ENERGY in the 21st Century: Need for bold thinking & action

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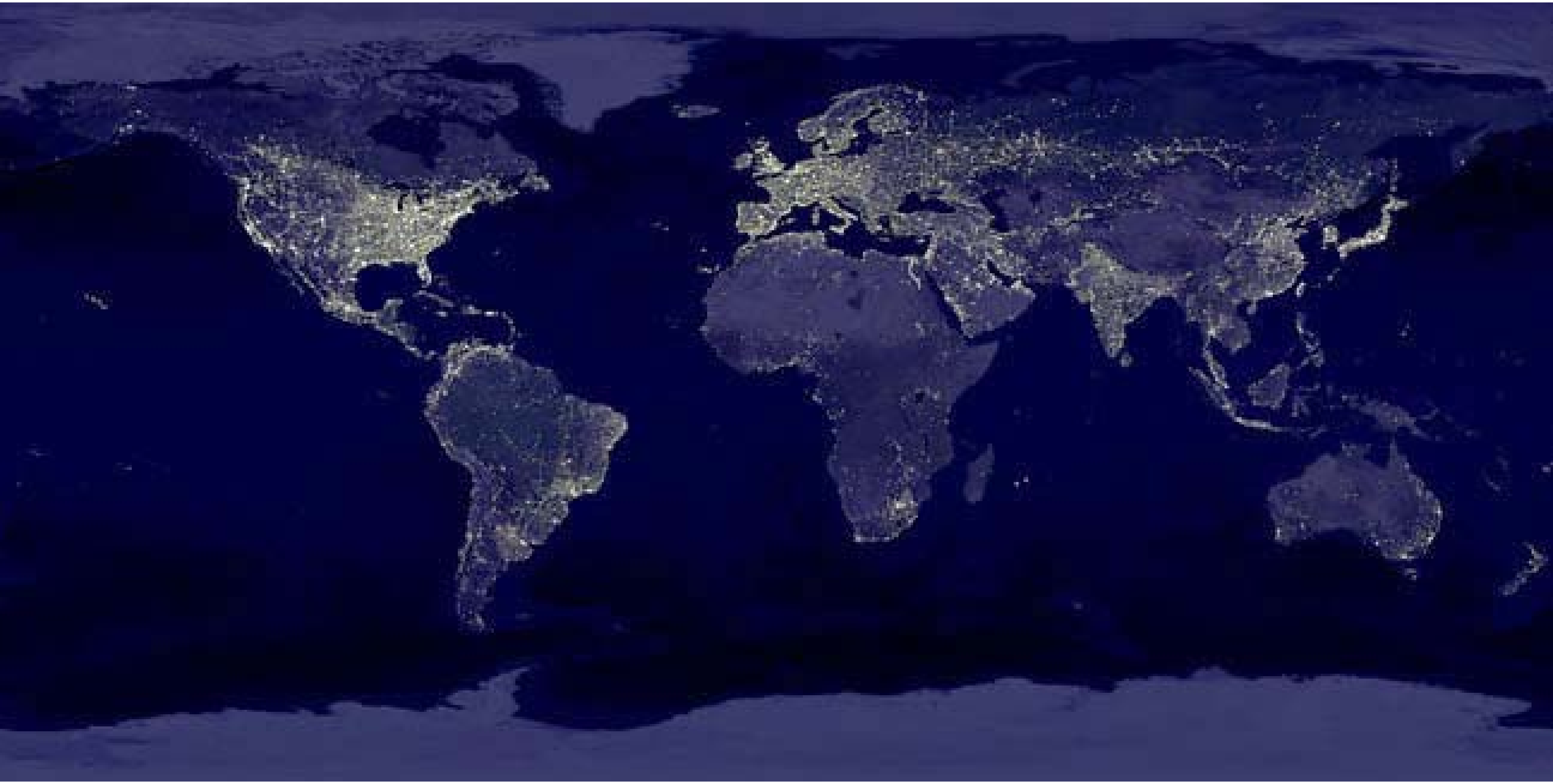
Special thanks to

Mike Fehler, Fernando Garzon, George Guthrie, Joe Gutierrez, Phil Jones, Ning Li, Ben Luce, Greg Swift, Hans Ziock

Lighting up darkness

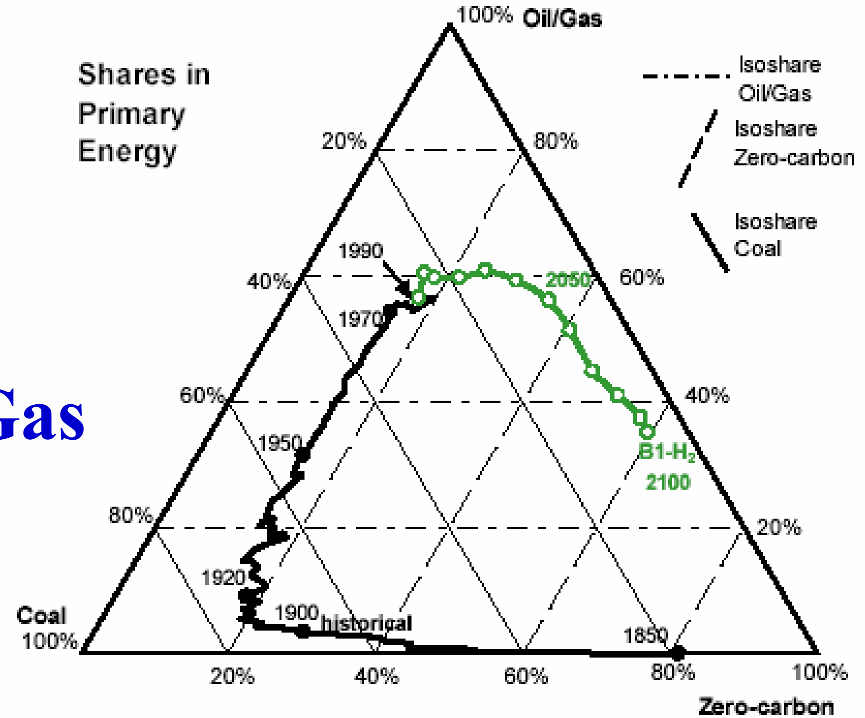


OUTLINE

- Energy and Modern Society
- Energy: needs, usage and growth
- Oil: Reserves & Hubbert's peak
- National Security: Oil & Gas
- Coal
- Energy and Environment
- Energy Security=[Inter]National Security
  - Needs, options, costs
- Nuclear
- Renewables
- Summary, Recommendations, Hope

Major transformations

- Pre 1800 — Biomass
- 1800-1900 — Coal
- 1900-2050? — Coal, Oil, Gas



What next -- as 8 billion people demand energy?

Coal and Steam Engine

1750-
1850

post
1950

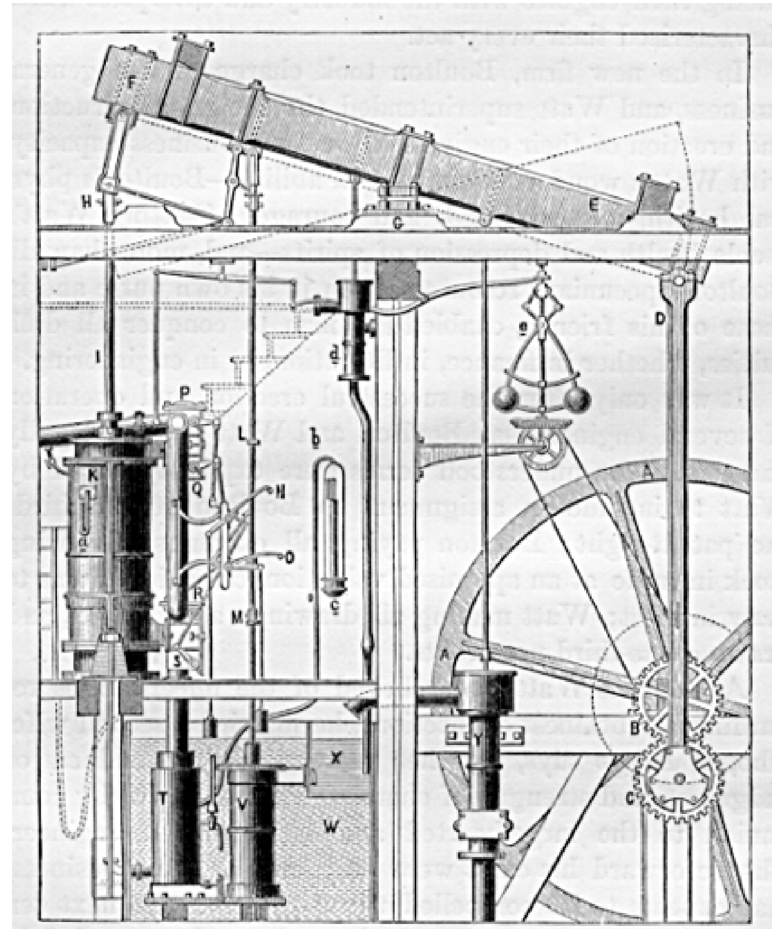
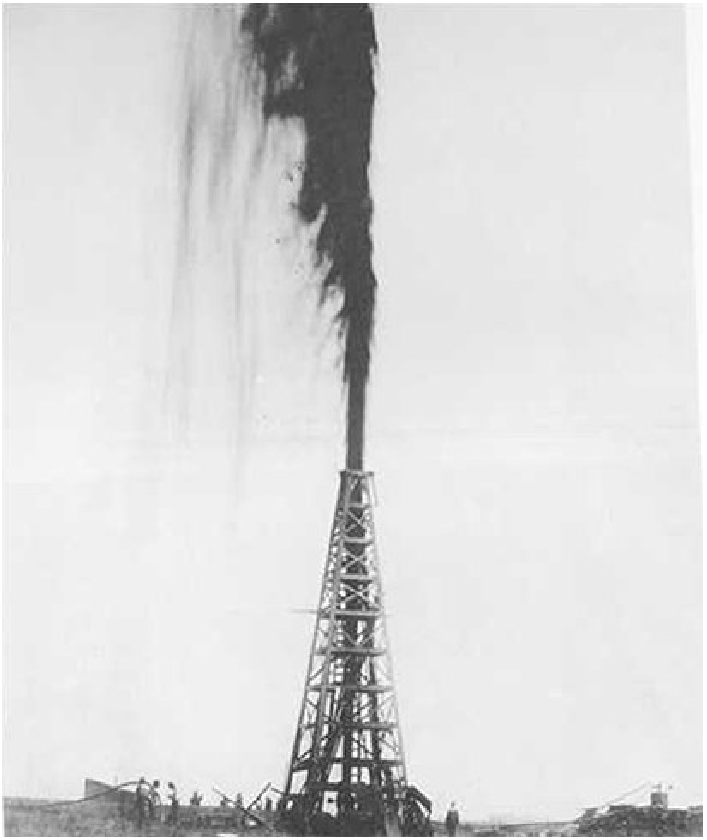


FIG. 27.—Watt's Engine, 1781.

Watts Steam Engine, patent 1769

Oil and ICE

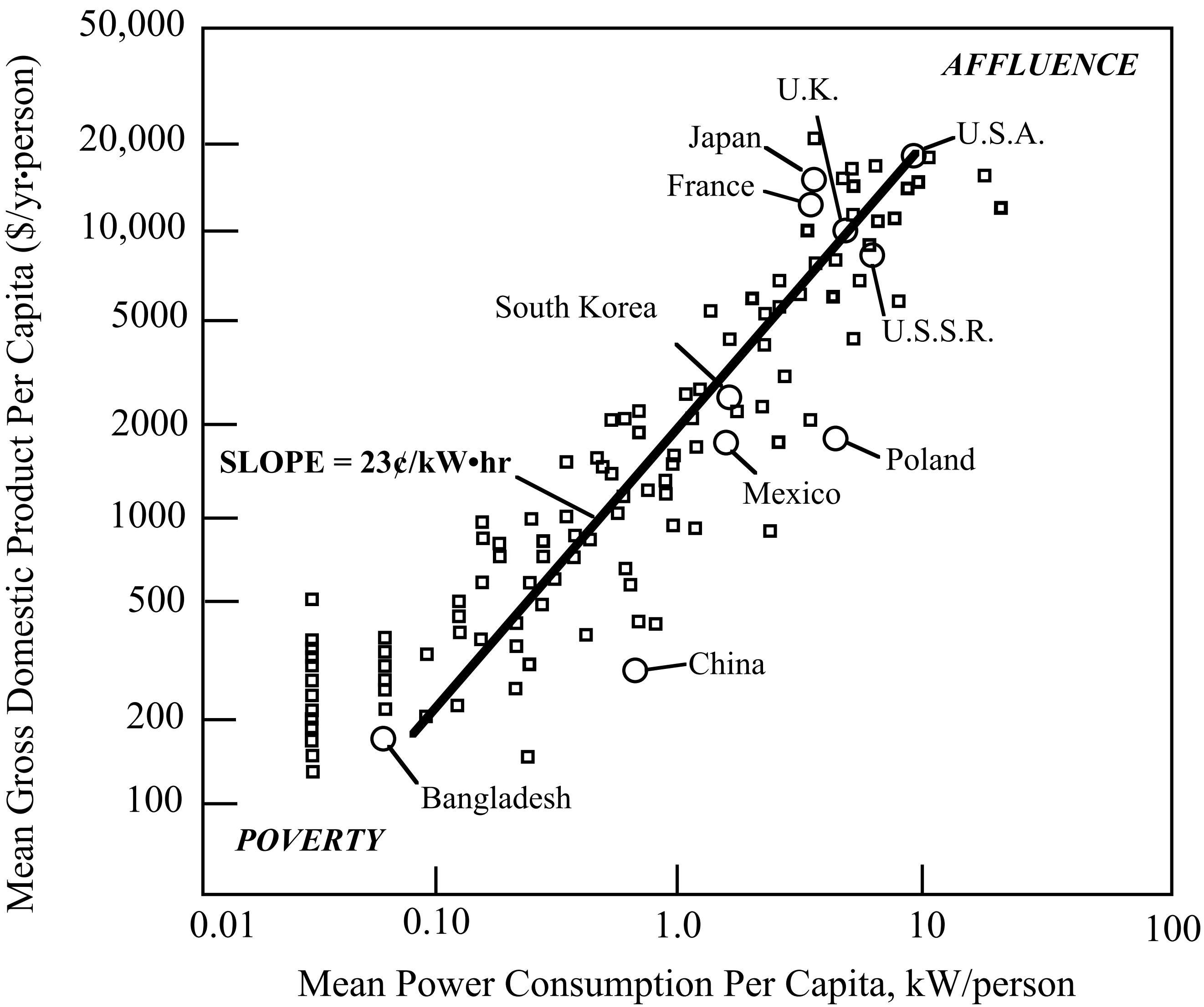


Spindletop, 10 Jan 1901

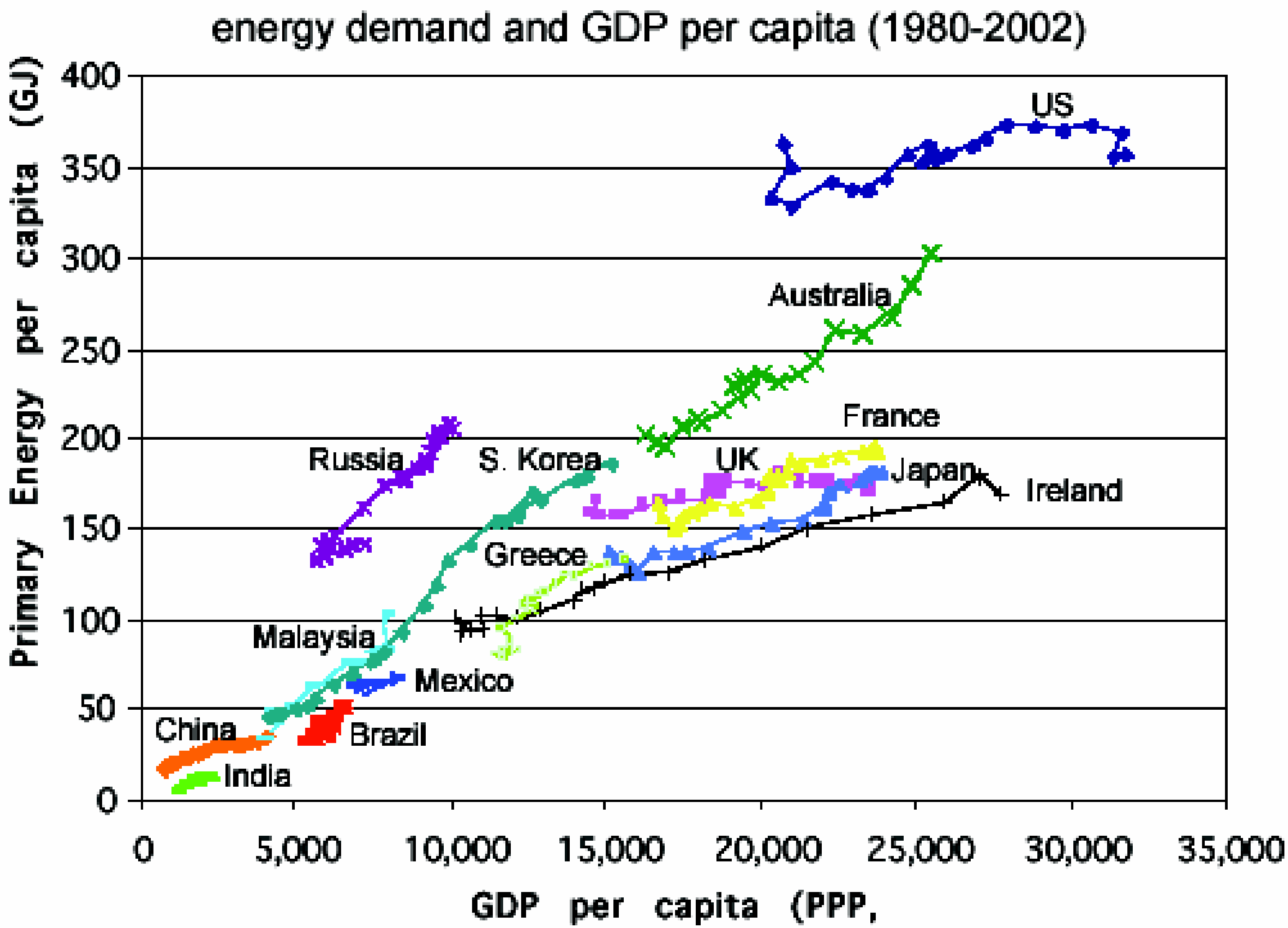
Ford Model T touring (1 Oct 1908)

Energy and potable water are two key resources necessary not just for development but for preserving the modern way of life itself

Correlation between energy use and GDP



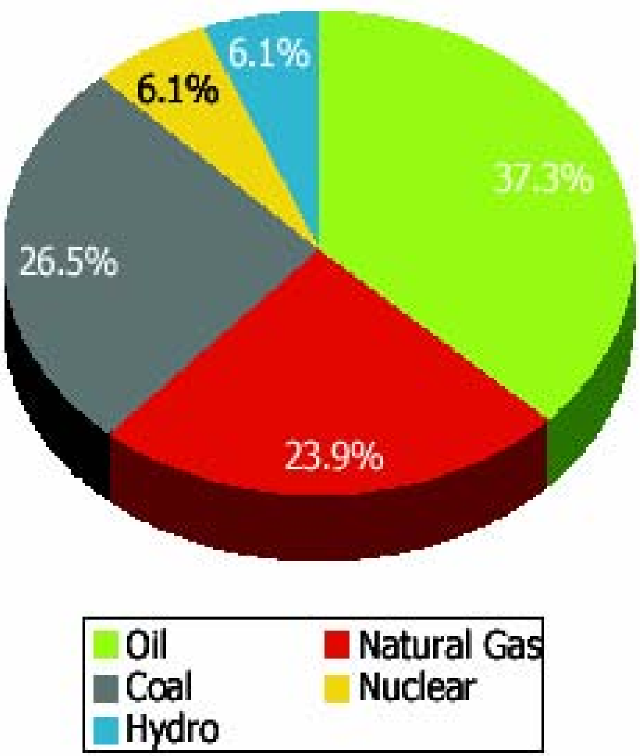
Energy use grows with economic development

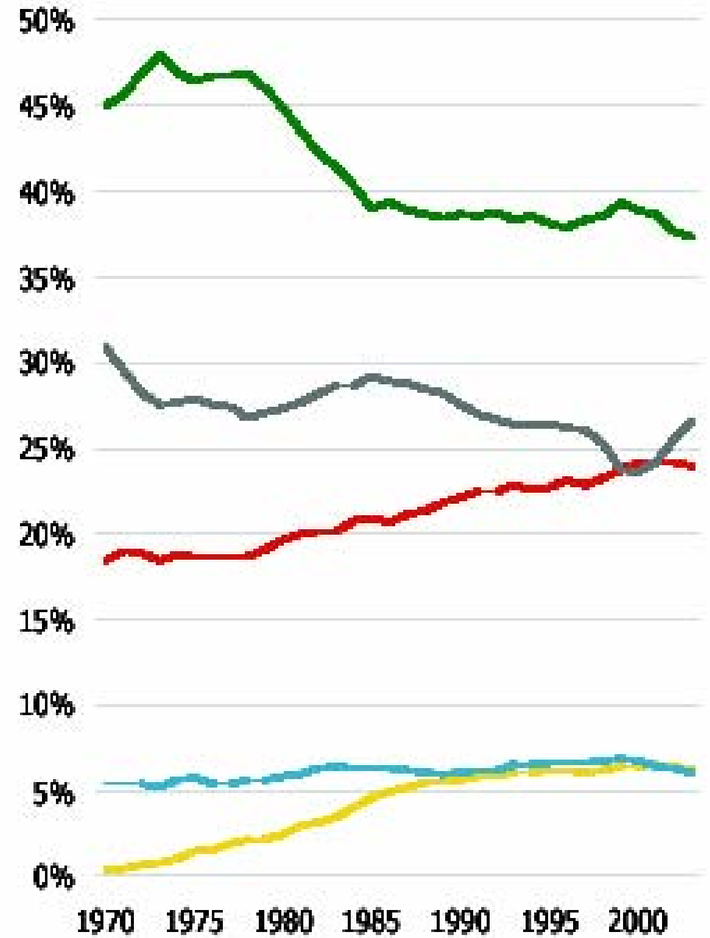


Source: UN and DOE EIA

current and historical global energy mix

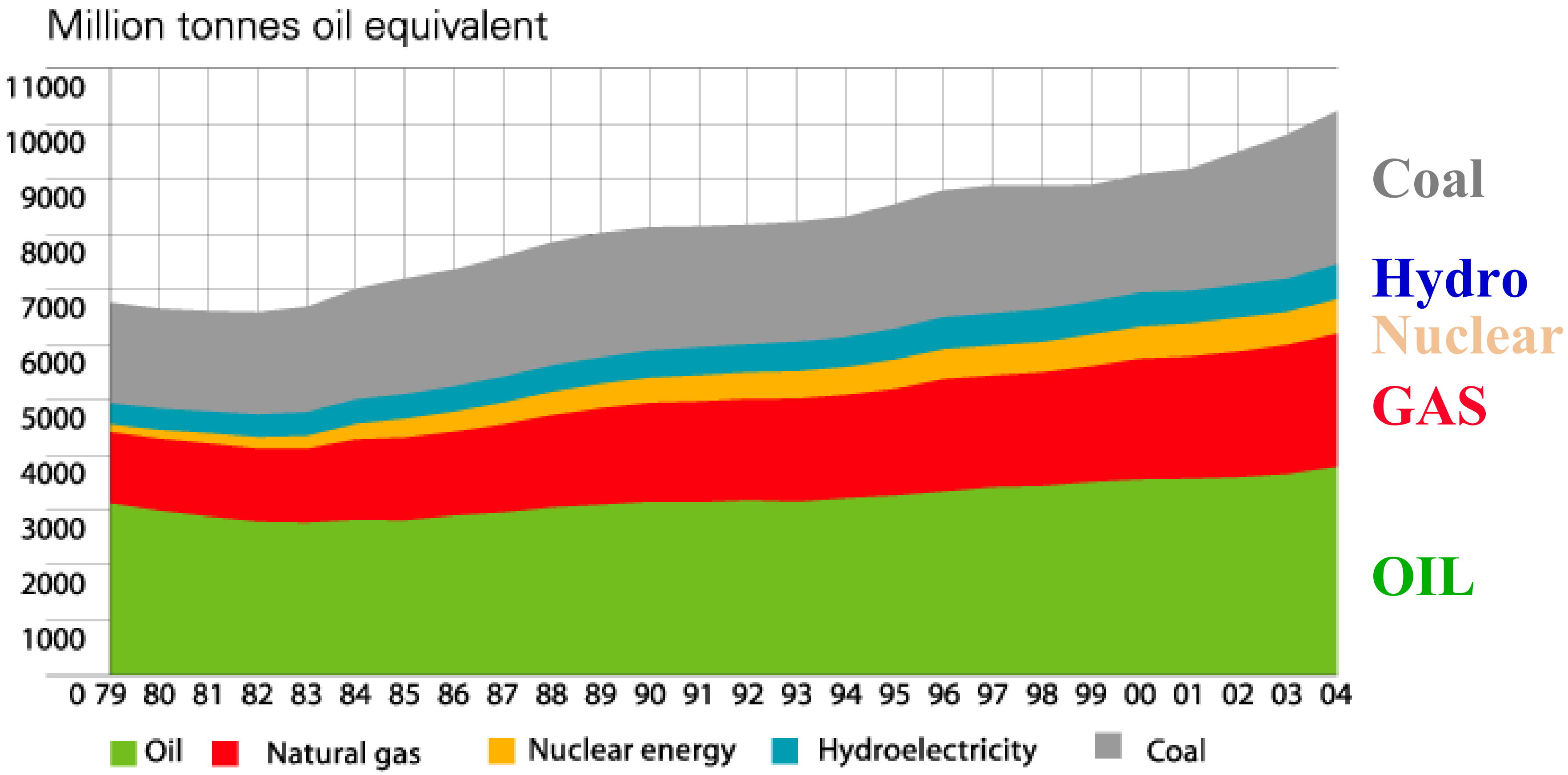
Current global energy supply is dominated by fossil fuels – oil has been the largest component of the energy mix for many decades; gas has grown strongly since the 1970's; coal has been growing in the last four years; hydro is constant and nuclear has plateaued





Source: BP Statistical Review

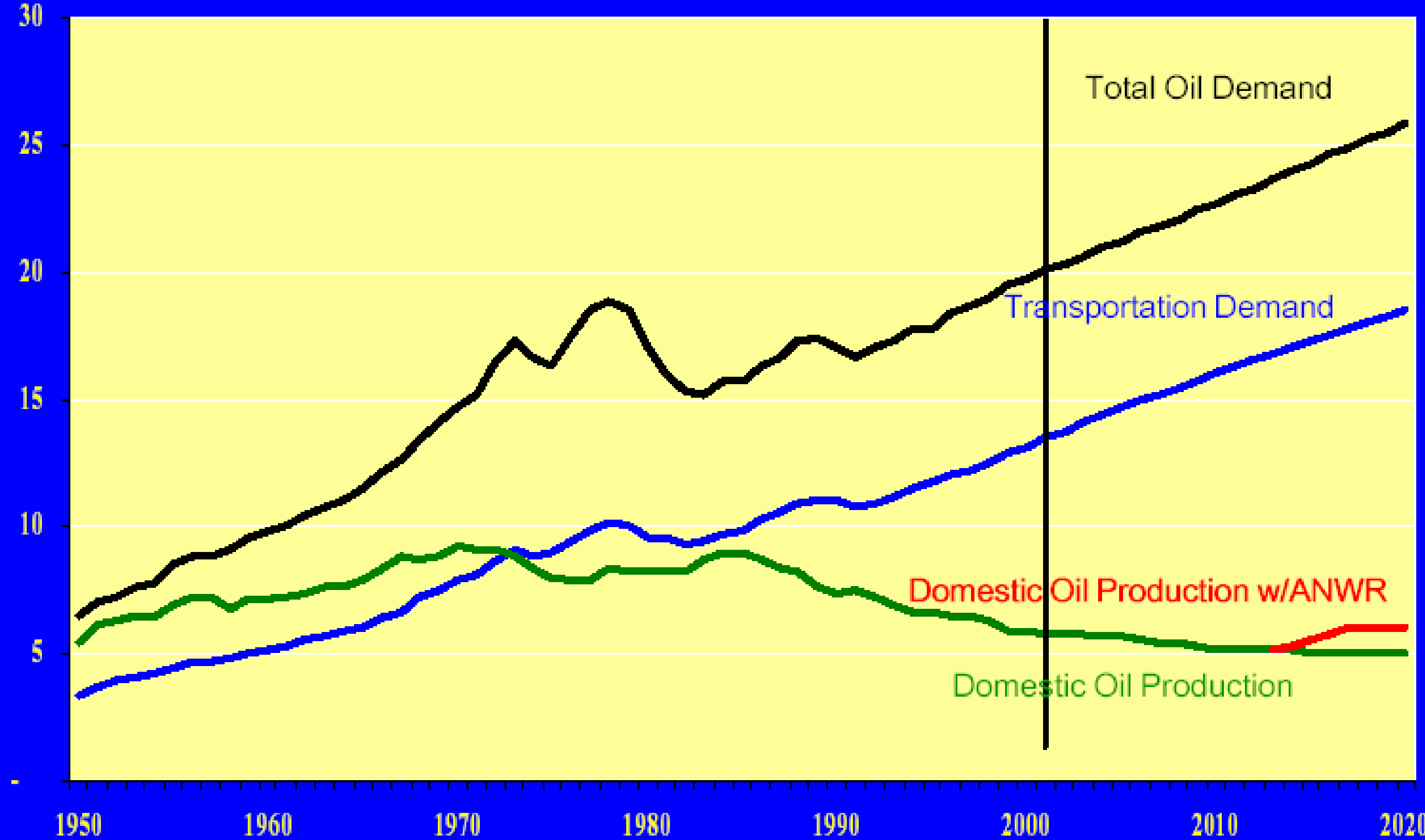
4.3% growth in 2004 primary energy consumption



Global primary energy consumption recorded the strongest incremental growth ever, rising by 4.3%. Growth was above the 10-year average in all regions and for all fuels.

BP 2005

US Oil Consumption (million barrels per day)

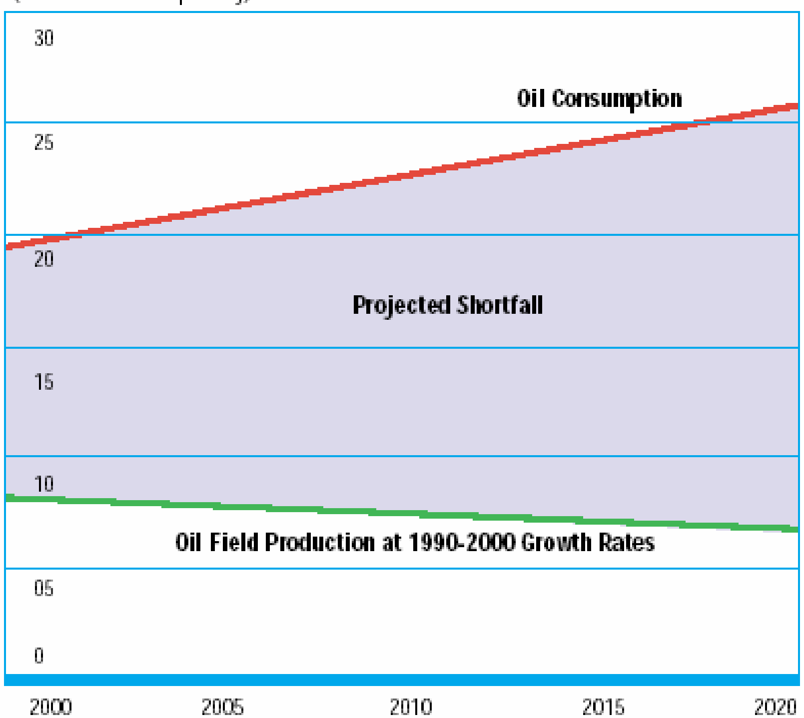


EIA, Annual Energy Outlook 2001; "Potential Oil Production from the Coastal Plain of ANWR," - EIA Reserves & Production Division

USA is increasingly dependent on imports for both oil and gas

U.S. Oil Consumption Will Continue to Exceed Production

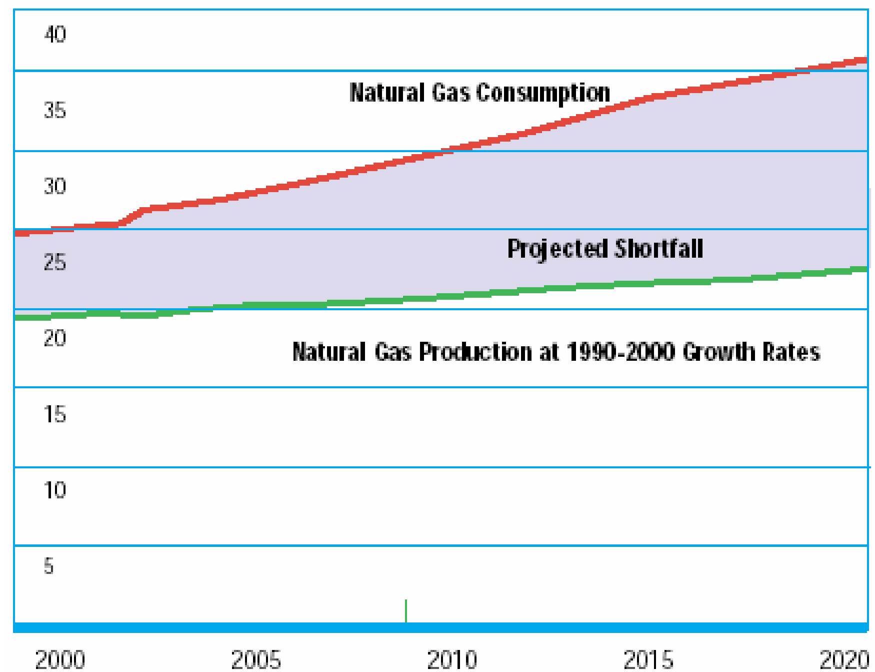
(Millions of Barrels per Day)



Over the next 20 years, U.S. oil consumption will grow by over 6 million barrels per day. If U.S. oil production follows the same historical pattern of the last 10 years, it will decline by 1.5 million barrels per day. To meet U.S. oil demand, oil and product imports would have to grow by a combined 7.5 million barrels per day. In 2020, U.S. oil production would supply less than 30 percent of U.S. oil needs.

U.S. Natural Gas Consumption Is Outpacing Production

(Trillion Cubic Feet)



Over the next 20 years, U.S. natural gas consumption will grow by over 50 percent. At the same time, U.S. natural gas production will grow by only 14 percent, if it grows at the rate of the last 10 years.

Source: NEP May 2001

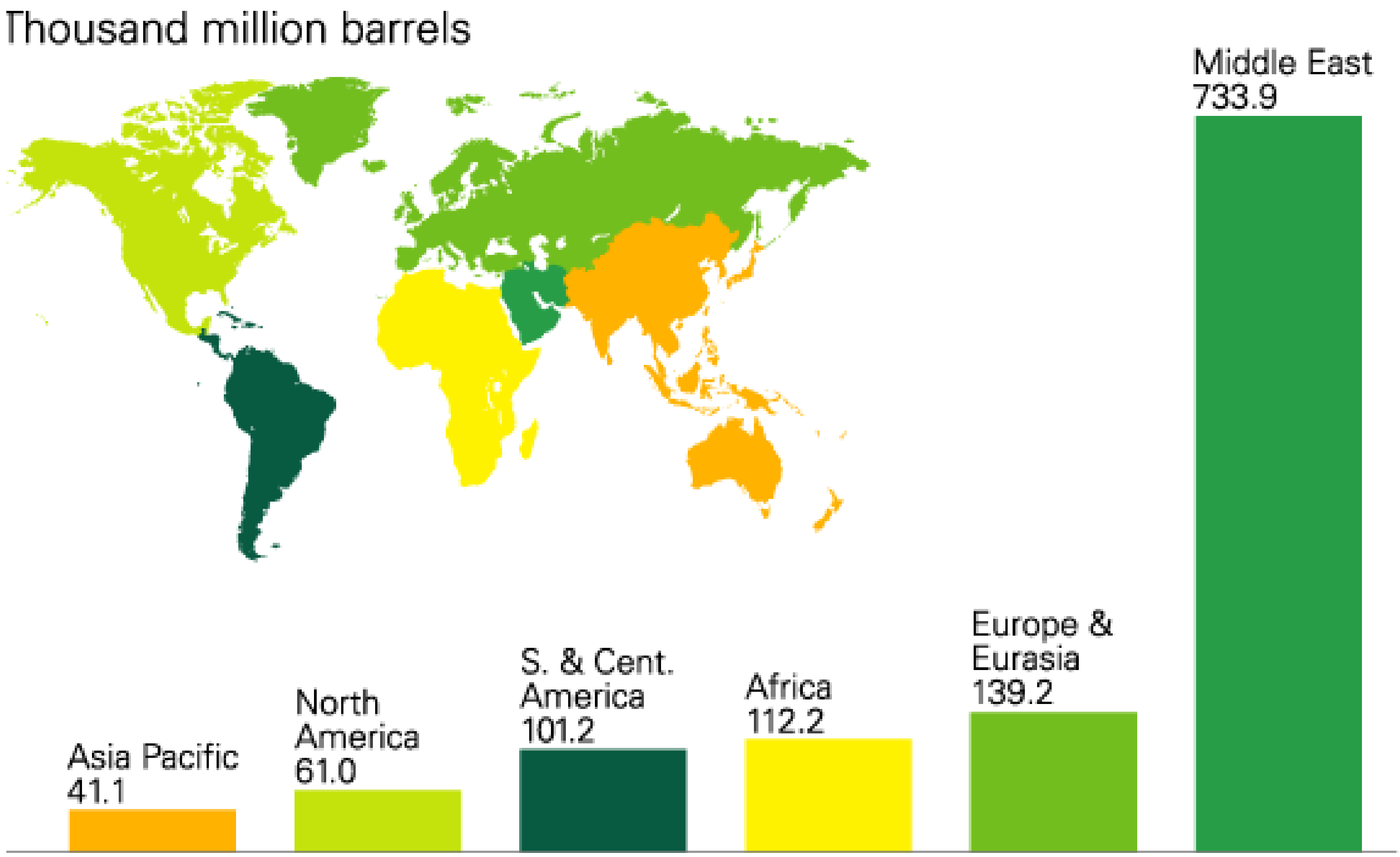
Geographical distribution of oil, gas, and coal reserves matters.

Pipelines, Shipping and Refining capacity matters

All factors will matter more with time as reserves dwindle

Proved oil reserves at end 2004

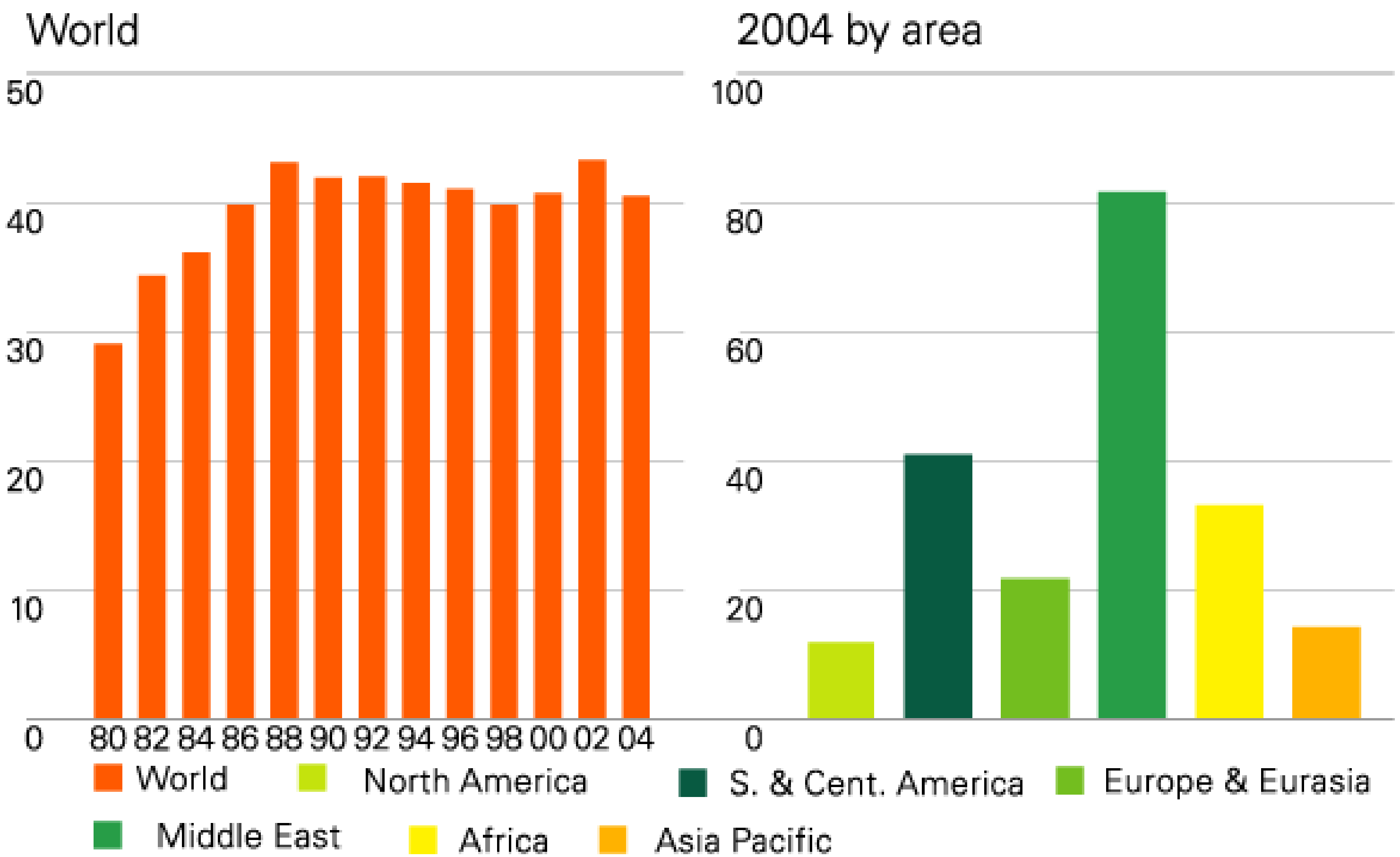
BP2005



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

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

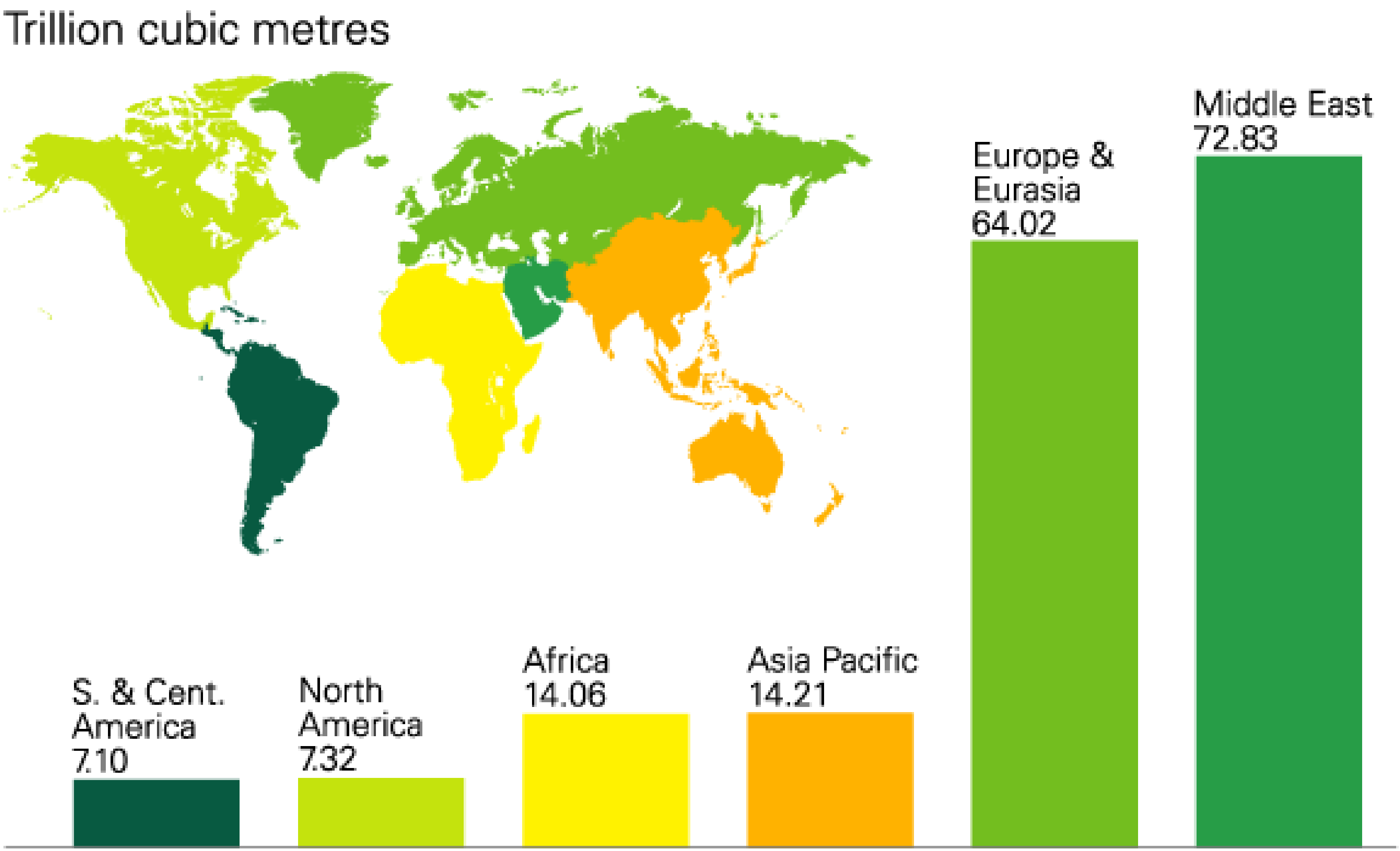
BP 2005



The world's oil reserves-to-production ratio fell to 40.5 years in 2004, down from 43.3 in 2002. Reserves have continued to increase and now stand 17% above the 1994 level; production is 20% higher.

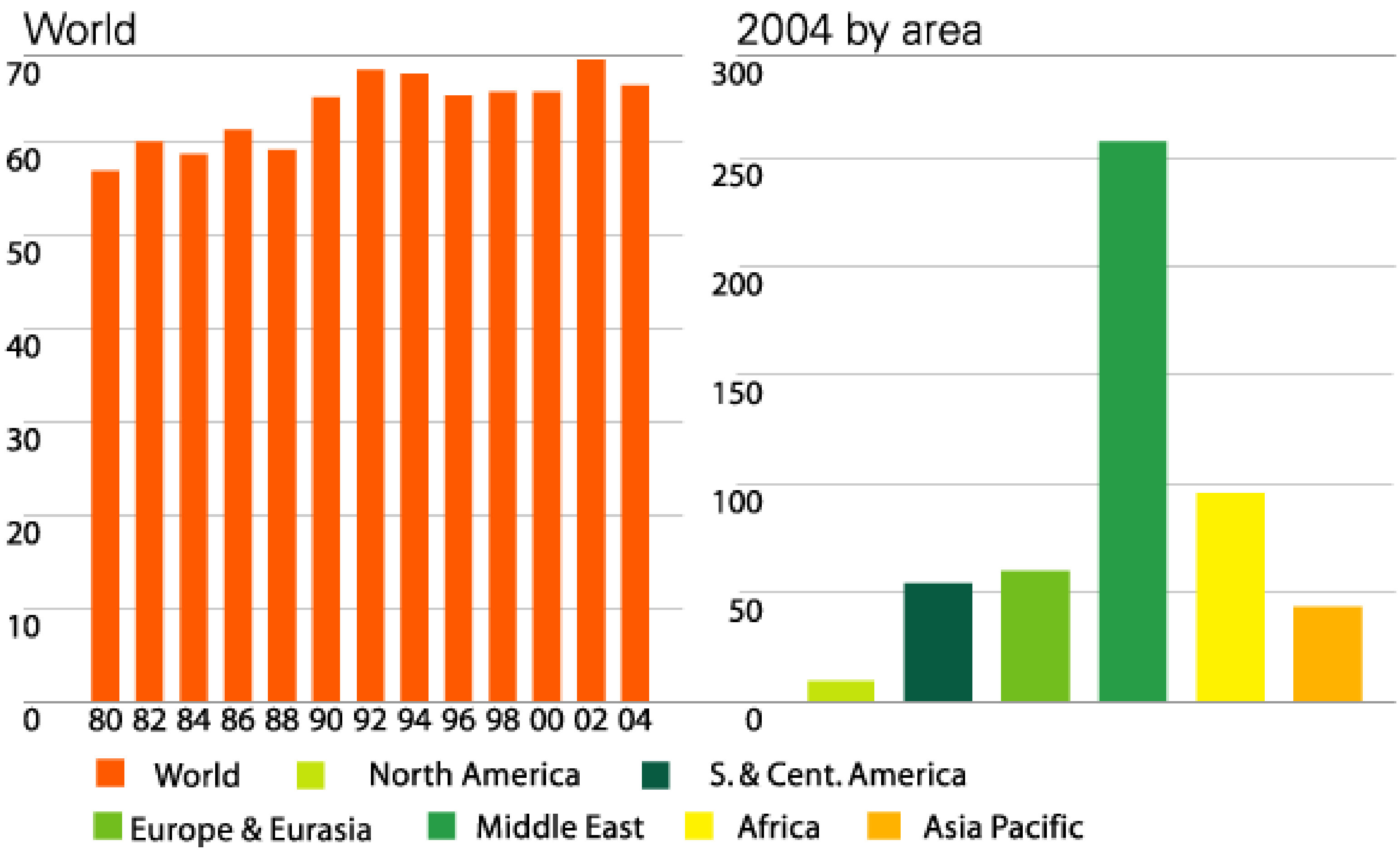
Proved natural gas reserves at end 2004

BP2005



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

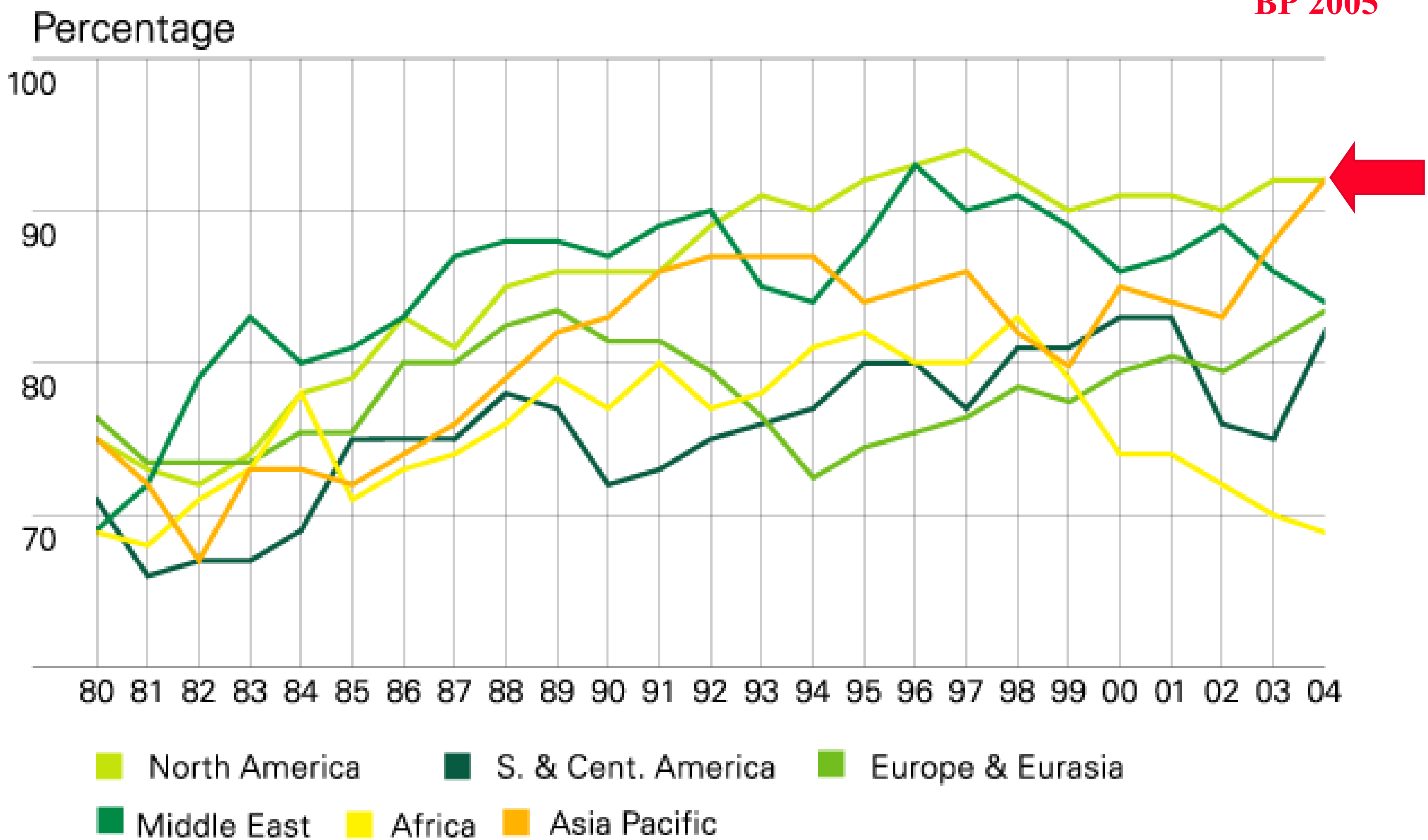
BP 2005



The world's gas reserves-to-production (R/P) ratio declined to 66.7 years in 2004, but remains well above the oil R/P ratio. Gas reserves are 26% higher than the 1994 level; production is 28% higher.

Oil refinery utilization

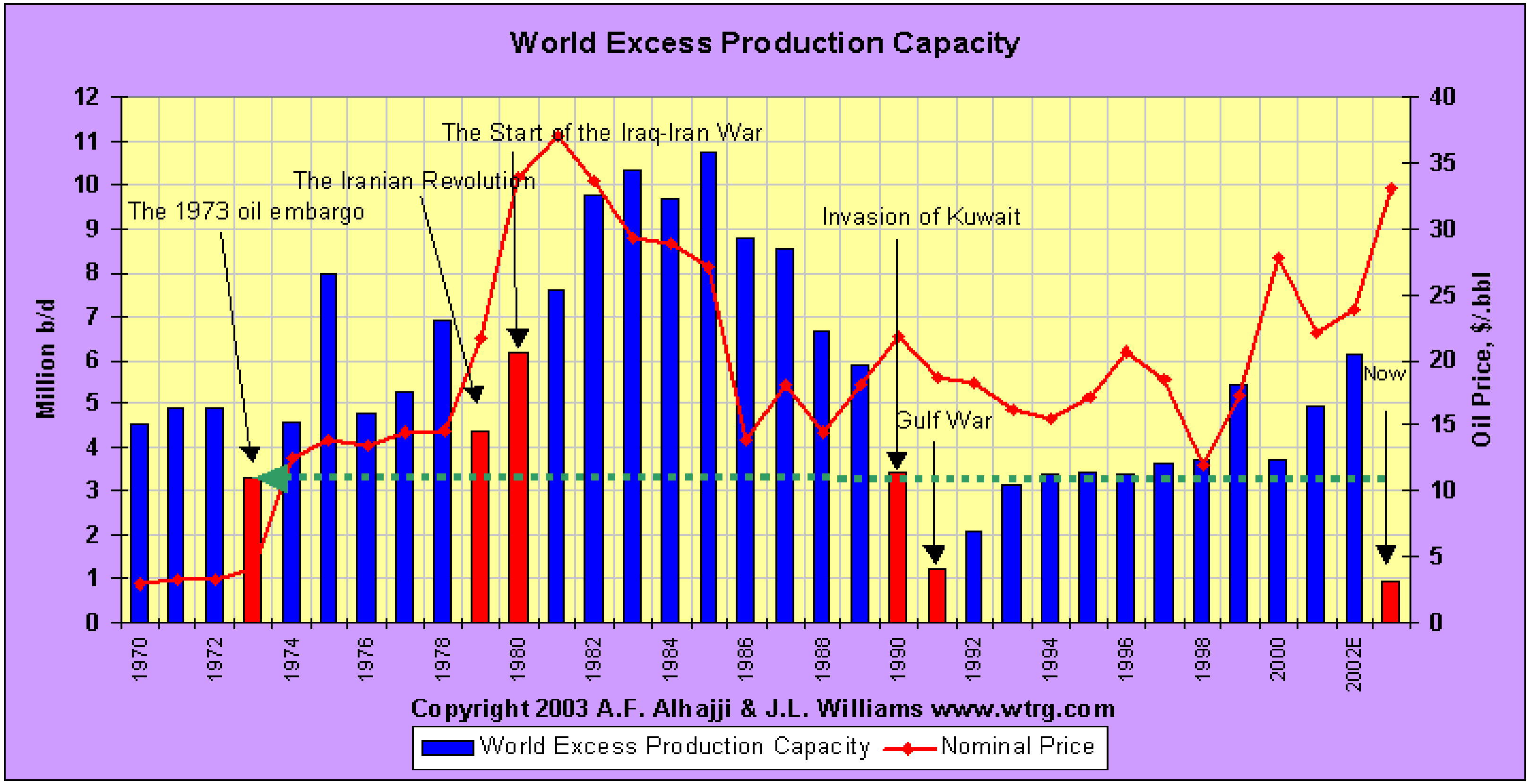
BP 2005



World refinery throughputs increased sharply in 2004 in response to very strong demand growth. The largest increases were in Asia Pacific, Europe and Eurasia, and South and Central America. As a result, global average refinery utilization increased to 87%, the highest level for at least 25 years.

Is There Excess Capacity?

- Many of the giant oil fields (54/65) are in decline
- Discovery is of smaller fields and in less accessible areas
- World consumption is increasing at ~2%
- In early Sept. 2004, excess world oil production capacity fell to 0.5-1.0 M b/d, all of which was in Saudi Arabia.



The scale of global energy needs and the associated infrastructure is mind-boggling

The pace of change of resource availability and competition necessitates new paradigms

Consumption of fossil fuels: The holes we are digging

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

- OIL: 1.7 × 1.7 × 1.7 km^3/year
- GAS: 2.1 × 2.1 × 2.1 km^3/year (as liquid)
- COAL: 1.6 × 1.6 × 1.6 km^3/year

CO_2 Sequestration needs roughly 3 times the mass/volume

Huge inertia in energy sector

- 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

The existing investment of >$10 trillion in oil cannot be changed overnight

NEED 3X

To sustain the 8 billion people expected by 2025 @ 5 kw/person we will need 40 Tw of power.

This is >3X today's 13Tw

What is driving change

- OIL: Global oil production expected to peak by 2010 while demand is increasing at ~2%!
- NATURAL GAS: expected to peak by 2025
- COAL: pollution

} CO2 and global climate change

- > 65% of remaining oil and gas reserves are in the Middle East and Russia
- USA will face increasing competition for oil and gas from China, India, Europe, …
- Business as usual: nuclear+solar+wind cannot cover expected shortfall in next 10++ years

No good alternative to oil for Transportation

Key Questions

- Can we continue to consume and assume that alternatives will be in place in time?
- Should change be left to market forces?
  - Higher gas prices → people buy more fuel efficient cars and drive less
  - Declining oil and gas → switch to [clean] coal and non fossil sources
- What new technology should we push?
- How real are the possibilities of major disruptions due to global climate change?

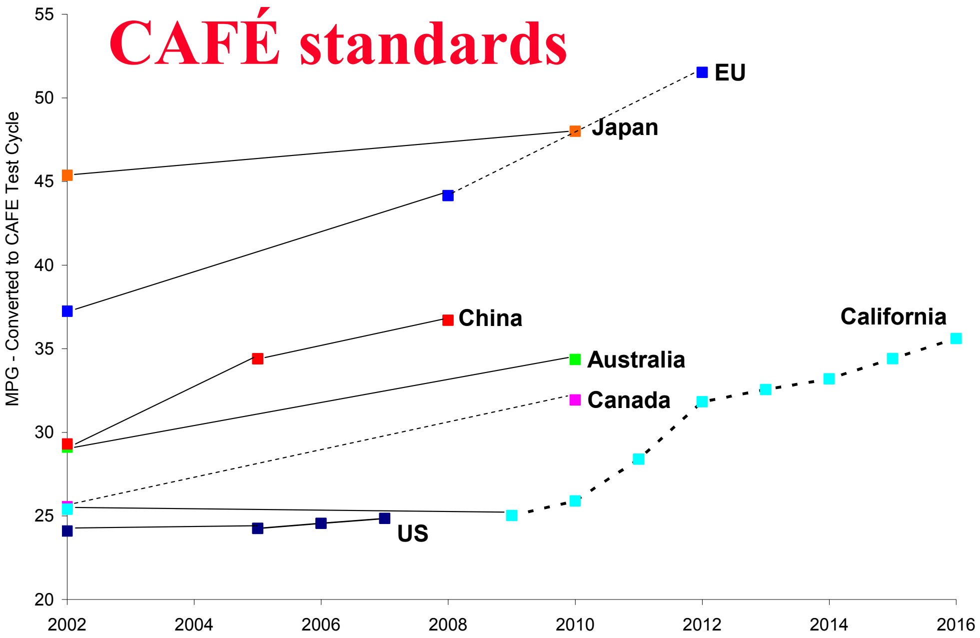
Overall Message: Need a national "Manhattan/Man on the Moon" program to

- Switch power generation to clean coal, nuclear and renewables
- Develop carbon capture and storage
- Develop non-fossil storage technology
- Improve fuel efficiency in transport, buildings, industrial processes, …
- Modernize transmission infrastructure
- Preserve oil for future needs in industrial processes and petrochemicals

Message

- There is no one solution
- There is no easy solution
- Solution: accumulation of many changes

The important question is whether we want a planned solution or a forced upon solution?



Source: An and Sauer, Pew Center

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KEY IMMEDIATE QUESTION

Is there abundant oil remaining?

Or are alarmists crying wolf again?

Demand is increasing at ~2%

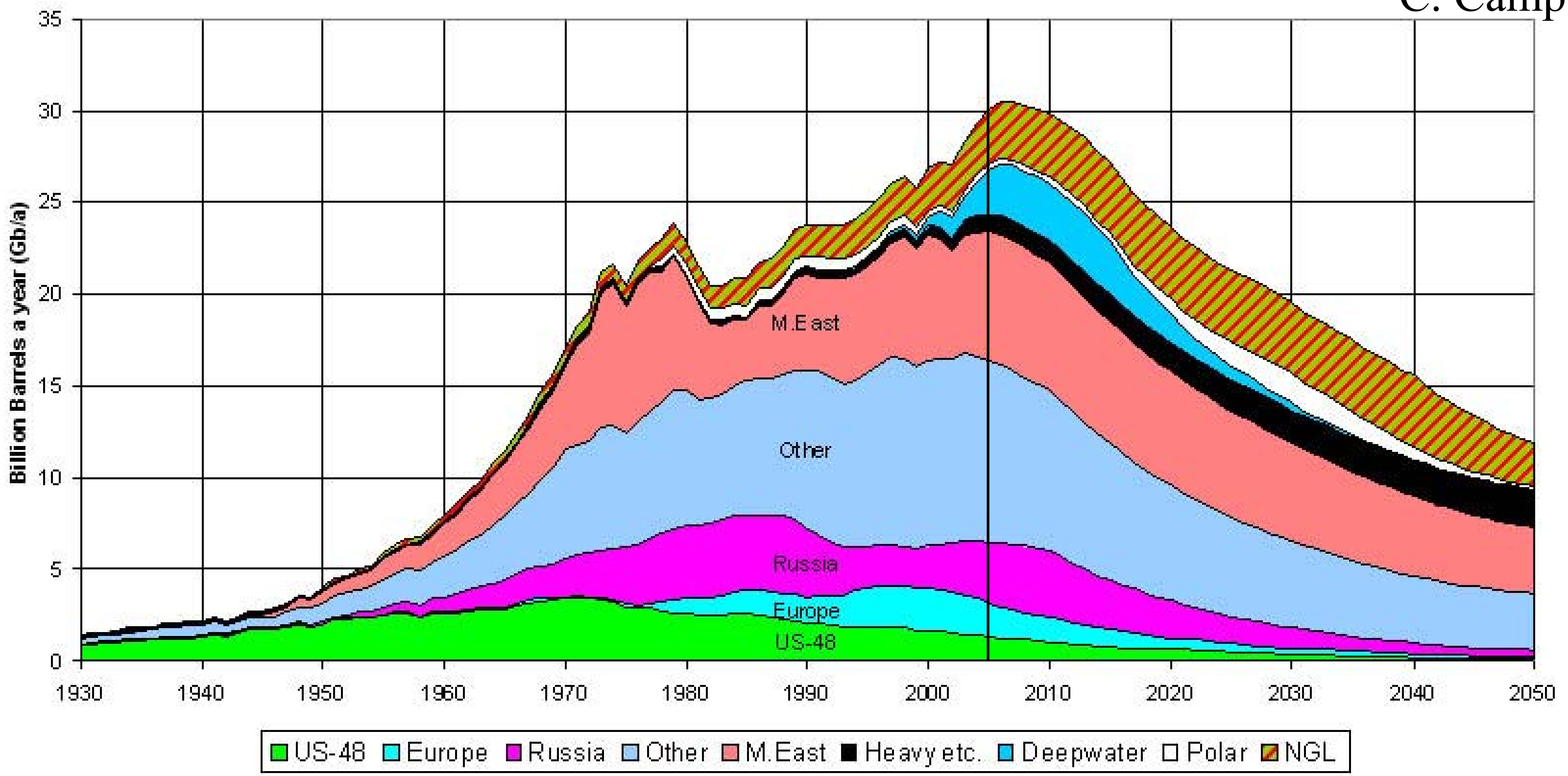
Many fields/regions are in decline

Supply gap will open after the peak

Production decreases rapidly after Hubbert's Peak (by 2010)

OIL AND GAS LIQUIDS
2004 Scenario

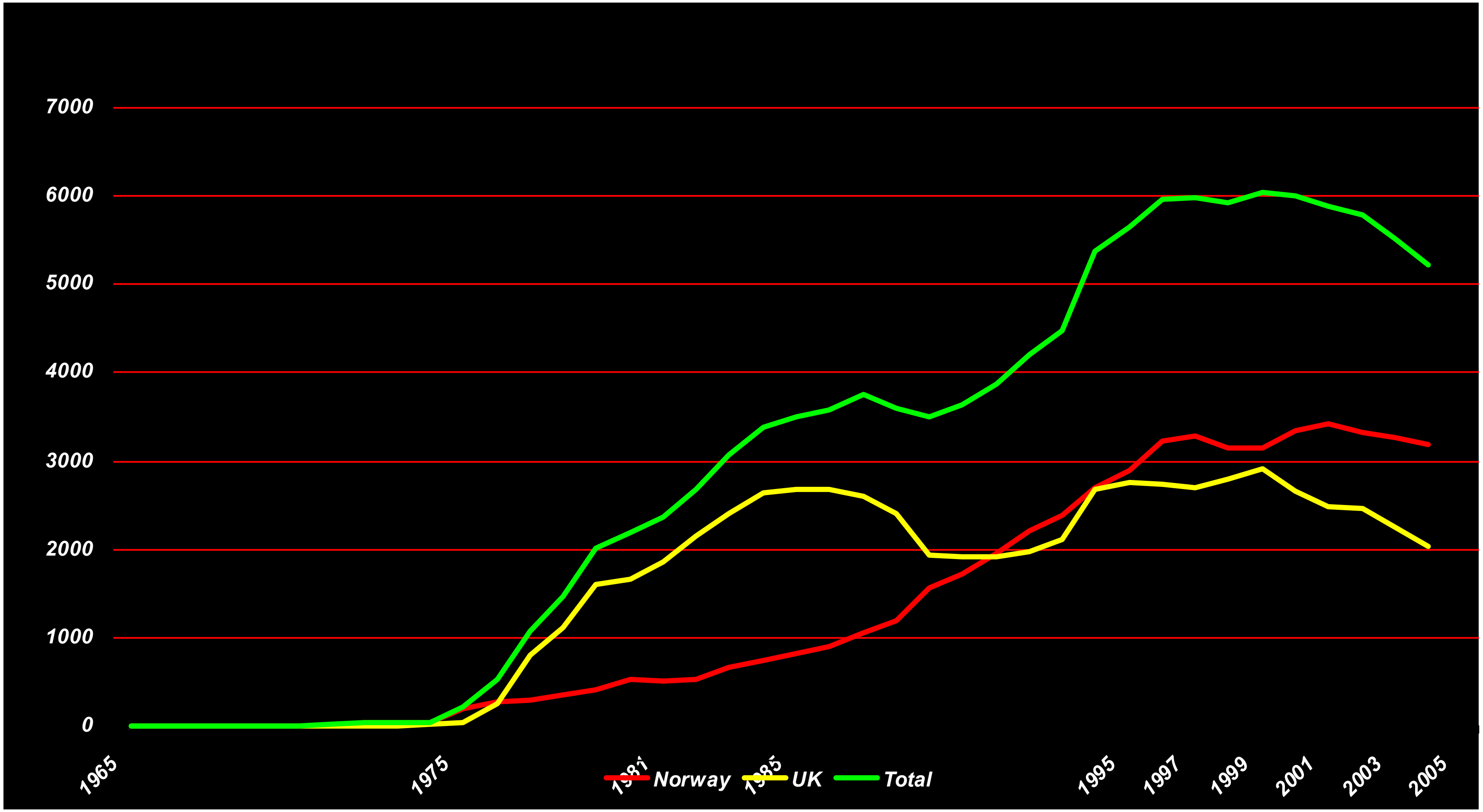
C. Campbell



A well understood example: North Sea Oil

Peaked in 1999 at 6.05 million bbl/day.

1999-2004: average decline at 2.8% to 5.22 million bbl/day



Source: EIA North Sea summary, BP statistical review 2005

If oil reserves are finite, when will global decline begin?

Debate: are there 1.0 or 1.7 tera barrels of recoverable oil remaining globally?

Unfortunately, the difference buys the world only 20 more years at current rates of withdrawal!

OIL

Energy surplus factor 20-50

No viable substitute yet for oil in transportation sector

Light oil is mostly alkanes C_nH_{2n+2} and alkenes C_nH_{2n}

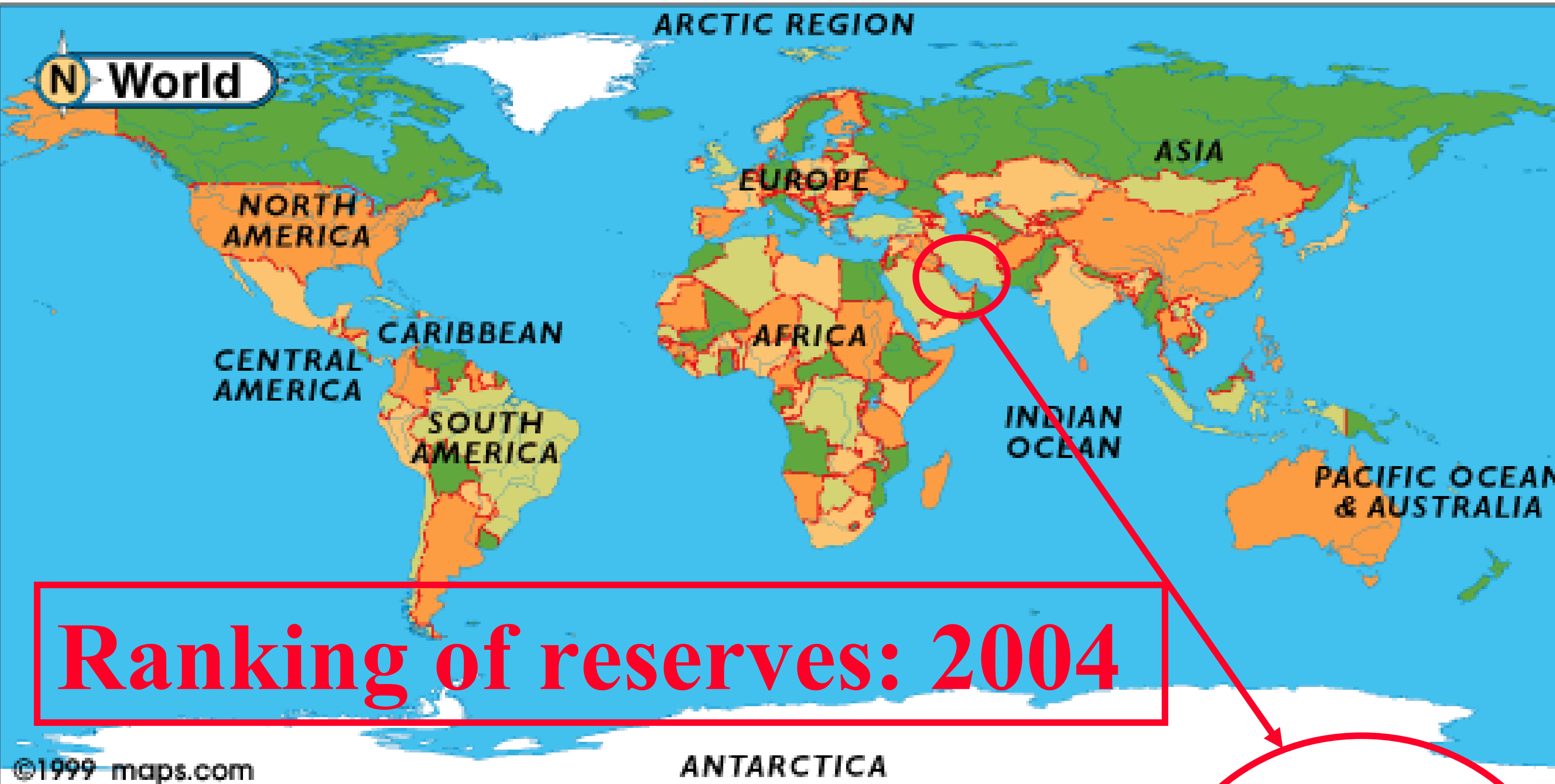
Rank	Country	Reserves BB	Prod./Consume MB	Export/Import
1	Saudi Arabia	261	10.37/1.64	8.73
2	Canada	180	3.14/2.29	0.85
3	Iraq	115	2.03	1.48
4	UAE	98	2.76	2.33
5	Kuwait	97	2.51	2.20
6	Iran	90	4.09	2.55
7	Venezuela	78	2.86	2.36
8	Russia	49	9.27	6.67
9	Libya	39	1.6	1.34
10	Nigeria	35	2.51	2.19
13	Mexico	15	3.83	1.80
	Norway	8.5	3.18	2.91
11	China	29	3.62/6.63	/3.0
12	USA	21	8.69/20.52	/11.8
	Japan		/5.4	/5.3
	Germany		/2.6	/2.5
	India	6	0.8 /2.4	/1.6

Natural Gas

- Methane CH_4
- Ethane C_2H_6
- Propane C_3H_8
- Butane C_4H_{10}

2002 rank	Country	2002 proved GAS reserves (trillion cubic feet)
1.	**Russia**	**1,700.0**
2.	**Iran**	**939.4**
3.	**Qatar**	**757.7**
4.	**Saudi Arabia**	**228.2**
5.	**United Arab Emirates**	**204.1**
6.	**United States**	**183.5 @ 22Tcf /per year**
7.	**Algeria**	**175.0**
8.	**Nigeria**	**159.0**
9.	**Venezuela**	**149.2**
10.	**Iraq**	**112.6**

Ranking of reserves: 2004



USA 12,6,1

China 11,-,3

EU -, -, 6

Russia 8,1,2

India -, -, 4

AT -, -, -

Persian Gulf

OIL 1,2,3 4,5

GAS 2,3,4, 5,10

No Coal

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Fast forward to 2020

USA -,-,1

China -,-,3

EU -, -, 6

Russia -,1,2

India -, -, 4

AT -, -, -

Persian Gulf

OIL 1,2,3 4,5

GAS 2,3,4, 5,9

No Coal

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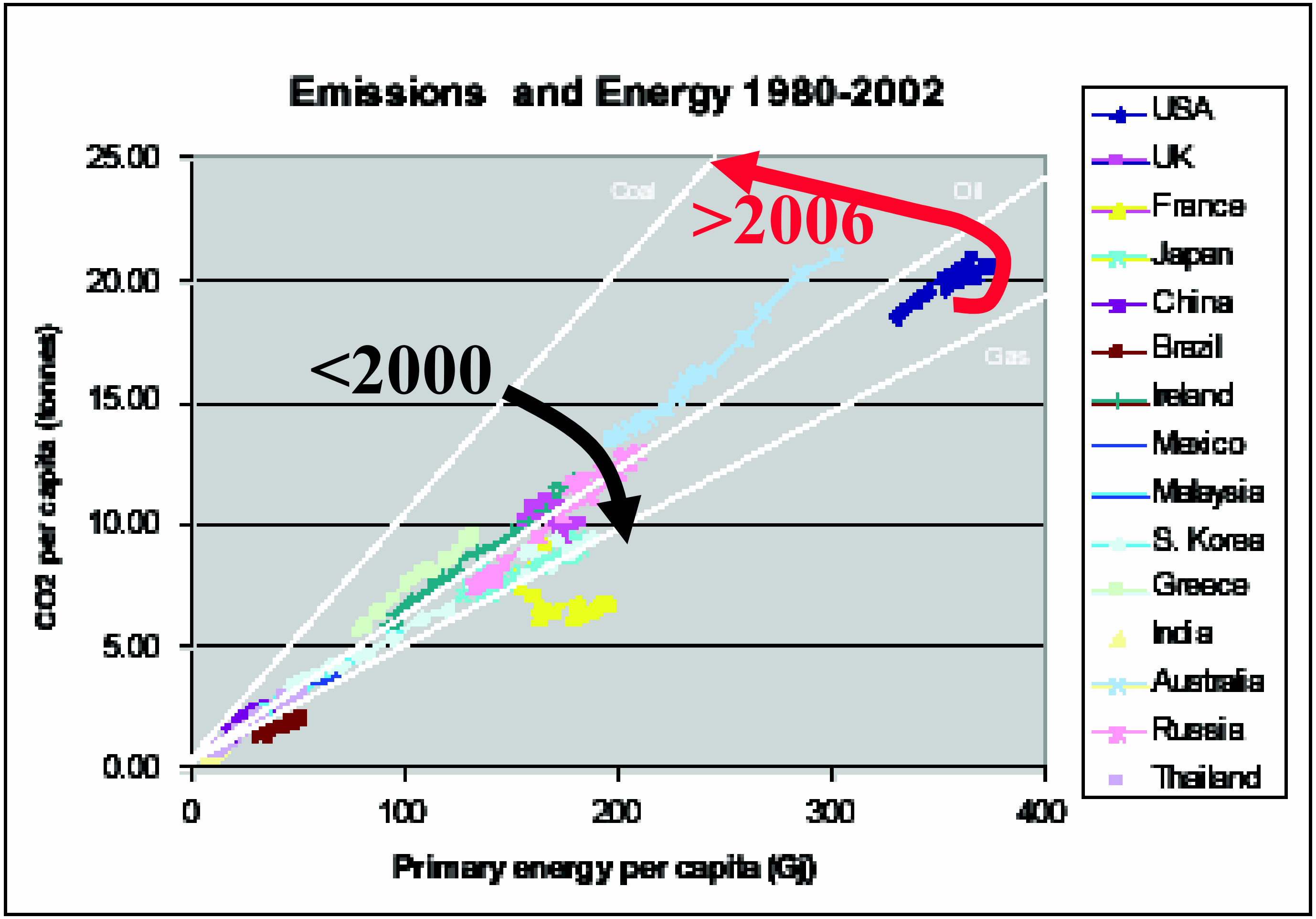
http://t8web.lanl.gov/people/rajan/

Headed towards coal → emissions



COAL

- Mostly carbon
  - composition varies between C and CH
  - produces most CO_2 on burning
- Contains many pollutants
  - Sulfur $\rightarrow SO_2 \rightarrow H_2SO_3$
  - NO_x
  - Mercury
  - Arsenic

COAL is abundant

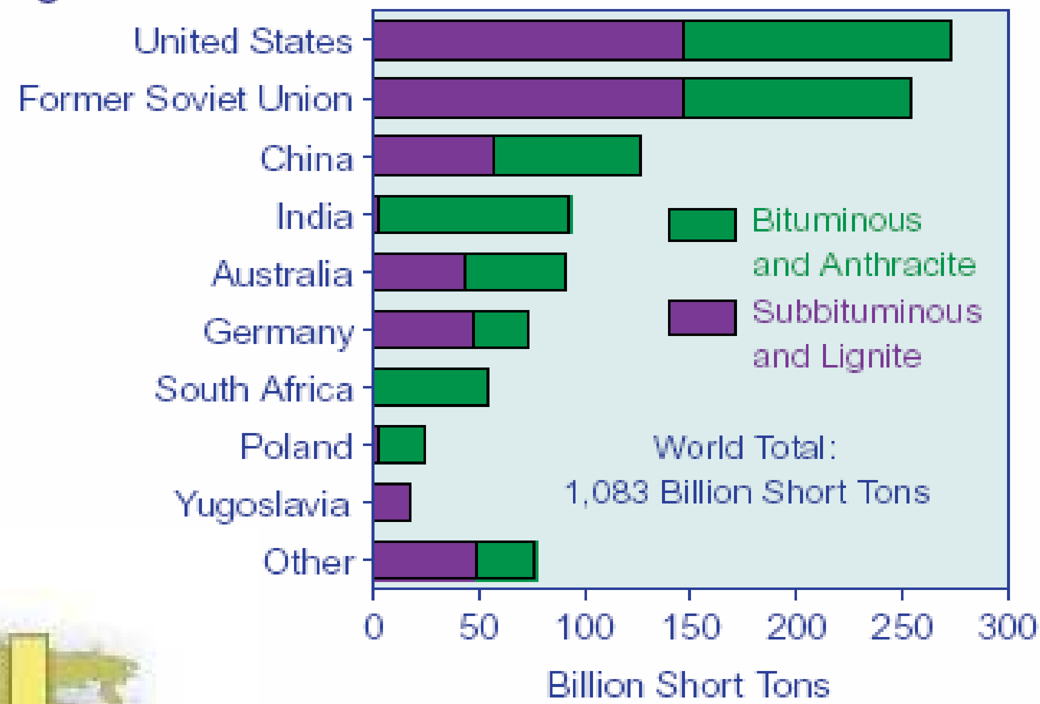
Based on 2001 production figures, global coal reserves will last about

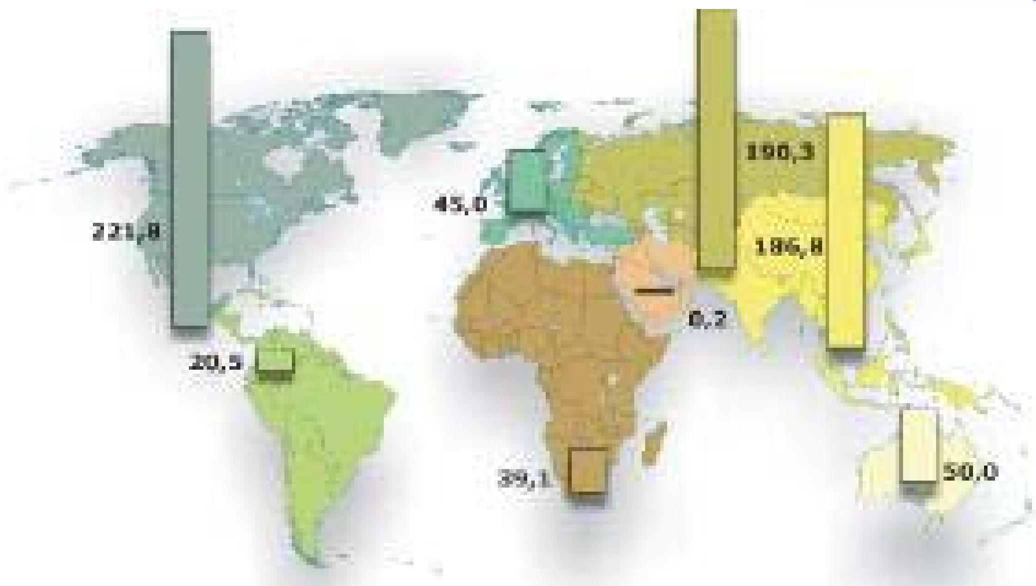
- **207 years for hard coal**
- **198 years for soft brown coal**

The US can lead the world by innovating clean coal technology for generating electricity

>90% of global coal reserves are in 10 countries

Figure 55. World Recoverable Coal Reserves





Source: International Energy Outlook 2004

Examine energy futures from three perspectives

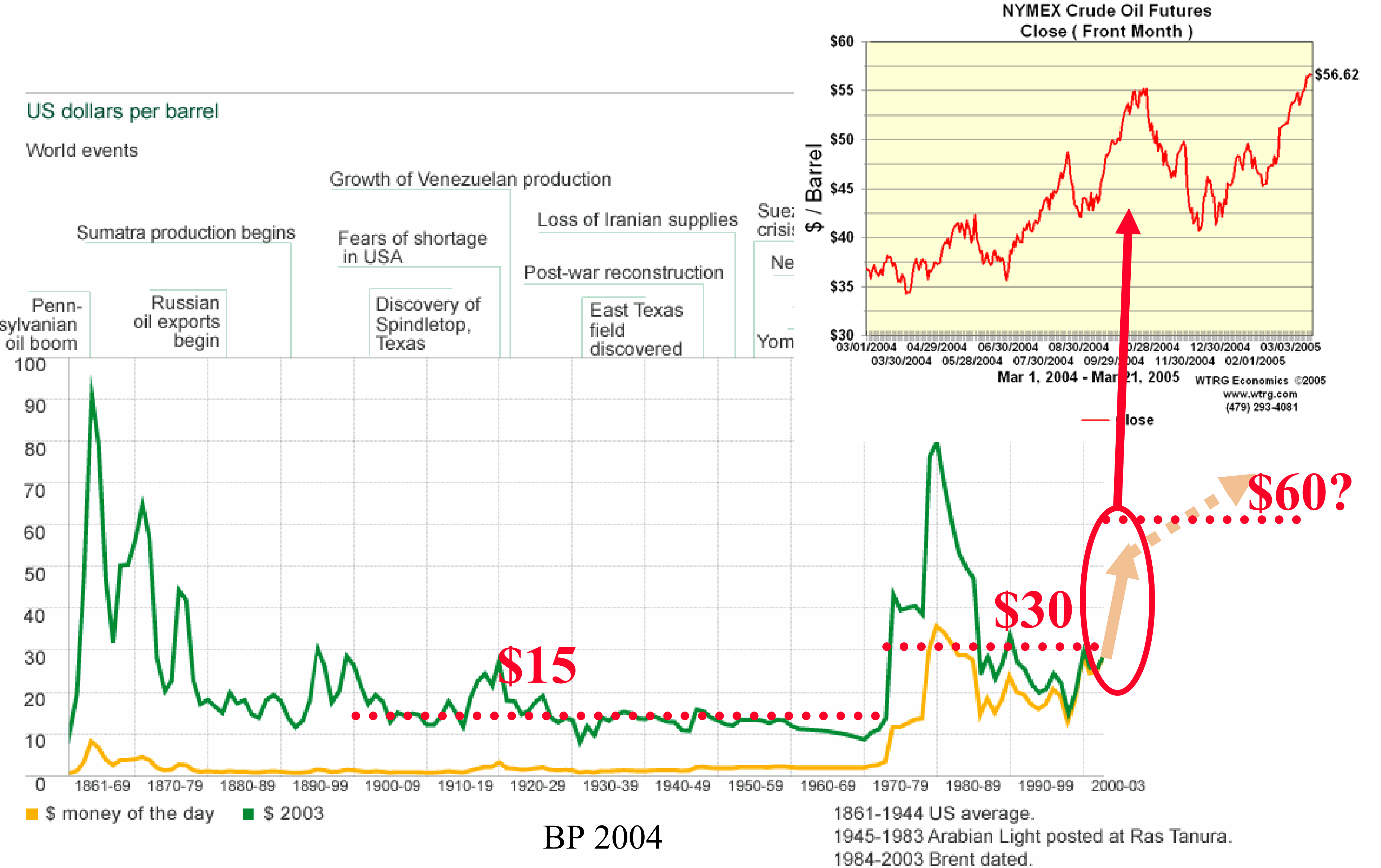
- Cost and Economic development
- National and International security
- Environment

NEED for timely action: ***Investment in power systems is recuperated over 40-70 years. It takes 10-15 years to develop new capacity. Planning and execution has to happen decades before shortages.***

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

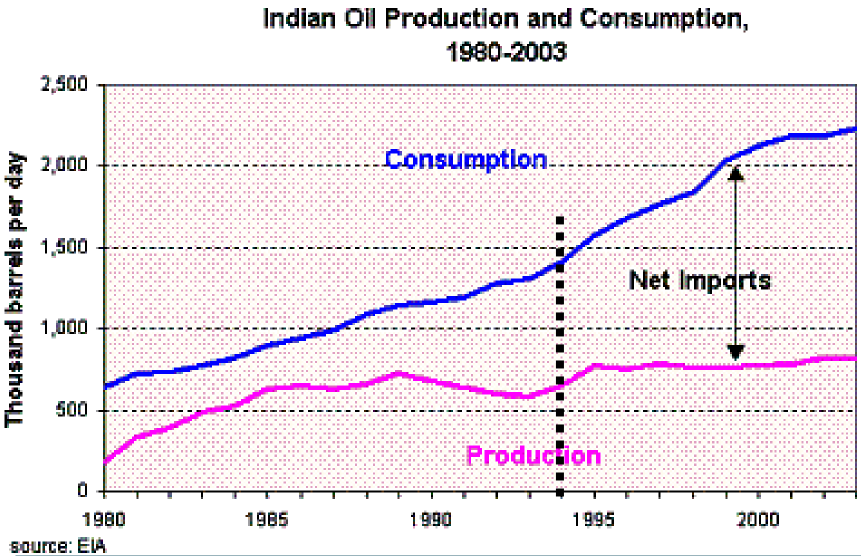
Where are we headed?

Increased volatility and high prices post 2004?



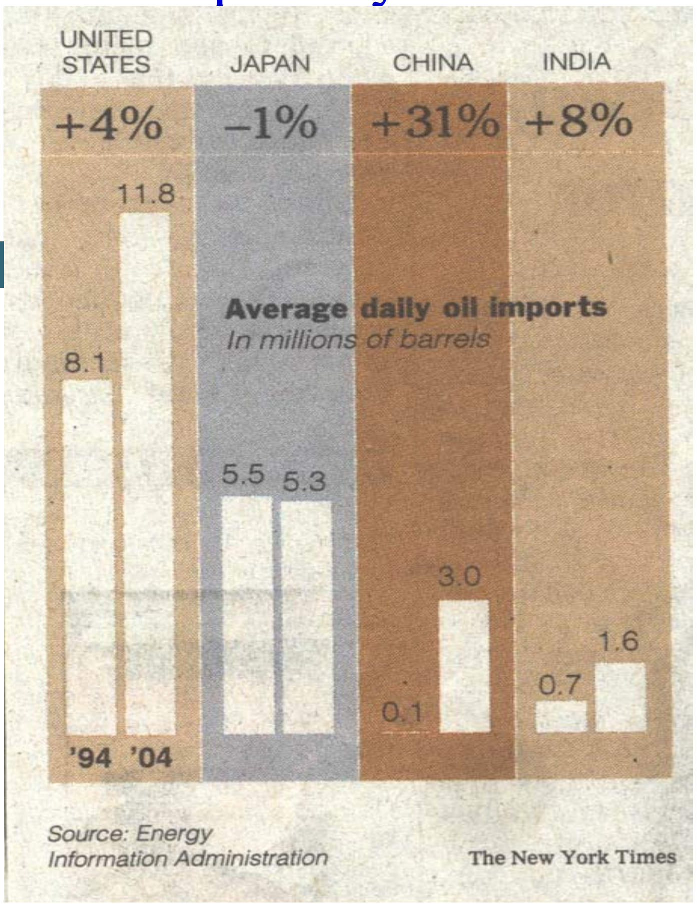
BP 2004

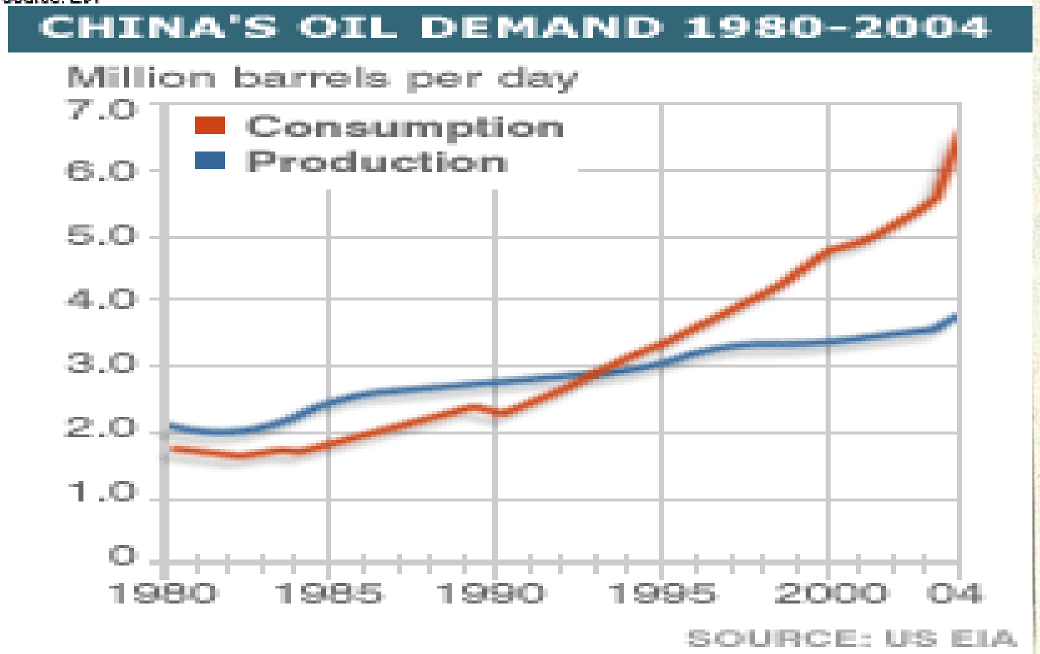
Increasing competition for oil and gas



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

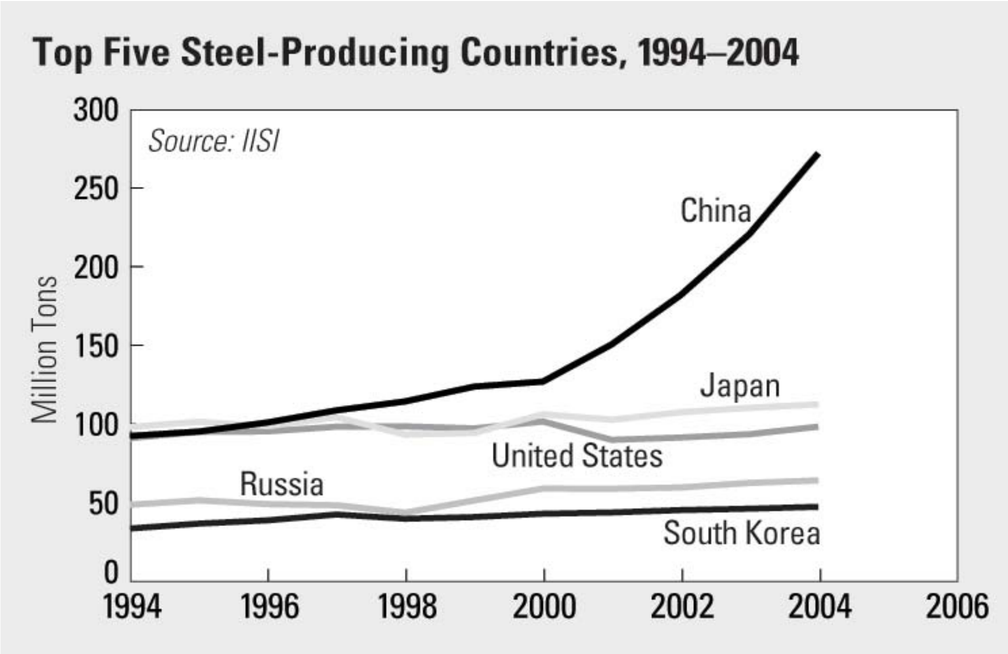
Chinese imports jumped by ~1Mbo/per day in 2004!

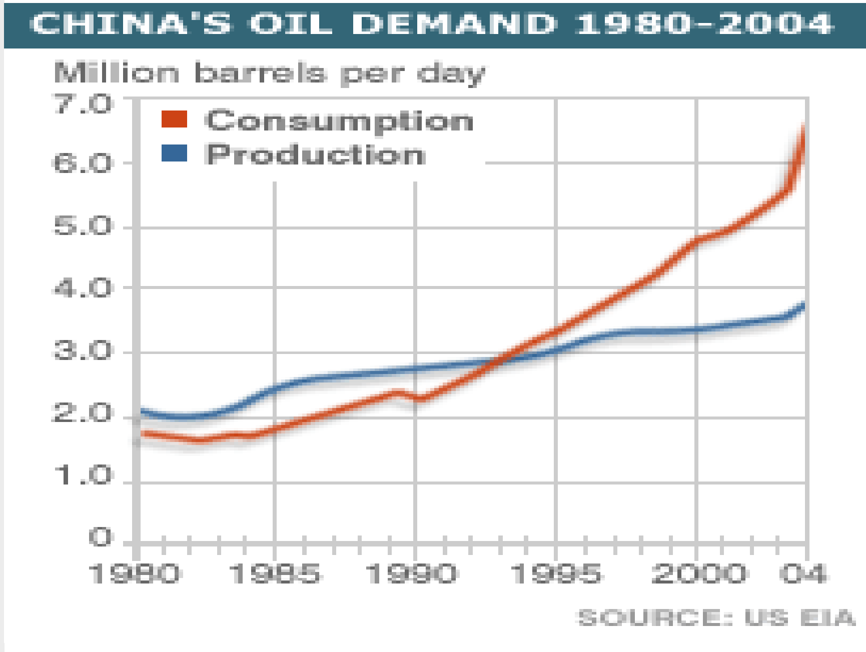


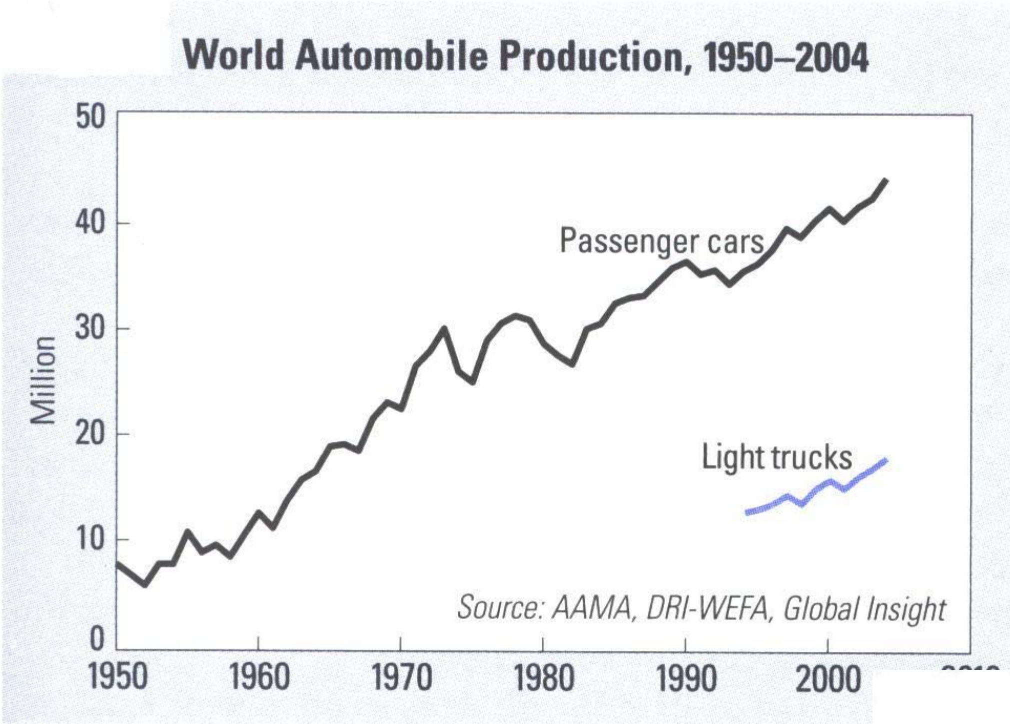


China and India are developing and they want more oil, gas, steel, cement, food, …

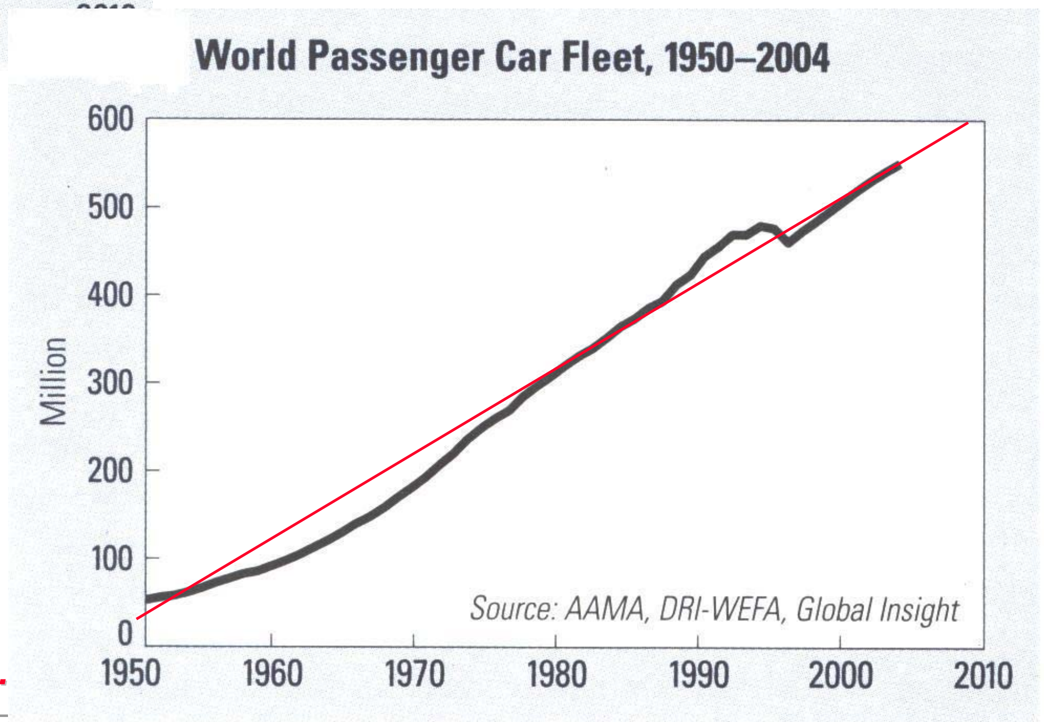
	2002	2003	2004
China: GDP	$1.3 T	$1.4 T	$1.6 T
China: Oil	4.92 Mbo/day	5.55	6.63
India: GDP	$0.51 T	$0.6 T	$0.69 T
India: Oil	2.2 Mbo/day	2.3	2.4

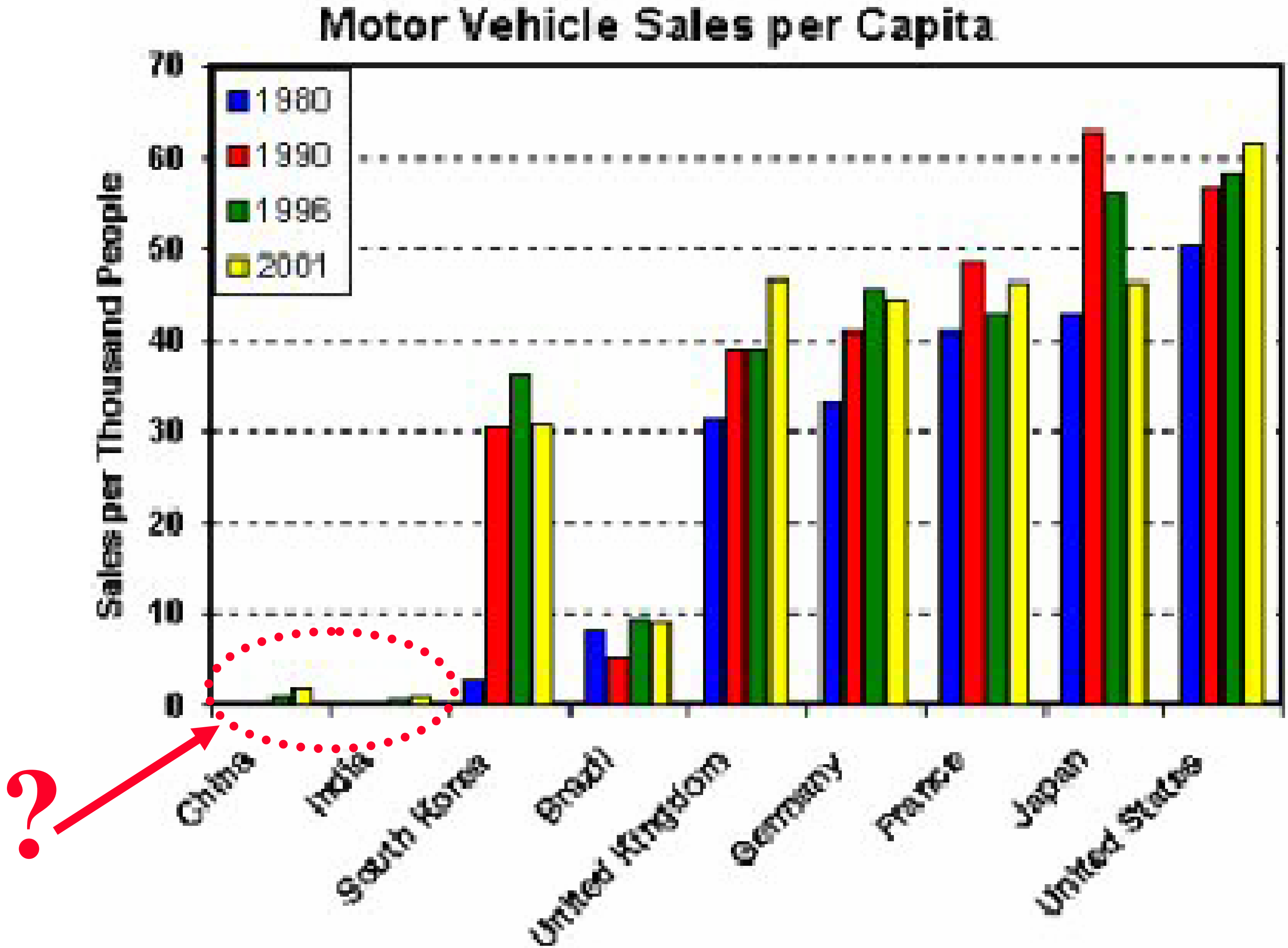






The world fleet of ~600 million cars/trucks need liquid fuel





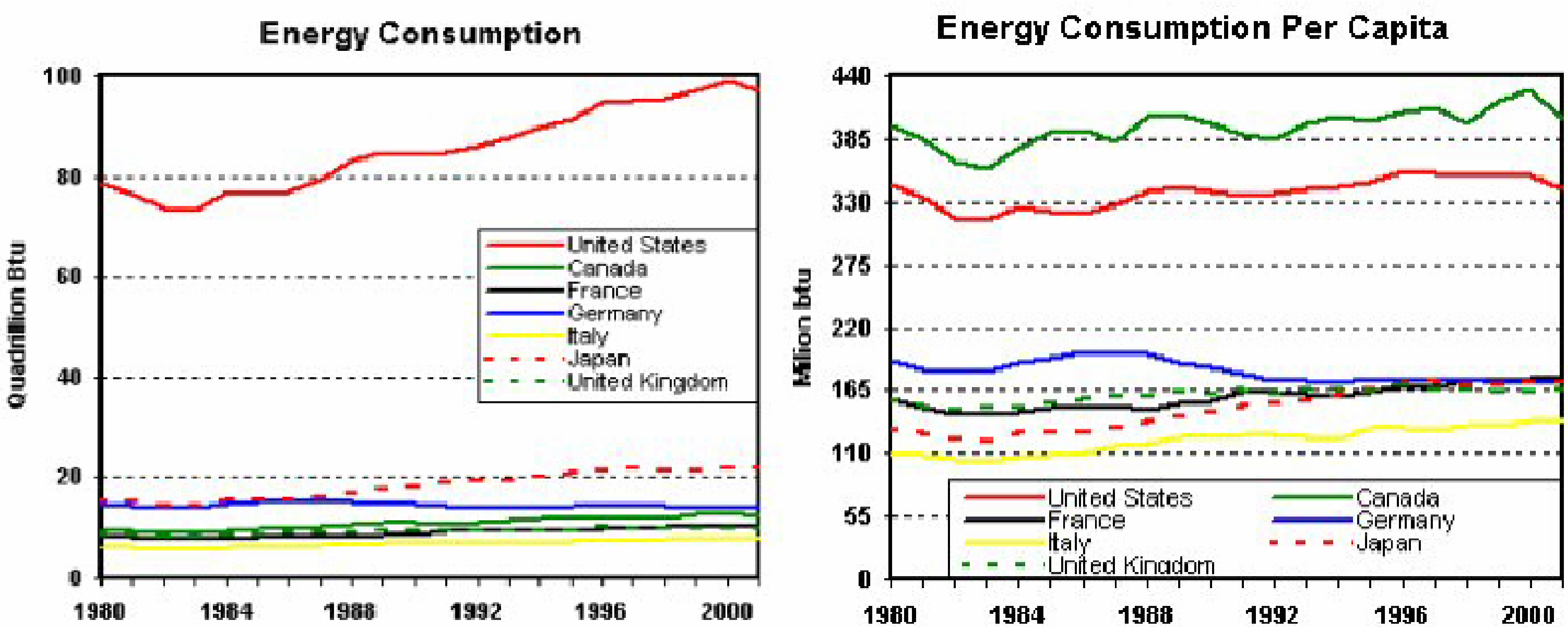
2nd USA? When China+India approach 80 vehicles/1000 people

If we <u>don't</u> want China, Pakistan, India, Bangladesh, Central Asia, Africa, … to fail

- They must have energy to develop!
- How much energy?
- How can we help them get clean energy inexpensively?

What is the global mean energy/per capita we should aim for?

G-7 Energy Consumption



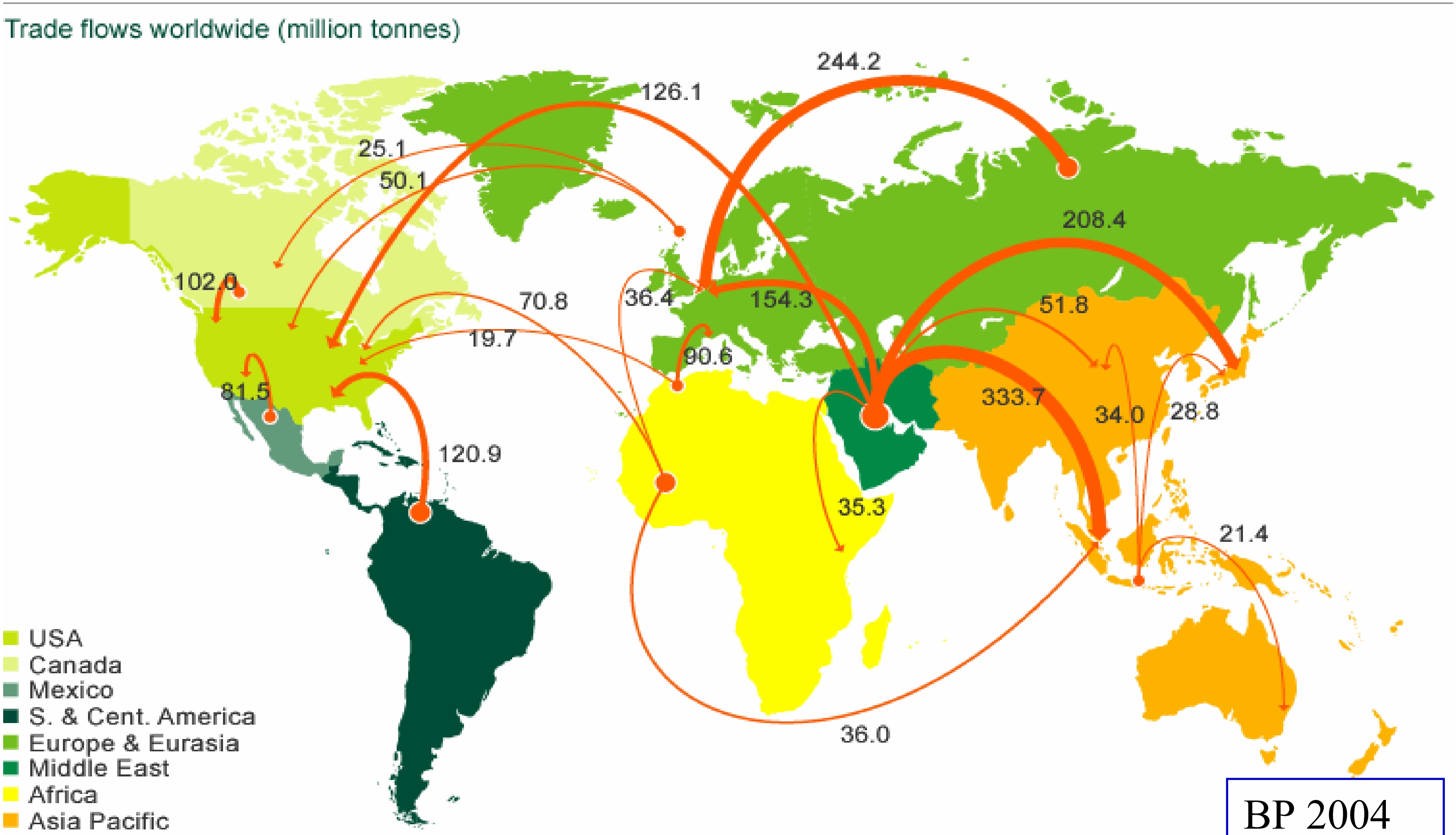
Japan, Germany, UK, France show a plateau at ~165 M btu/per capita → 5.5 kilowatt. The current global mean is ~2 kilowatt. How do we get it to 5.5kw?

GEOPOLITICS

Driven by

Oil and Gas Politics

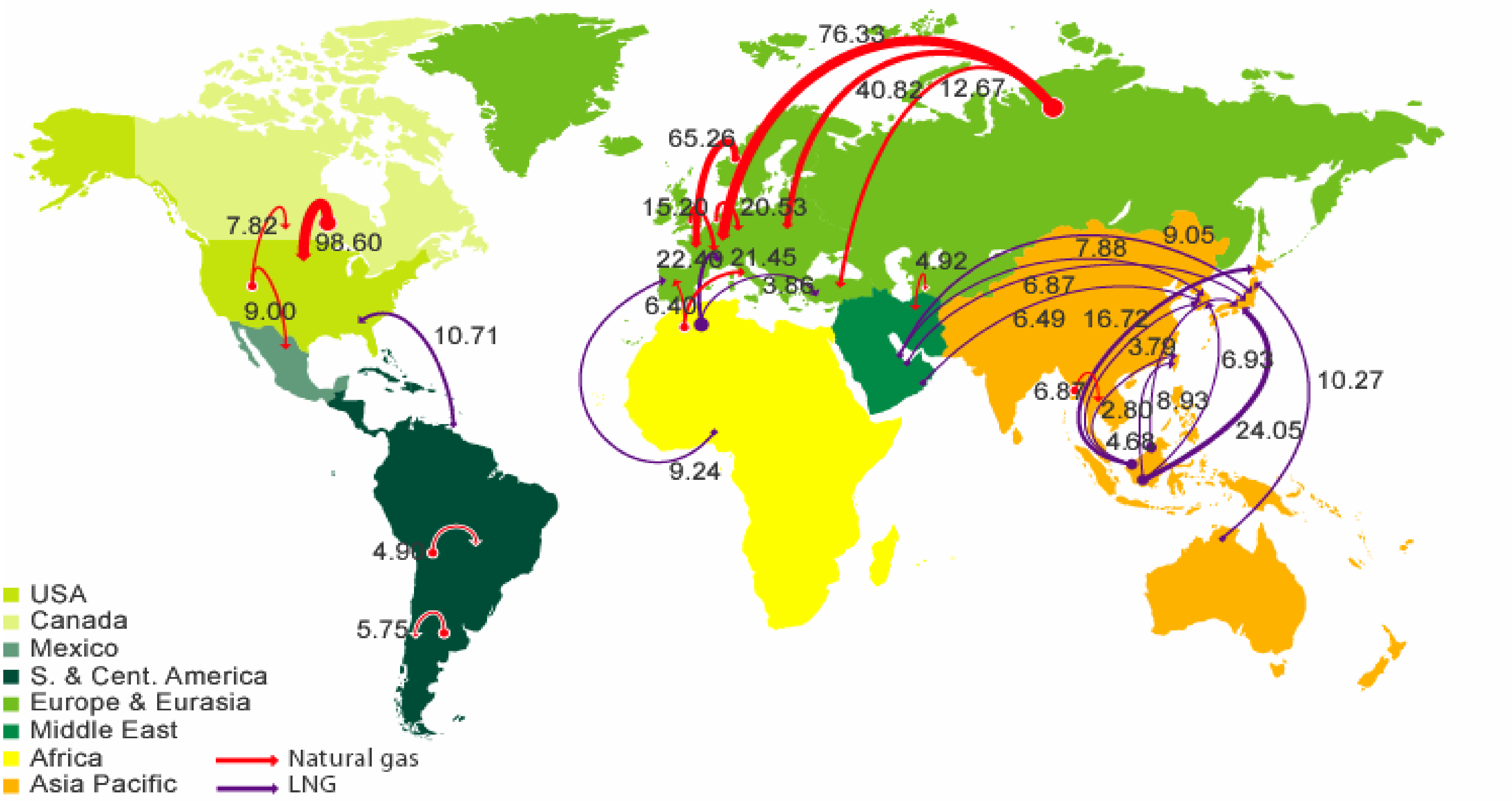
Major oil trade movements



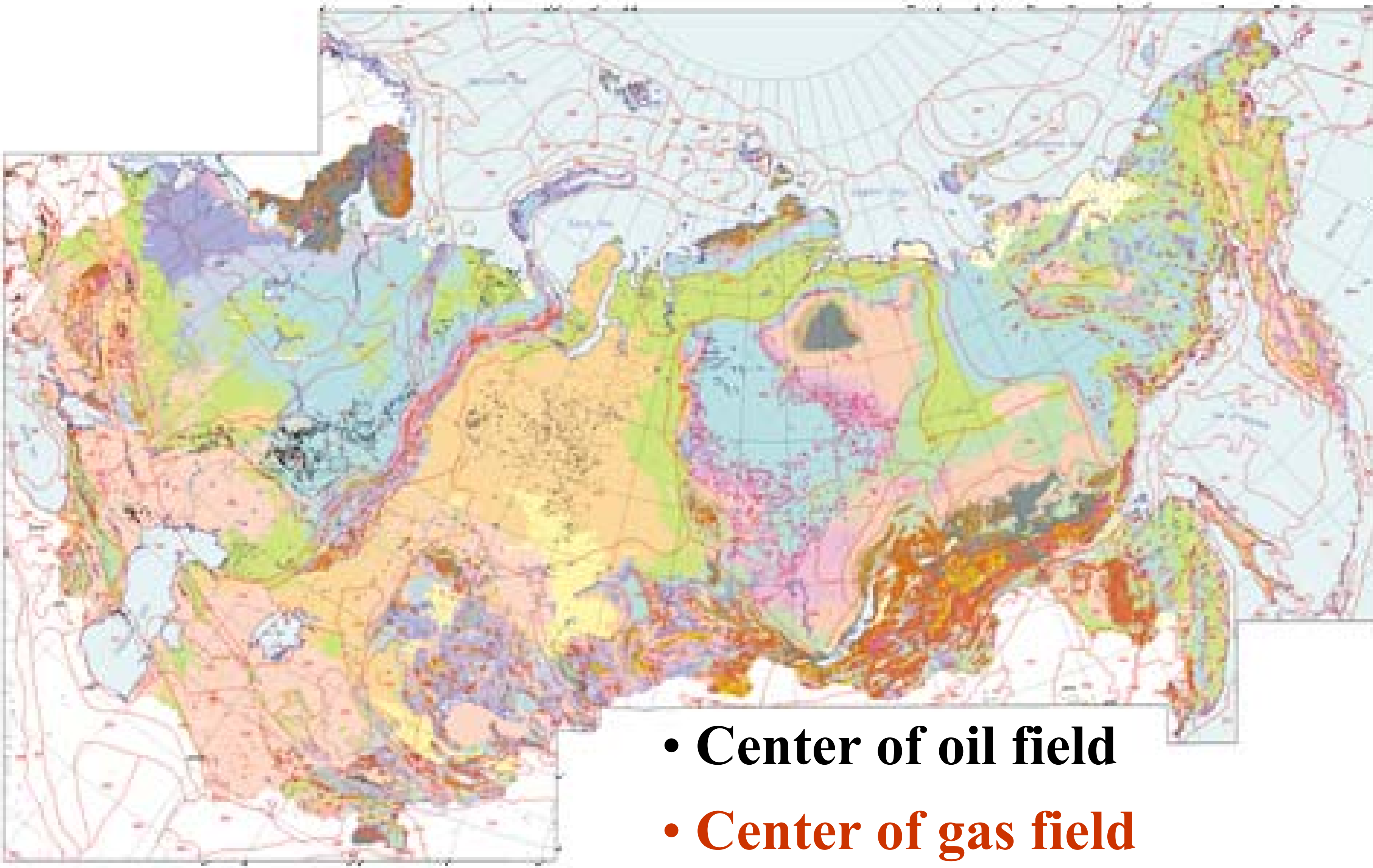
BP 2004

Major natural gas trade movements

Trade flows worldwide (billion cubic metres)



Where will Russian oil and gas go?

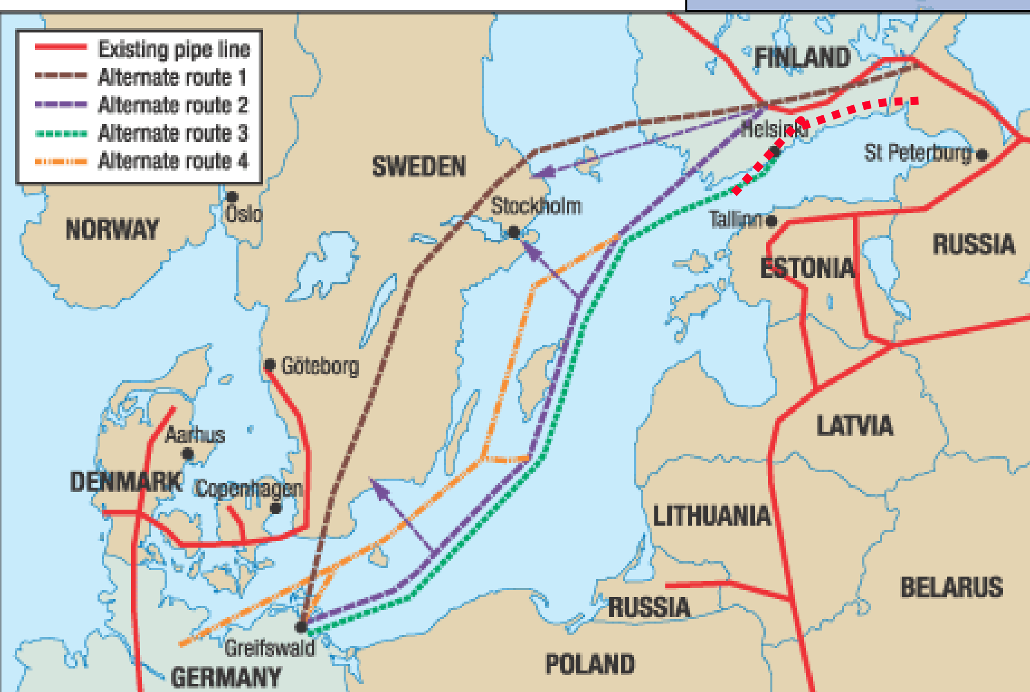


- Center of oil field
- Center of gas field

http://pubs.usgs.gov/of/1997/ofr-97-470/OF97-470E/fsumapG.html

PHILIPPE REKACEWICZ

Which countries will get Eurasian oil and gas in 10 years time?



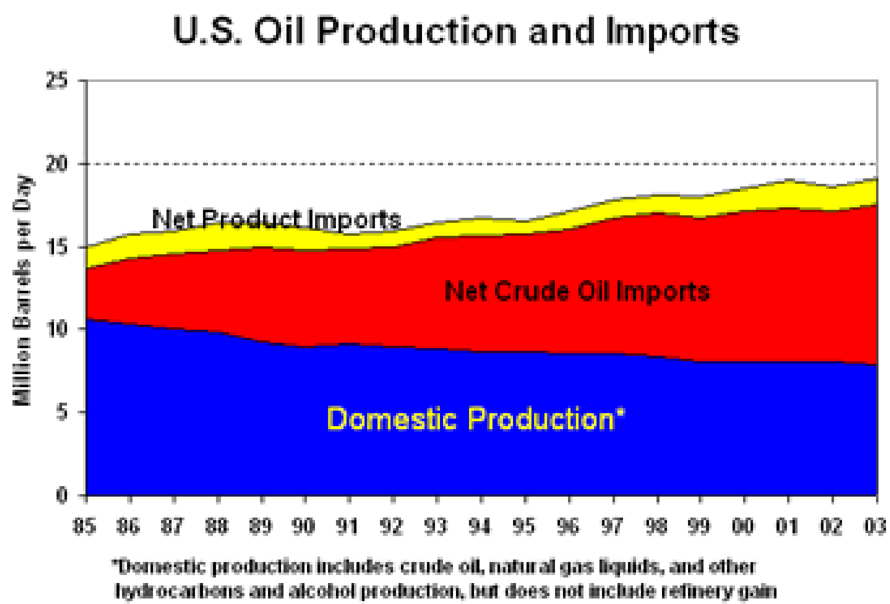
Russia bypassing Ukraine and Eastern Europe

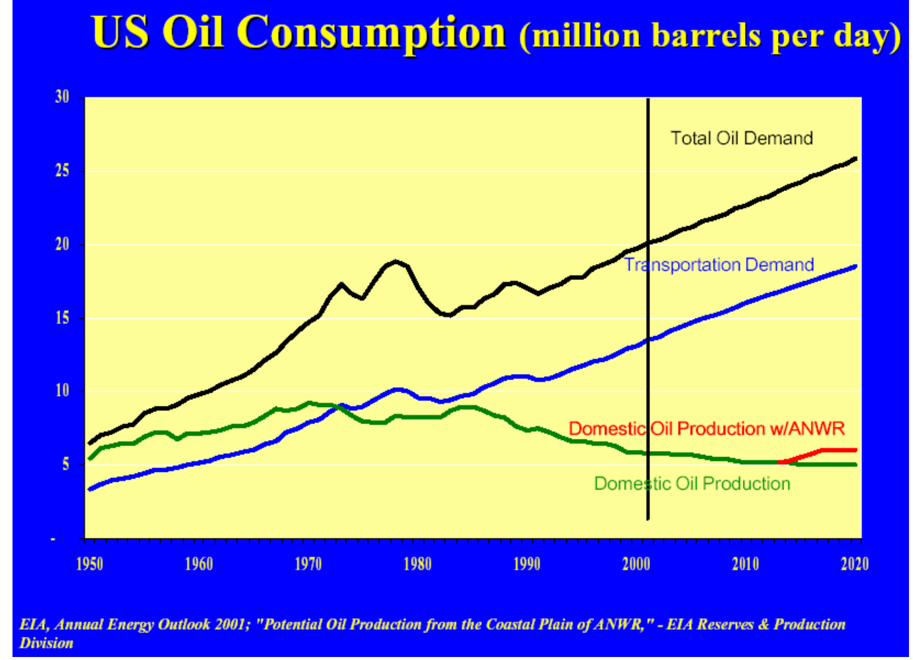
The natural destination for Persian gulf, Caspian Sea and Russian oil and gas is EURASIA

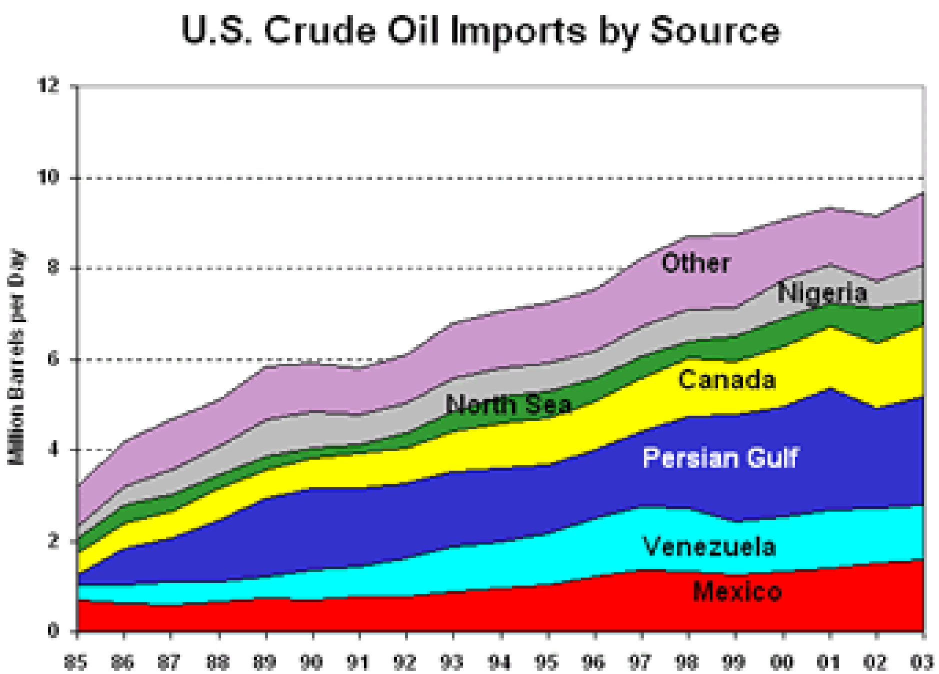
But the US needs them too!

What role will pipeline, tanker, refining capacity play?

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







Diversification

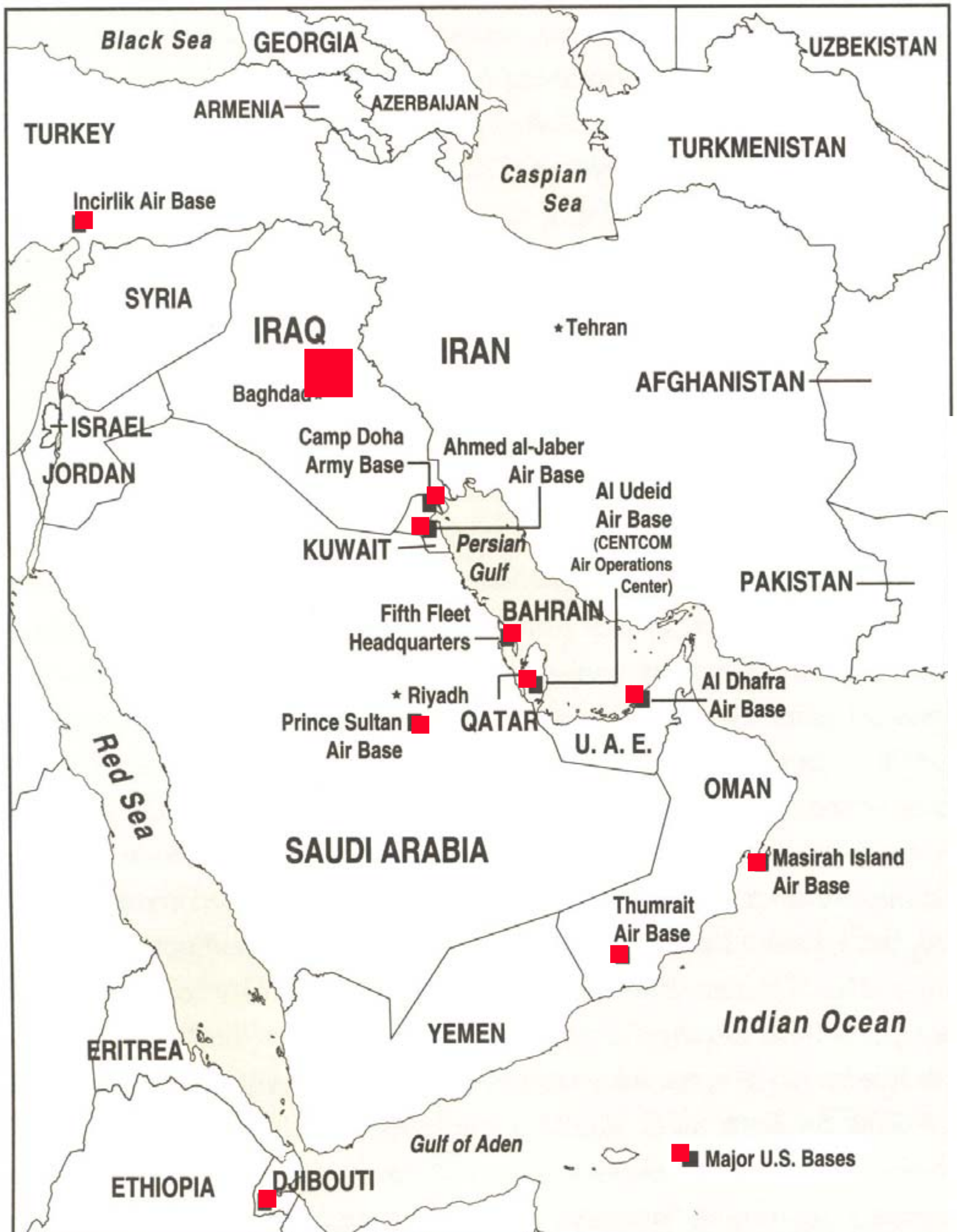
Middle East:	2.5 M barrels
Africa:	2.0 M barrels
Venezuela:	1.5 M barrels
Canada	1.8 M barrels
Mexico:	1.4 M barrels
North Sea:	0.9 M barrels
Far East:	0.4 M barrels
Soviet Union:	0.1 M barrels

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 Middle East and Central Asia.

A very successful but costly military investment



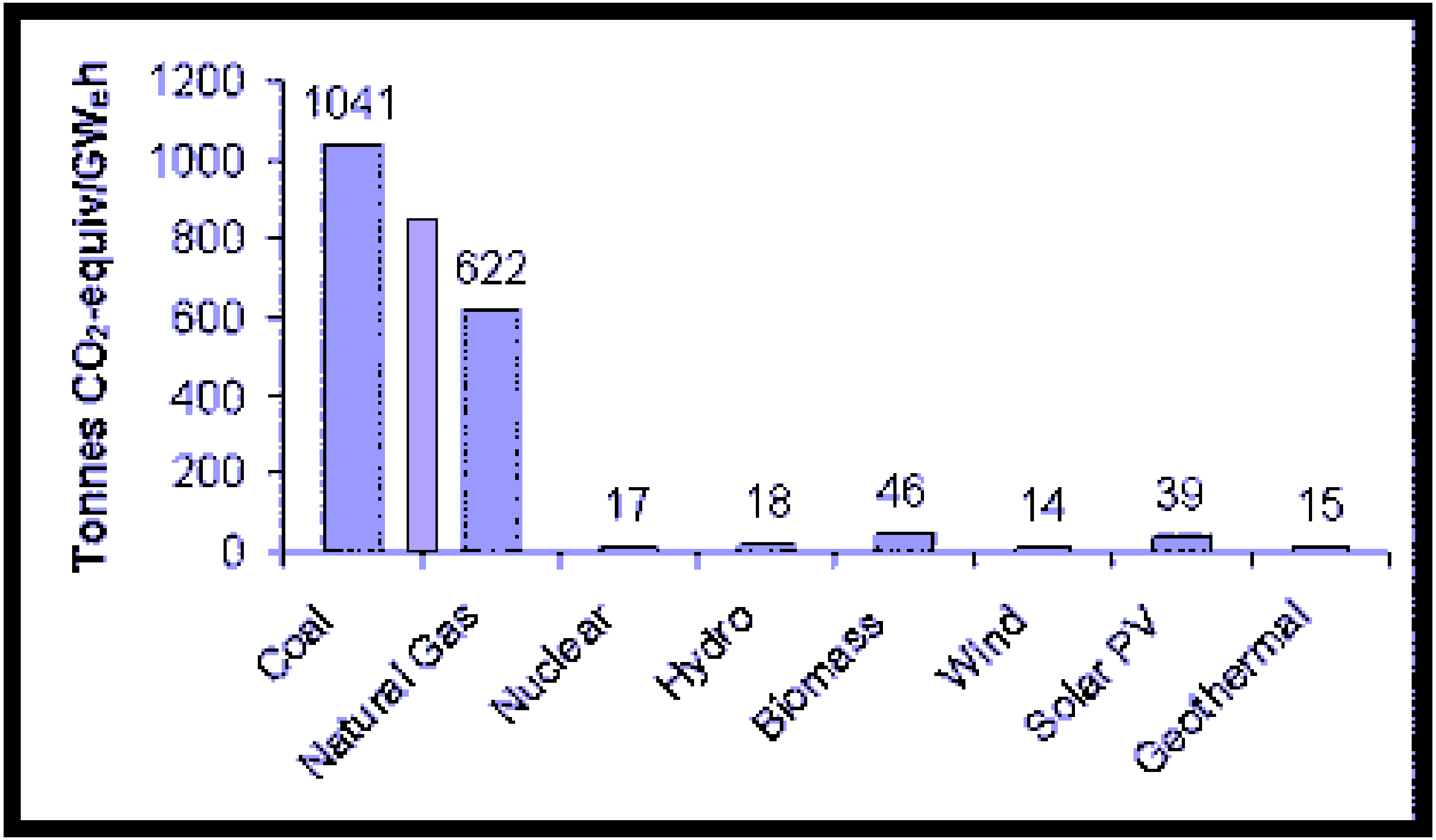
What is the true cost of USA's thirst for oil?

- Should we continue to demand more?
  - Use our military to guarantee supplies?
  - Or burn more coal?
- Or use innovation (R&D) to reduce dependence on imported oil and gas
- And conserve and preserve our reserves for future use in petrochemicals?

Energy and Environment

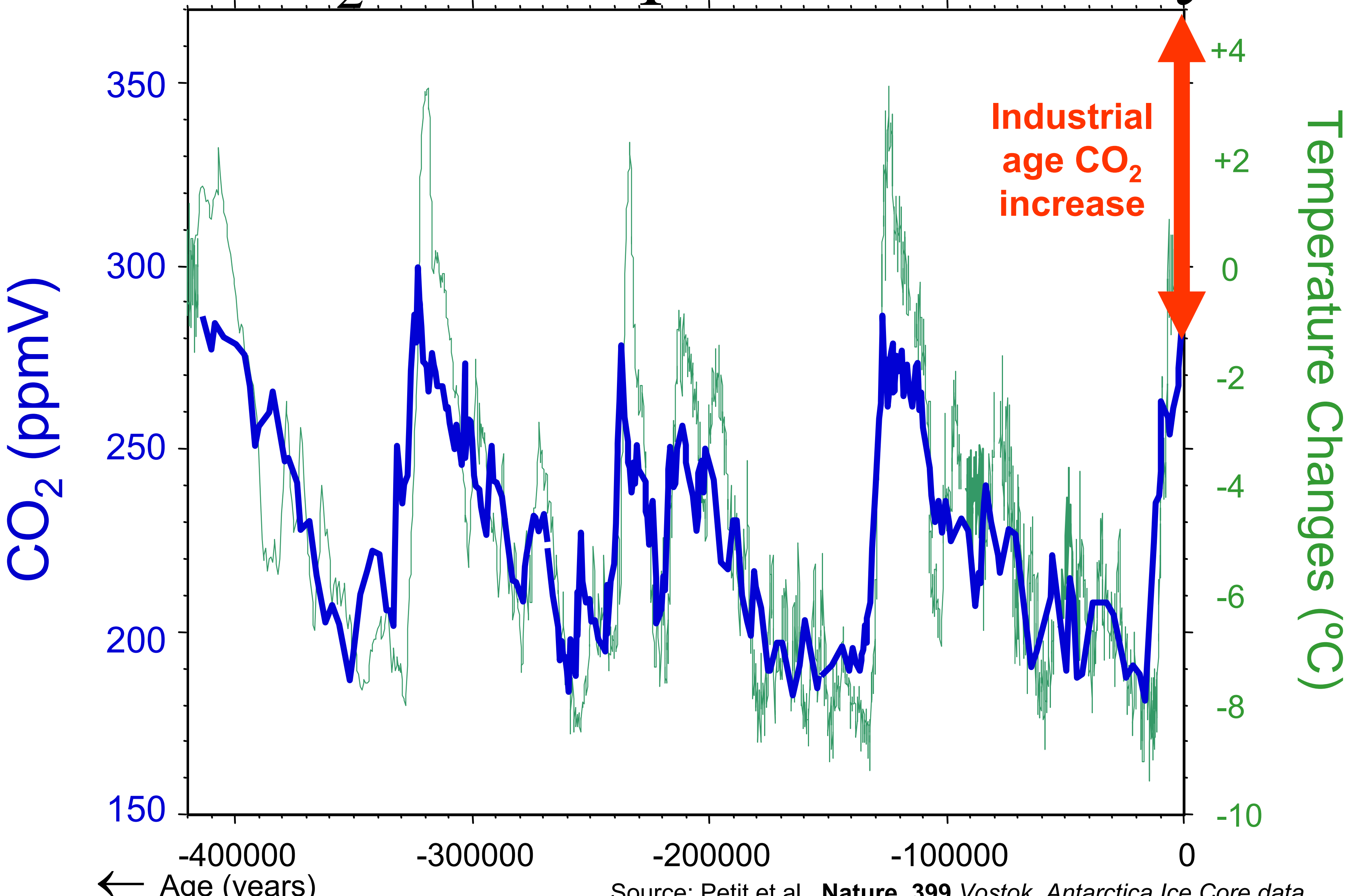
Climate change is the largest and costliest uncontrolled experiment being done

The hidden and ignored environmental cost of CO2 emissions

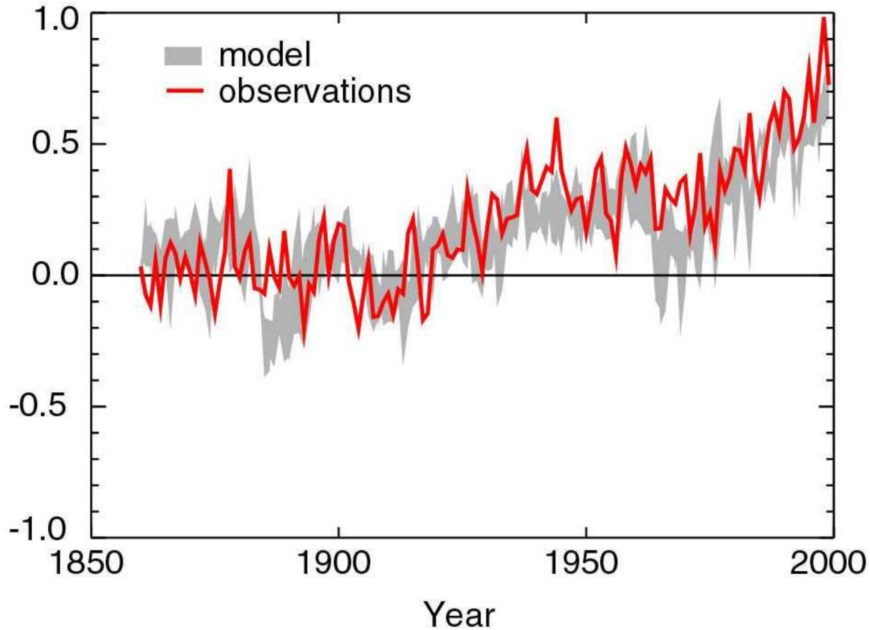


Comparison of life-cycle CO2 emissions from different electricity generation options. Emissions from oil are roughly in between coal and natural gas. (Source: "Life-Cycle Assessment of Electricity Generation Systems and Applications for Climate Change Policy Analysis," Paul J. Meier, University of Wisconsin-Madison,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

CO_2 & Temperature History



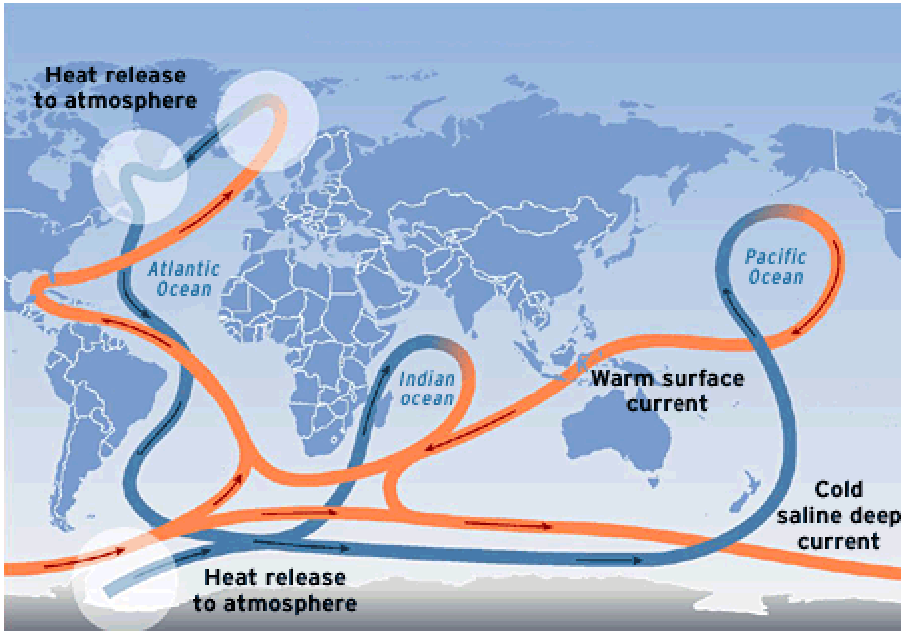
Source: Petit et al., **Nature 399** *Vostok, Antarctica Ice Core data*



Increasing evidence for temperature rise due to fossil-fuel burning

Possibility of catastrophic change:

Shutdown of the thermohaline



Energy Security
is
National Security
and
Environmental Security

NEED

- **Cheap**
- **Clean**
- **Copious**

ENERGY

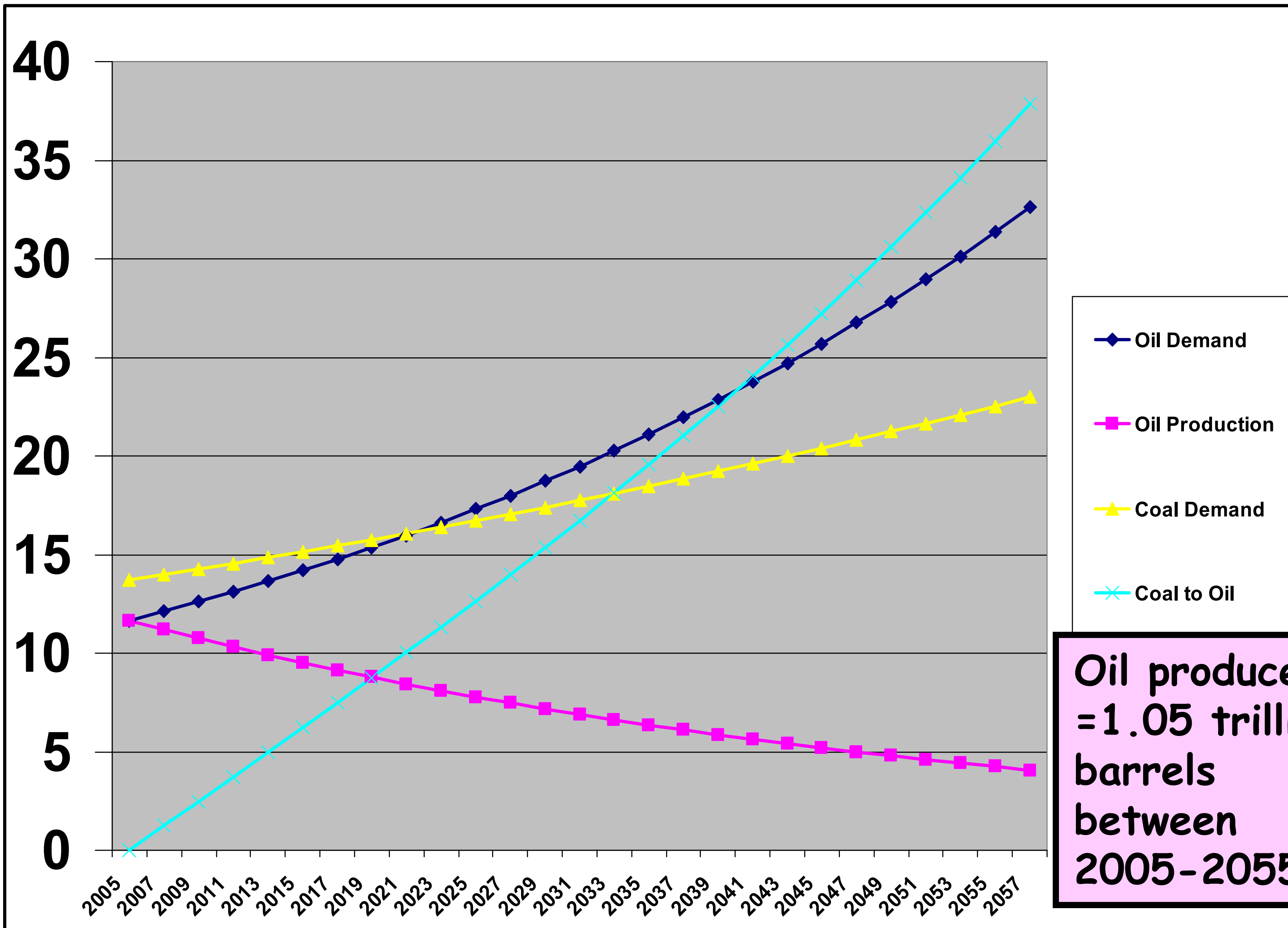
How do we help tailor the right mix for a given nation?

Clean coal technology has yet to be implemented

What happens if conventional oil peaks in 2006, demand continues to rise, and coal is used to cover the shortage?

Oil demand growth 2% /per year coal demand growth 1%

Oil production decline 2% coal to oil to cover shortfall



Oil produced =1.05 trillion barrels between 2005-2055

The magnitudes are staggering. Without clean coal we have a huge environmental problem

Pollution and global climate change

Priority: Clean Coal

- Integrated Gasification Combined Cycle (IGCC)
- FutureGen
- Vision 21

When?

- **Multiple feedstock**
- **Higher efficiency (CC)**
- **Multiple products (modular)**
- **Zero polluting emissions**

Long-term Musts

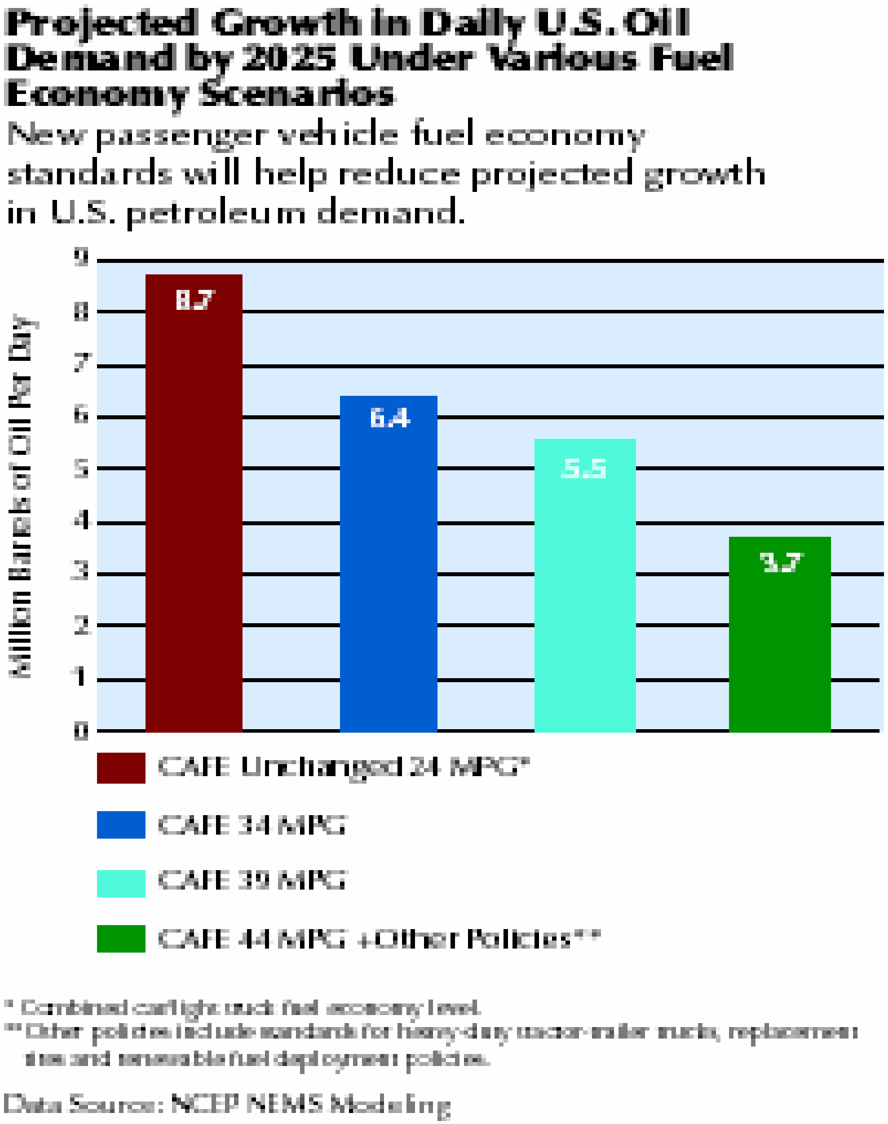
To use fossil fuels we need Carbon sequestration by 2020

We must have an alternate to fossil fuels as energy carrier/storage that is fully functional by 2030

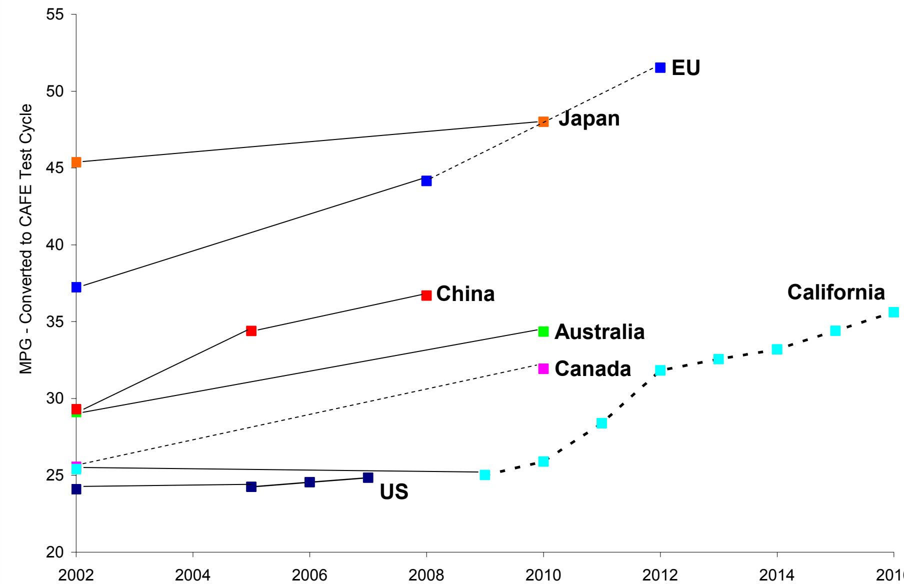
Short term Options: Transportation

- Change lifestyles
- Fossil fuels with sequestration
  - Coal $\rightarrow$ oil
  - Unconventional Sources
  - Compressed Natural Gas
  - Hydrogen

Drive less, Drive efficient (hybrids)



We have lagged on CAFÉ



Has cheap gasoline and electricity lead to complacency?

Coal → Oil

- 1 ton of coal → 5.5 barrels of oil = 0.75 ton of oil
- To replace 10% of world crude by synoil from coal would need processing 1.54 million tons of coal a day (USA 2004 daily production was ~3 M tons)
- 72% more CO_2 is emitted when gasoline is produced from coal than from crude
- Costs $25/barrel to produce oil from coal versus $2-4 for Saudi oil. Syn oil becomes economical for > $30.
- Need to remove sulphur, mercury, arsenic, ….

Needs CO2 sequestration

Unconventional sources

- Extra-heavy oil (Orinoco oil belt in Venezuela)
- Tar sands (Athabaska Canada, in-situ mining)
- Shale oil (Huge resources in North America)
- Synthetic crude (from tar, gas, coal)
- Coal bed methane
- Methane hydrates

Need more R&D to scale up

Unconventional sources

- Need more energy and water to extract
- Are more polluting
- Have larger environmental impact

Consequences of production at 10s of megatons a day are unknown

Example: Tar Sands

- 2 tons bitumen + 3 barrels of water + energy (800 ft^3 of gas) $\rightarrow$ 1 barrel oil
- Much more sulphur, mercury, ... have to be captured and processed.
- Tailings slurry contains heavy metals, inorganic salts and hydrocarbons
- Production cost: Syncrude Canada = $12 per barrel of oil versus $2-4 for Saudi oil.
- Commercially viable for > $25/barrel

Energy Return on Energy Invested (EROEI)

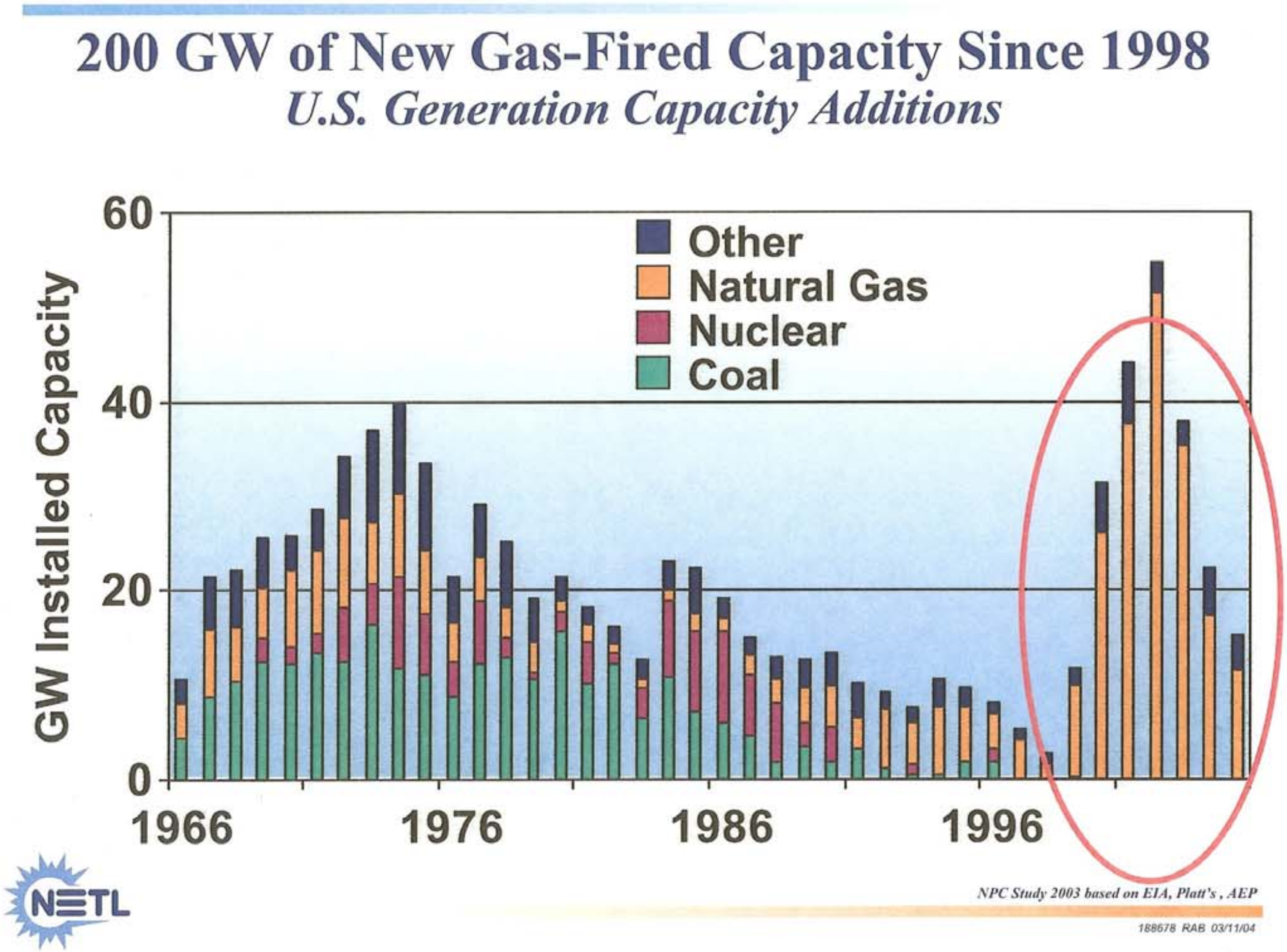
ME crude oil	30+	
Oil (deep wells)	5-10	
Coal	25	Depends on access to coal
Tar Sands	5-7	800 ft^3 stranded gas/ barrel
Methanol from corn	~1	Thus the need for subsidies
Nuclear	5-20	
Hydro power	45	
Solar PV	5-15	Improving
Wind	4-10	V90-3.0MW offshore ERORI=35

EROEI decreases with age of oil and gas field.

Net gain if fuel substitution → higher value fuel

Power generation

Coal → Gas → Coal



Did we not anticipate the gas crunch or planned on importing it without strings attached?

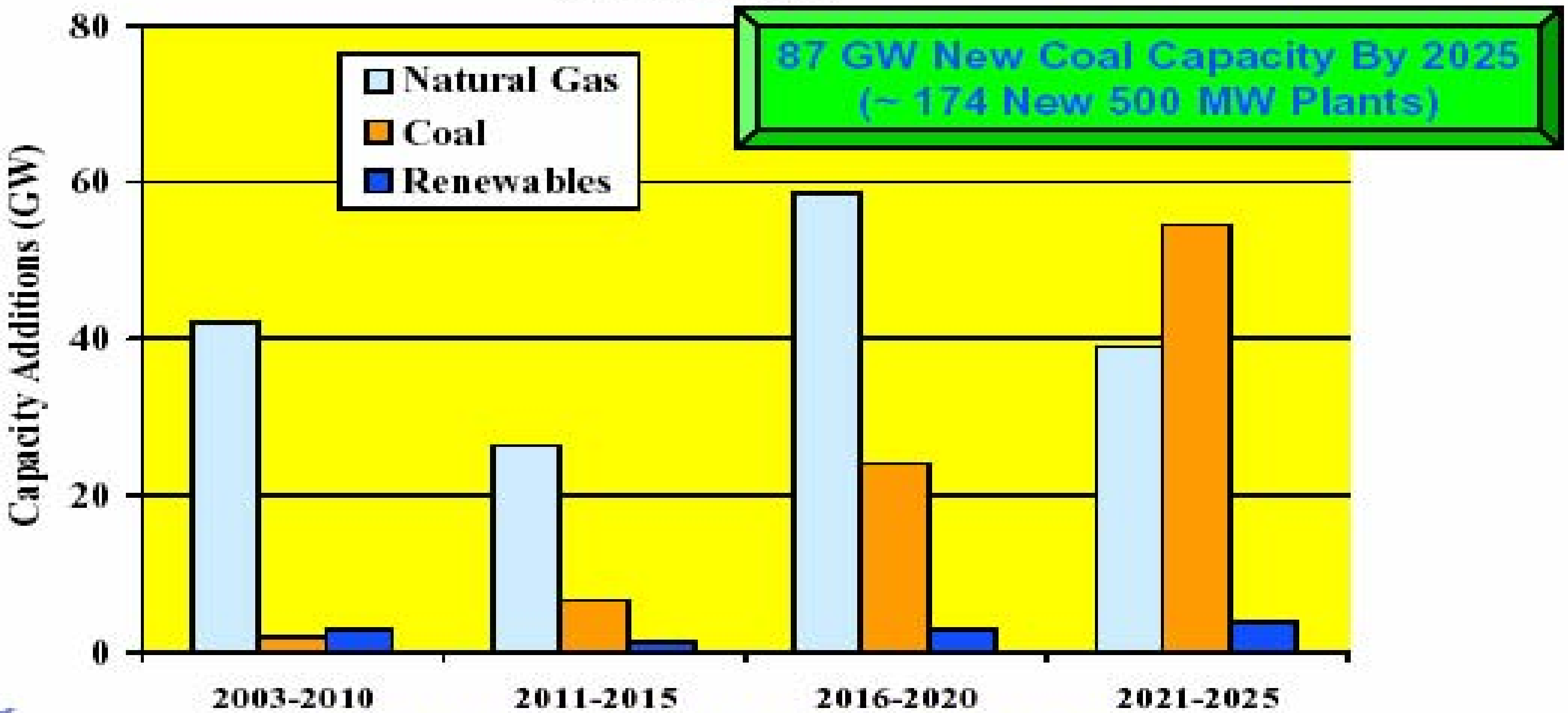
Will Gas and Coal continue to dominate new power generation?

87 GW New Coal Capacity By 2025

(Accounts for 33% of New Capacity Additions)

New Electricity Capacity Additions

(EIA Reference Case)



Source: Data Derived From EIA Annual Energy Outlook 2005

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

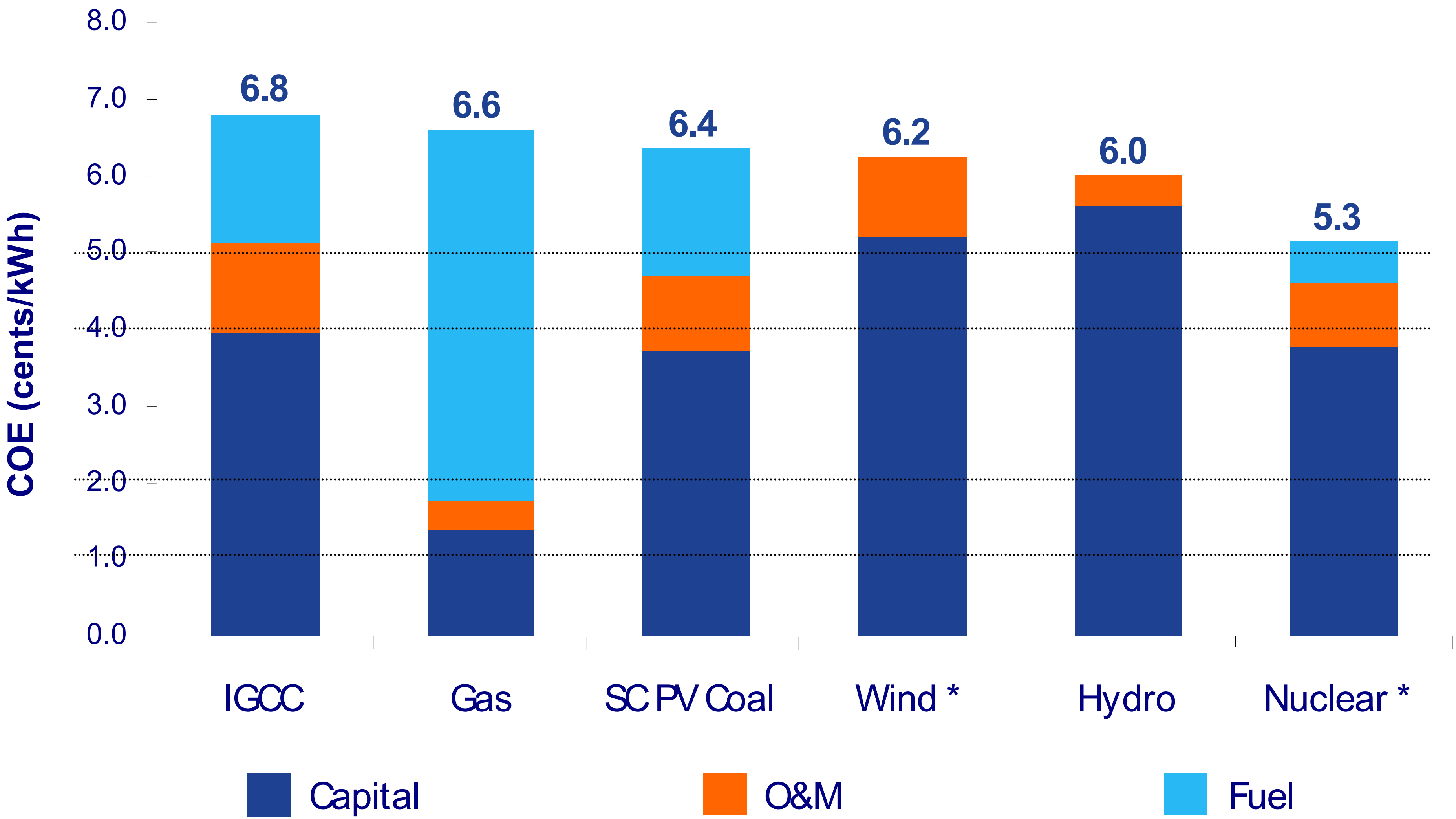
OCES 11/1/2005

Immediate Options

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

What does the market say?

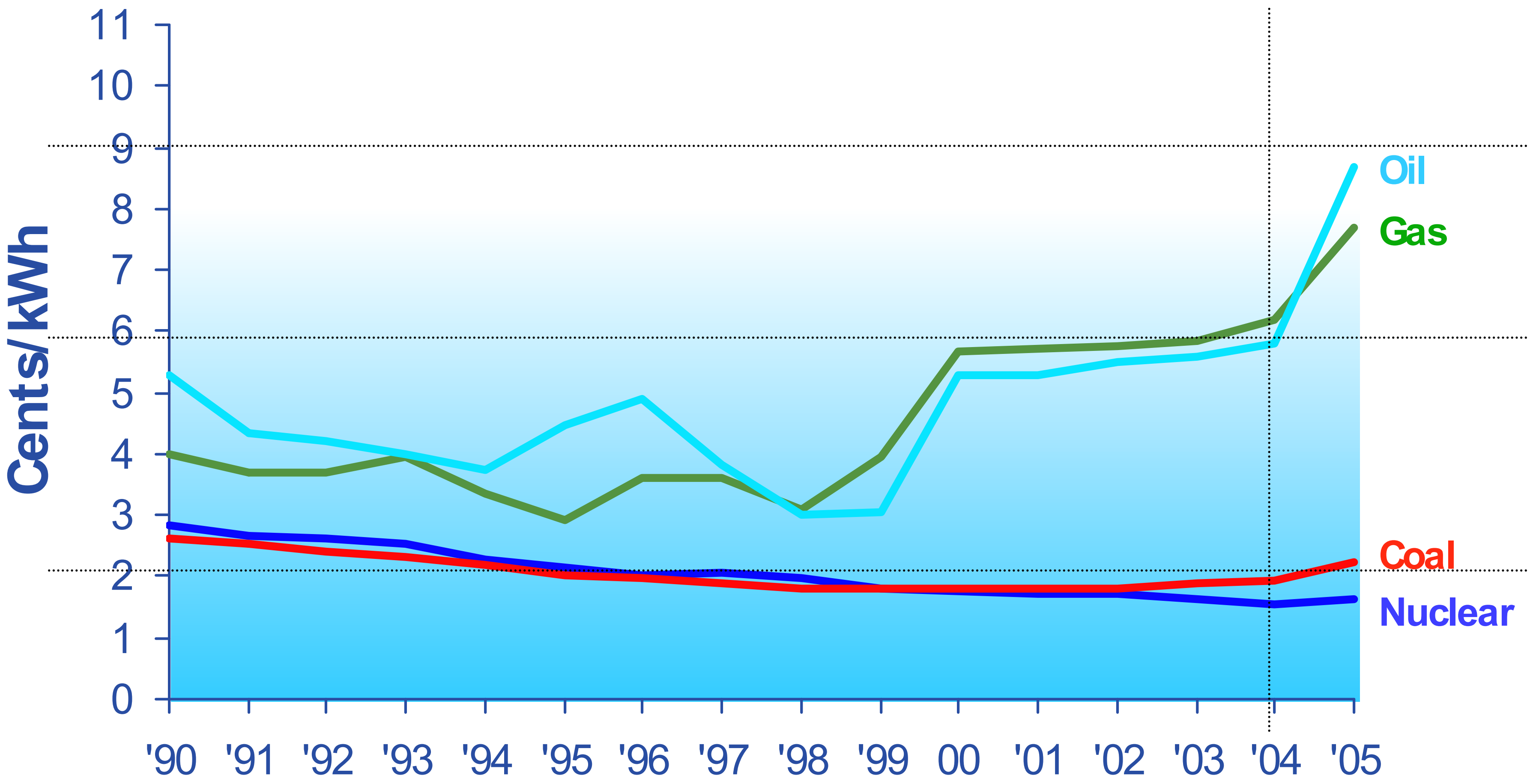
Cost for New Build



** Includes U.S. Production Tax Credits*

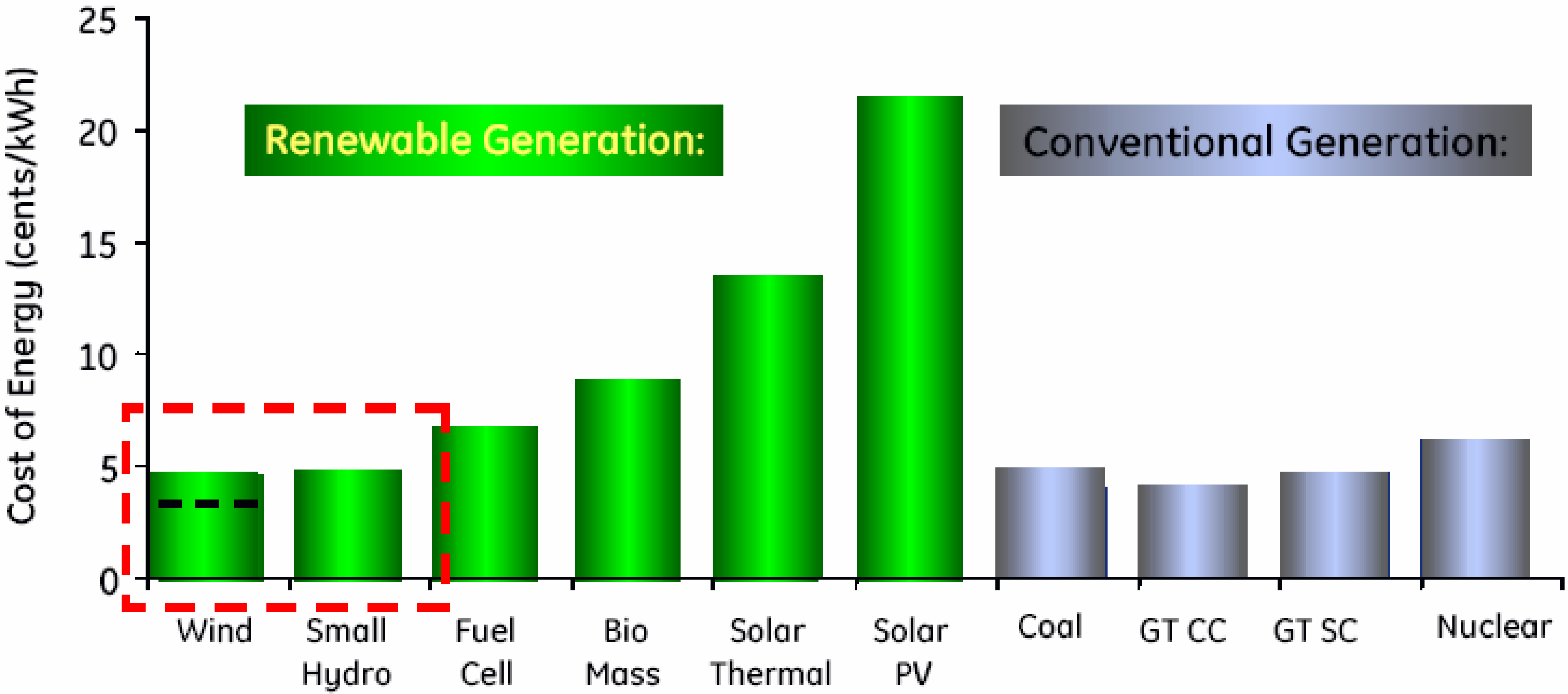
imagination at work

Operating Cost for Existing Plants



imagination at work

Cost of Energy



Source: Lawrence Berkeley Lab
Biomass : Direct fueled

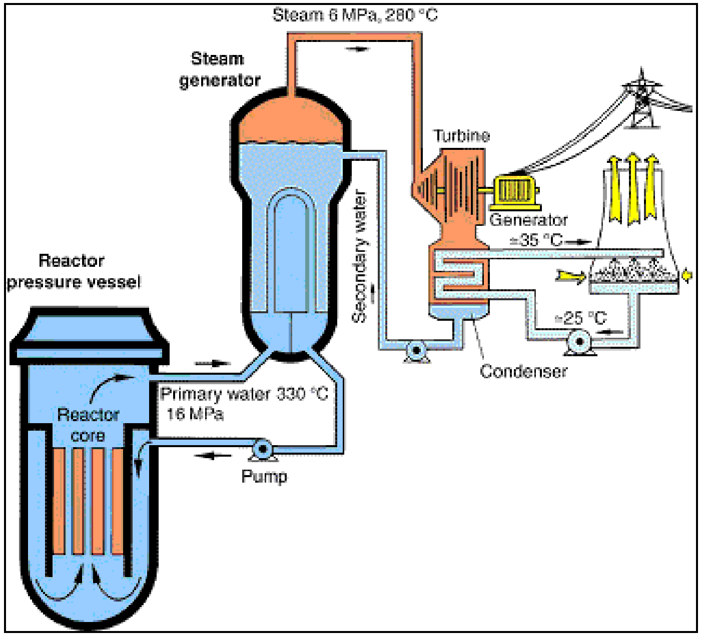
Wind: The Most Practical Renewable Technology

Installation cost and time for a new plant

	Installation Cost	Installation Time
Nuclear	$2 / watt	7-10 years
Coal	$1 / watt	3-5 years
Gas	$0.6 / watt	2-3 years
Wind	$0.7-1.0 / watt	months
PV	$8 / watt	Weeks (home use)

Nuclear power “CO2 clean”

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

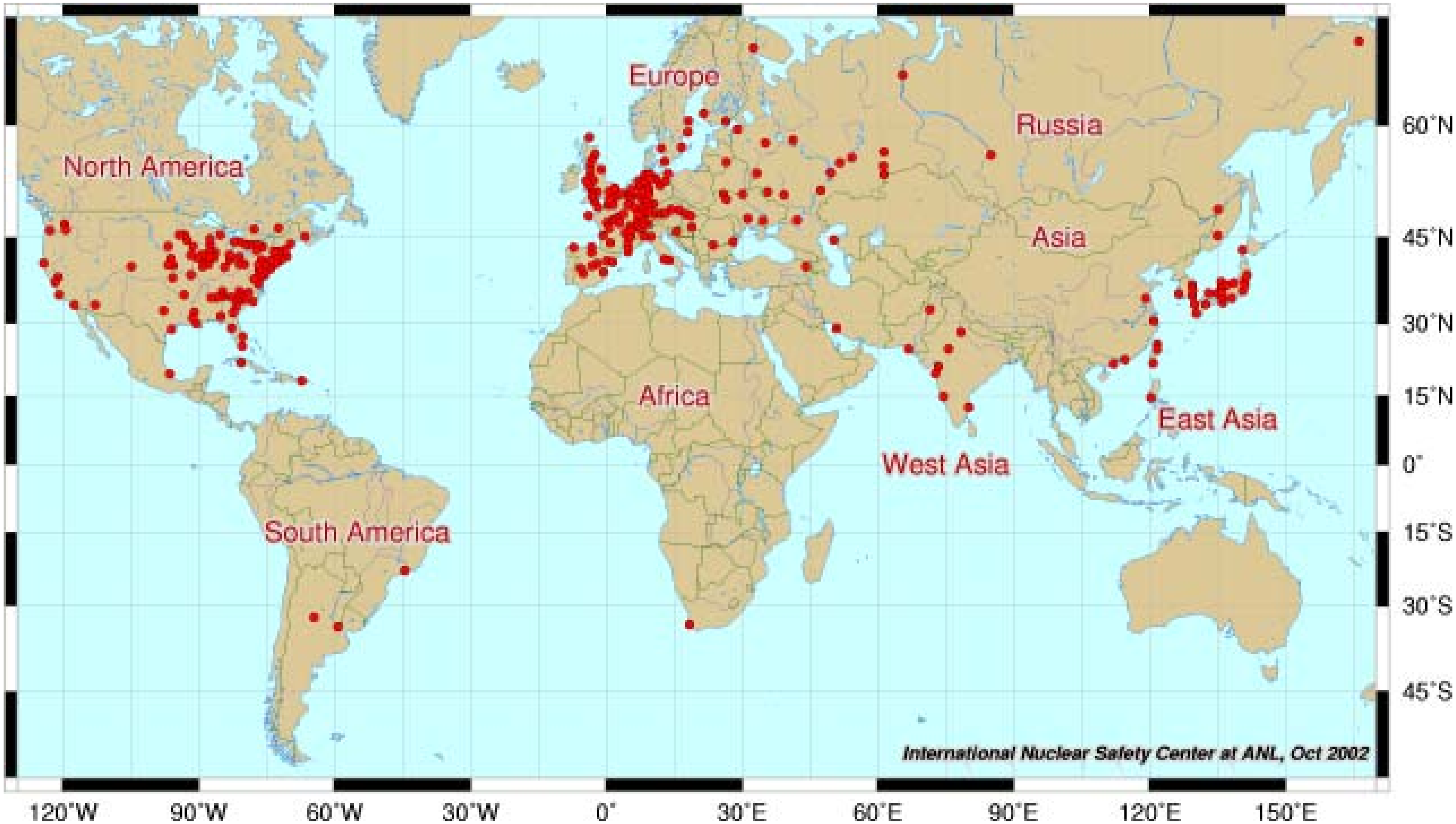


Nuclear Power (2004)

- 442 plants in 32 countries produce ~ 0.2 Terawatts. This represents 6.7% (18%) of world energy (electricity) use.
- Typical lifetime of operation ~ 40 years
- 442 plants produce ~2000 tons of highly radioactive fuel waste per year
- Issues of proliferation of HEU and Pu^{239} and diversion to nuclear weapons
- No new plants in the US since 1978
- Manpower (Nuclear scientist and engineers)???

WORLD POWER REACTORS

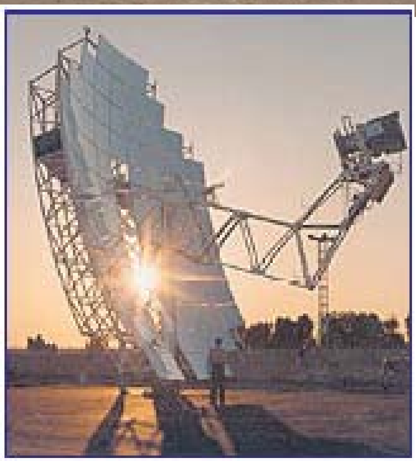
[Source: INSC - Argonne]



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

COUNTRY	**Nuclear Reactors** in Operation		Reactors under Construction		Nuclear Electricity Supplied in 2003		Total Operating Experience to June 20004	
	No of Units	Total MW(e)	No of Units	Total MW(e)	TWh	% of Total	Years	Months
CANADA	17	12113			70.29	12.53	495	5
CHINA	9	6587	2	2000	41.59	2.18	43	5
FRANCE	59	63363			420.70	77.68	1375	8
GERMANY	18	20643			157.44	28.10	657	0
INDIA	14	2550	8	3622	16.37	3.30	230	5
IRAN			2	2111			0	0
JAPAN	54	45464	2	2371	230.80	25.01	1150	4
KOREA, REPUBLIC OF	19	15850	1	960	123.28	40.01	230	2
PAKISTAN	2	425			1.81	2.37	36	10
RUSSIAN FEDERATION	30	20793	3	2825	138.39	16.54	776	4
SPAIN	9	7584			59.36	23.64	223	8
SWEDEN	11	9451			65.50	49.62	316	7
UKRAINE	13	11207	4	3800	76.70	45.93	286	4
UNITED KINGDOM	27	12052			85.31	23.70	1343	2
USA	104	98298			763.74	19.86	2923	8
Total (15 countries)	**386**	**326,380**	**22**	**17689**	**2251**		**10083**	
Total (32 countries)	**442**	**363,380**	**27**	**22676**	**2525**		**11364**	

Renewables



Good News: Investment in renewable energy is growing

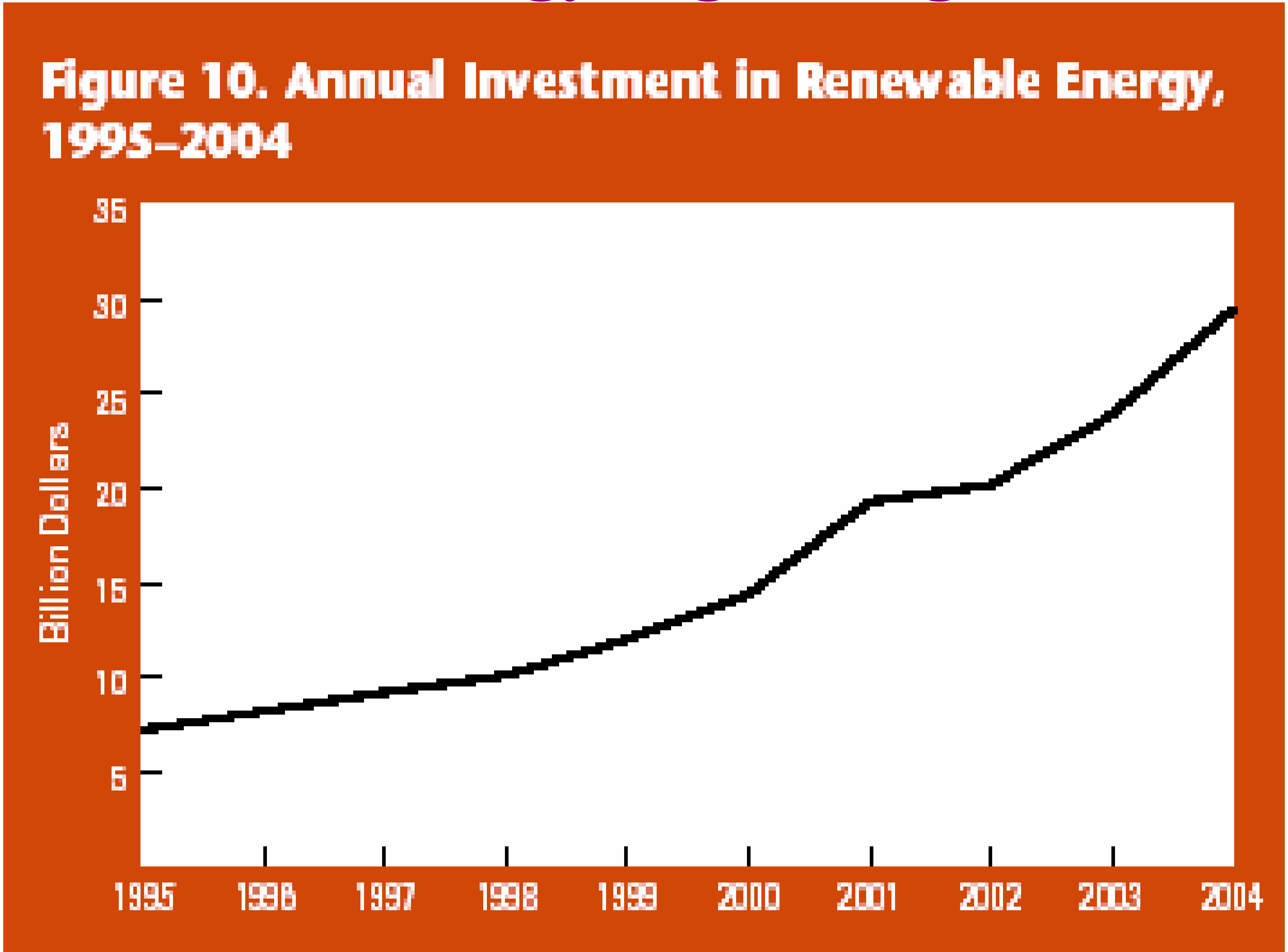
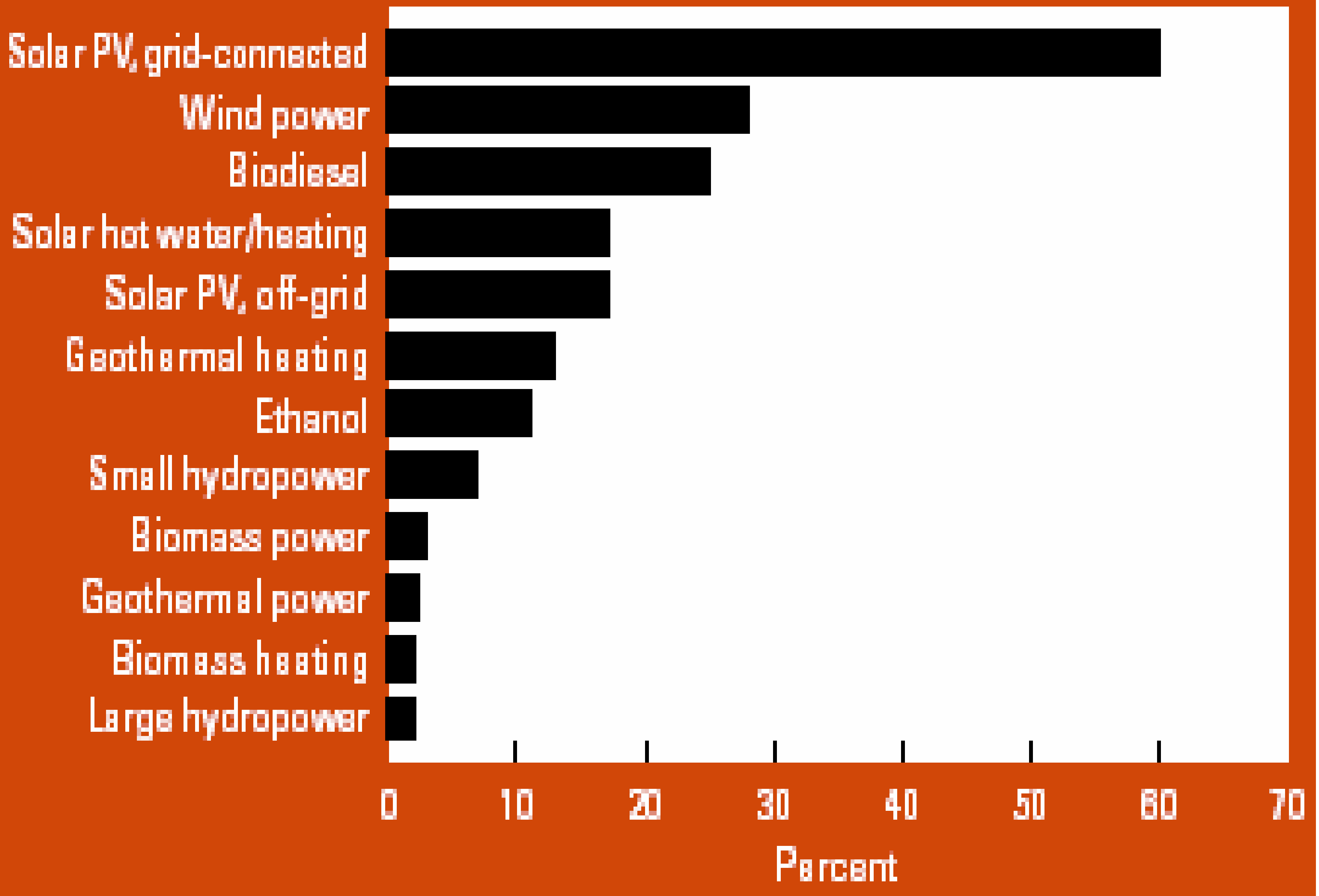
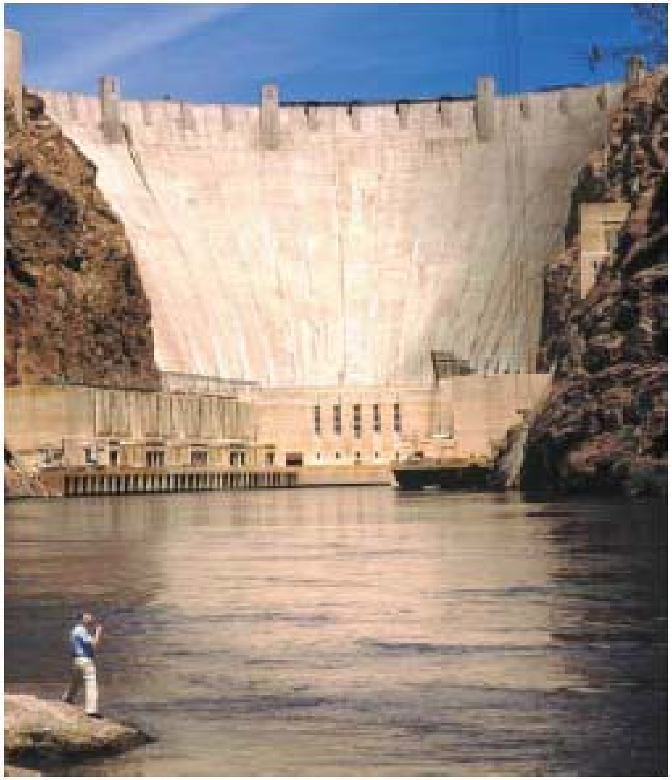


Figure 2. Average Annual Growth Rates of Renewable Energy Capacity, 2000–2004

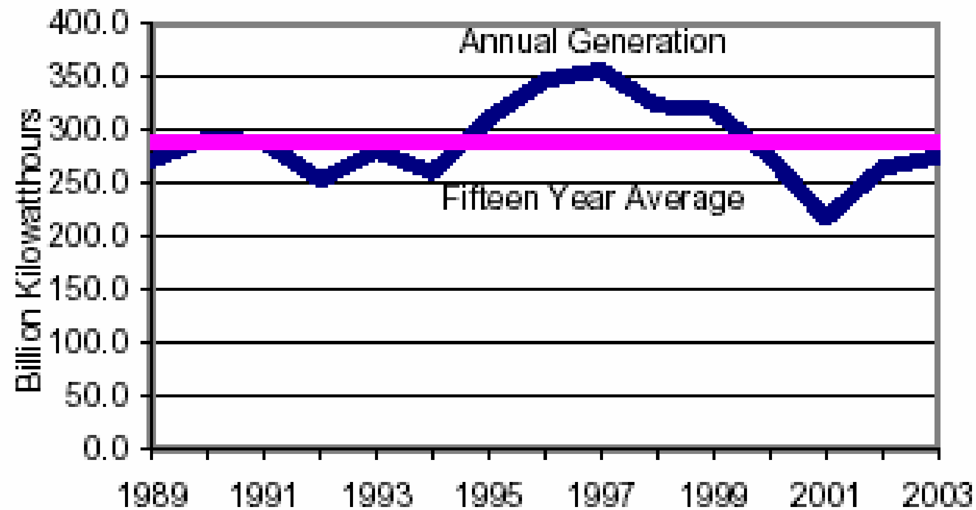




Hydroelectric Dams

- **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.

- **Silting**
- **Ecological impact**
- **Large versus small dams**

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http://t

Biomass (needs water+land)

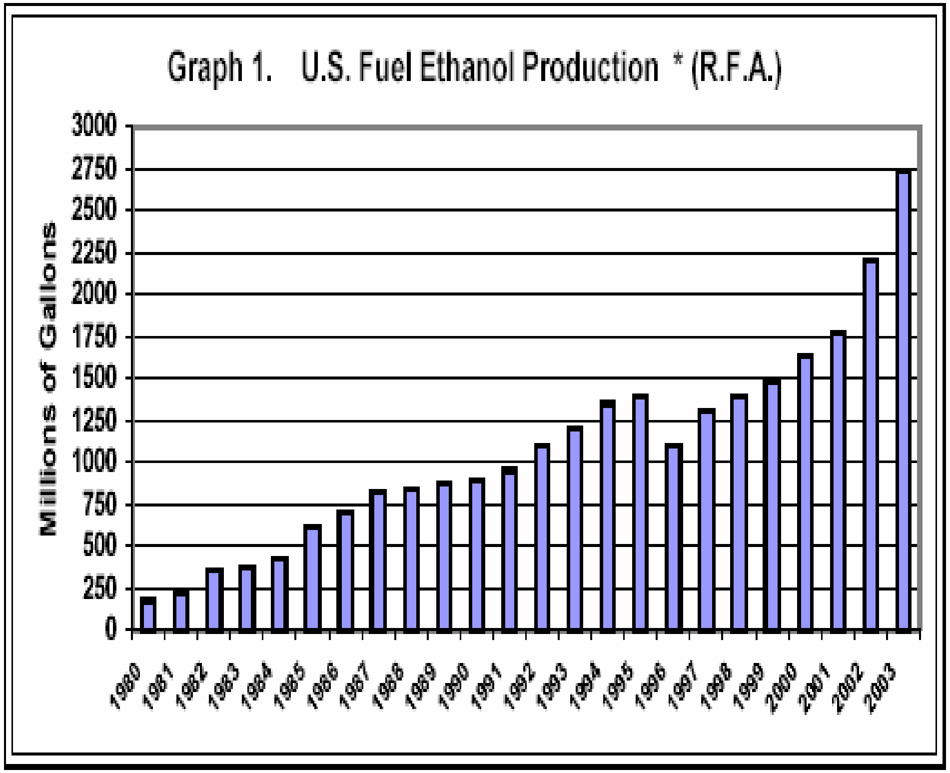
- Ferment starch $(C_6H_{10}O_5)_x$ in grain into ethanol
  - Corn kernel → 1/3 ethanol + 1/3 distiller's grain + 1/3 CO_2 ($Starch \rightarrow C_6H_{12}O_6 \rightarrow 2C_2H_5OH + 2CO_2$)
- Cellulosic biomass (waste, wood) is "free" but needs gathering; Plant oils → Biodiesel; …

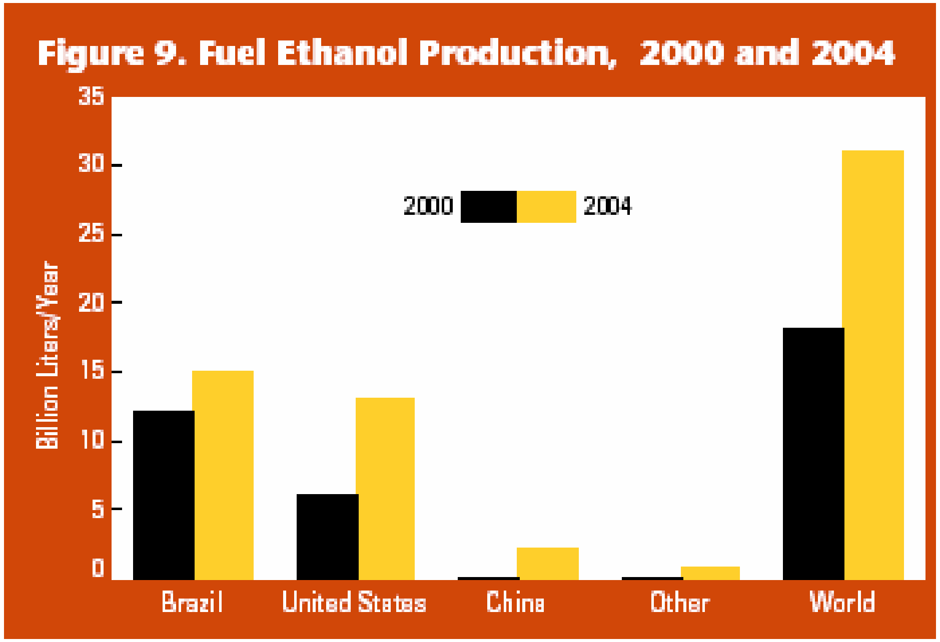
Comparison:

Photochemical: 1 hectare+water (120 days → 9 tons corn → 800 gallons ethanol) → **14** Million watt hrs

Photovoltaic: 1 hectare PV farm ($5000\ m^2 \times 200w \times 24hrs \times 10\% \times 120$ days) → **288** Million watt hrs

Ethanol: goal 5 billion gallons

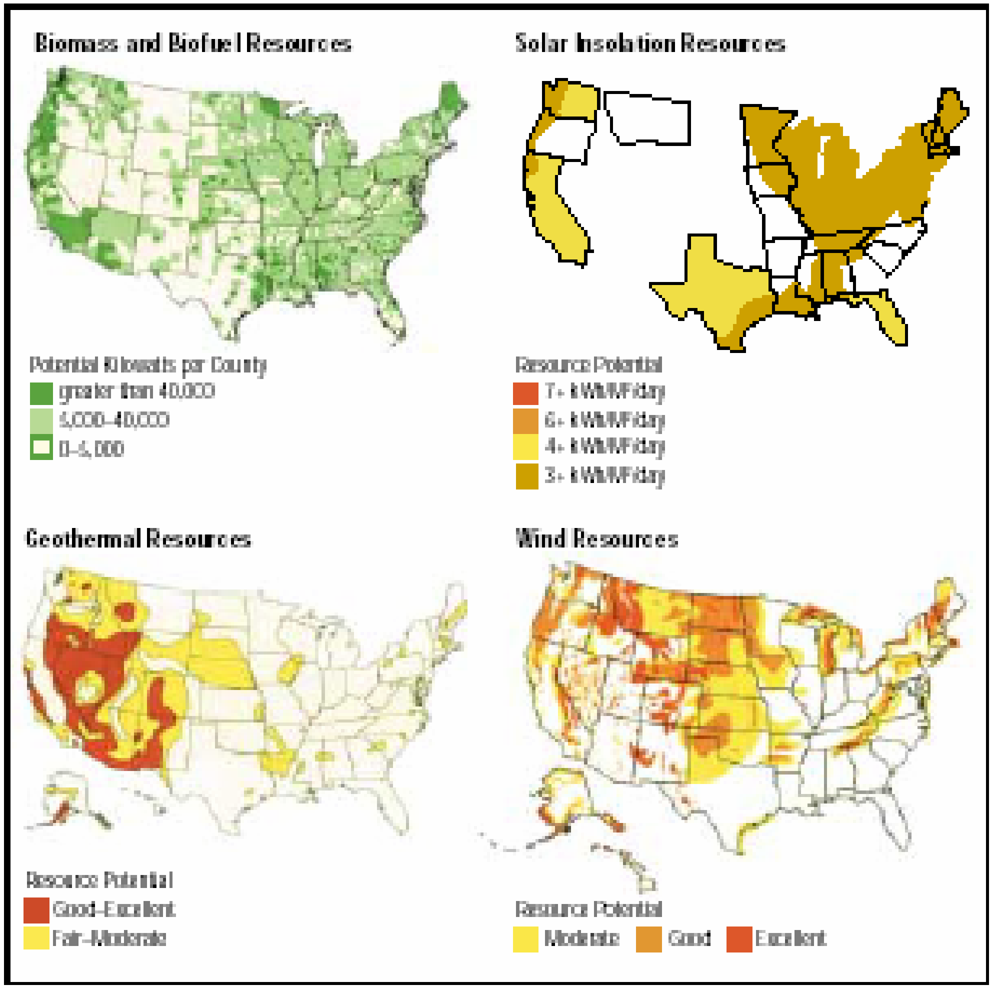




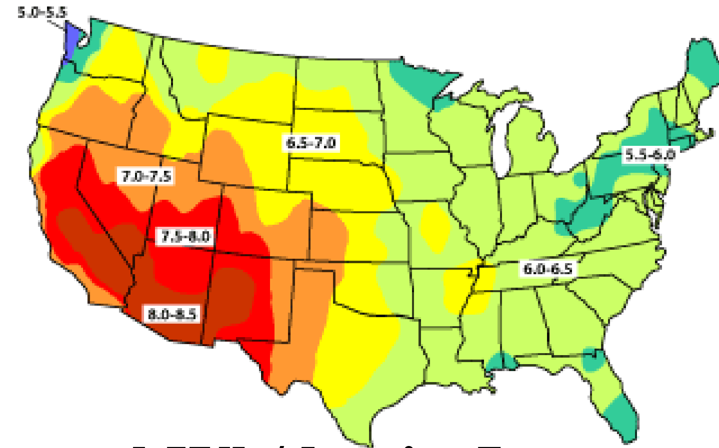
Energy input in (corn to ethanol) production ≈ stored!
→Ethanol: a way to convert coal and gas into liquid fuel!

Solar and Wind

U.S. Resource Potential for Renewable Energy



Almost every state has the potential for wind energy and for biomass and biofuel production. The Southwest has the greatest potential for solar energy, and geothermal energy resources are most abundant in the West.

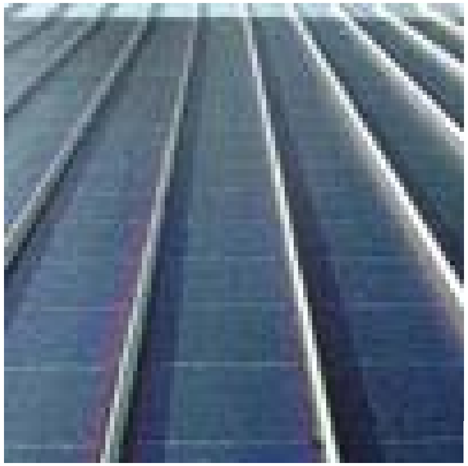


kWh/day in June

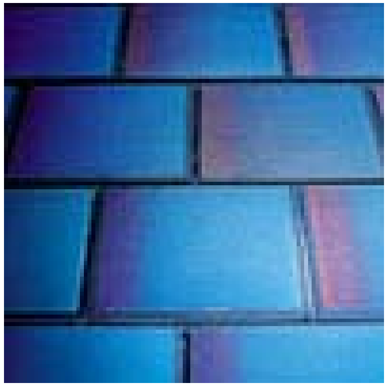
Power is intermittent → need ~3X demand OR energy storage to function without backup

Solar PV options reaching 15% efficiency

Average output: 30-45 watts / m^2



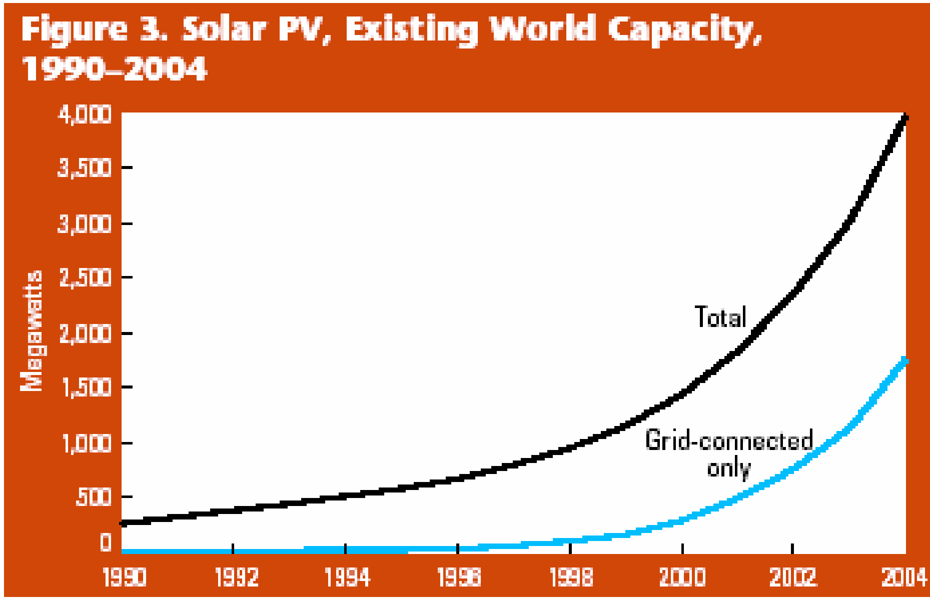
Laminate



Tiles /Shingles

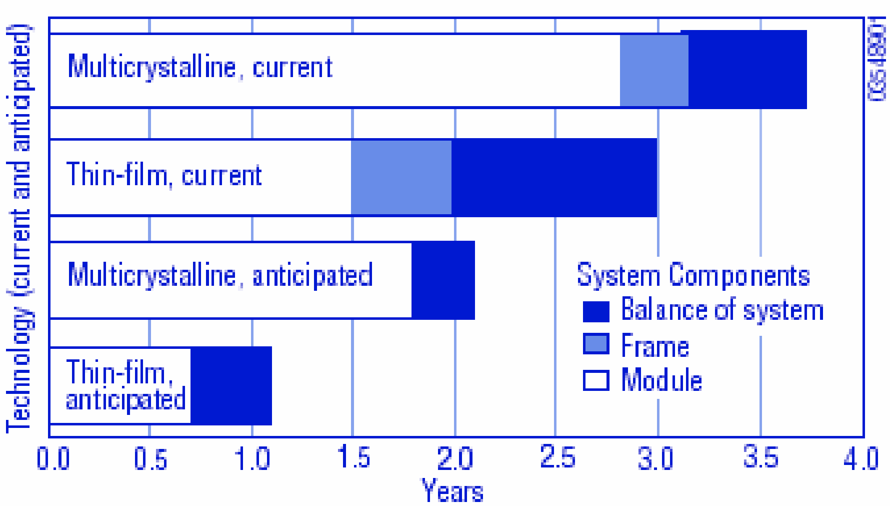
PV polycrystalline

Thin films



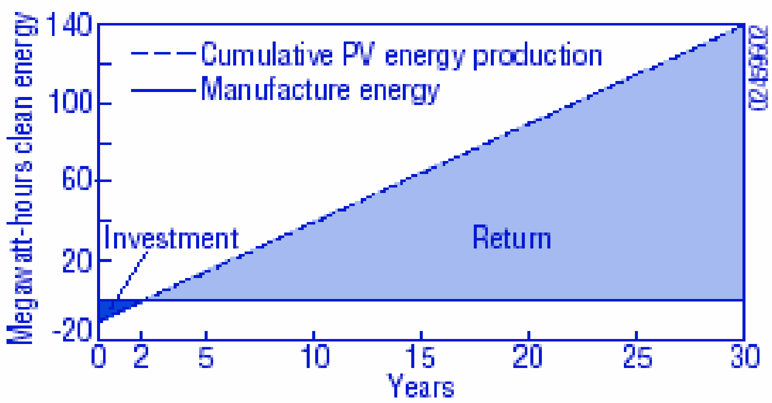
Payback of PV: homes & buildings

Figure 1. Energy Payback for Rooftop PV Systems



Reaping the environmental benefits of solar energy requires spending energy to make the PV system. But as this graphic shows, the investment is small. Assuming 30-year system life, PV systems will provide a net gain of 26 to 29 years of pollution-free and greenhouse-gas-free electrical generation.

Figure 2. Cumulative Net Clean Energy Payoff



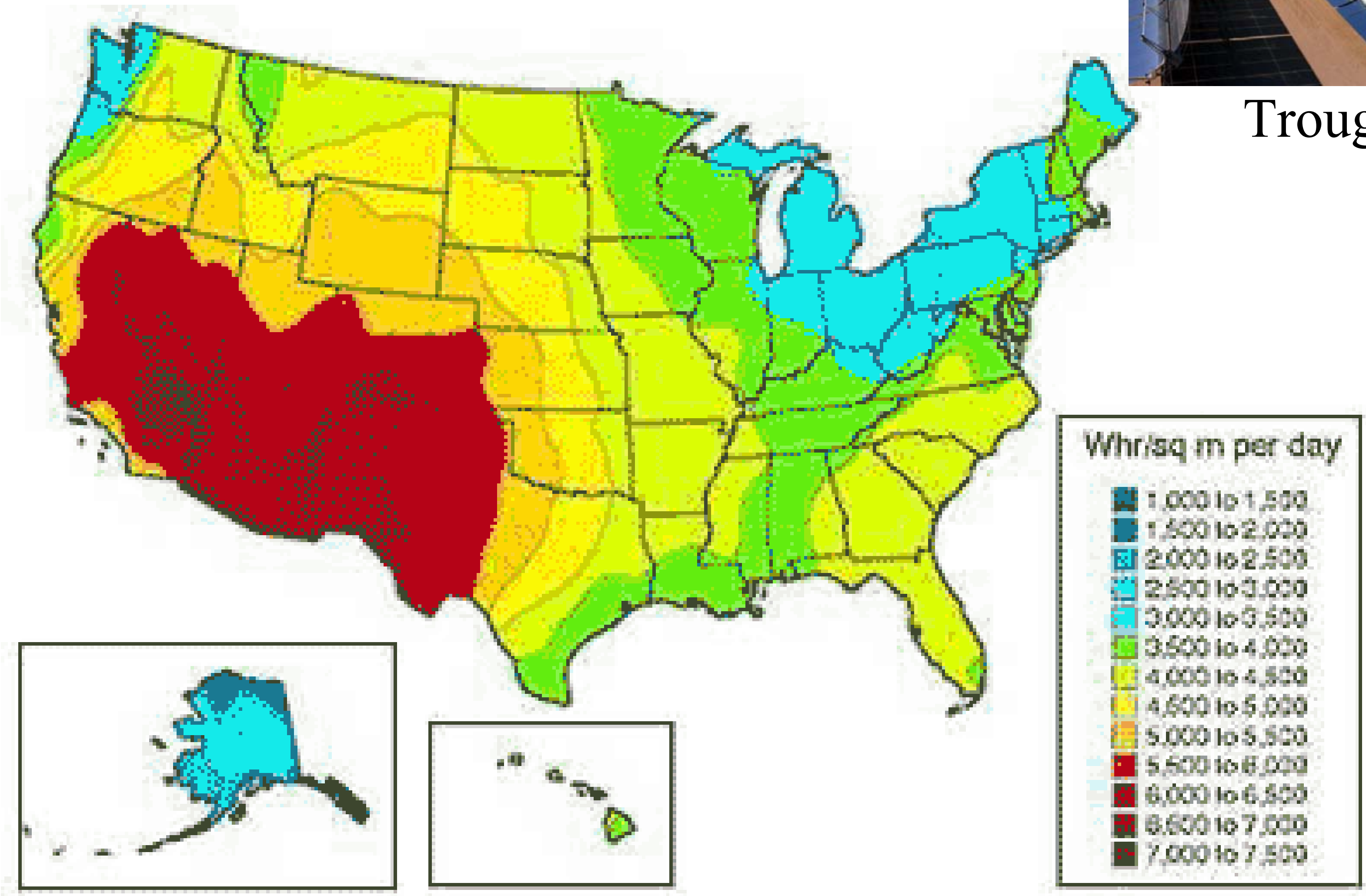
PV systems can repay their energy investment in about 2 years. During its 28 remaining years of assumed operation, a PV system that meets half of an average household's electrical use would eliminate half a ton of sulfur dioxide and one-third of a ton of nitrogen-oxides pollution. The carbon-dioxide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

My gas bill was $1800 in 2004 (+30% in 05).
Installing a 2 kilowatt PV system costs $16000

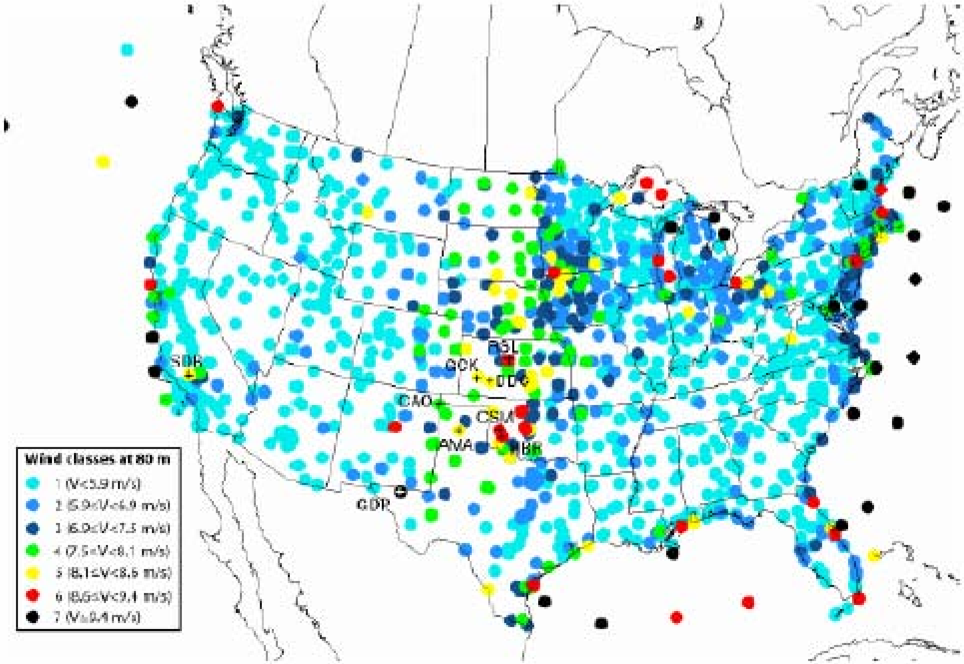
⇒Building a house today I would consider it

Solar Concentrators

Troughs



Solar resource for a concentrating collector



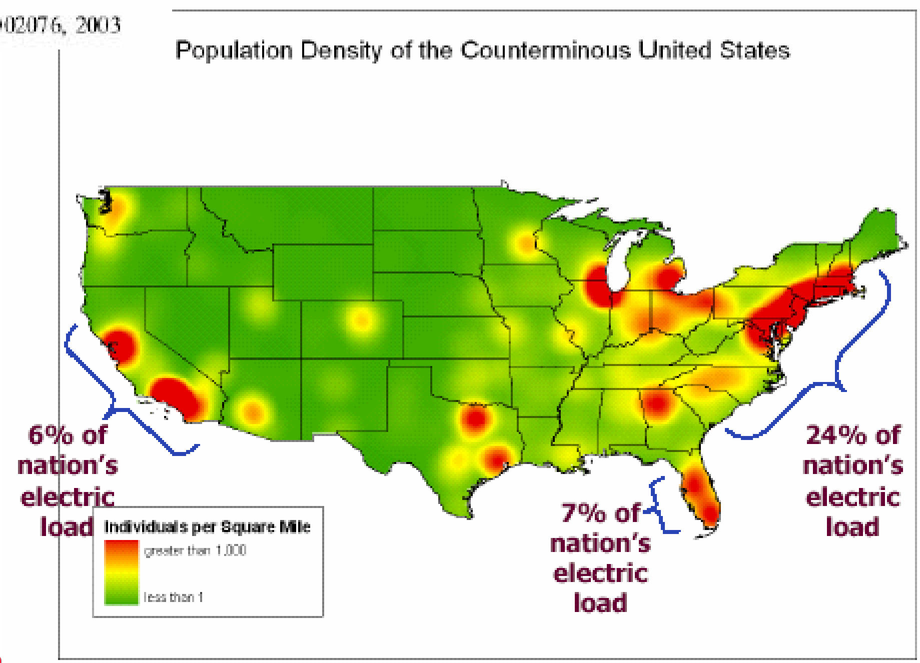
JOURNAL OF GEOPHYSICAL RESEARCH, VOL. 108, NO. D9, 4289, doi:10.1029/2002JD002076, 2003

Wind potential

Speeds at 80m height

GE2005

Good offshore wind potential near high population density



Source: W. Musial, NREL

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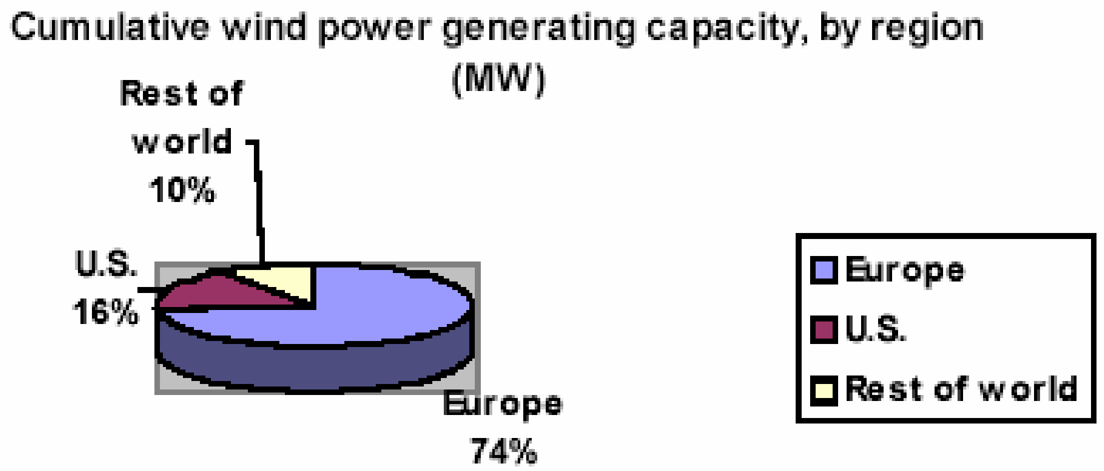
Wind 2003: Total=40 gigawatts peak

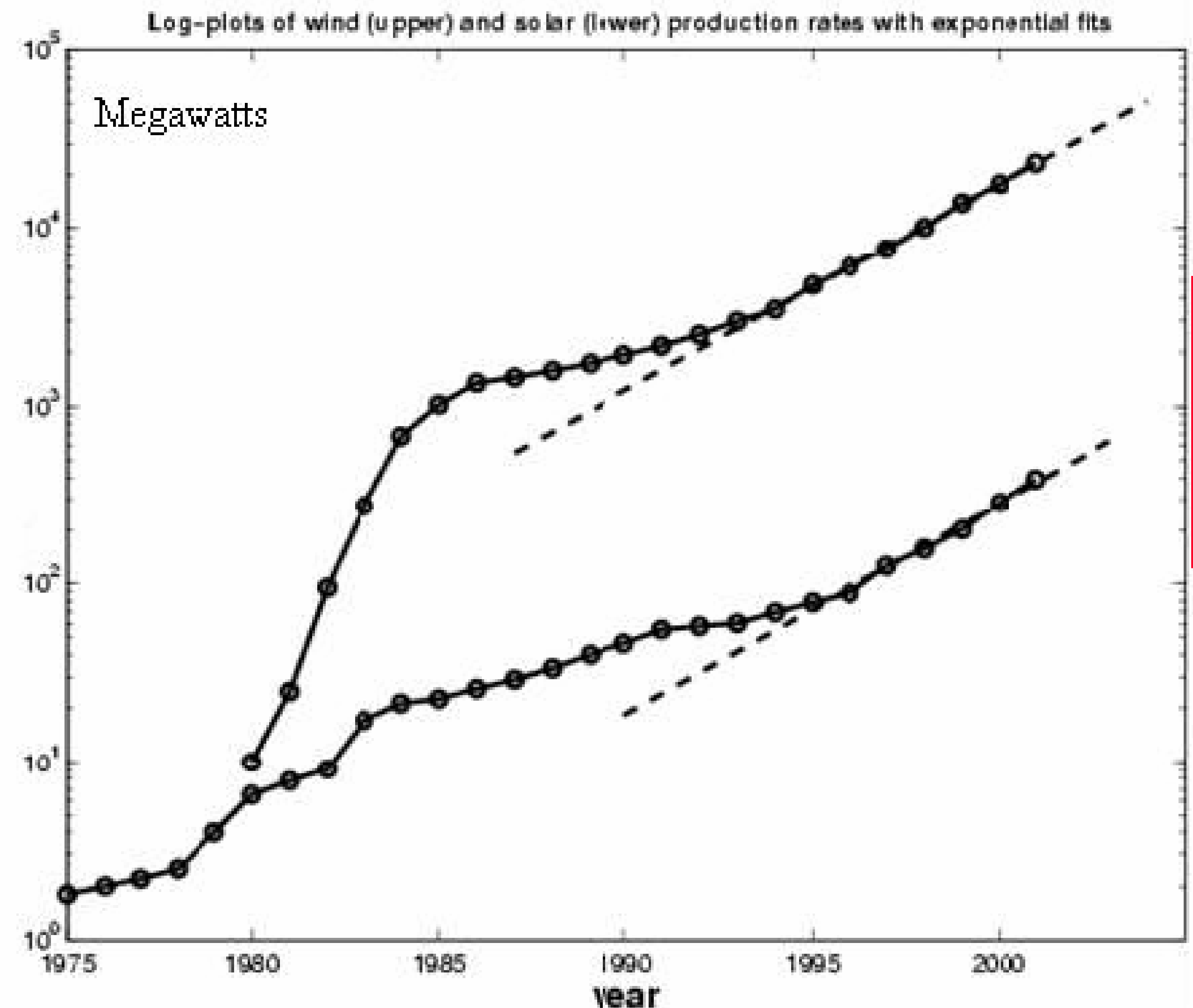


Worldwide, Europe and the U.S. account for 90% of cumulative capacity.

Top five wind energy markets (installed capacity, in MW)	2002 Additions	2002 Year End Total	2003 Additions	**2003 Year End Total**
Germany	3,247	12,001	2,645	**14,609**
United States	410	4,685	1,687	**6,374**
Spain	1,493	4,830	1,377	**6,202**
Denmark	407	2,880	243	**3,110**
India	195	1,702	408	**2,110**

Source: AWEA

International wind & PV growth



1995-2004 show ~30% growth

Log-linear plot for Wind & PV

Source: Ben Luce

Wind & PV: Long Way To Go (2003)

World energy use ~ 420 quads ~ 1.2 x 10^{17} W hr

- Power from Wind ~ 3.5 x 10^{14} W hr (4 x 10^{10} W)
- New capacity(2003) ~ 7 x 10^{13} W hr (8.2 x 10^{9} W)
- Cost: 3-6 cents / kW hour
- Assuming growth at 30% (10^{17} W hr in 22 years)

- Power from PV ~ 3 x 10^{13} W hr (3.2 x 10^{9} W)
- PV added (2003) ~ 7.5 x 10^{12} W hr (8.5 x 10^{8} W)
- Cost: \$8/watt (installed) in 2004 $\Rightarrow$ \$0.20/kWh
- Assuming growth at 30% (10^{17} W hr in 31 years)

Will growth flatten out soon under BAU?

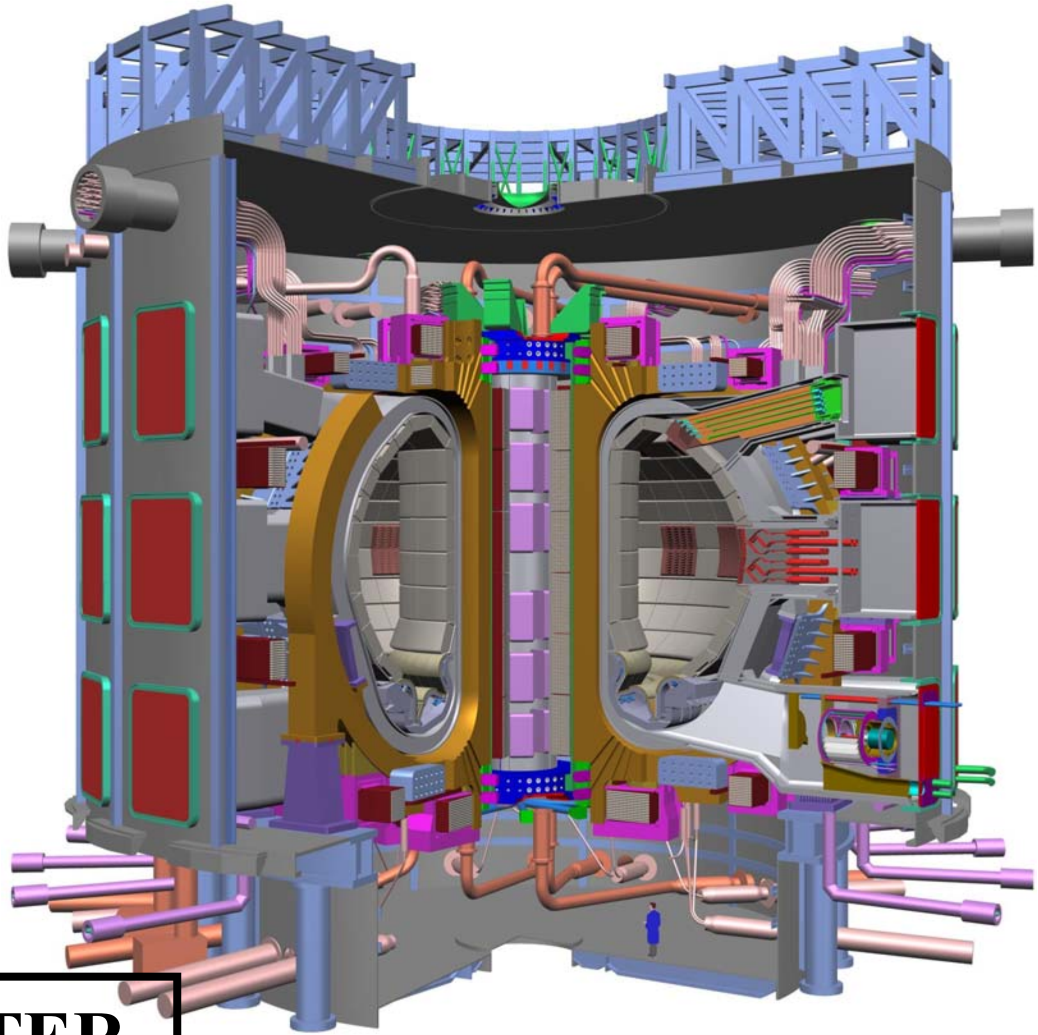
What must be done to sustain this growth?

What is needed

- **PV:** Reduce cost; improve efficiency, lifetime and reliability (goal 2010 = 2X)
- **Solar:** Low cost solar concentrators
- **Photochemical:** $n(H_2O + CO_2) \rightarrow (CH_2O)_n + nO_2$
  $2(H_2O) + h\nu \rightarrow 2H_2 + O_2$
  Needs major breakthroughs in chemistry
- **Wind:** Wind systems need integration into grid to overcome intermittency

R&D, Incentives and tax credits

Fusion: ultimate source but challenged



ITER

Fusion as an energy source is unlikely to be realized until 2050+ with current R&D investment.

We need all non-fossil sources: Each has a niche

- **Nuclear:** bogged down by proliferation and waste issues
- **Biomass:** small, peak at ~1%, WATER
- **Hydro:** most rivers tapped
- **Solar:** tiny but will grow as cost ↓
- **Wind:** small but has potential for rapid growth
- **Fusion:** Needs investment in R&D

My conclusions

- **Oil** (will peak at ~86 million barrels/day: 2006)
- **Gas** (will peak around 2025. Fuel for Eurasia)
- **Coal** (will grow. Zero emissions only >> 2025)
- **Nuclear** (proliferation issues will limit growth)
- **Hydro** (no significant growth)
- **Wind** (will grow driven by market)
- **Solar** (will grow driven by home & building use)
- **Biomass** (useful for excess "corn" & waste disposal)

Long term vision: Dominant power use will be electric with H_2 or CH_4 the intermediate carrier/storage

FUTURE

- **Oil, Gas, Coal** (Resource limited. Mounting impact on environment)
- **Nuclear** (security, proliferation and waste issues)
- **Renewables** (R&D, Technology=growth)

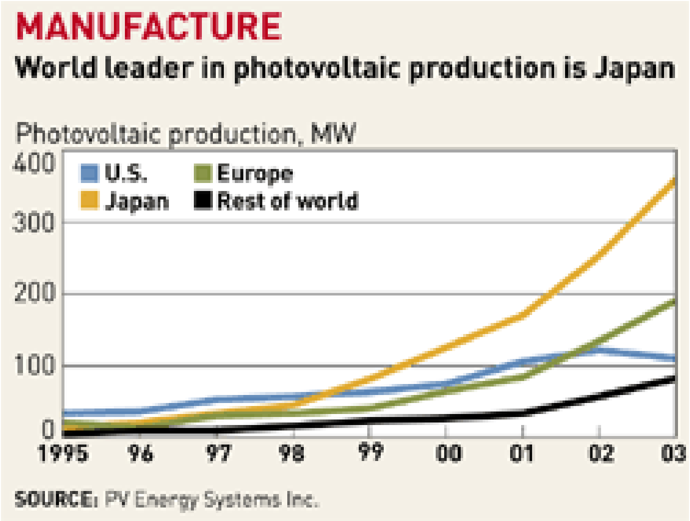
Clean energy is increasingly becoming a value added commodity. To be the dominant player US must invest heavily in R&D and develop integrated systems analysis capability

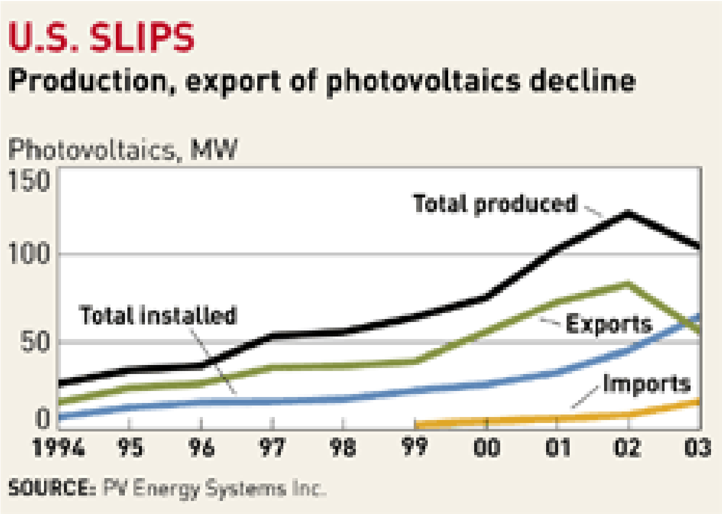
Economic Opportunity

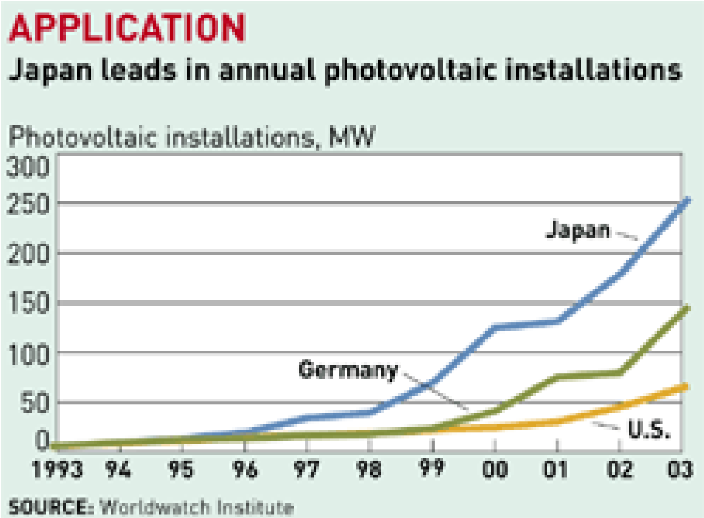
- **Clean Energy**
- **Electric power grids**
- **Fuel for Transportation**

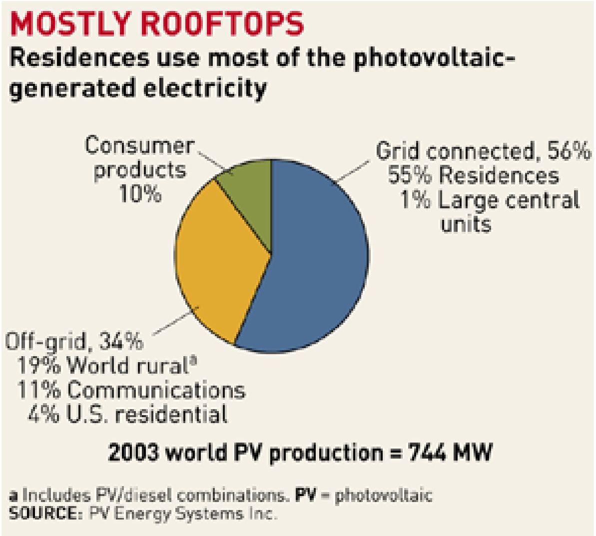
Are increasingly value added products. 40 Terawatts of global power demand translates into a $48billion/day market at $0.05 kW hr

No incentive in the US: Electricity & gasoline are cheap!









Will *GE* turn US around?

Jeff Johnson, Chemical and Engineering News: June 21, 2004 Volume 82, Number 25 pp25-28

Recommendations

- **Education to change behavior: the oil and gas crisis is not a ploy by producing countries or companies. Global oil production is approaching its peak.**
- **Improve efficiency and conserve fossil fuels**
- **Increase CAFÉ standards by 1 mile / year for next 15 years and classify SUVs as automobiles**
- **Accelerate development of clean coal technology**
- **Accelerate development of solar and wind**
- **Reinvest in nuclear power. R&D in waste management**
- **Upgrade electric transmission grid**

Enlightened policy, incentives (rebates, credits) can have major impact

Promote American innovation and ingenuity. Reduce oil and gas imports by 1% every year!

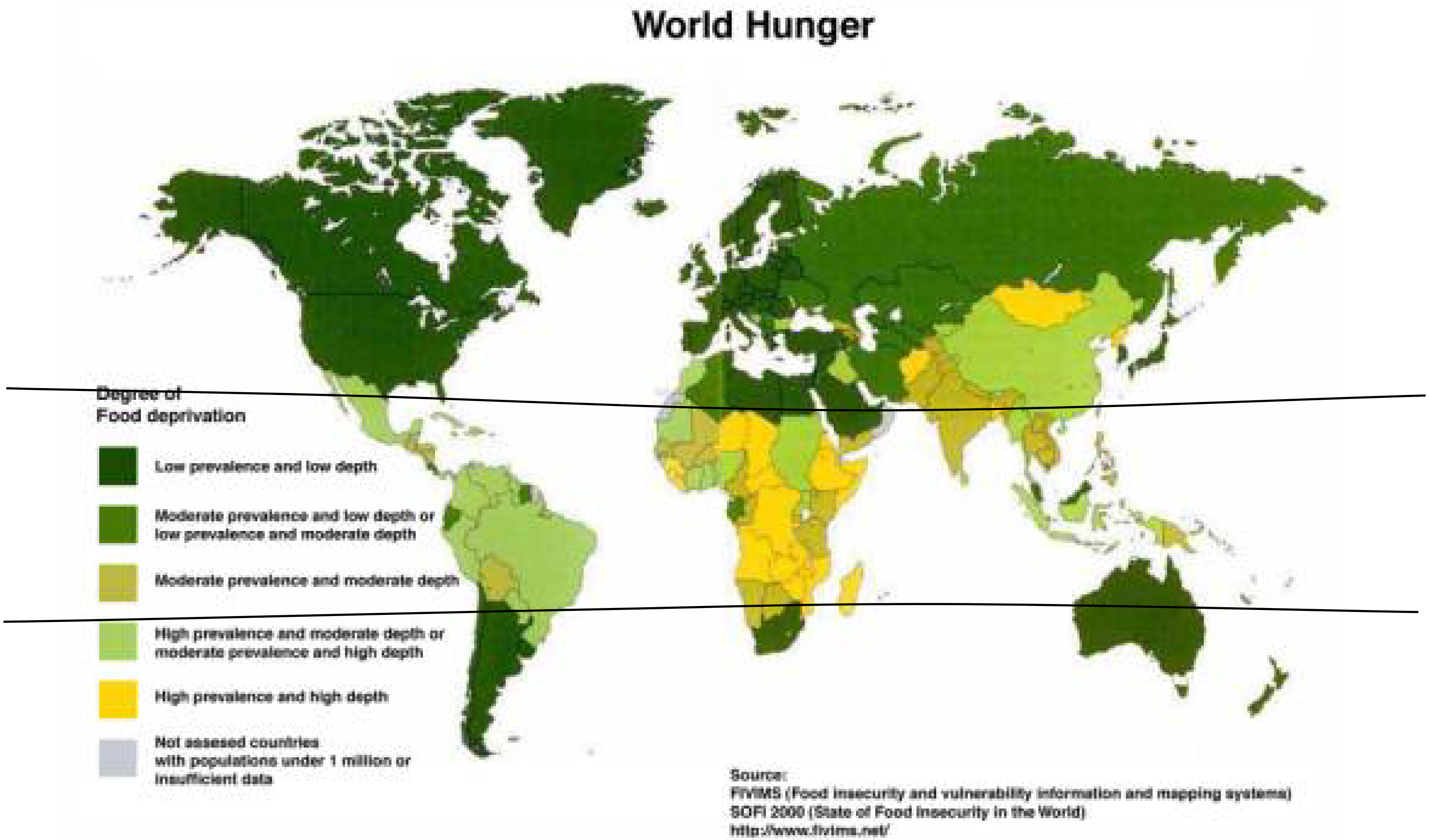
- Switch electricity generation to clean coal, nuclear and renewables. Share of renewables will increase as costs come down.
- Improve fuel efficiency in transport. In short term switch to efficient hybrid automobiles
- Re-examine centralized versus distributed power generation as clean coal and fuel cells technology develops
- Invest in broad based R&D

Make New Mexico a prototype for

- **Intelligent, designed, evolving mix**
- **Empowering incentives, credits, regulations**
- **Power grids that facilitate/embrace distributed and intermittent generation with attractive buy back offerings.**

<u>Hope for the future!</u>

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

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