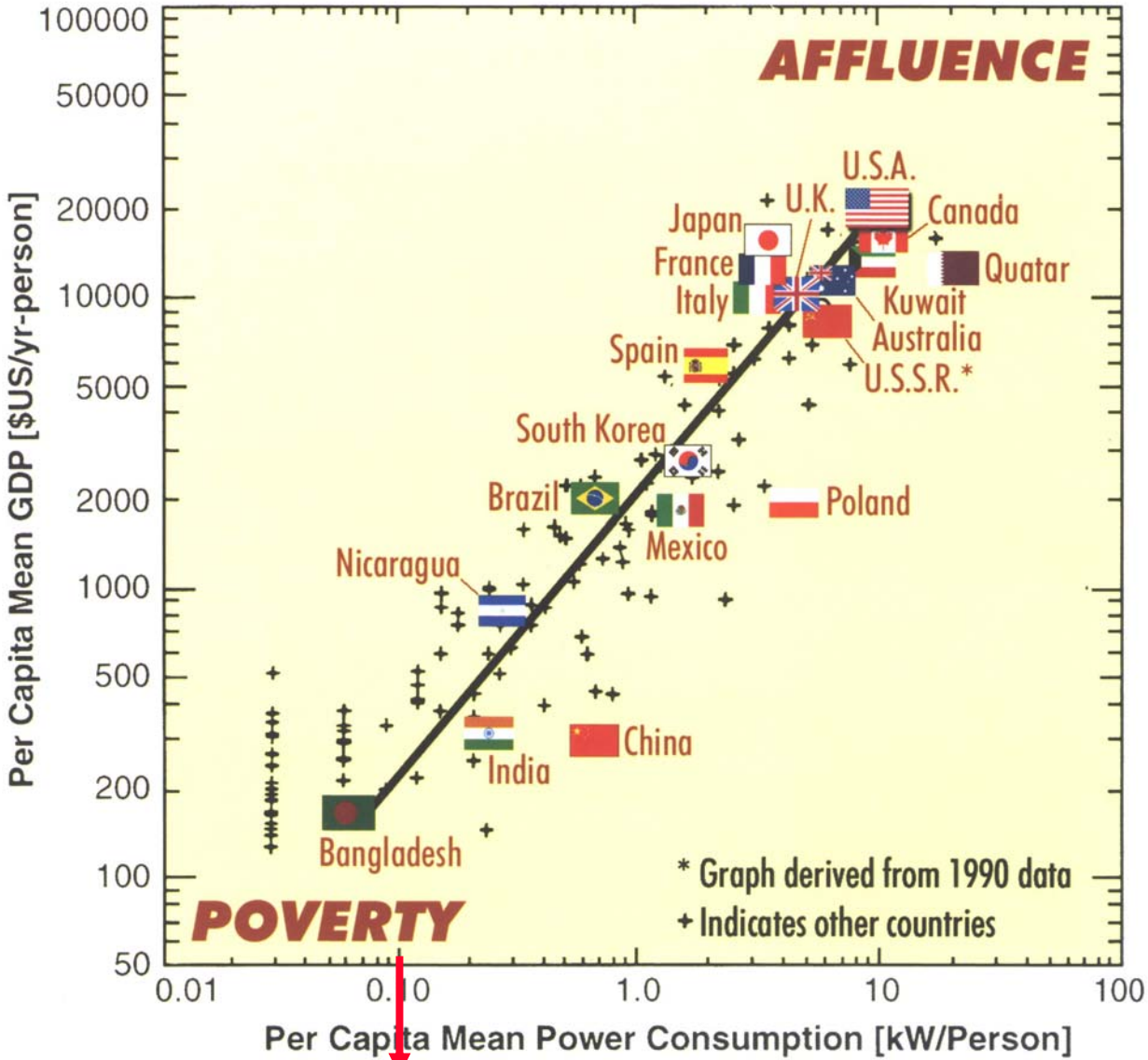


6 hours per day of electricity to the poor (women) will change their lives and the world

Special Thanks To

- Greg Swift
- Woody Woodruff
- Hans Ziock
- Ning Li
- Ben Luce
- Phil Jones
- Jean Challacombe
- Charryl Berger
- Dana Christensen
- Mike Fehler
- George Guthrie
- Fernando Garzon
- Joe Gutierrez

Energy = prosperity → need cheap clean energy

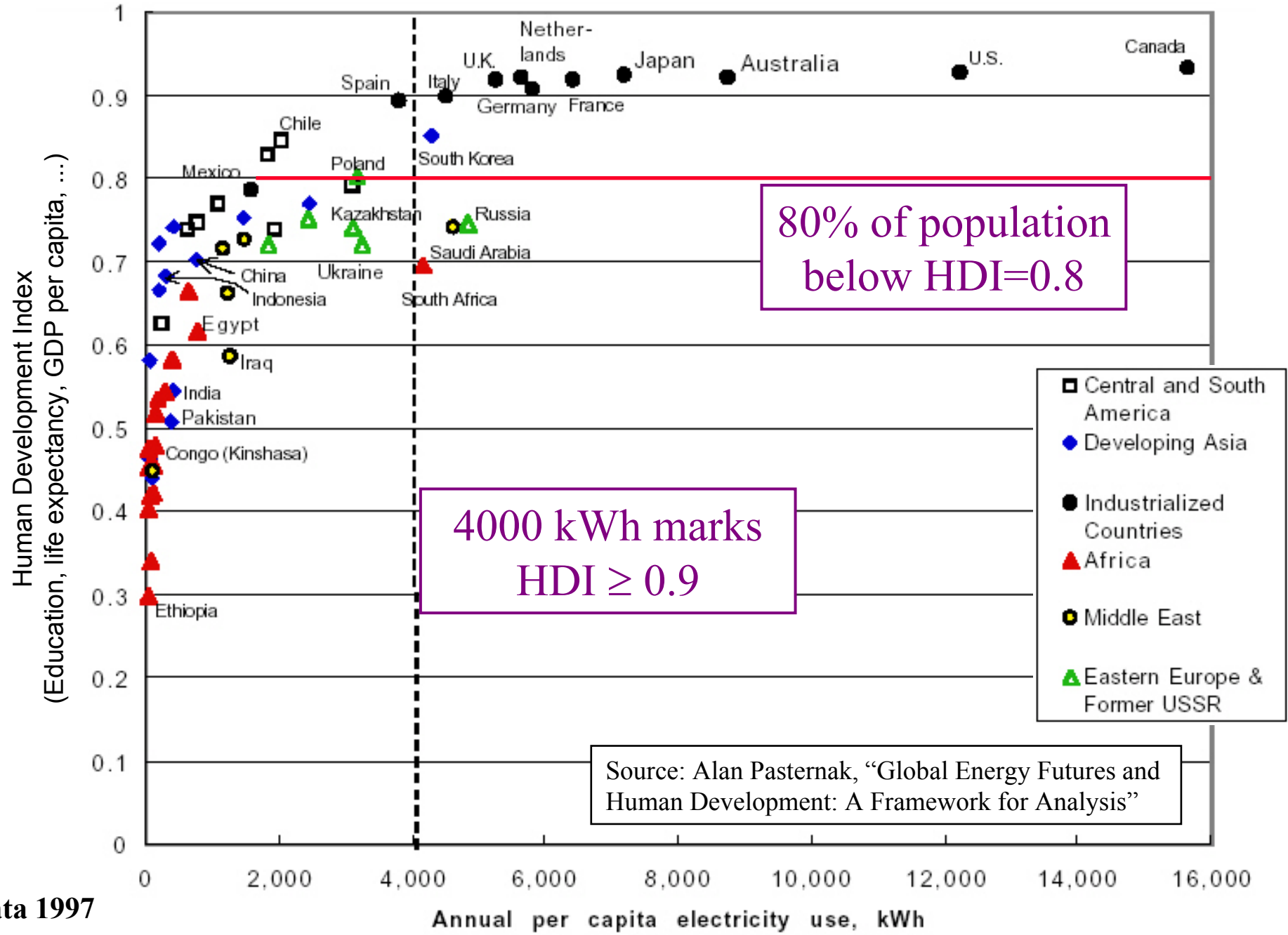


Per capita GDP related to per capita energy consumption. A nation's wealth is directly related to its access to affordable energy. What will happen to resource availability and the environment as countries like India and China move up the sloped line?

Source: Watts, Robert G. *Engineering Response to Global Climate Change: Planning a Research and Development Agenda*. CRC Press LLC: Boca Raton, 1997.

Human metabolism ~ 100 watt

Global Distribution of Electricity & Development



Data 1997

Today, global consumption is 13 trillion watts of primary power

To sustain adequate standard of living for the 8 billion people expected by 2025, and without improvements in efficiency, we need 2.5 times today's energy.

OUTLINE

- Modern society – relies on lots of cheap energy
- Where does our energy come from?
- Emerging challenges in supply of oil and natural gas
- Rapidly changing world – Geopolitics
- Environmental concerns with current use
- No magic solutions. Need R&D
- Challenge to US innovation
- Make New Mexico and USA a leader

We take energy for granted

Think beyond your 2005 oil, natural gas, electricity, bills

Each day each one of us uses

Source: Greg Swift

There is an enormous global energy infrastructure ($10+ trillion) that is mind-boggling

- Oil contracts, rigs, exploration technology
- Tankers and pipelines
- Refineries
- Auto industry
- 600 million cars running on gasoline
- Service stations and gasoline stations
- Existing coal/gas electricity generation plants

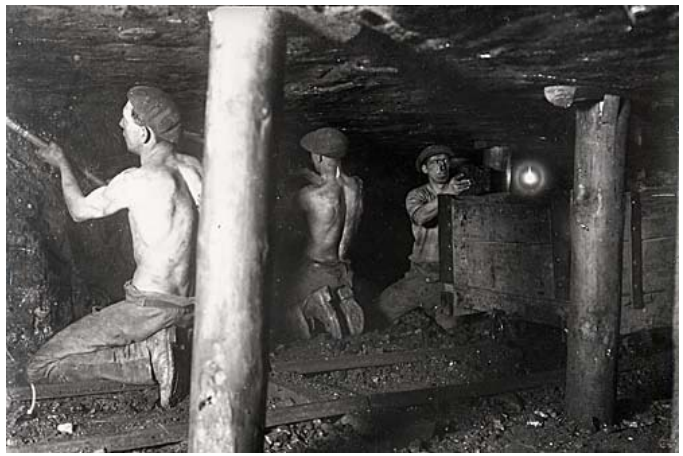
This cannot be changed overnight!

How did we get to this point?

Major transformations in our primary energy resources, use and related technology

Biomass → Coal and Steam Engine

1750-
1850



post
1950

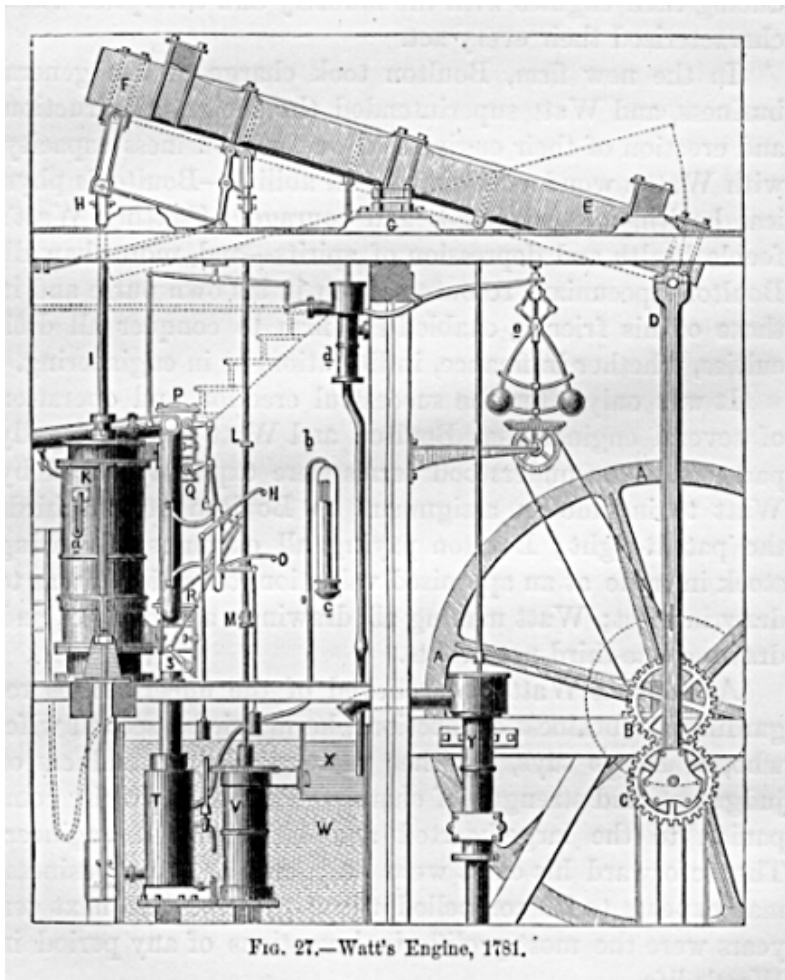


Fig. 27.—Watt's Engine, 1781.

Watt's Steam Engine, patent 1769

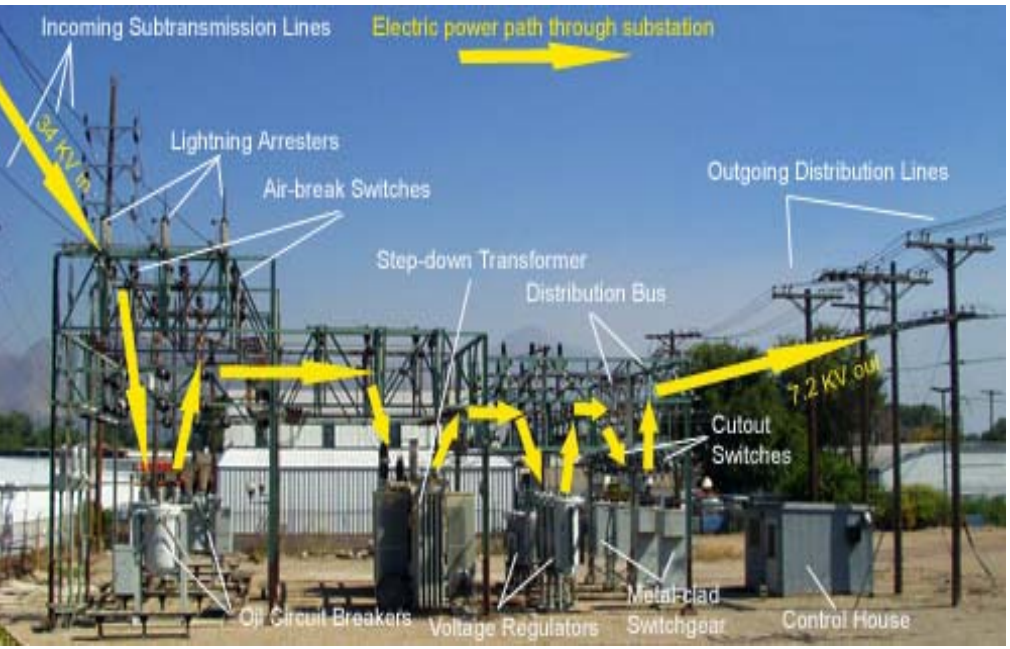
Oil and Internal Combustion Engine

Spindletop, 10 Jan 1901

Ford Model T touring (1 Oct 1908)

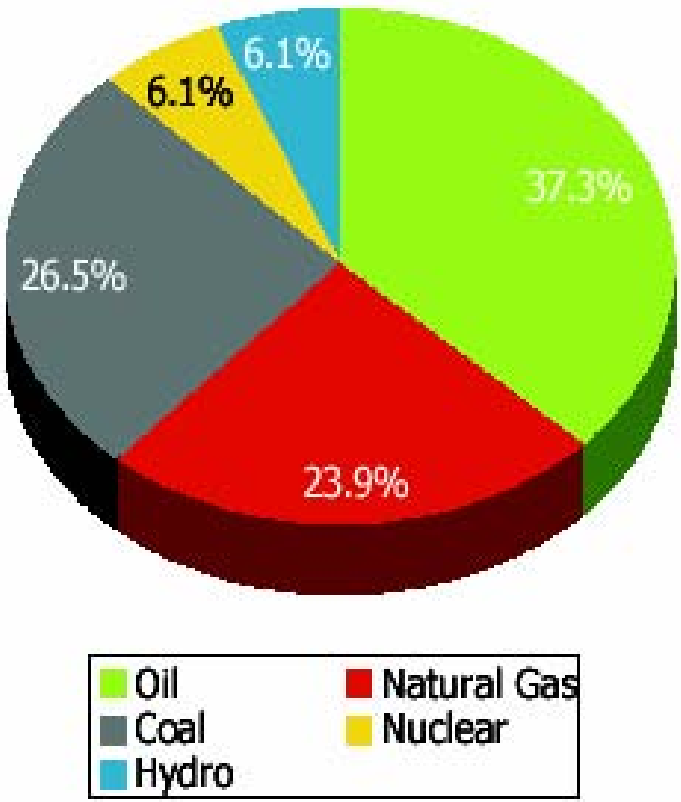
The real growth in use of fossil fuels (=prosperity) starts

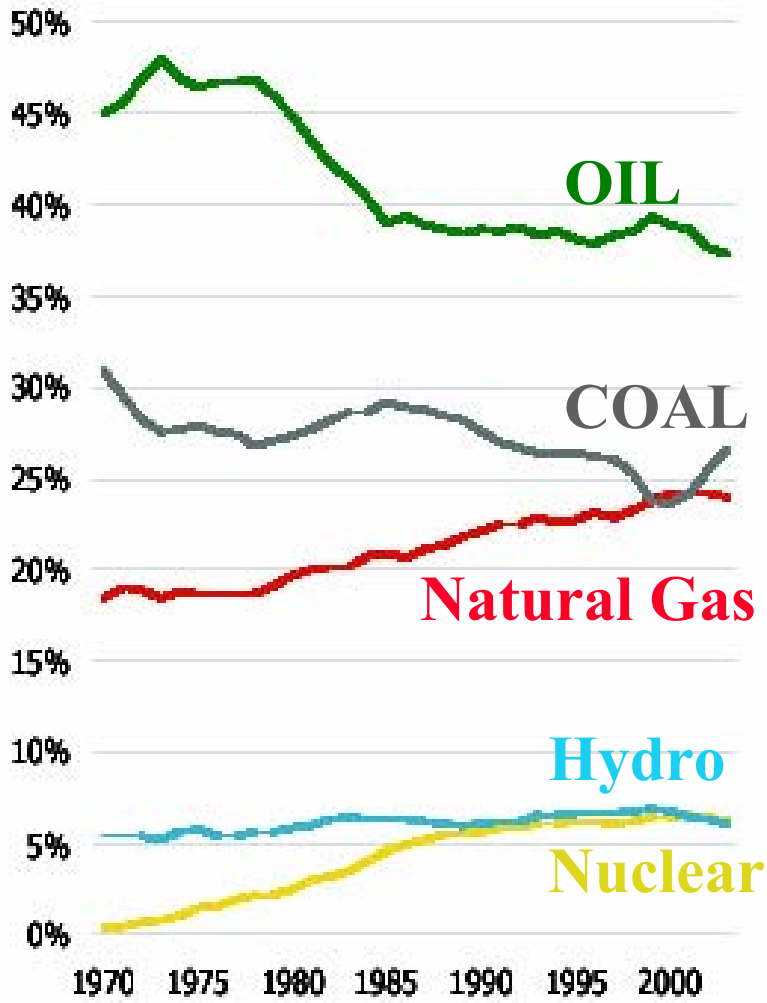
Electricity



current and historical global energy mix

Current global energy supply is dominated by fossil fuels – oil has been the largest component of the energy mix for many decades; gas has grown strongly since the 1970's; coal has been growing in the last four years; hydro is constant and nuclear has plateaued





Source: BP Statistical Review

Consumption of fossil fuels per year (The holes we dig and must fill)

- OIL: 85 million barrels/day
- NATURAL GAS: 260 billion cubic feet/day
- Coal: 14 million tons/day

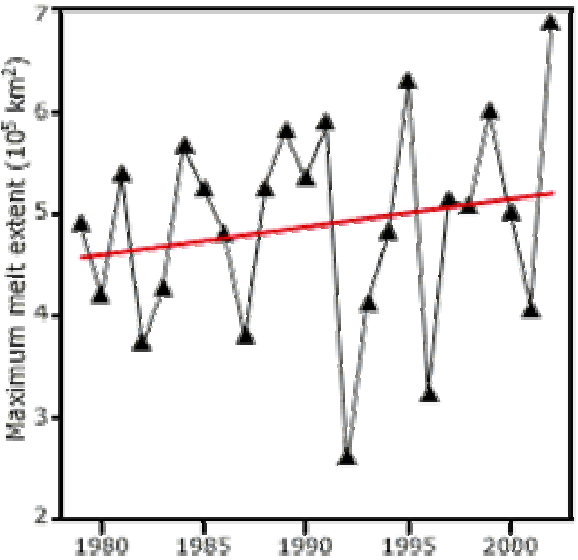
- OIL: $1.1 \times 1.1 \times 1.1$ cubic miles per year
- As liquid: $1.3 \times 1.3 \times 1.3$ cubic miles per year
- COAL: $1.0 \times 1.0 \times 1.0$ cubic miles per year

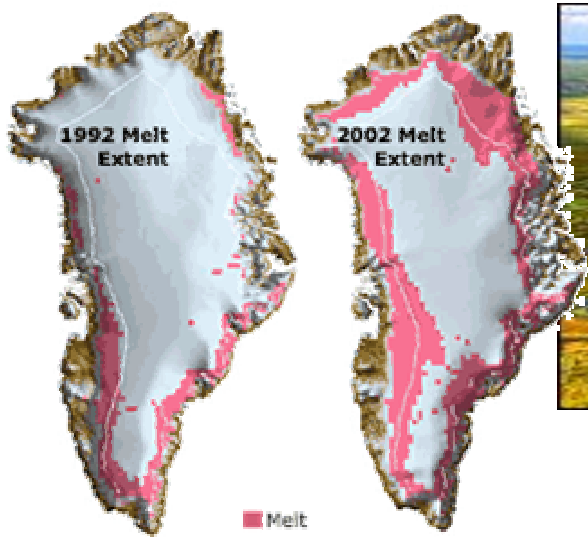
3500 cubic miles of CO_2 gas must be sequestered

Fossil fuels and Environment

In the 20th century we started to act on pollution (mercury, NOx, SOx, acid rain, soot, ...) but <u>not</u> CO_2 and the associated global climate change

CO_2 is a greenhouse gas. *It forms a blanket around the earth that causes warming*





http://earthobservatory.nasa.gov/Study/vanishing/

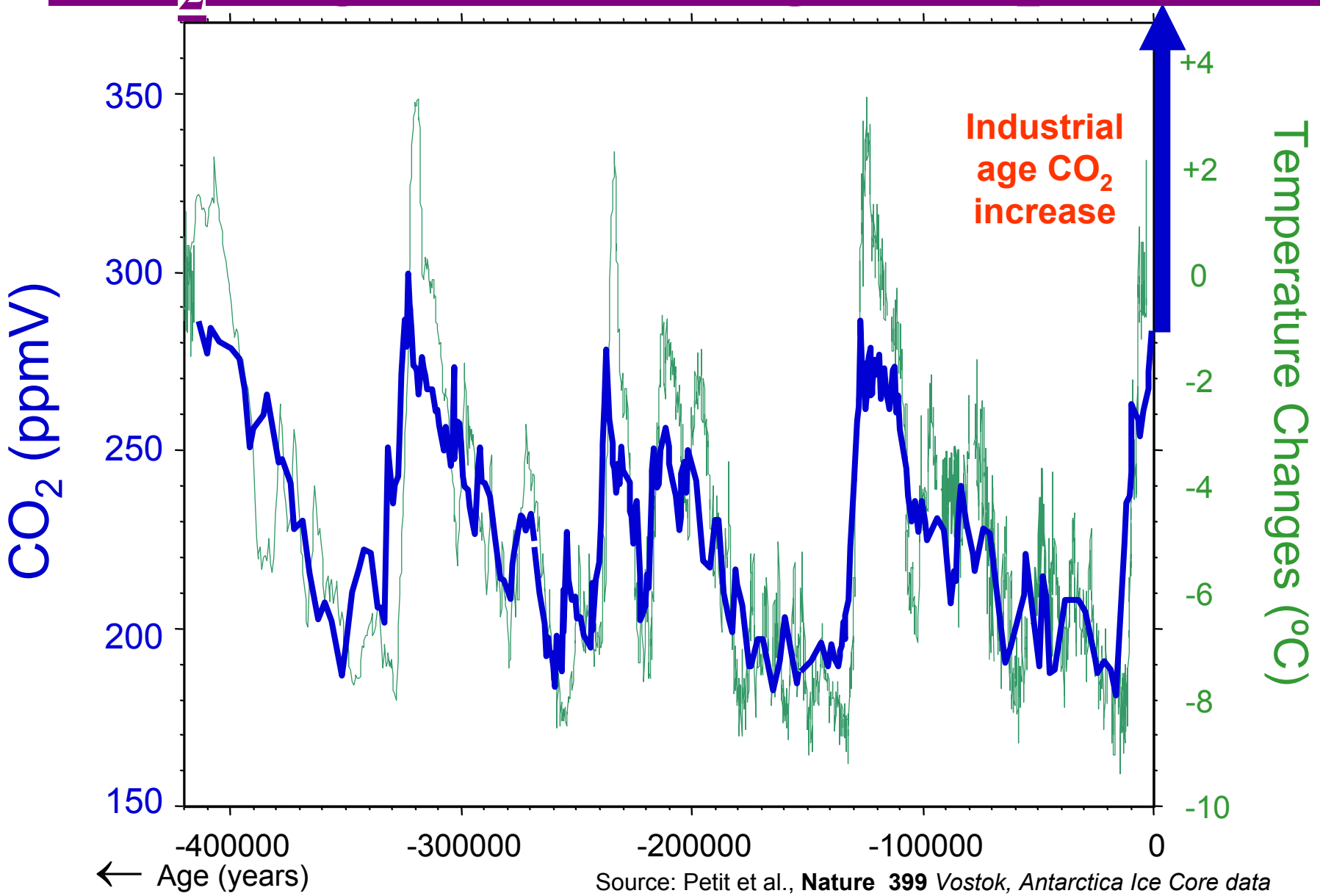
Melting of glaciers in Greenland and around the world. Is it global warming?

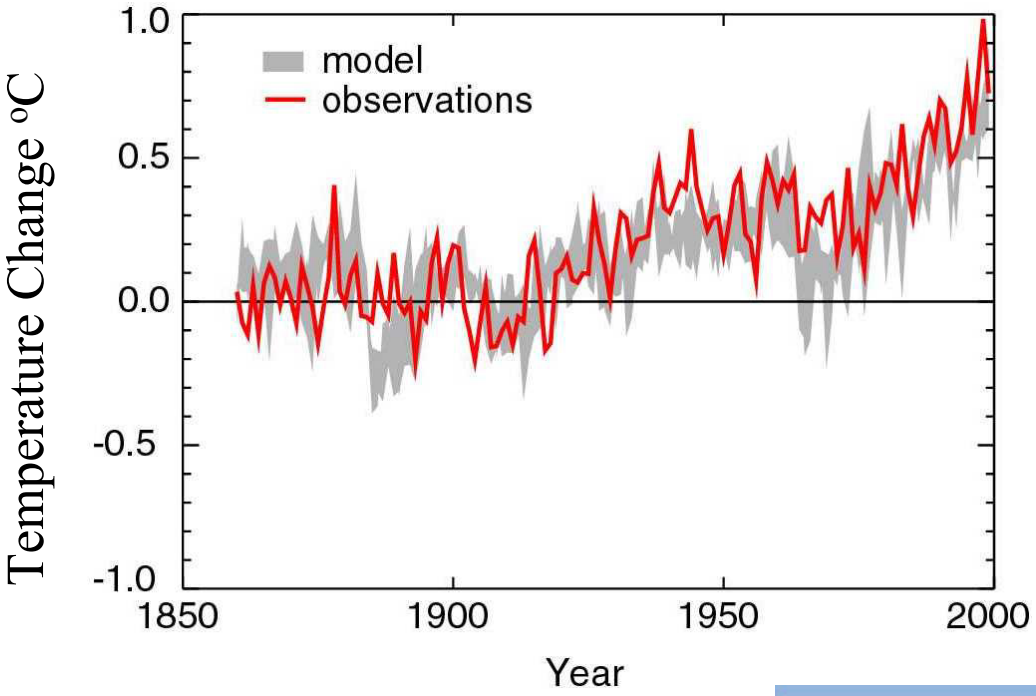
Melting of permafrost

Intense storms

Sequestration of CO_2: First capture CO_2 and then store it

CO_2 & global average temperature

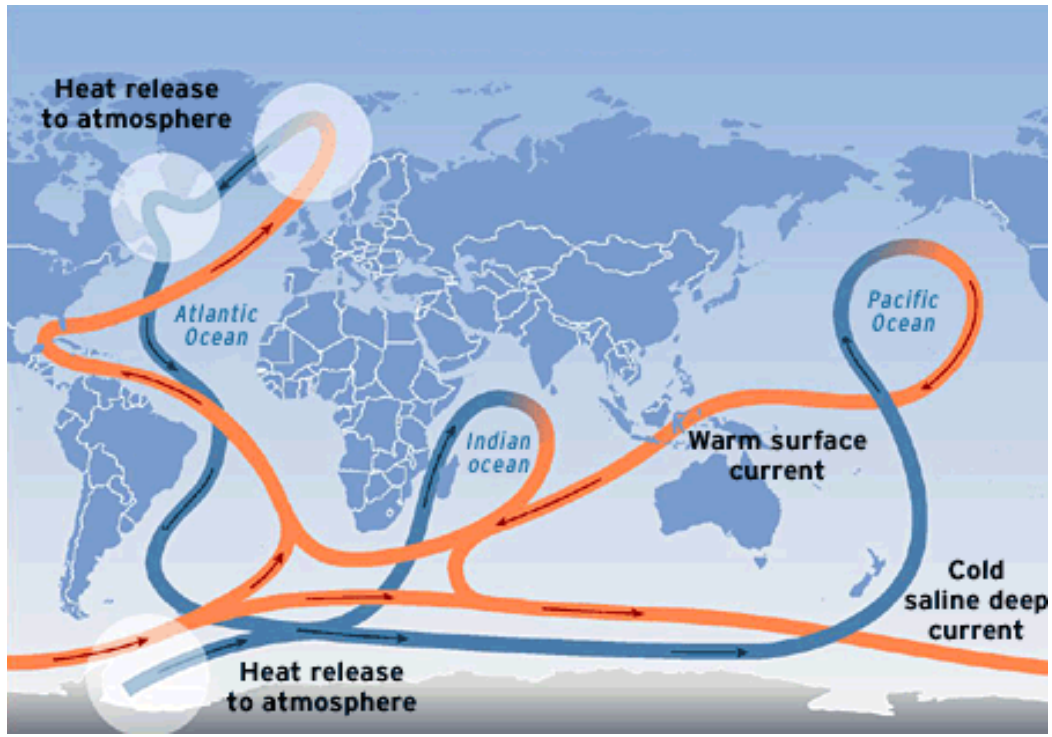




Increasing evidence for temperature rise due to fossil-fuel burning

Possibility of catastrophic change:

Shutdown of the thermohaline in 10s of years



Climate change is the largest, costliest, most dangerous, uncontrolled experiment ever done by mankind

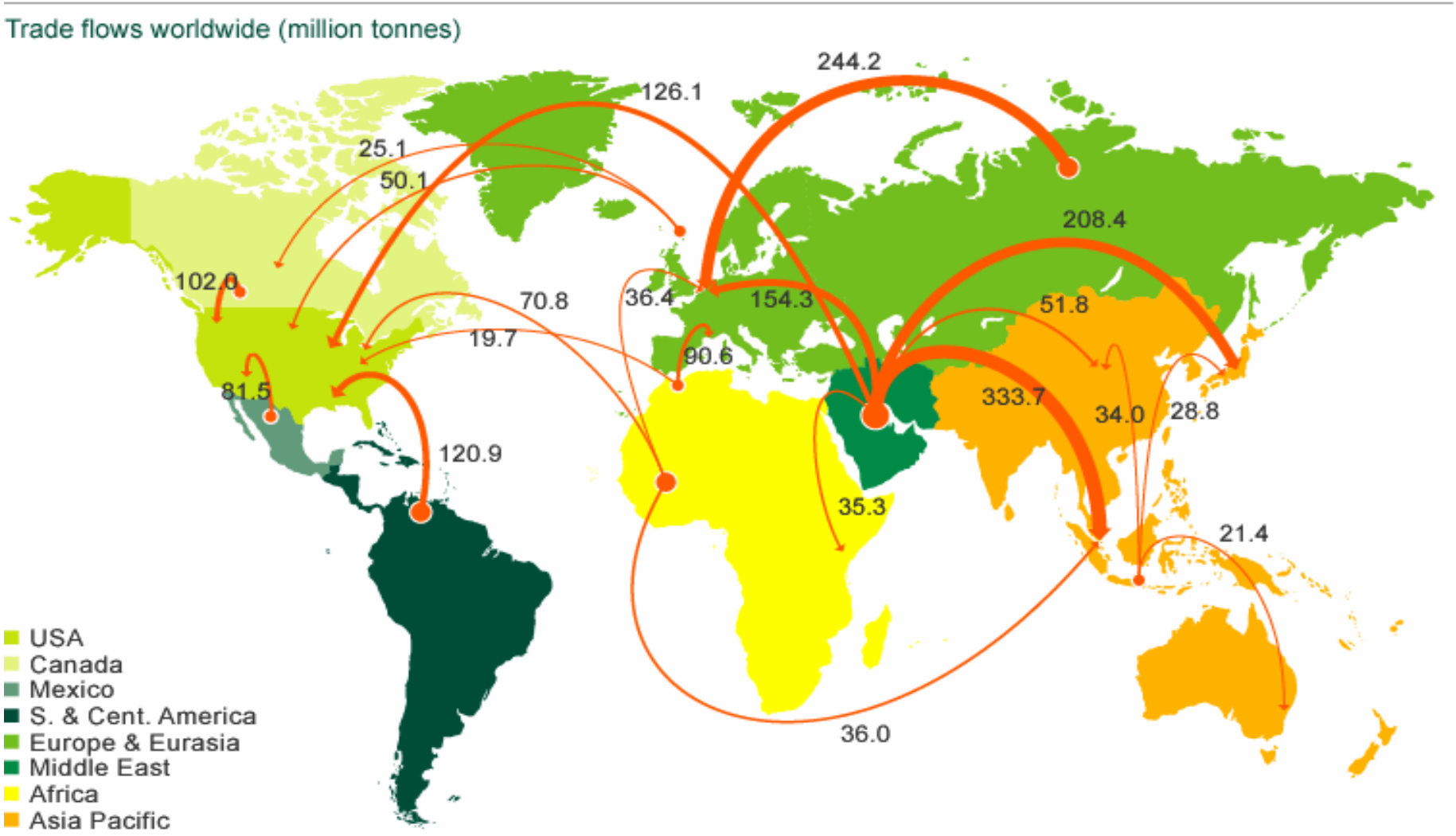
What is in the future?

Where do we get our oil and natural gas from?

And

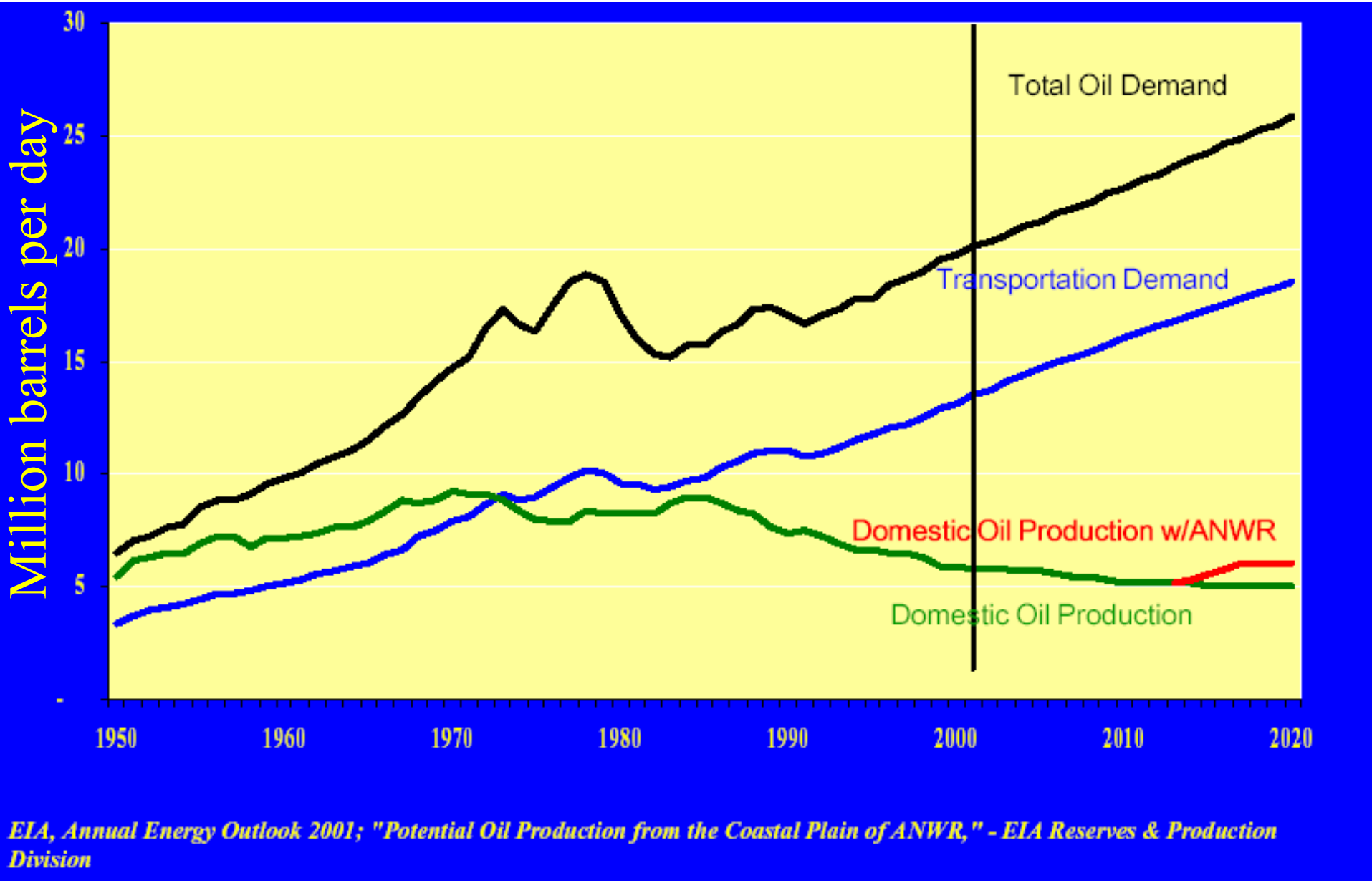
Emerging Challenges to this supply?

Oil is easy to move and trade



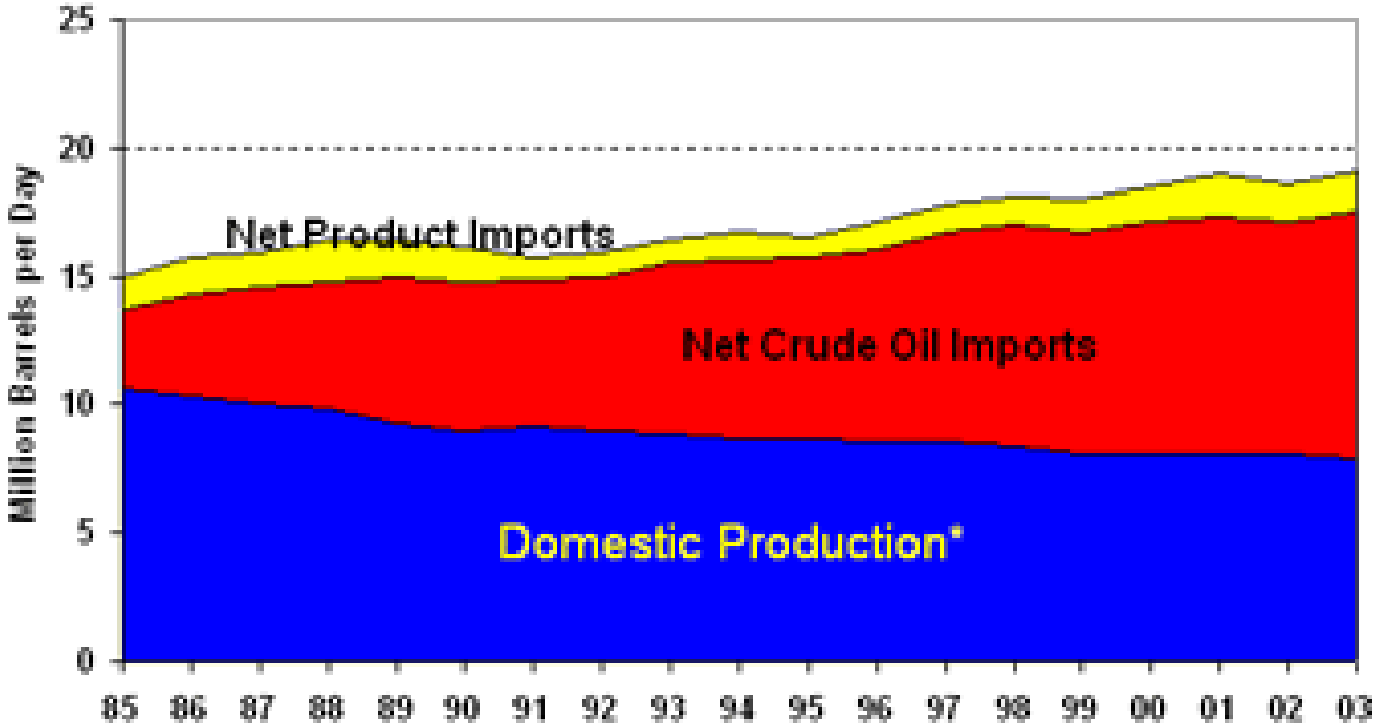
BP 2004

US oil consumption: Large (25% of global) & Growing



EIA, Annual Energy Outlook 2001; "Potential Oil Production from the Coastal Plain of ANWR," - EIA Reserves & Production Division

US imports 2/3 of its oil



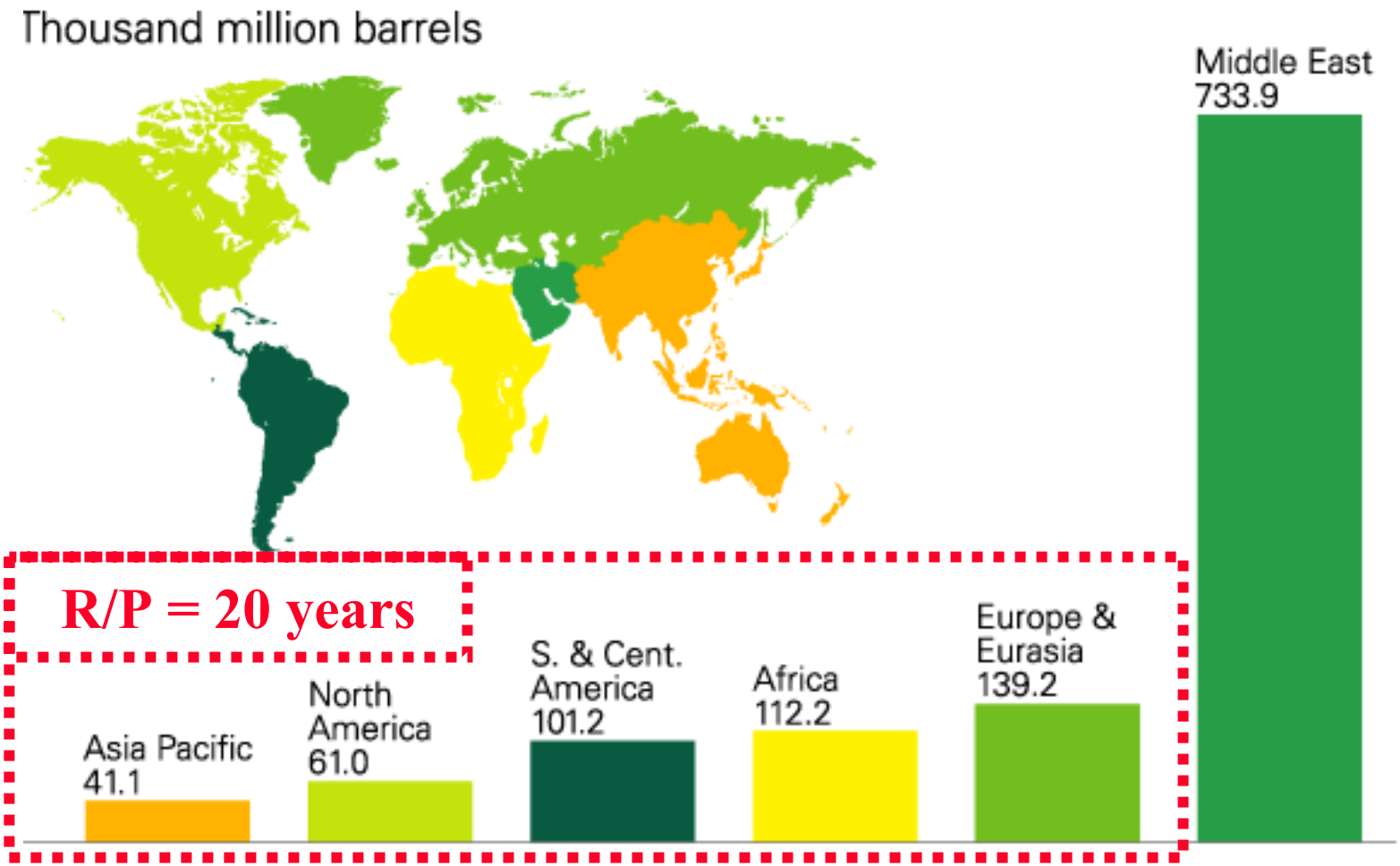
Friendly nations cannot fulfill our oil needs

Middle East:	2.5 M barrels	Canada	2.3 M barrels
Africa:	2.4 M barrels	Mexico:	1.8 M barrels
Far East:	0.4 M barrels	Venezuela:	1.2 M barrels
Russia:	0.2 M barrels	North Sea:	0.9 M barrels

(EIA 11/05)

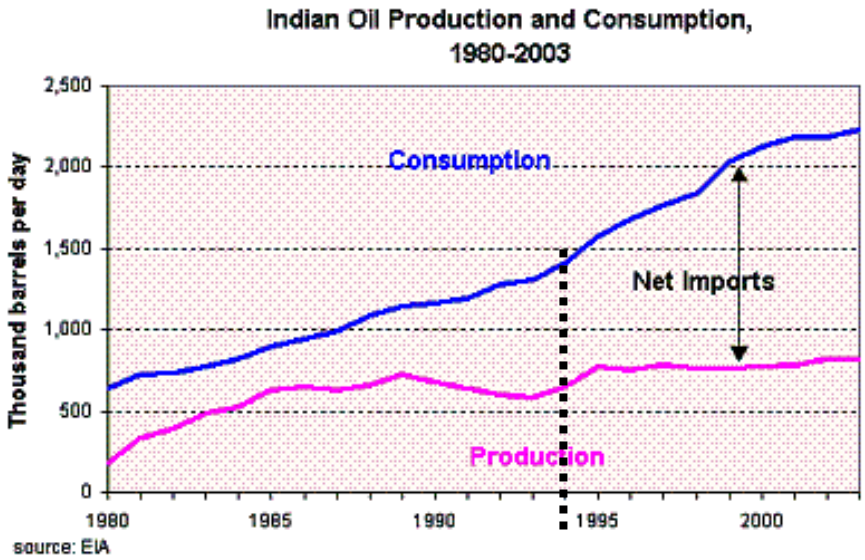
Proven oil reserves at end of 2004

BP2005

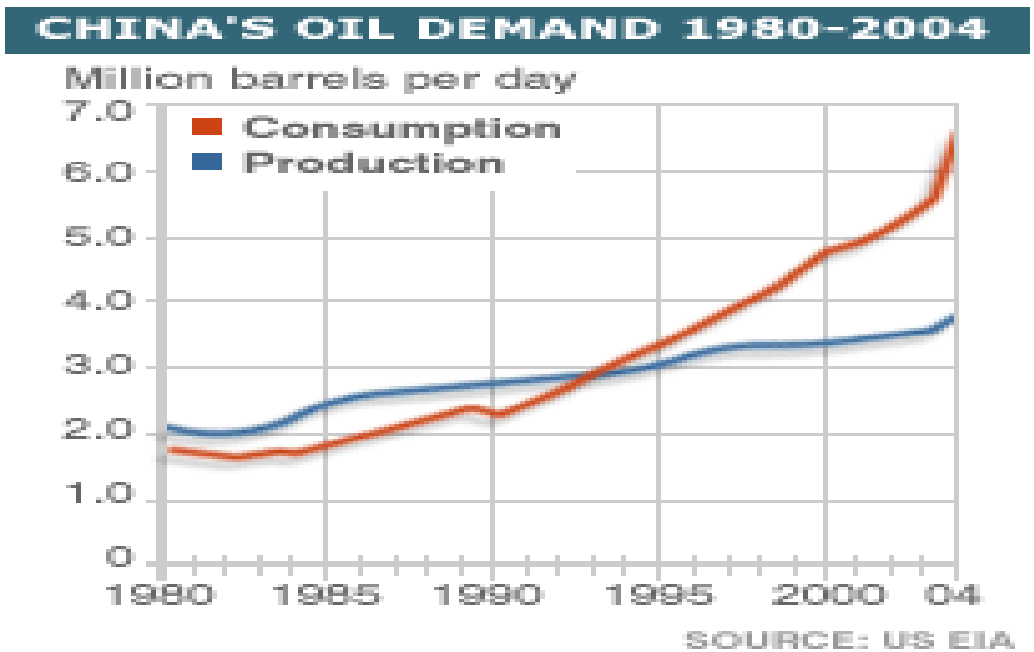


2004 Usage = 31Bbo/year ⇒ R/P = 40 years

Increasing competition for oil and gas

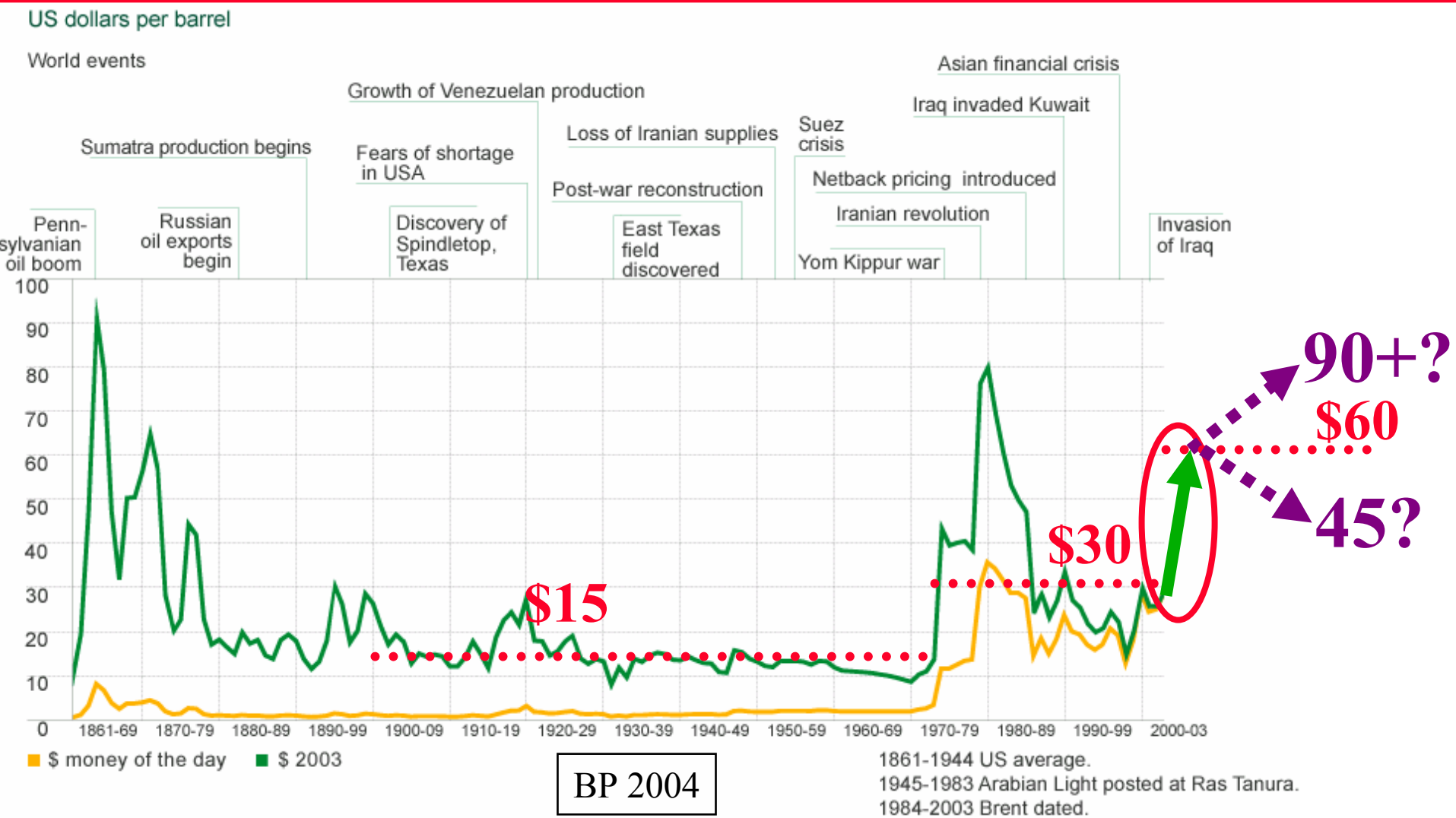


China and India are making deals with Iran, Sudan, …



Oil Imports 1994-2004	
USA	+4% / year
Japan	-1% / year
India	+8% / year
China	+31% / year

Saturated Market: Increased volatility and high prices post 2004

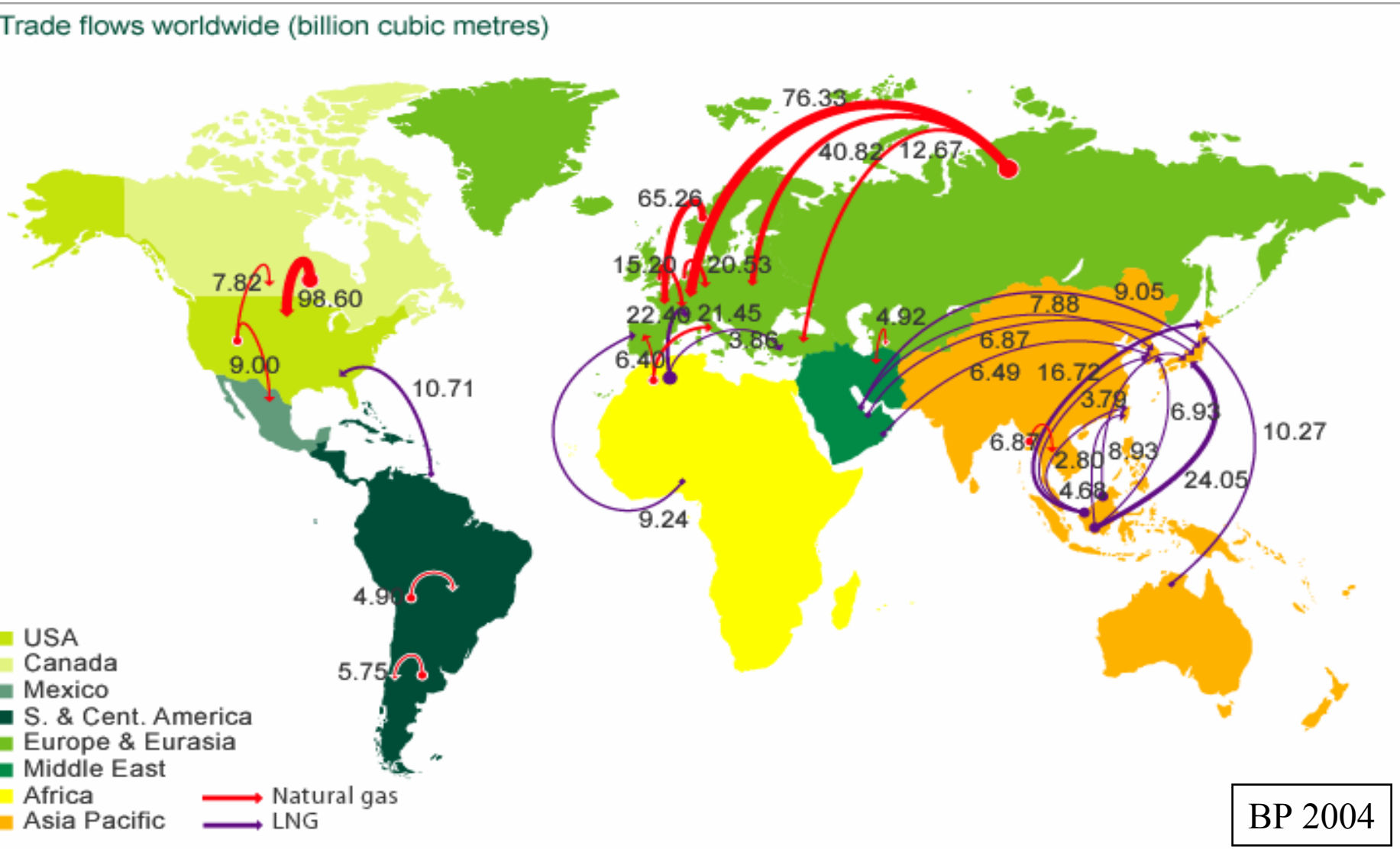


BP 2004

Natural Gas

USA produces 85% of its natural gas. The rest is imported from Canada and Trinidad

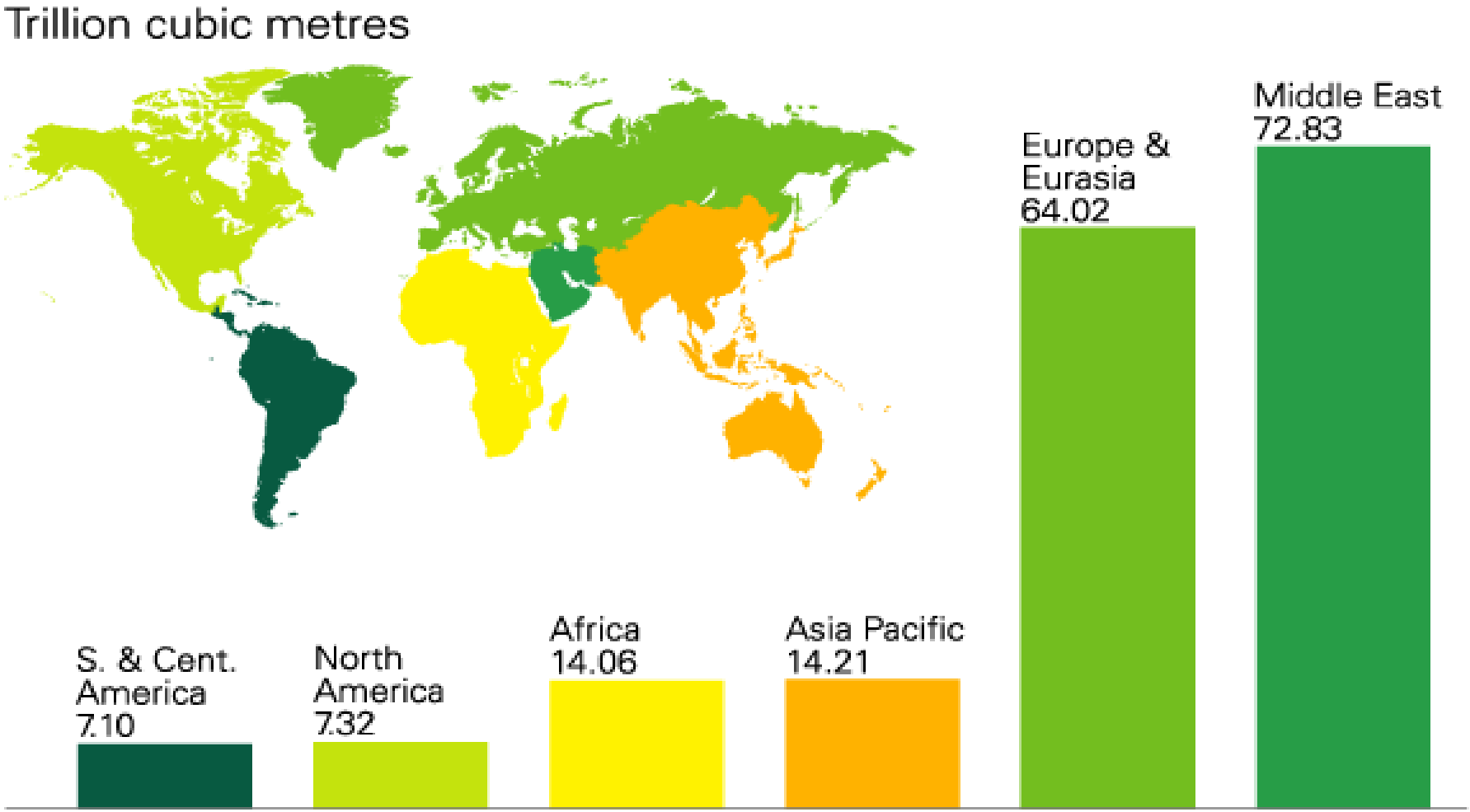
Major natural gas trade movements



BP 2004

Proven natural gas reserves at end 2004

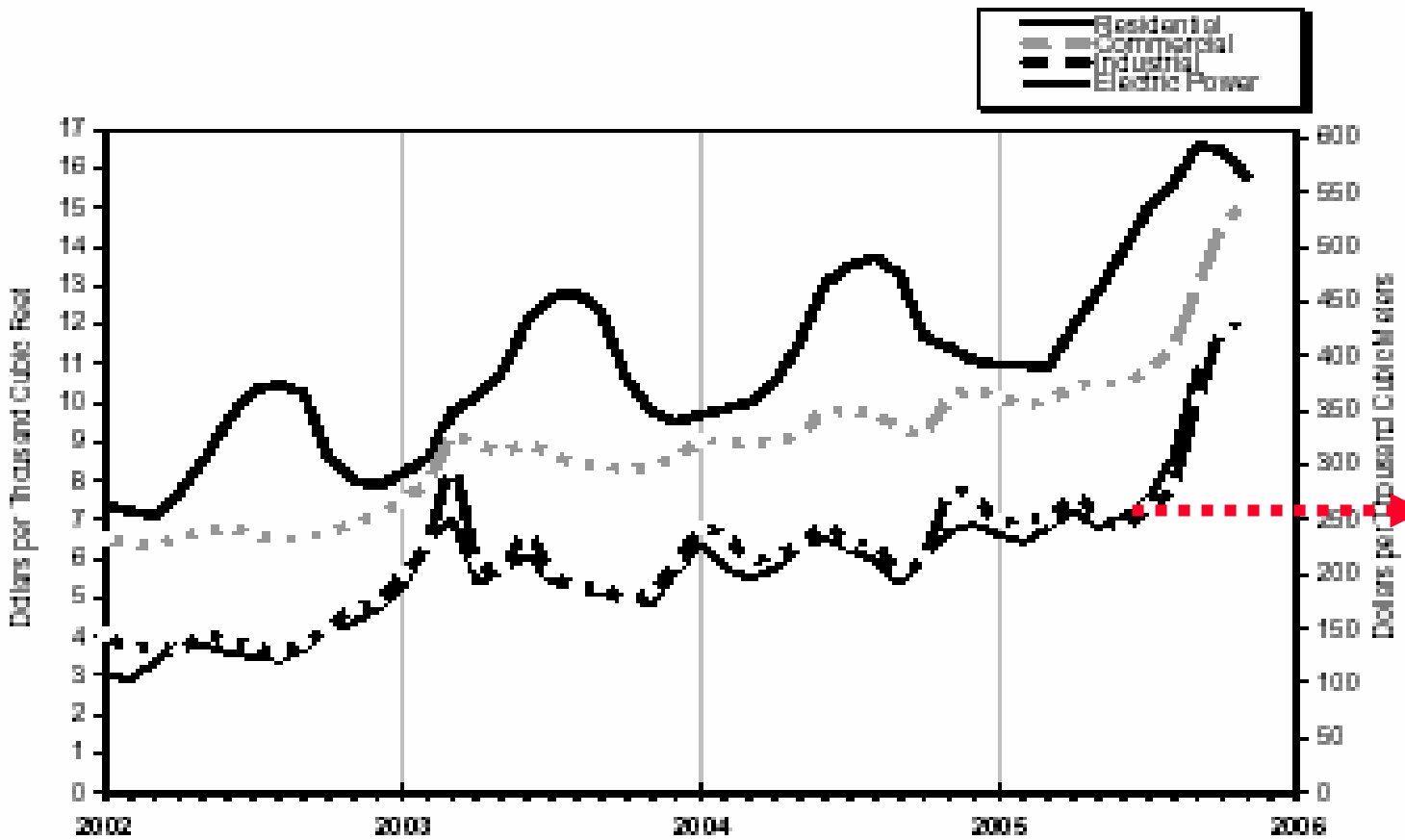
BP2005



North America uses about 0.8 trillion cubic meters a year

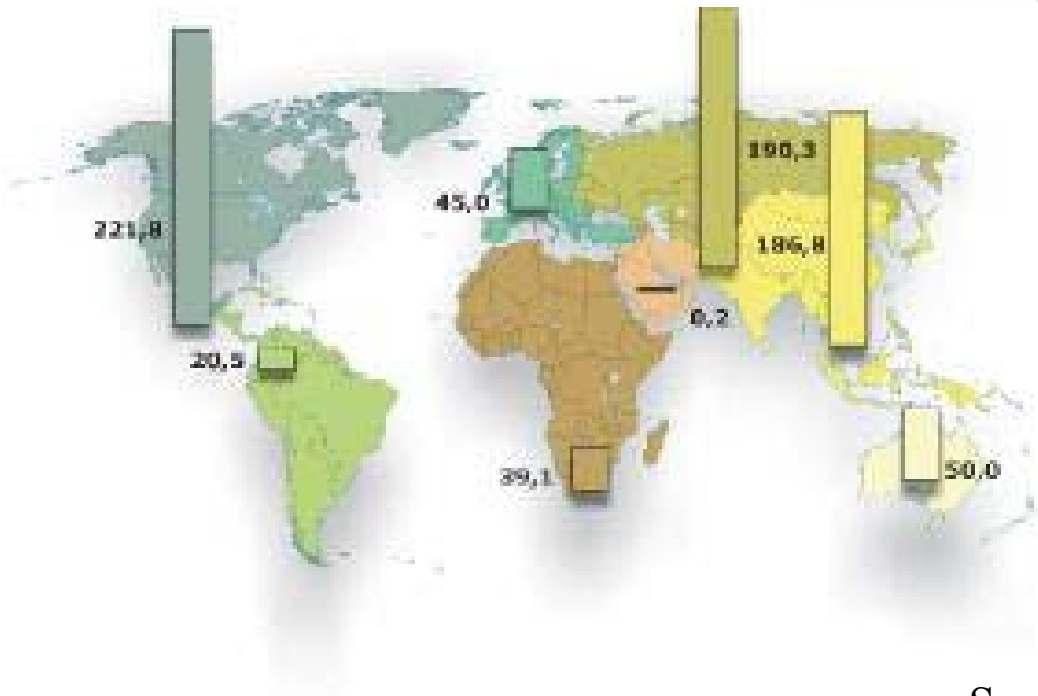
Natural gas:
Oversubscribed → producers can charge more → price increases

Figure 3. Average Consumer Price of Natural Gas in the U.S., 2002-2005



COAL

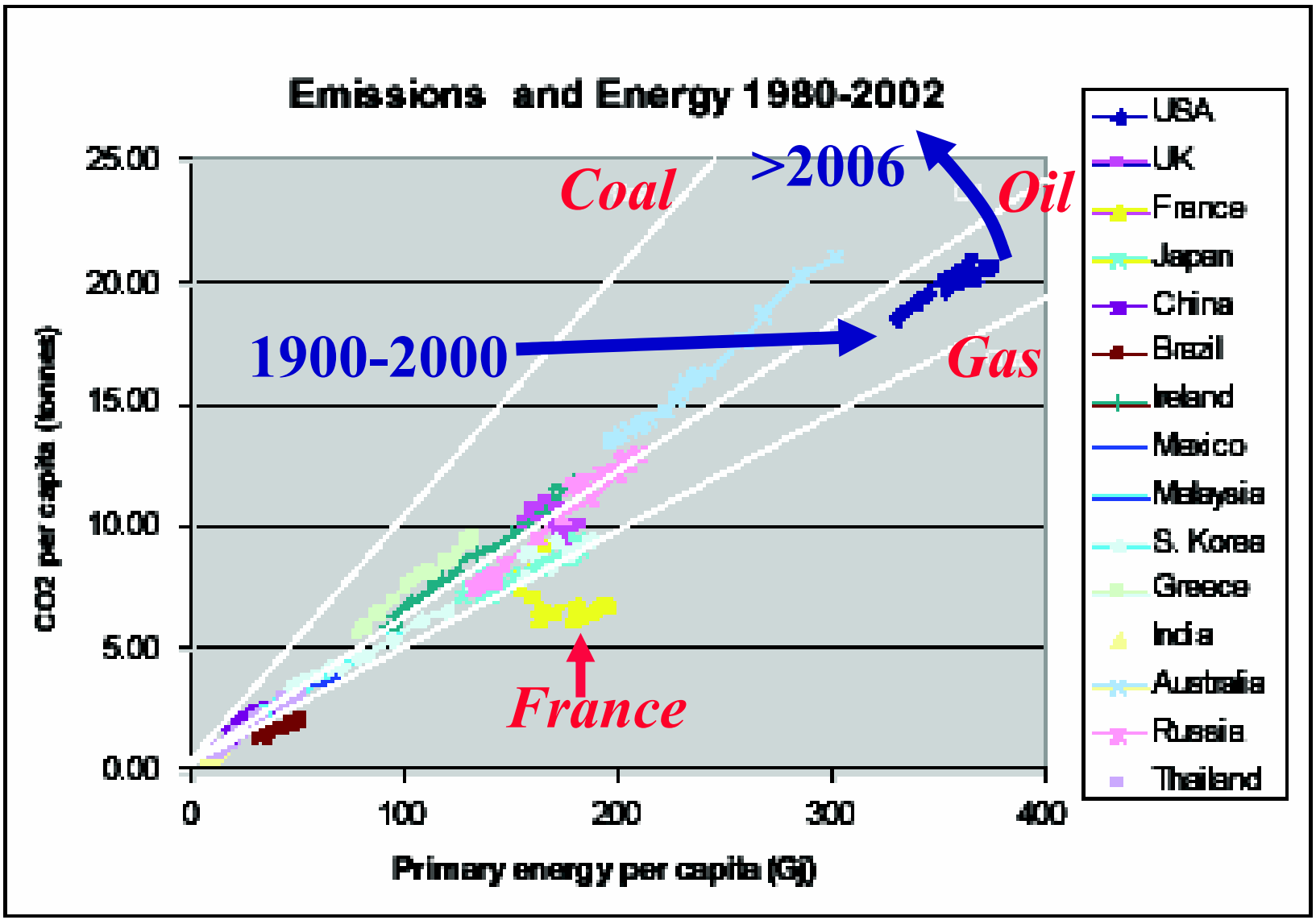
* Cheap
* US has largest reserves
* Pollution



USA also has the largest deposits of oil shale

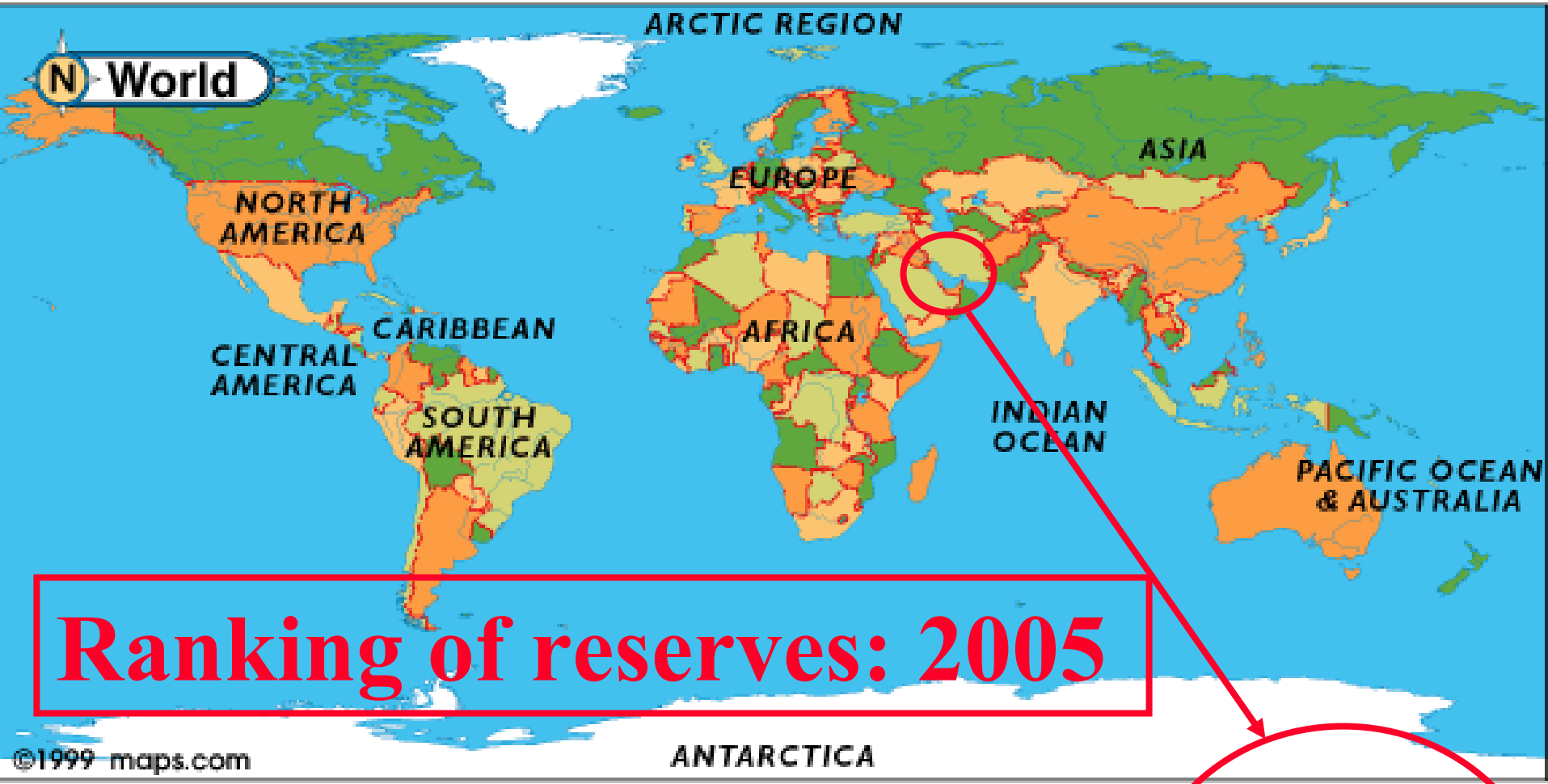
Source: International Energy Outlook 2004

Using coal/shale → pollution and CO_2



Problems with business as usual

- We import 2/3 of oil used
- Share of imported natural gas set to increase rapidly
- Market saturated, volatile, unstable
- CO_2 emissions $\rightarrow$ global warming



Ranking of reserves: 2005

USA 12,6,1

China 11,-,3

EU -, -, 4

Russia 8,1,2

India -, -, 5

AT -, -, -

Persian Gulf

OIL 1,2,3 4,5

GAS 2,3,4, 5,10

No Coal

USA -,-,1

China -,-,3

EU -, -, 4

Russia -,1,2

India -, -, 5

AT -, -, -

Persian Gulf

OIL 1,2,3 4,5

GAS 2,3,4, 5,9

No Coal

The natural destination for Persian gulf, Caspian Sea and Russian oil and gas is EUROPE and ASIA

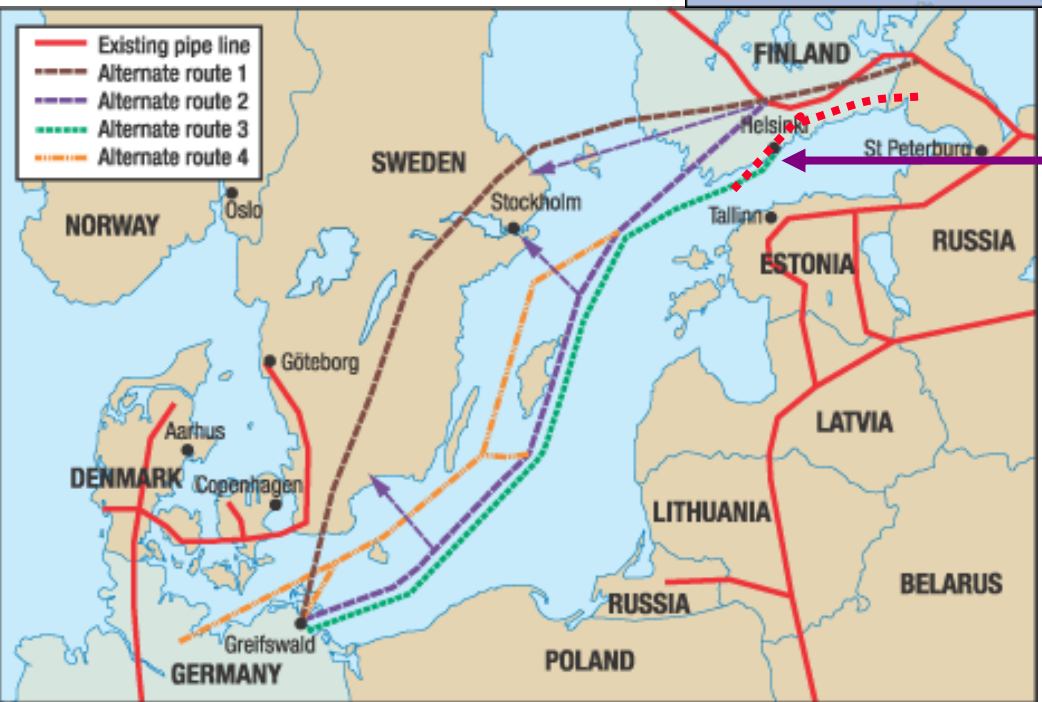
But the US needs them too!

What role will pipeline, tanker, refining capacity play?

PHILIPPE REKACEWICZ

Who owns the pipe lines?

Which countries will get Russian natural gas in 10 years time?



New pipeline from Russia to Germany bypasses Ukraine and Eastern Europe

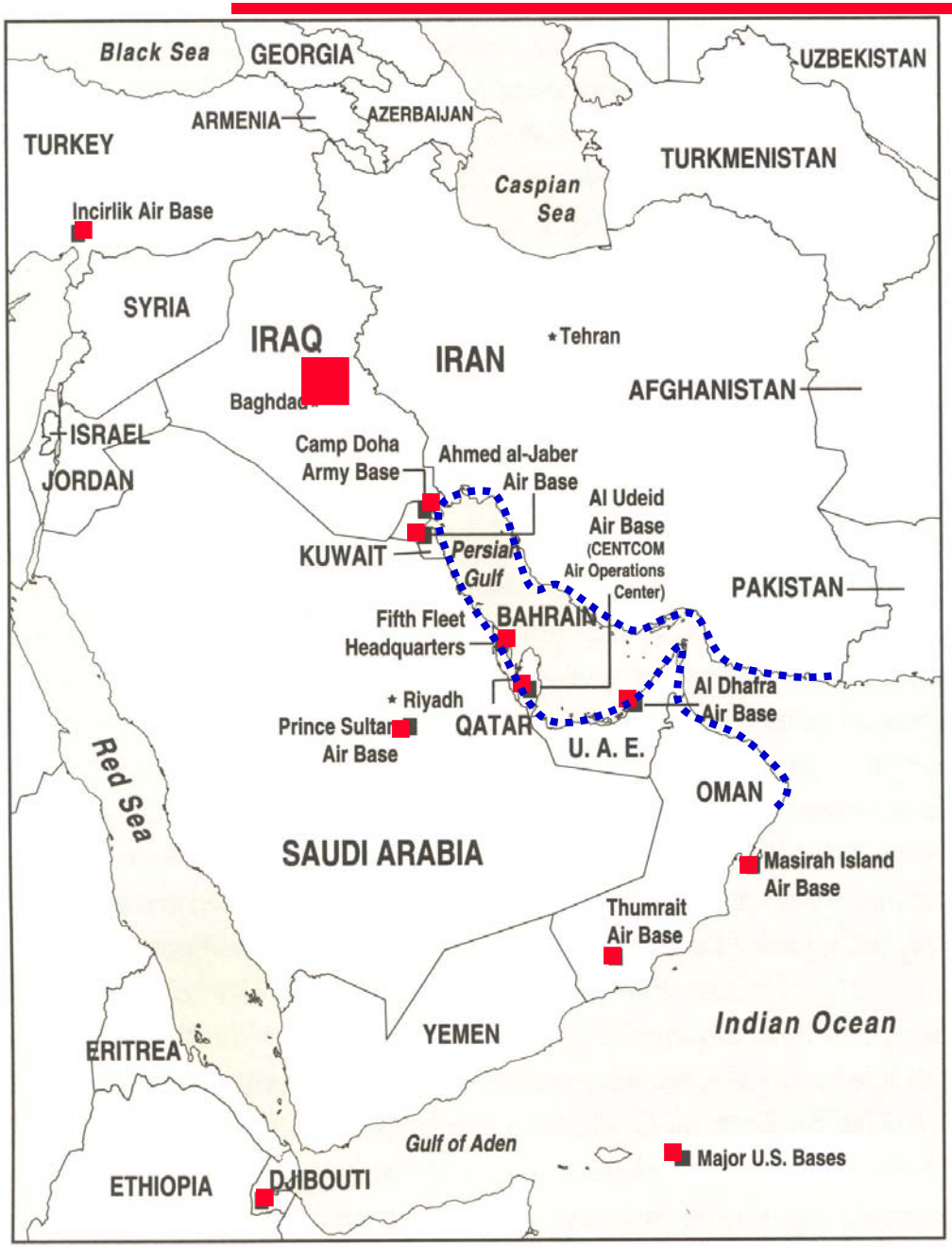
Middle East and Russia control conventional natural gas and oil

The global oil and gas situation has been anticipated by the US and has guided its policies since WWII

Oil: key driver of foreign policy

- 1945
  - F. Roosevelt and King Abdel Aziz “oil for security”
- 1947: Truman Doctrine
  - Stop the spread of communism (Greece, Turkey, Iran)
- 1957: Eisenhower Doctrine
  - Protect friendly interests
- 1969: Nixon
  - Protect interests through surrogate friendly rulers
- 1980: Carter Doctrine
  - To protect Saudi Arabia and the free flow of oil from the Persian Gulf
- 1983: Establishment of Central Command
  - Protecting the free flow of oil from the Middle East and Central Asia

US bases in the Middle East



A very successful but costly military investment to protect the flow of oil (=prosperity)

Can we continue to bank on this solution?

Examining energy futures from three perspectives

- **National and International Security**
- **Cost, Economics and Development**
- **Environment**

Be more efficient
Sequester CO_2
Develop alternatives to fossil fuels

What are the fixes to USA's "addiction to oil"?

- **Continue under business as usual?**
  - **Use our military to guarantee supplies?**
  - **Develop coal and shale to get oil and gas?**
- **Innovate (R&D): Sequester CO_2; develop alternate sources to reduce our dependence on imported oil and gas?**
- **Be more efficient → use less + preserve reserves for future use in petrochemicals?**

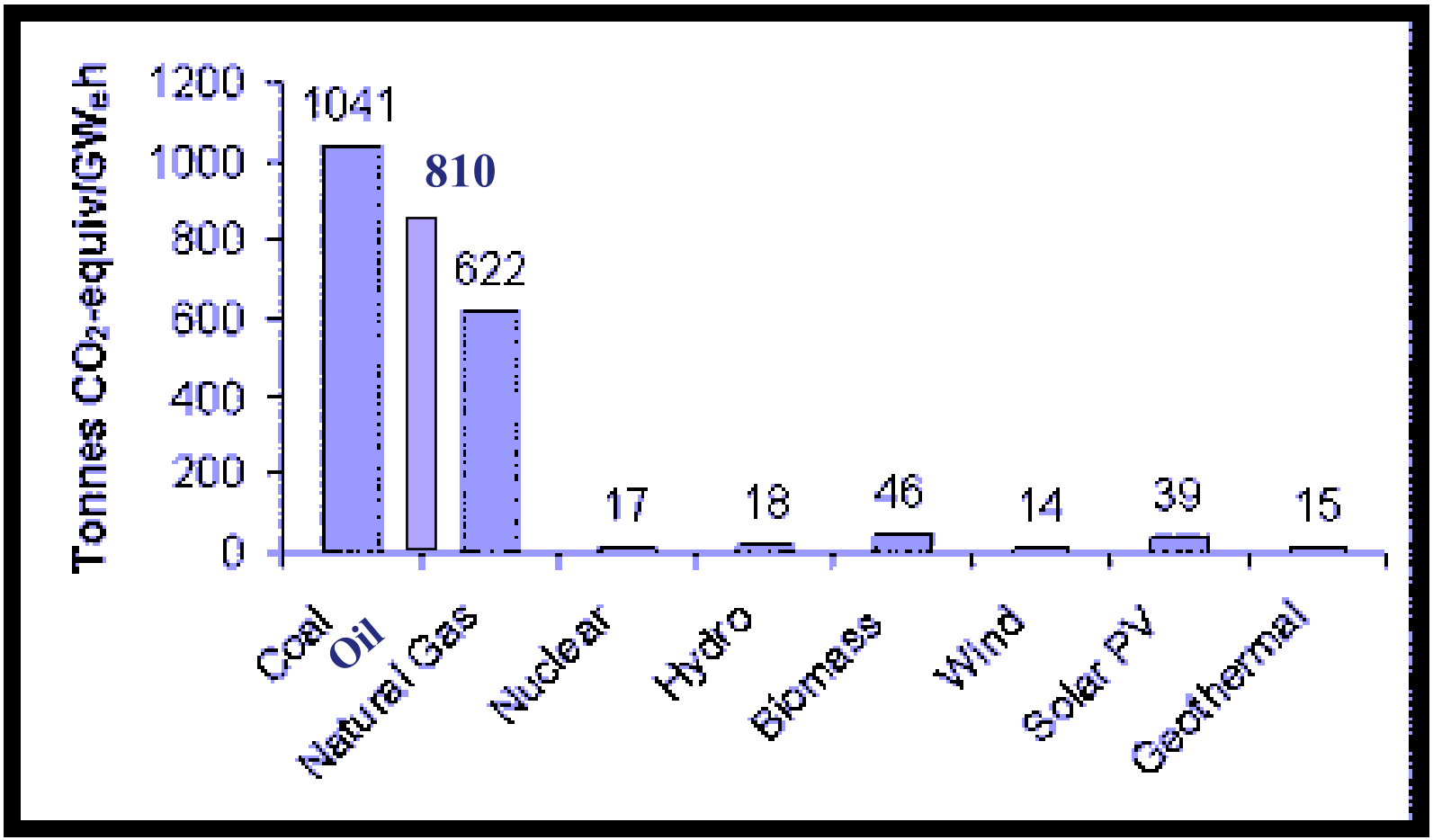
Use Coal (Shale)

Based on 2001 production figures, global coal reserves will last about

- **207 years for hard coal**
- **198 years for soft brown coal**
- **USA has the largest reserves**

Coal is abundant but

The hidden and ignored environmental cost of CO_2 emissions



Comparison of life-cycle CO2 emissions from different electricity generation options. Emissions from oil are roughly in between coal and natural gas. (Source: "Life-Cycle Assessment of Electricity Generation Systems and Applications for Climate Change Policy Analysis," Paul J. Meier, University of Wisconsin-Madison, August, 2002.)

To use coal the US must lead the world by innovating clean coal technology for generating electricity and producing oil

Navajo Power Plant

– pollution

R&D

– CO_2

FutureGen (No emissions)
But 10+ years away

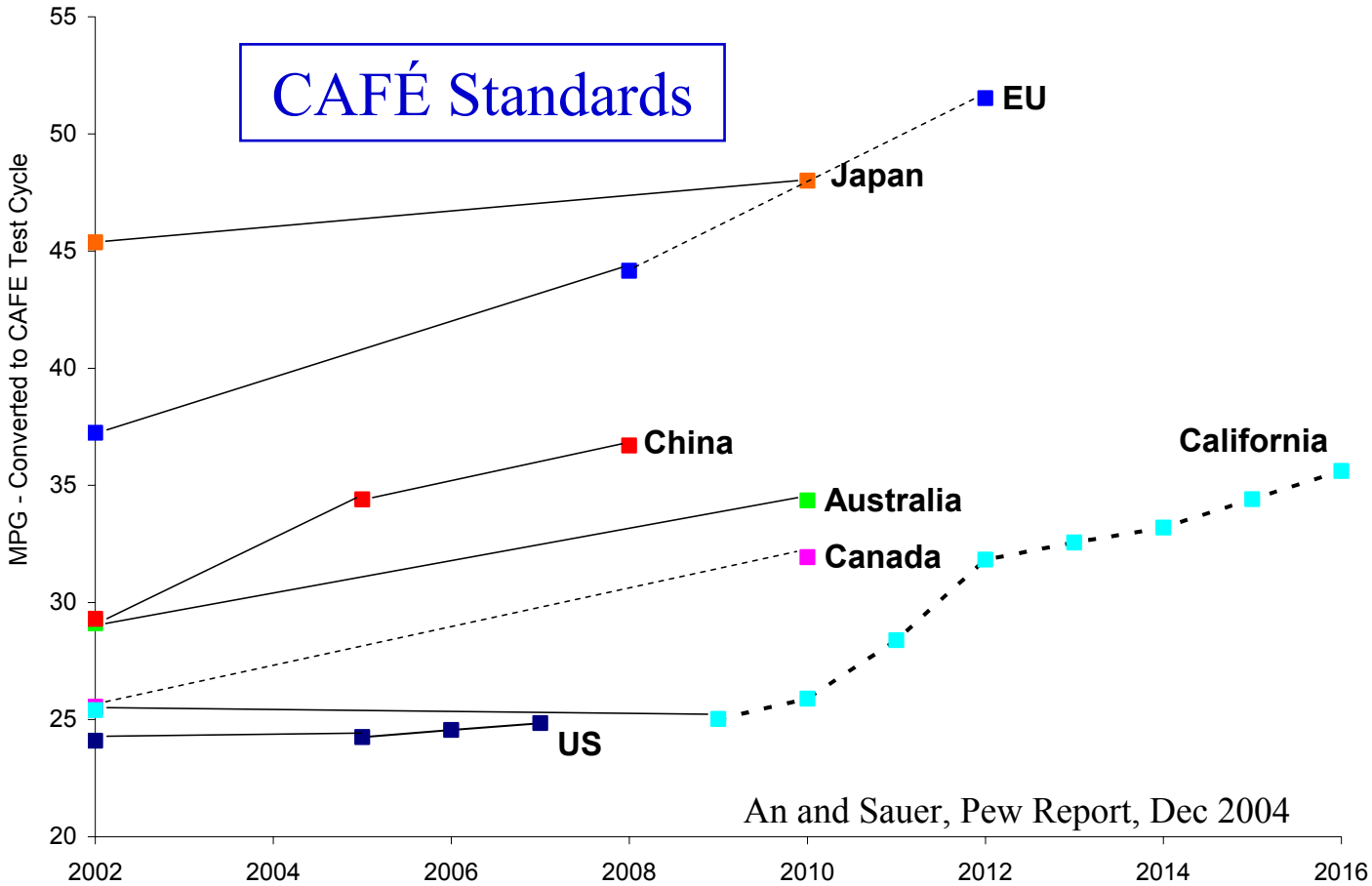
Even if we get all the fossil fuel we want we still need to solve pollution and CO_2 problems. *Need action starting today*

- Need large-scale sequestration of CO_2 by 2020
- Need alternatives to fossil oil, coal, natural gas as energy source/carrier/storage

Can we reduce use of fossil fuels without stalling economic development?

Short term Option: Behavior Change

- Lighting
- Appliances
- Heating
- Insulation
- Transport



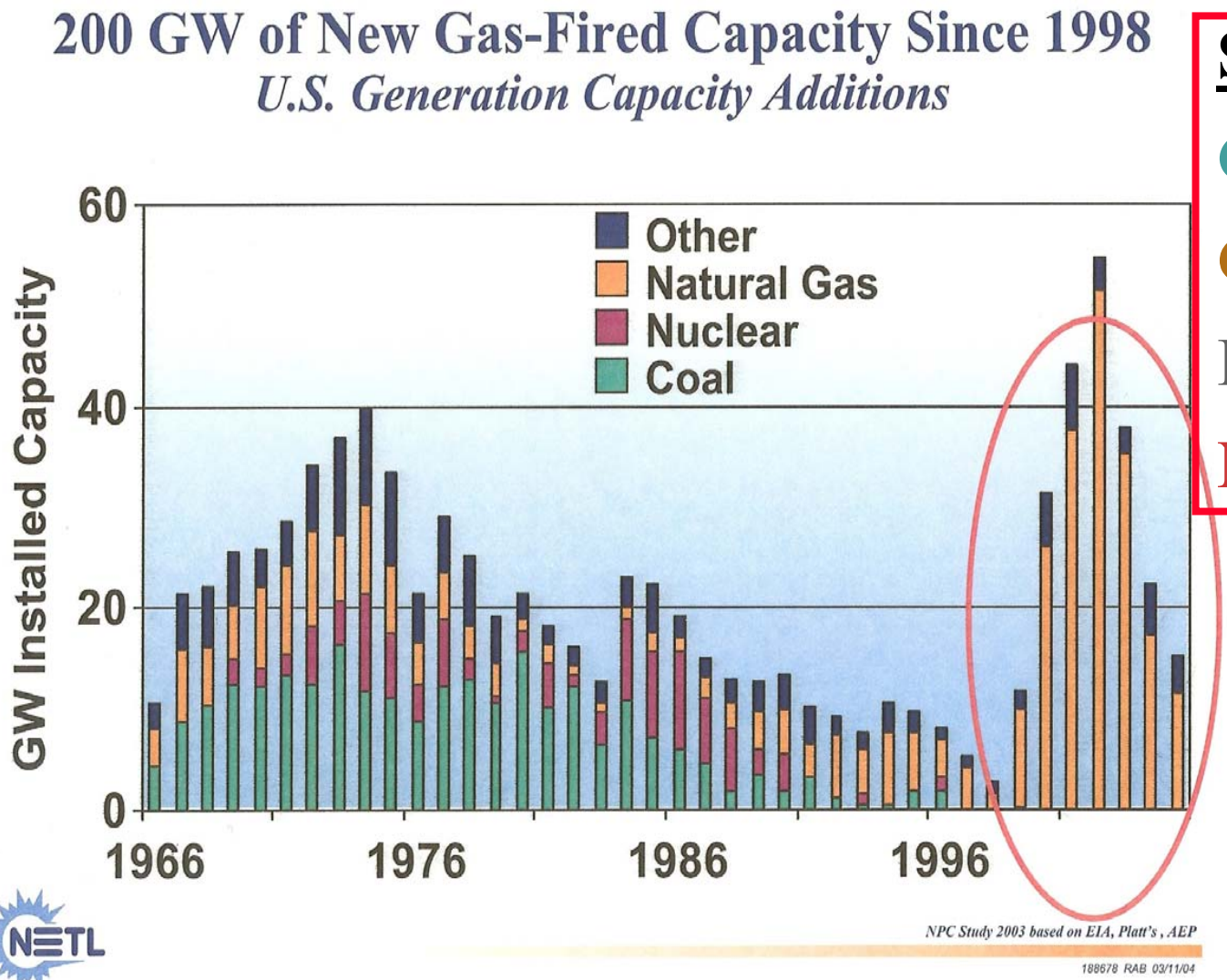
Drive less and Drive efficient cars (hybrid)

Power generation

NEED for timely action:

- ***Power systems need 10-15 years to plan and build***
- ***They have lifetimes of 40-70 years.***
- ***Planning and construction must begin decades before actual shortages/crises.***

Will coal and natural gas continue to dominate power generation?



Starting in 1980s

Coal was dirty

Gas was cheap

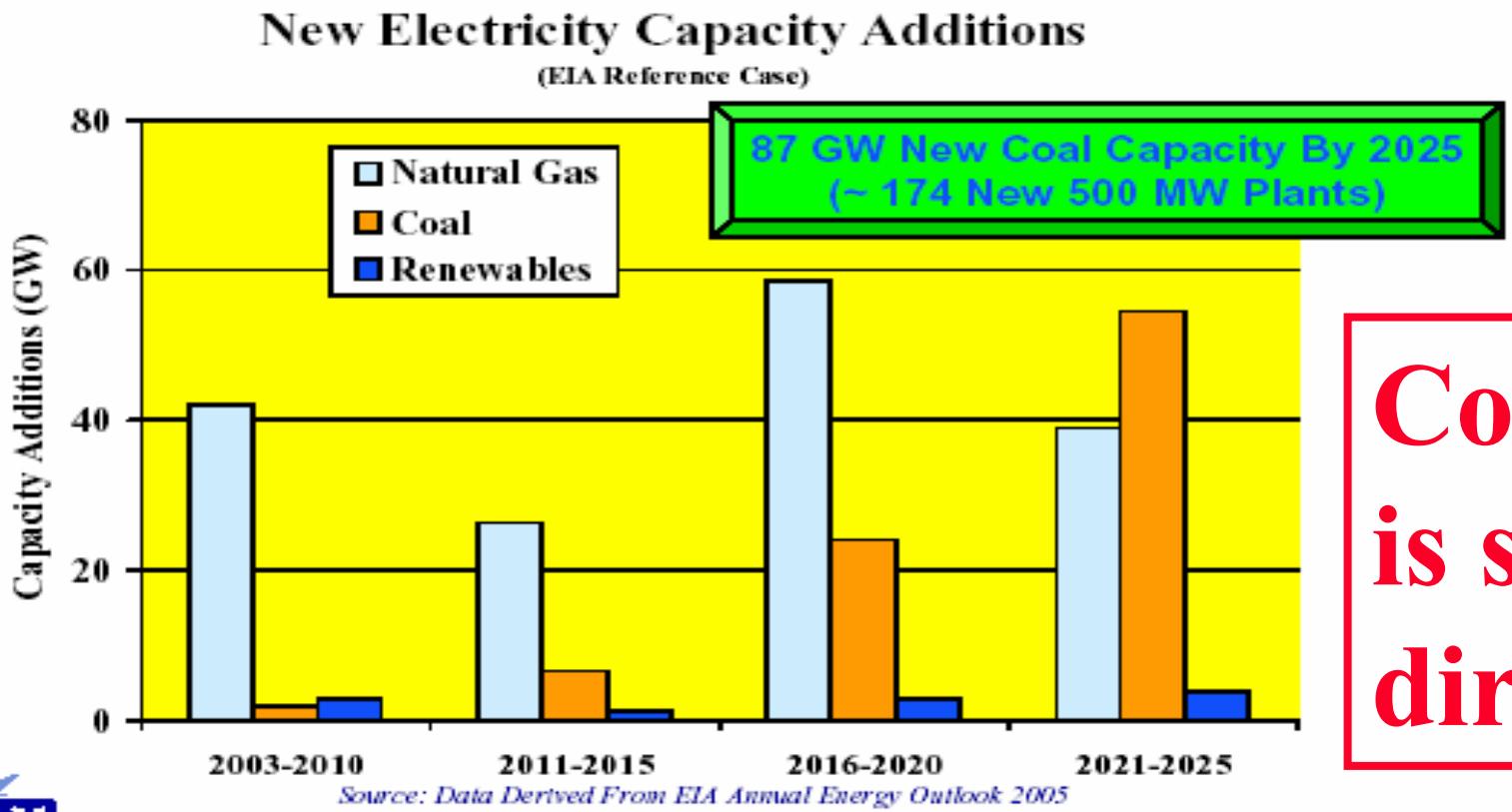
Hydro was flat

Nuclear was bad

For natural gas we will be dependent on Russia and/or the Middle East

87 GW New Coal Capacity By 2025

(Accounts for 33% of New Capacity Additions)



Source: Data Derived From EIA Annual Energy Outlook 2005

Coal is still dirty

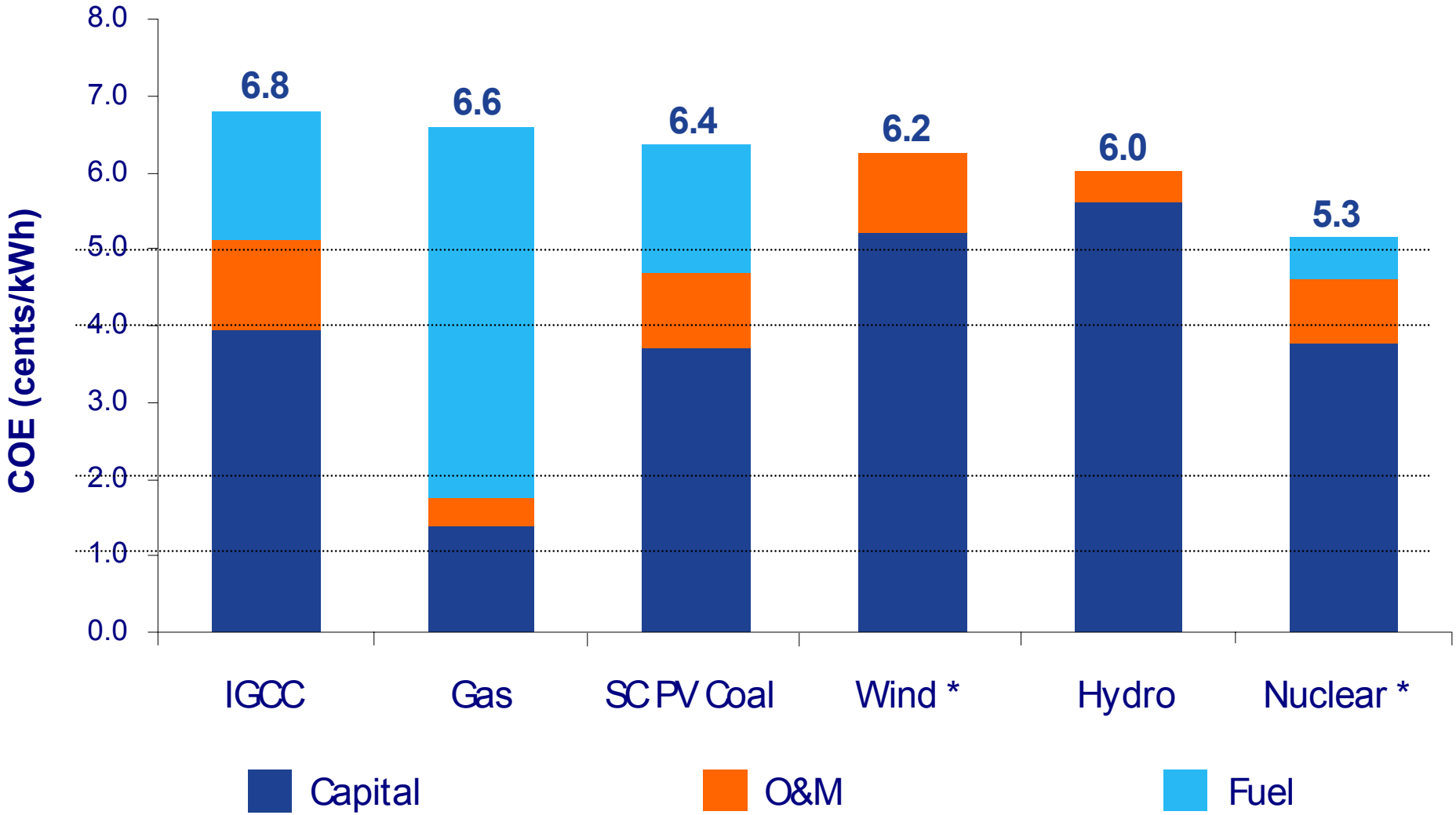
NETL Contacts: Scott Klara, klara@netl.doe.gov
Erik Shuster, erik.shuster@sa.netl.doe.gov

We need all options: Each has a niche market

- Clean coal and gas
- Nuclear
- Hydro
- Wind
- Solar and Biomass

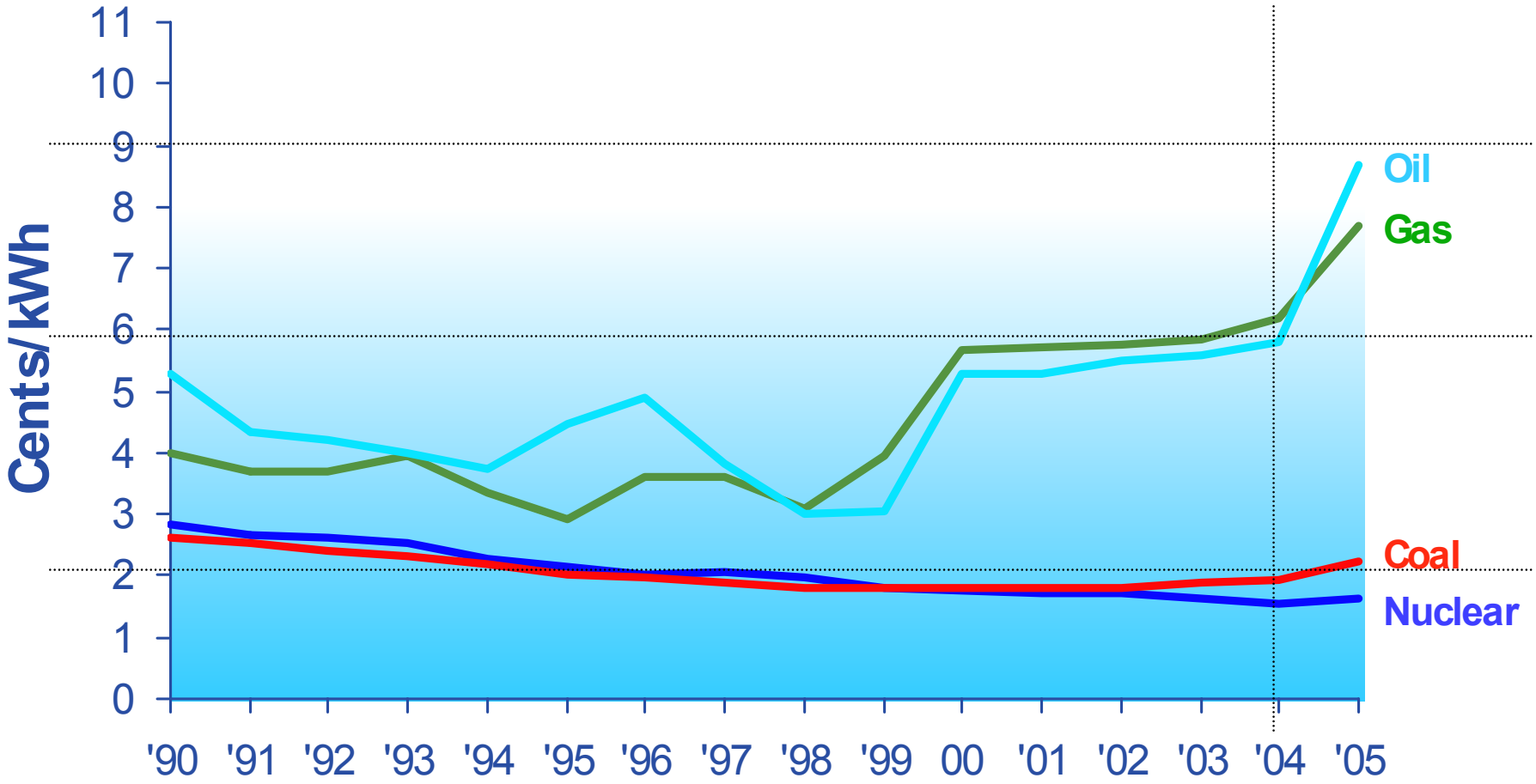
What does the market say?

Cost for New Build



** Includes U.S. Production Tax Credits*

Operating Cost for Existing Plants

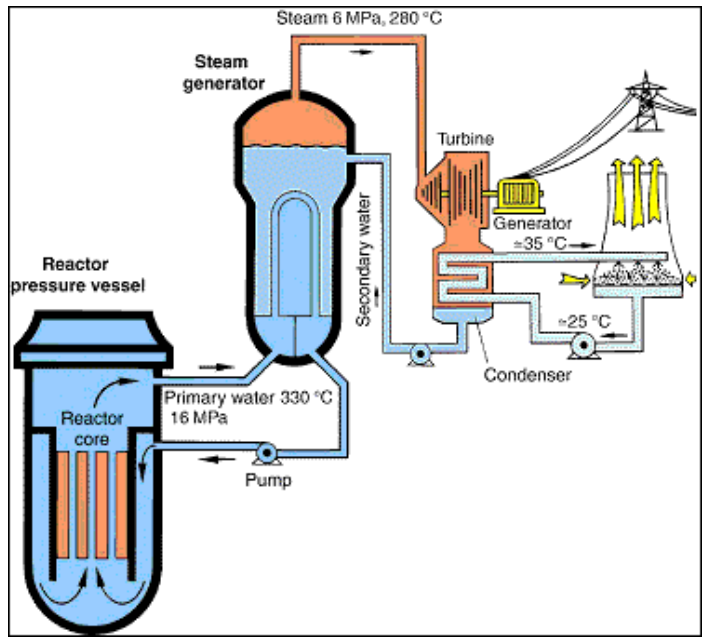


imagination at work

Nuclear power "CO_2 clean"

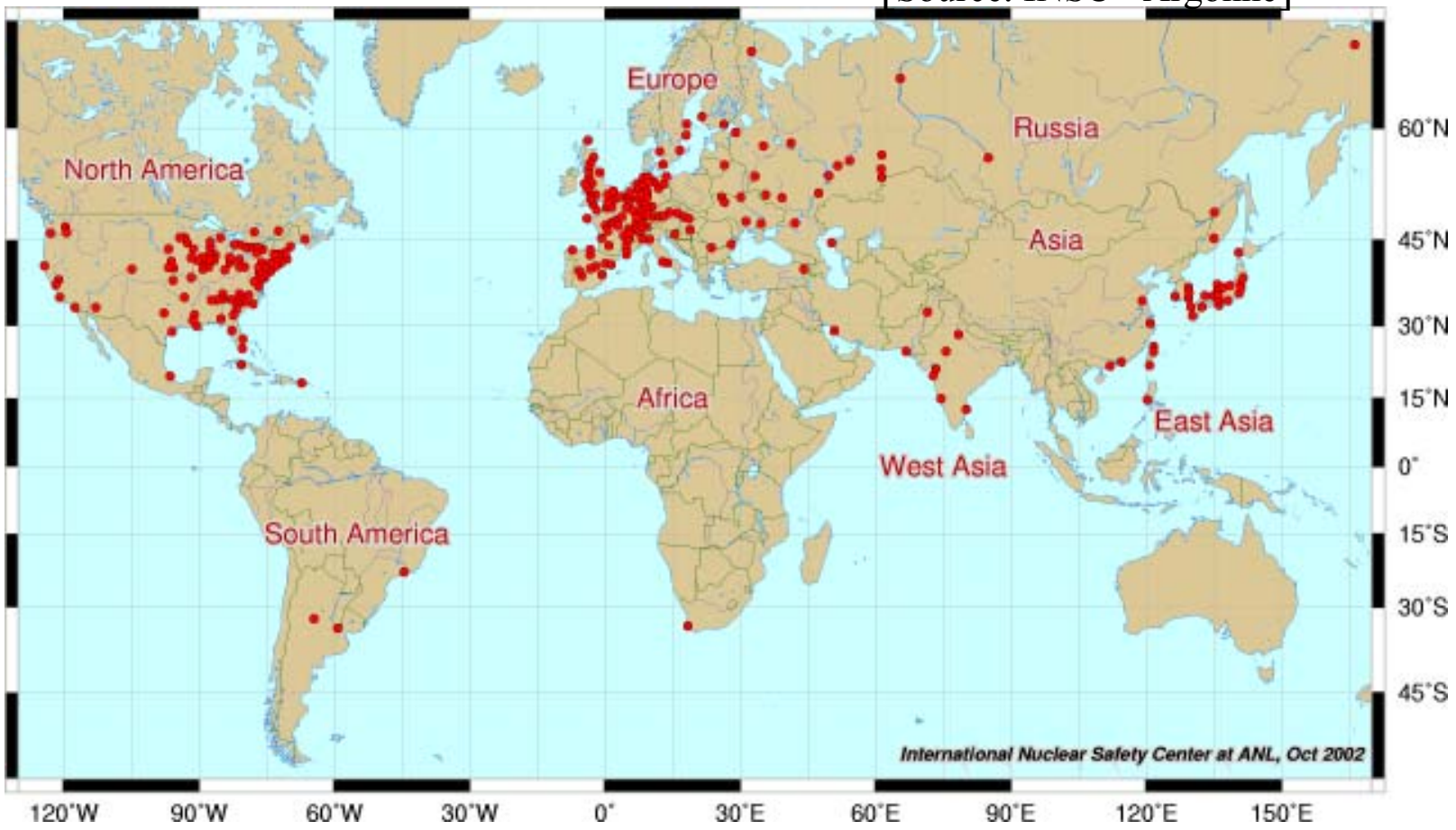
Not in my backyard

- Principles of nuclear fission are known
- Natural ^{235}U is a limited resource
- Generation IV reactors
- Breeder reactors?
  - $^{232}Th \rightarrow {}^{233}U$
  - $^{238}U \rightarrow {}^{239}Pu$
- **Accidents**
- **Proliferation HEU, ^{239}Pu**
- **Waste management**



WORLD POWER REACTORS

[Source: INSC - Argonne]

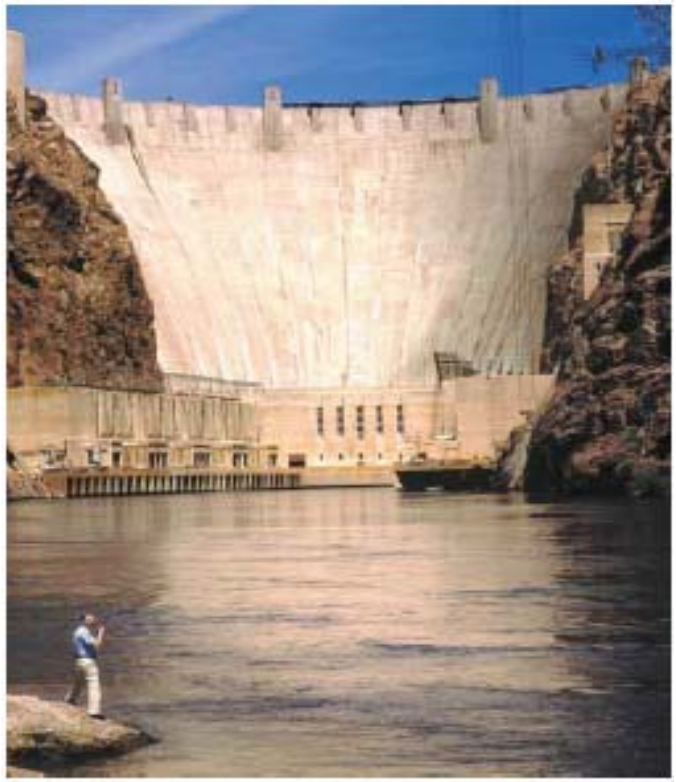


To replace 10 Terawatts by nuclear power would require 10,000 one GW plants – 1 new plant a day for 30 years.

Don't have enough nuclear scientists or engineers

Renewables

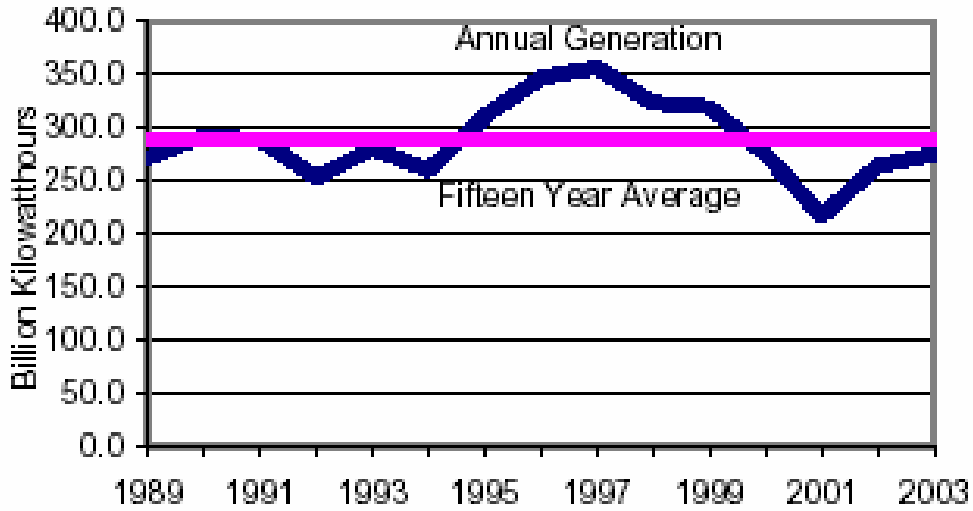
Hydroelectric Dams



- Silting
- Ecological impact
- Large versus small dams
- Impact of climate change

- **Electricity generation**
- **Water management**

NO significant growth



Sources: 1989-1998: Energy Information Administration, Annual Energy Review 2002, DOE/EIA-0384(2002) (Washington, DC, October 2003), Table 8.2a. 1999-2003 Table 4 of this report.

USA is rich in bio materials, wind, solar, geothermal

Bio-fuels: R&D to cut time & cost

Food Crops (corn, sugarcane, ...) → ethanol

Vegetable oils (soybean, …) → bio-diesel

→ **Arable land**
Water
Energy neutral

Cellulose (wood waste, switchgrass, ...) → **digesters (enzymes, microbes)** → ethanol

Animal (cows, pigs) dung → methane

Waste (animal, industrial) → thermal → oil

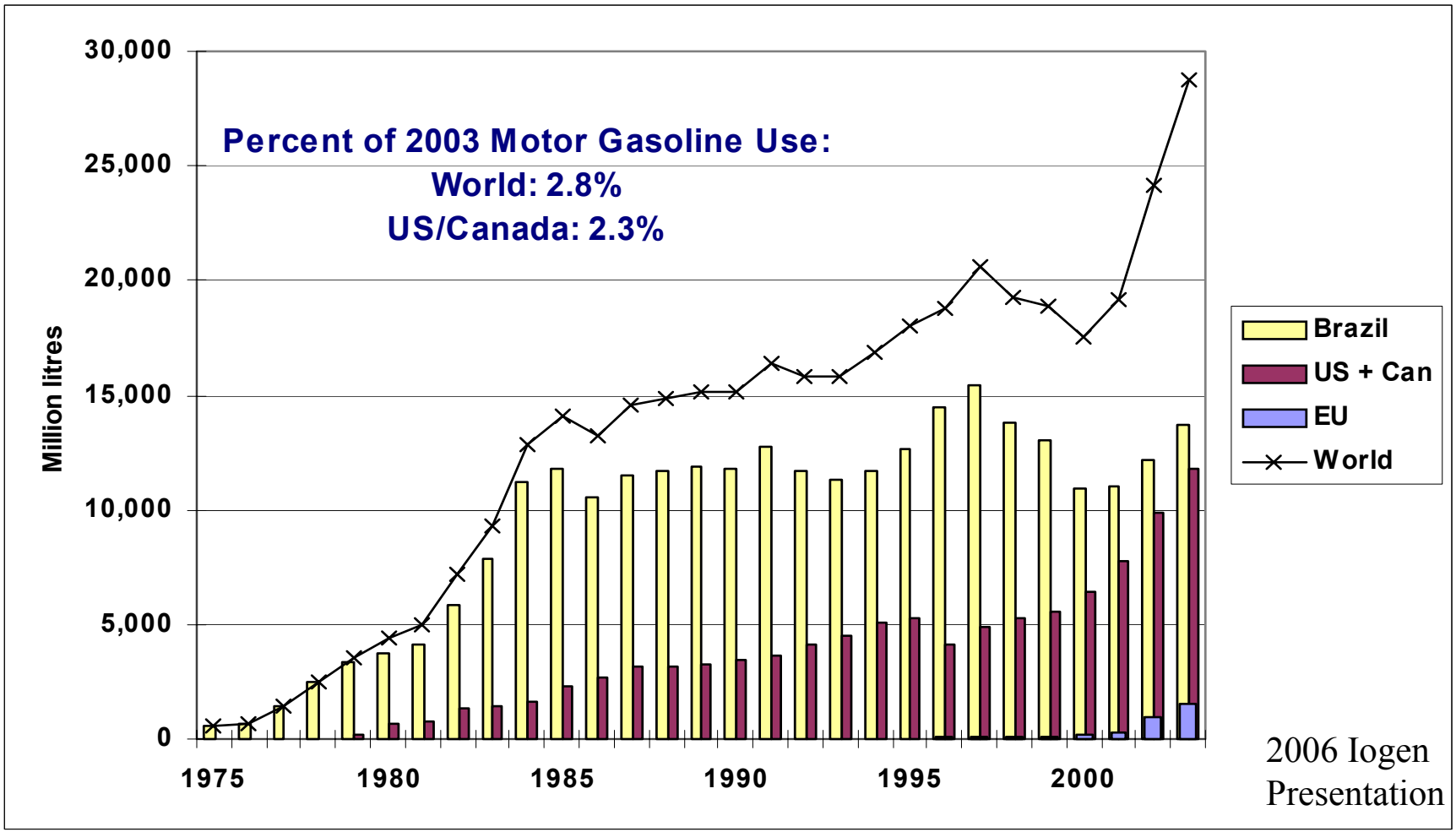
} **Replacing 18th century uses by 21st**

Algae → oil → bio-diesel

Microbes → oil → bio-diesel

Need to beat cost & efficiency of photovoltaic

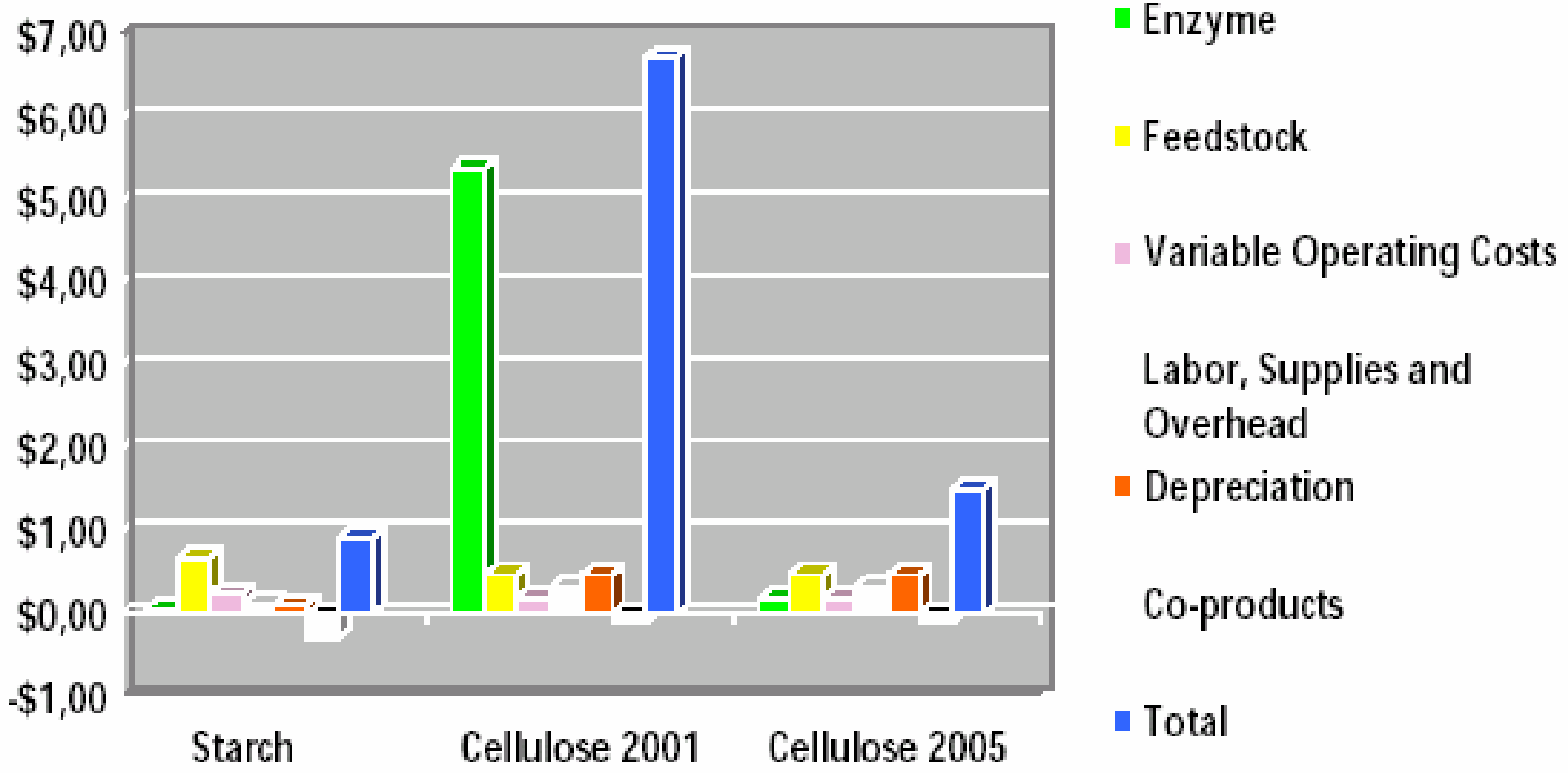
food crops → Ethanol



Energy input in corn to ethanol production ≈ stored.
→Ethanol: a way to convert coal and gas into liquid fuel!

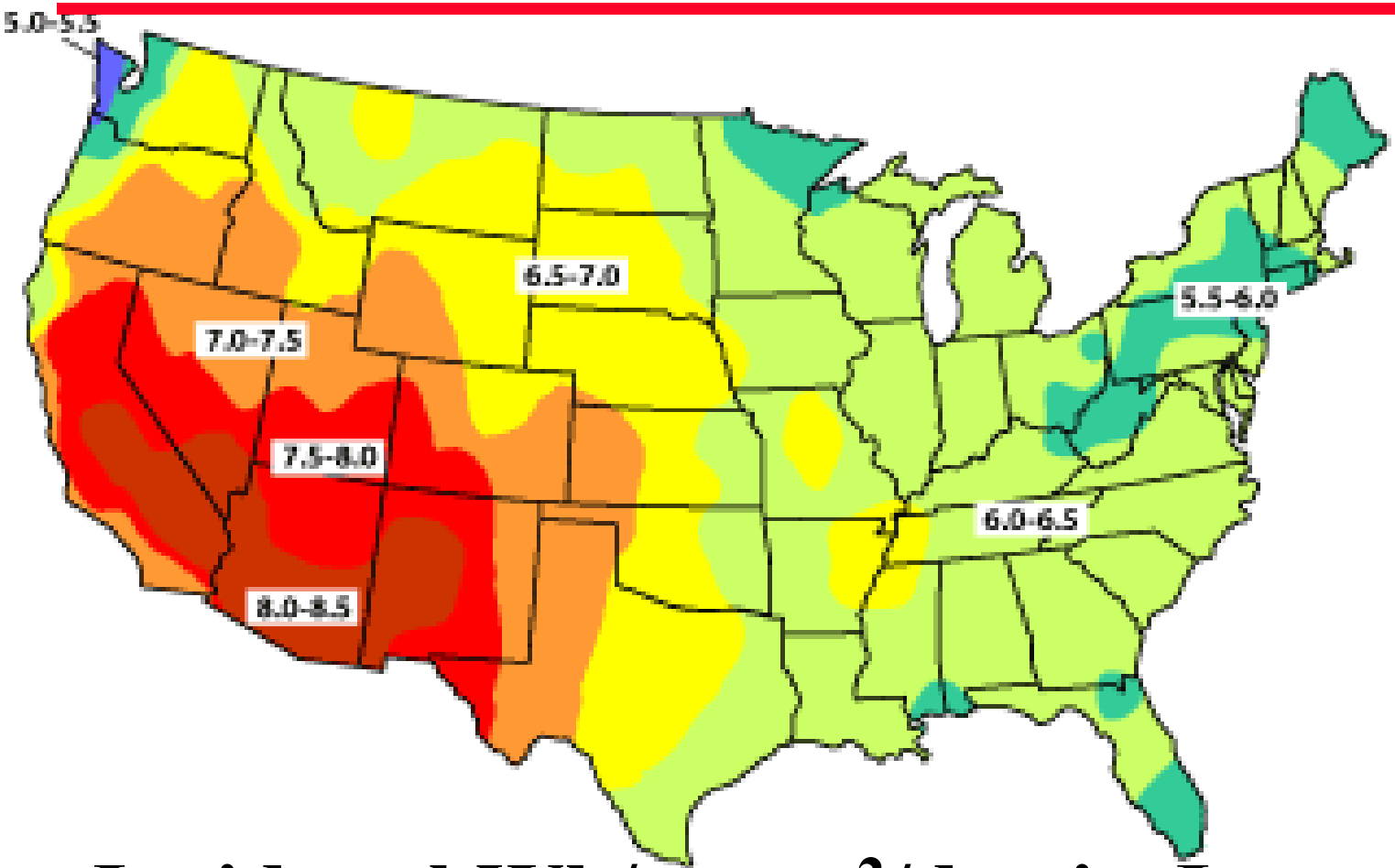
Enzyme cost no longer dominates the bioethanol picture

Cost comparison after recent achievements: Grain vs. biomass in USD/gallon ethanol, April,



novozymes

Solar: We have sun & land

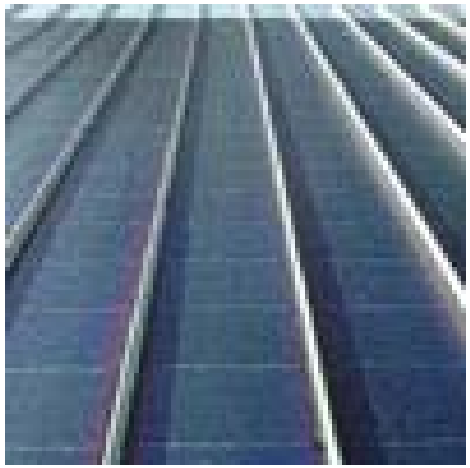


Incident kWh/meter^2/day in June

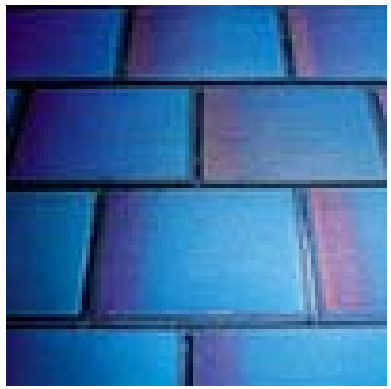
Lots of solar but very dilute and only during the day

Solar PV options reaching 15% efficiency

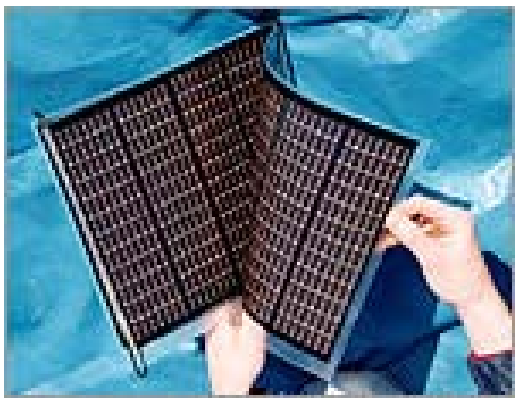
Average output: 30-45 watts / meter^2



Laminate



Tiles /Shingles



Thin films

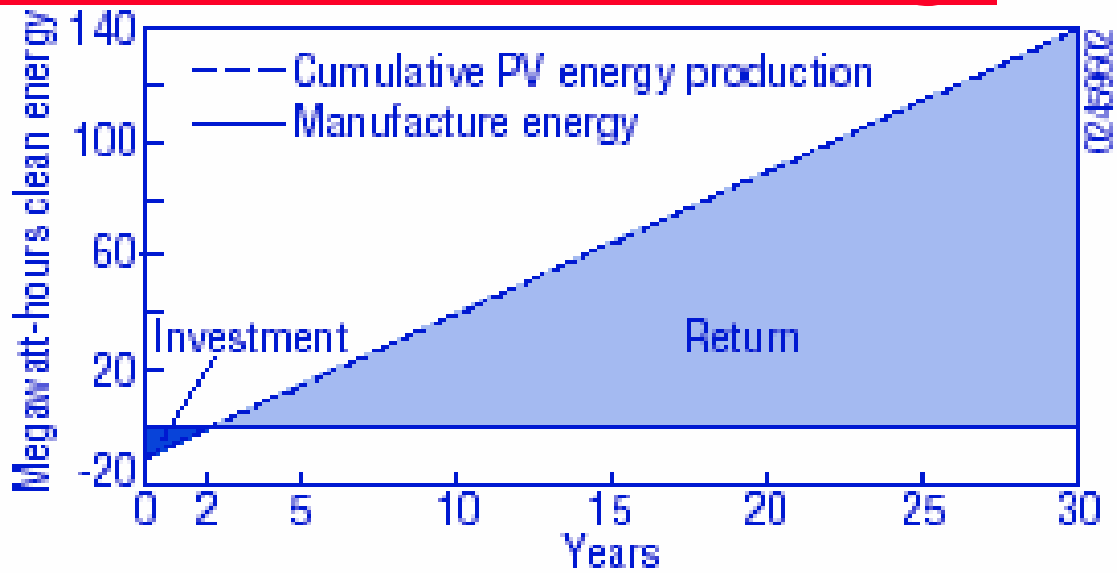
Polycrystalline PV

Technology is here & improving. Costs coming down from $10/watt to $1/watt

Payback of PV: homes & buildings

My gas bill was $1800 in 2004 and $2300 in 05.

Installing a 2 kilowatt PV system costs $20000



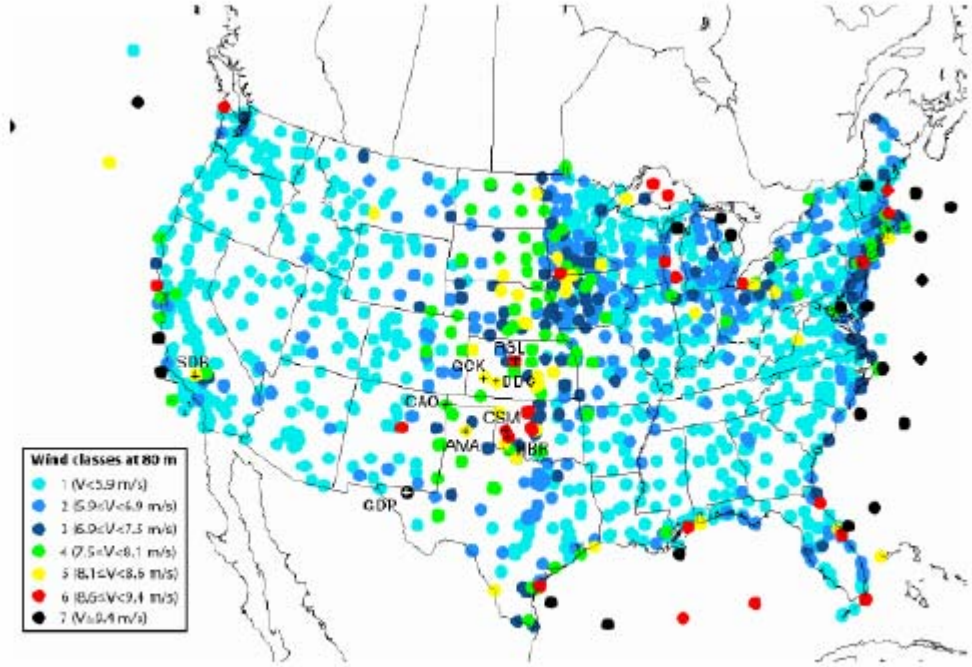
PV systems can repay their energy investment in about 2 years. During its 28 remaining years of assumed operation, a PV system that meets half of an average household's electrical use would eliminate half a ton of sulfur dioxide and one-third of a ton of nitrogen-oxides pollution. The carbon-dioxide emissions avoided would offset the operation of two cars for those 28 years.

⇒Building a house today I would use PV.

Incentives = 3 kW system for same $$

Wind potential

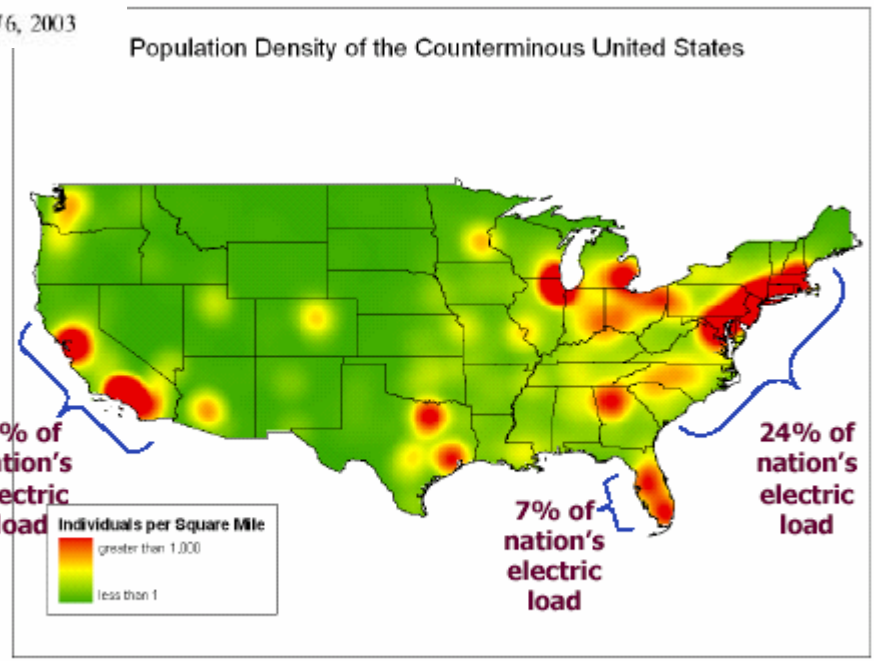
Speeds at 80 m height



2005

JOURNAL OF GEOPHYSICAL RESEARCH, VOL. 108, NO. D9, 4289, doi:10.1029/2002JD002076, 2003

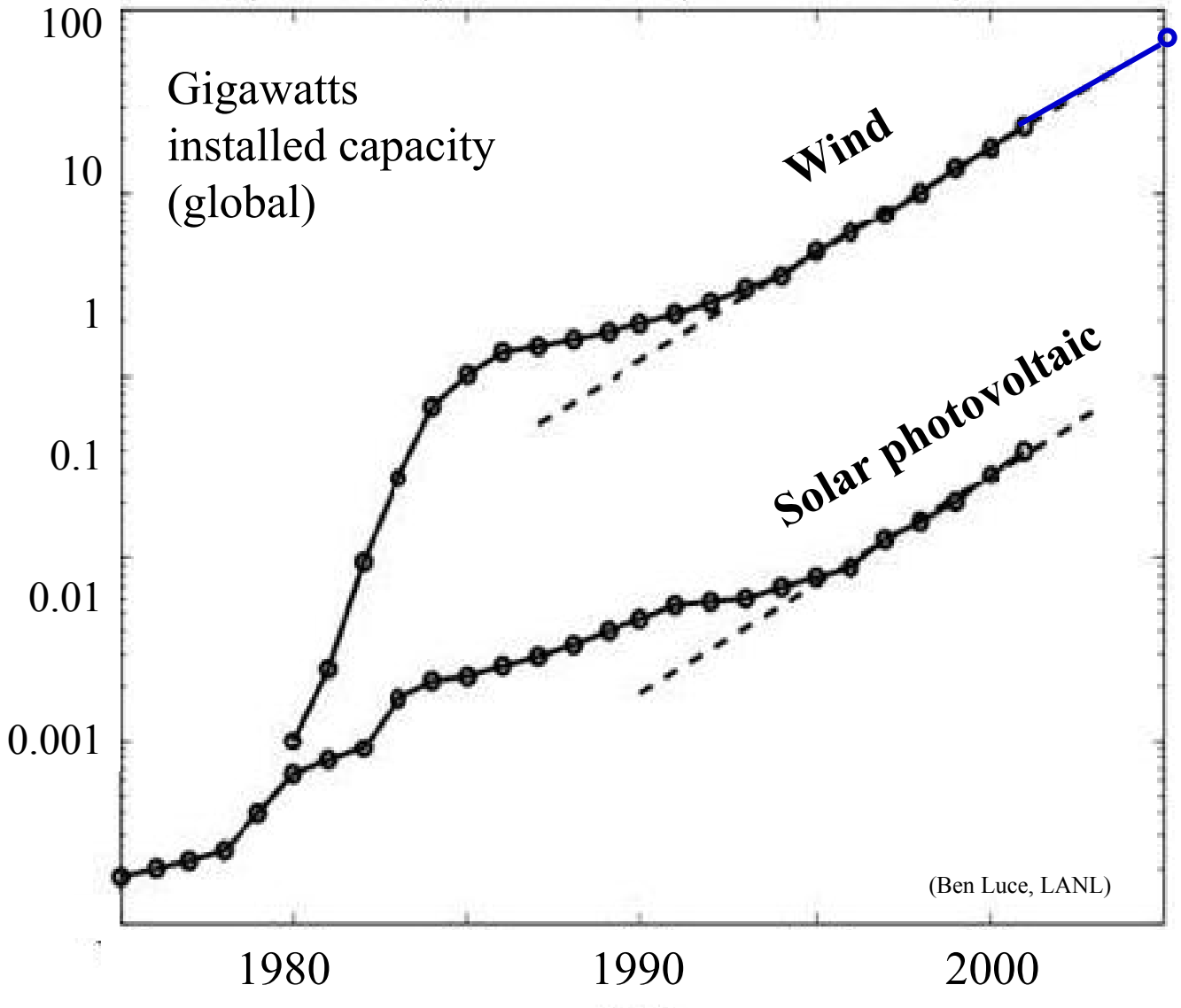
Good offshore wind potential near high population density areas in the US



Source: W. Musial, NREL

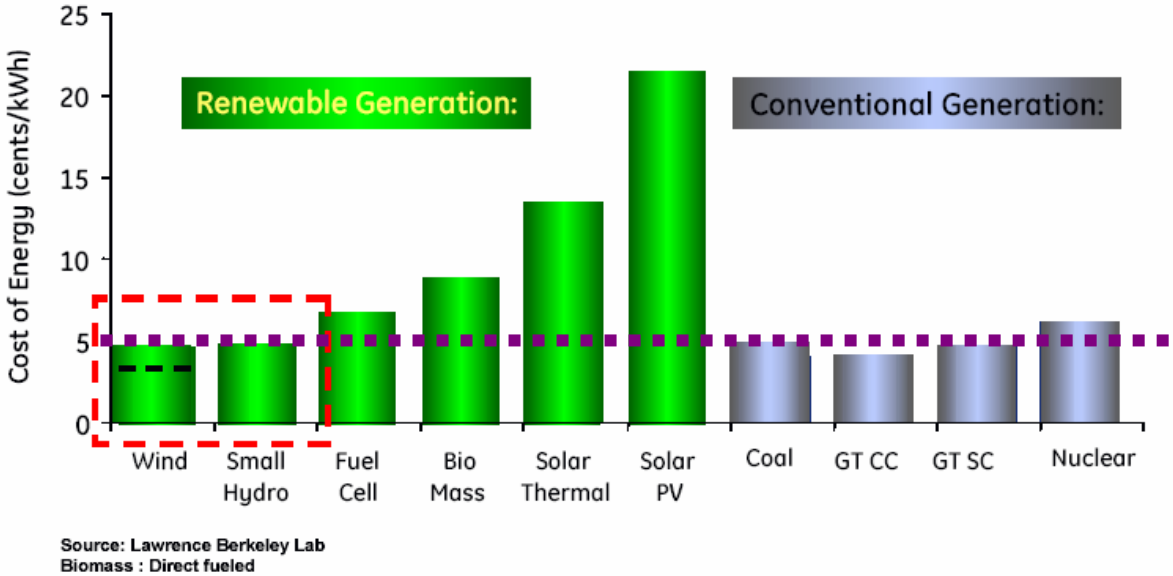
International wind & PV growth

Wind & PV show ~30% growth over 1995-2005



WIND

Cost of Energy



Source: Lawrence Berkeley Lab
Biomass : Direct fueled

Wind: The Most Practical Renewable Technology

Will GE make USA a major player in wind and PV systems?

Missing an Economic Opportunity

- **Clean Energy**
- **Electric power grids**
- **Fuel for Transportation**
- **Efficient machines/appliances**

are increasingly value-added products.

40 Terawatts of global power demand translates into a $48 billion/day market at $0.05 kW hour

The World has changed since 1970s

- **Most major oil fields outside of the Middle East are in decline. Estimate of Reserves???**
- **Most of the world mapped for oil and gas – no major new oil discoveries since 1980**
- **Many more countries (China, India, …) competing for oil and gas**
- **Fossil fuels → CO_2 → global climate change**
- **Nuclear remains *"not in my backyard"***
- **Solar, wind, biofuels, fuel cells moving from "green" novelties to large scale deployment**
- **Revolution in many relevant technologies**

Business as usual→ Challenges we face

- We are increasingly dependent on Russia and Middle East for oil and natural gas
- Once the global production reaches "peak" (or demand > supply) prices will stay high
- Competition for oil and natural gas will continue to increase
- Unconventional oil and natural gas means more cost, environmental impact, emissions
- Use of fossil fuels without CO_2 sequestration will lead to global climate change
- Poor most vulnerable to **Climate change** **High cost of energy**

Energy Security
is
National Security
and
Economic security
and
Environmental Security

= Future of our children

Senator Lugar: "energy is the albatross of U.S. national security"

Brookings: 13 March 2006

Make New Mexico a Leader

- Exploit our solar and wind potential
- Intelligent power grids
- Bring together science at Labs with utility companies for large scale pilot projects for carbon sequestration
- Empowering incentives, credits, regulations
- Educate public on new opportunities, efficiencies

Educate the public on efficiency as a win-win option

- Buy fuel efficient cars
- Carpool and Combine shopping trips
- Promote public transport
- Efficiency in appliances and buildings
- Empower developers and builders to design and build green (mandatory codes)
- Convert parking lots and roofs to solar farms (ABQ: 5 square km $\rightarrow$ 200 MW daytime)
- Integrate wind farms (Santa Fe, ABQ, Las Cruces have good wind potential nearby)

Leverage the National Labs

Fund world class departments at NM Universities in

Energy and Water research

Nuclear Engineering and Science

New Mexico's Clean Energy Policy Foundation. A promising start

- 1998: Net-Metering Rule
- 2002: Production Tax Credits for Large Scale Renewable Energy
- 2004: Renewable Energy Standard (10% by 2011)
- 2005: Energy Efficiency Act
- 2005: Clean Energy Revenue Bonds
- 2005: Photovoltaic Credits Buy Back Program
- 2006: Solar Tax Credits
- 2006: Executive Order for 50% more efficient buildings
- 2006: Memorials for:
  - Renewable Fuel Standard
  - Examination of Electric Co-op consumer issues
  - Examination of Mercury Pollution Issues

G.W. Bush Words → Consensus → Action

President G. W. Bush, SoU address 2006

"Keeping America competitive requires affordable energy."

"... we have a serious problem: America is addicted to oil"

"To change how we power our homes and offices, we will invest more in zero-emission coal-fired plants, revolutionary solar and wind technologies, and clean, safe nuclear energy."

"change how we power our automobiles. Increase our research in better batteries for hybrid and electric cars ... pollution-free cars that run on hydrogen."

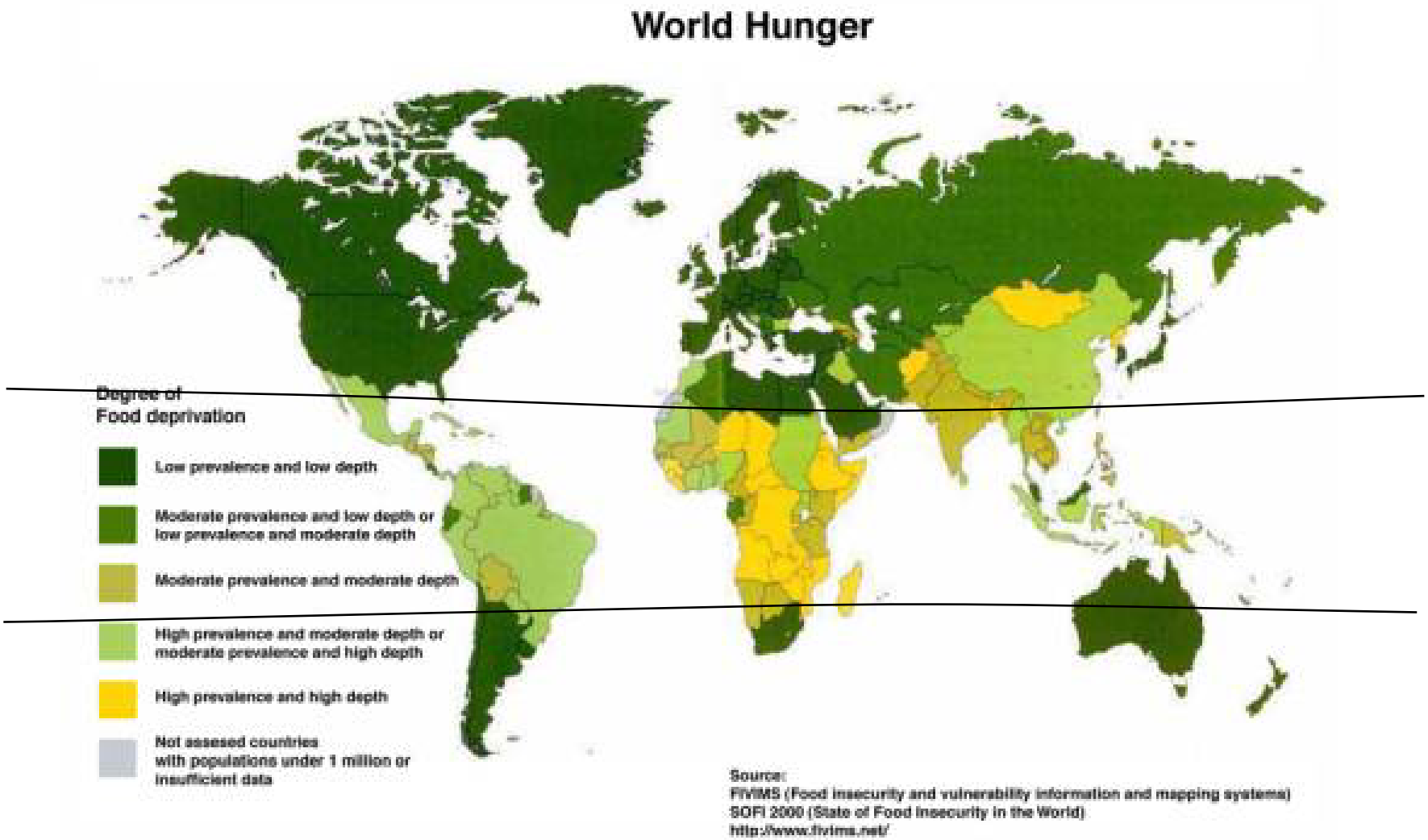
"Breakthroughs ... to replace more than 75 percent of our oil imports from the Middle East by 2025."

"By applying the talent and technology of America ... dramatically improve our environment ... move beyond petroleum-based economy ... make our dependence on Middle Eastern oil a thing of the past."

Industrialized nations must lead the R&D for cheap & clean energy (= hope) for all mankind

Hope for the future!

Wind and solar are the most abundant sources of energy in poor countries lying within the tropics. Having exhausted oil and gas, we owe them clean, copious and cheap energy.



Further reading and Sources

- http://www.eia.doe.gov/
- http://energy.cr.usgs.gov/oilgas/wep/wepindex_a.htm
- http://www.iea.org/
- http://www.nrel.gov/
- http://energytrends.pnl.gov/
- http://www.energycrisis.org/
- http://www.bp.com/
- http://www.simmonsco-intl.com/research.aspx?Type=researchreports
- "Hubbert's Peak" & "Beyond Oil", Kenneth Deffeyes
- "Out of Gas", David Goodstein, 2004
- "The End of Oil", Paul Roberts, 2004
- "Blood and Oil", Michael T. Klare, 2004
- "Twilight in the Desert" Matthew Simmons, 2005
- Senator Lugar http://www.brookings.edu/comm/events/20060313.pdf