Reaching cheap clean energy for all in the 21st Century?

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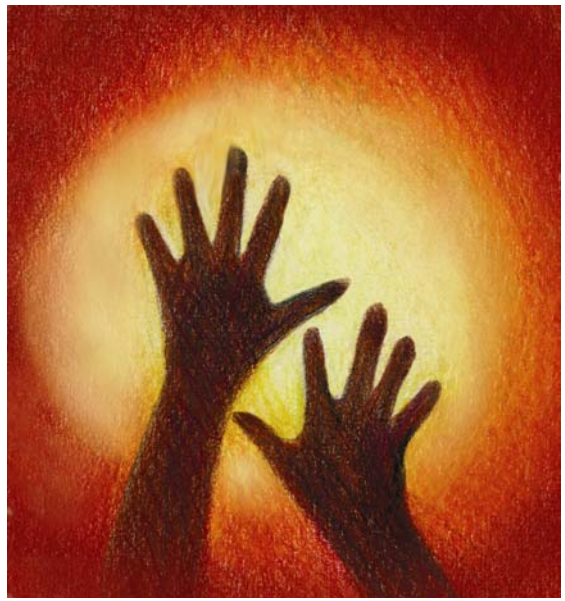


2 billion in 21st century

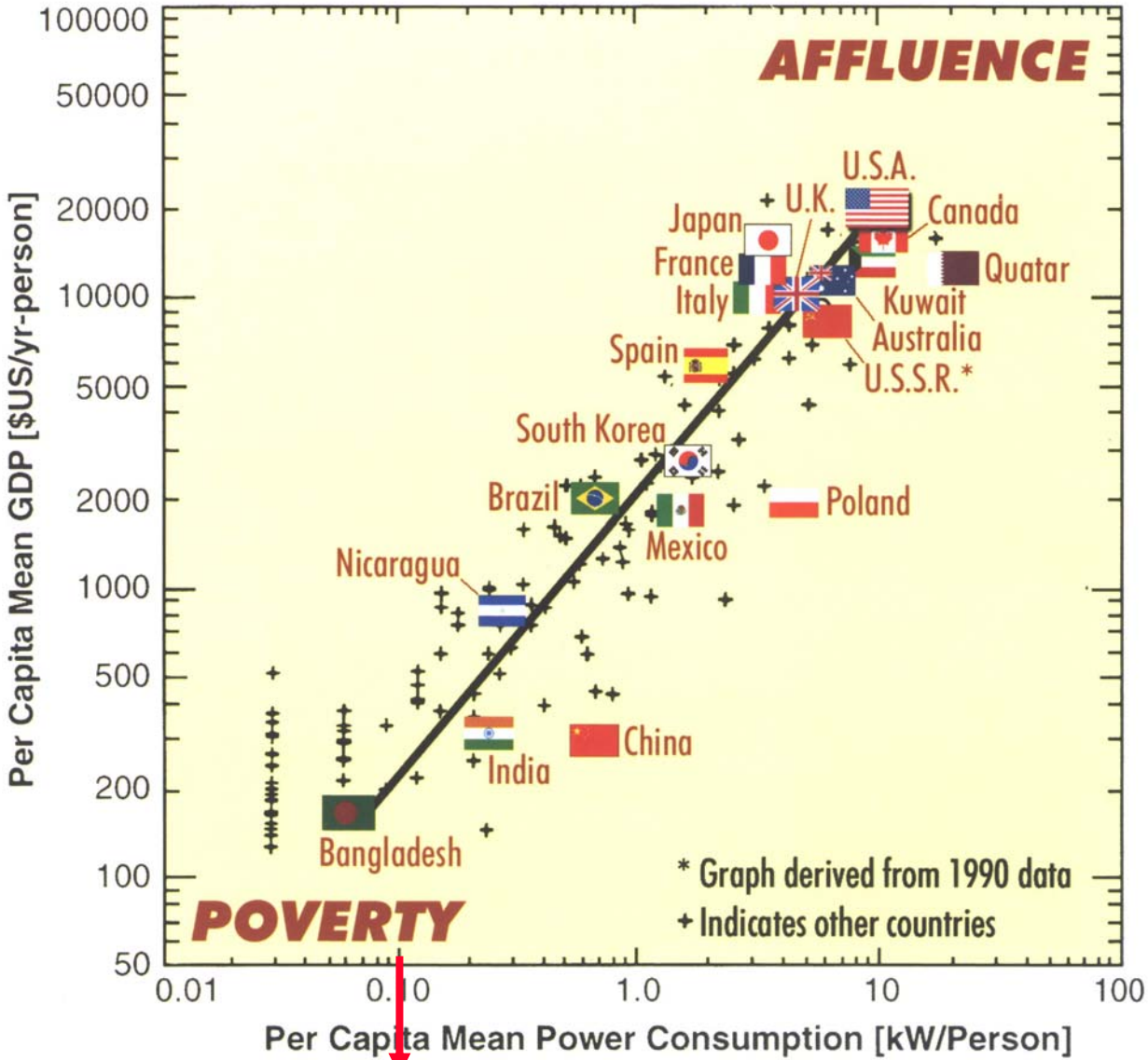
Resources & Skills

1.5B people in transition

3 billion in 18th century with less than $2 per day

(population growth is happening here)

Energy = prosperity → need cheap clean energy

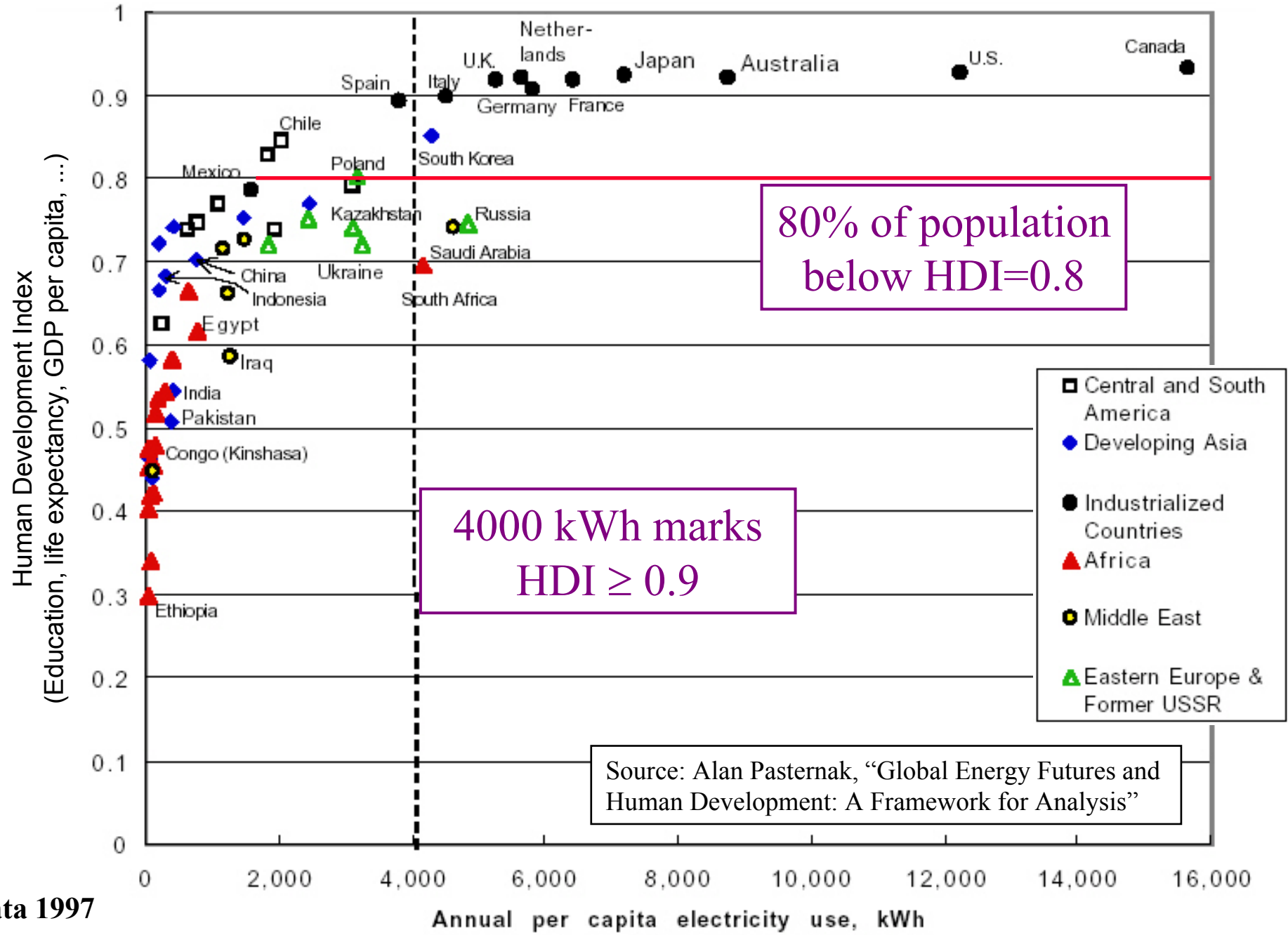


Per capita GDP related to per capita energy consumption. A nation's wealth is directly related to its access to affordable energy. What will happen to resource availability and the environment as countries like India and China move up the sloped line?

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

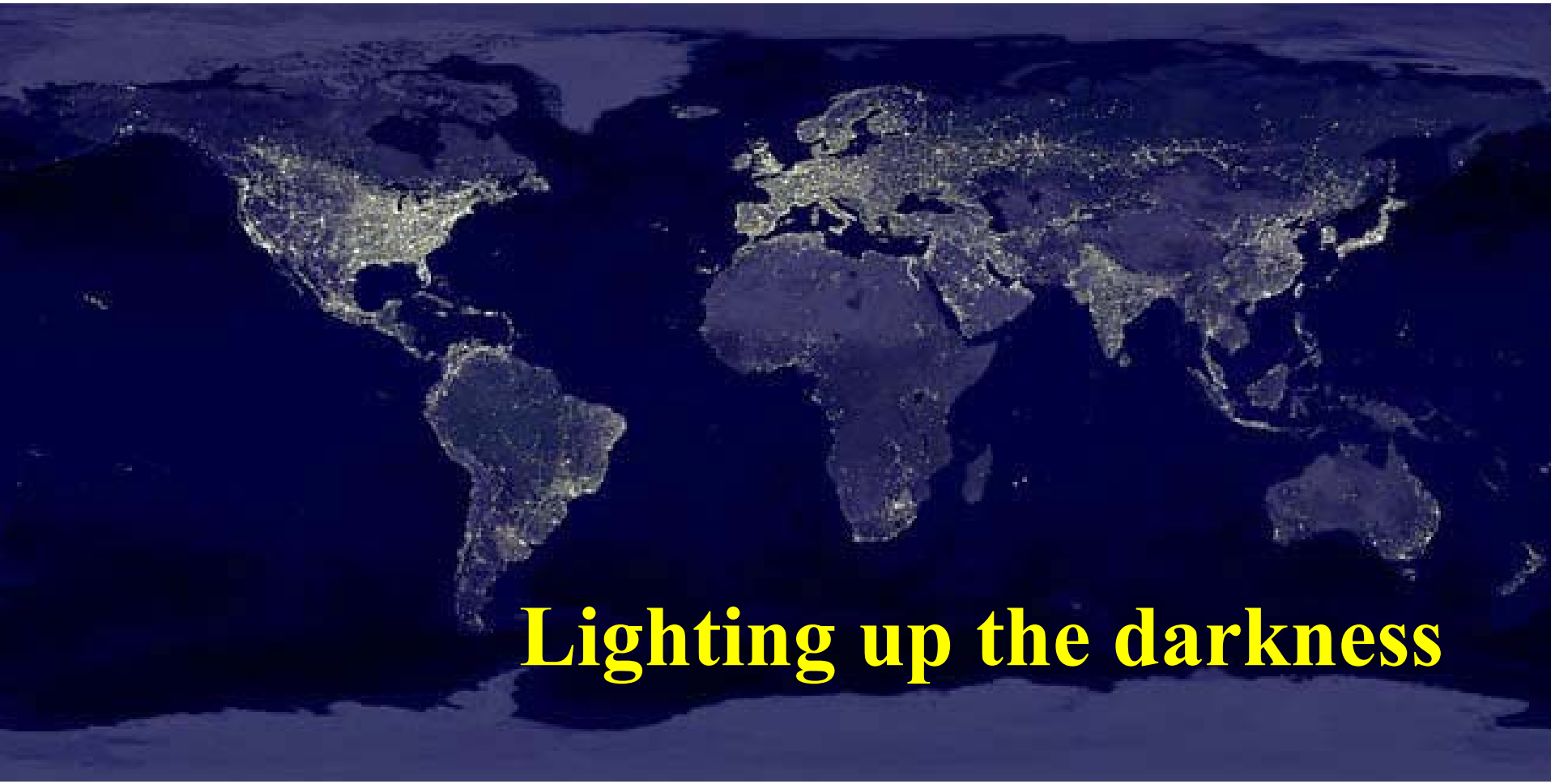
Human metabolism ~ 100 watt

Global Distribution of Electricity & Development



Data 1997

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

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.

Goal: 32 terawatts of cheap clean power

Efficient use versus developing new technology?

We need both

A mind-boggling global infrastructure (~$15 trillion) provides energy/mobility to ~3.5 billion people

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

This cannot be changed overnight!

We take energy for granted

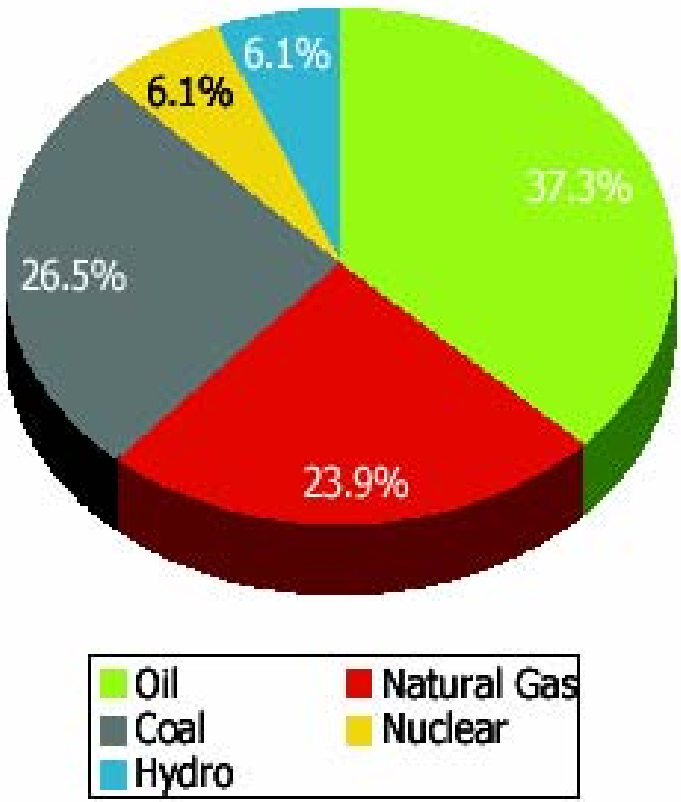
Think beyond your 2005 oil, natural gas, electricity, bills

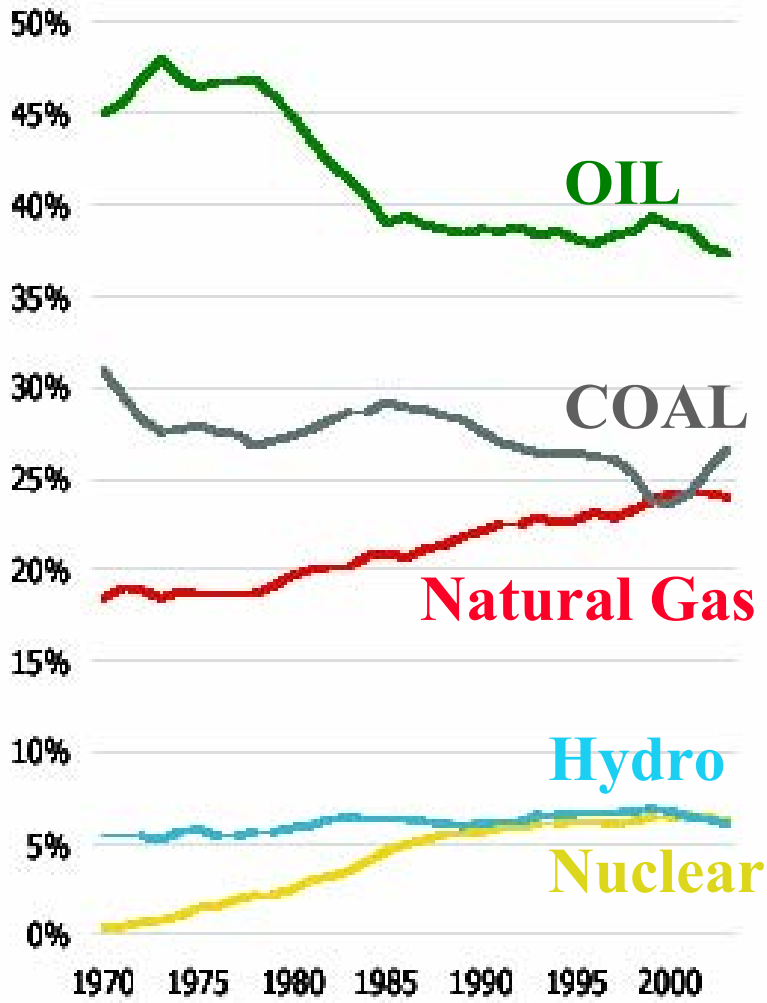
Each day each one of us uses

Source: Greg Swift

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



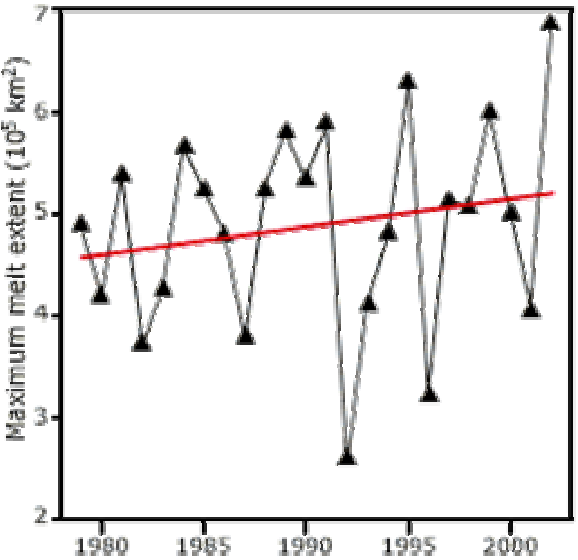


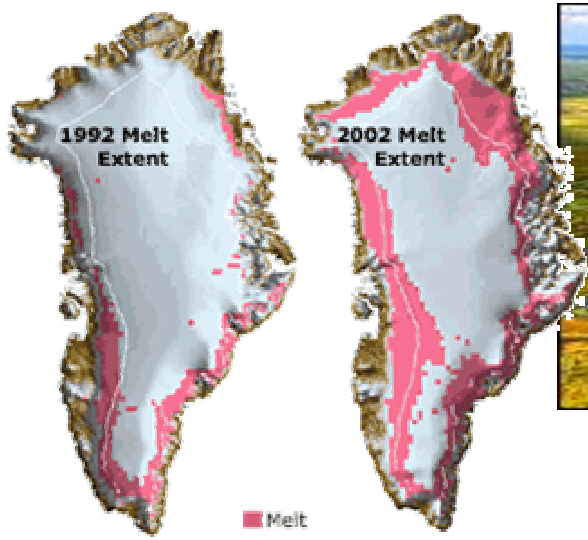
Source: BP Statistical Review

Fossil fuels and Environment

In the 20th century we started to act on pollution (mercury, NOx, SOx, acid rain, soot, ...) but <u>not</u> Green House Gasses like 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/

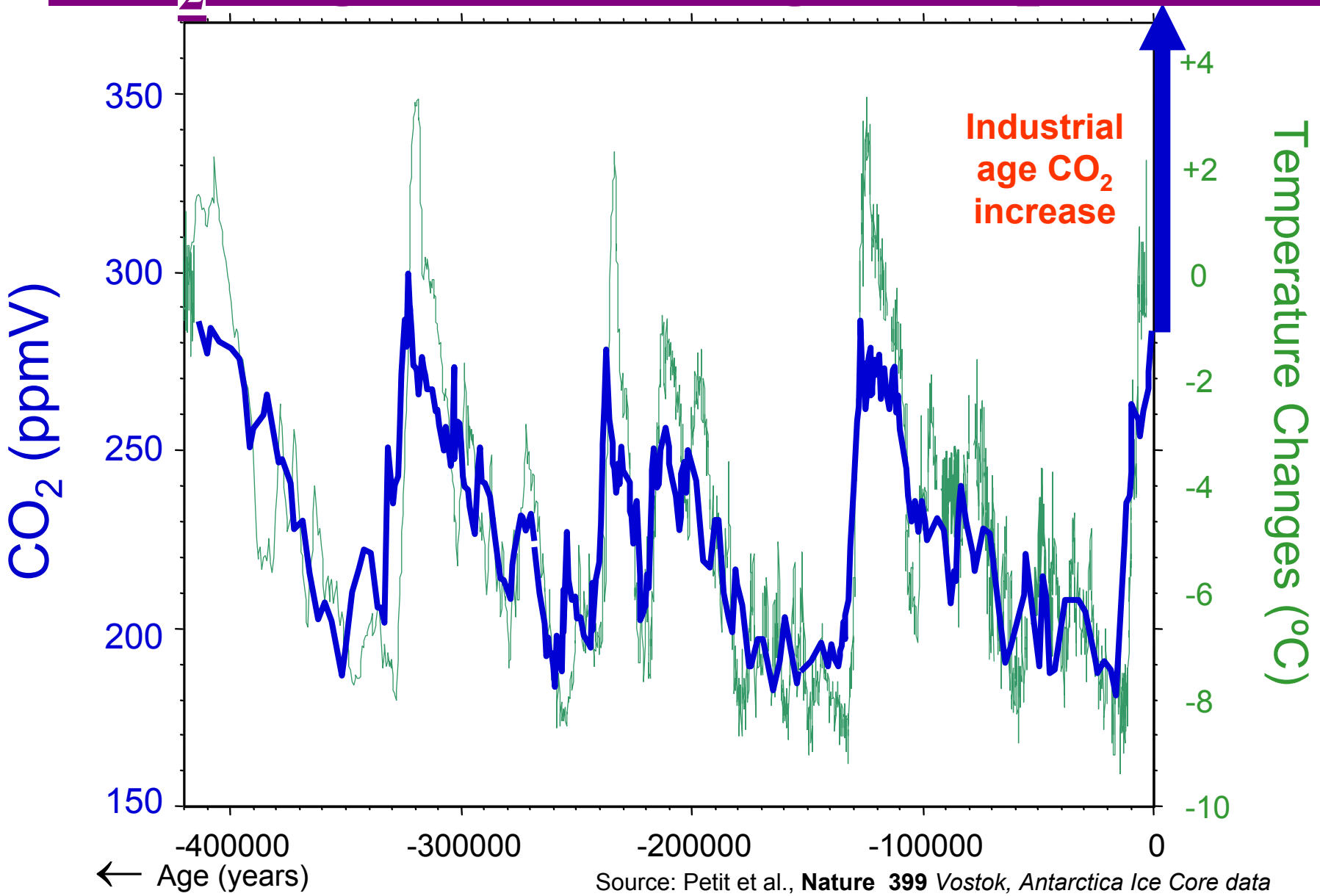
Melting of glaciers in Greenland and around the world. Is it global warming?

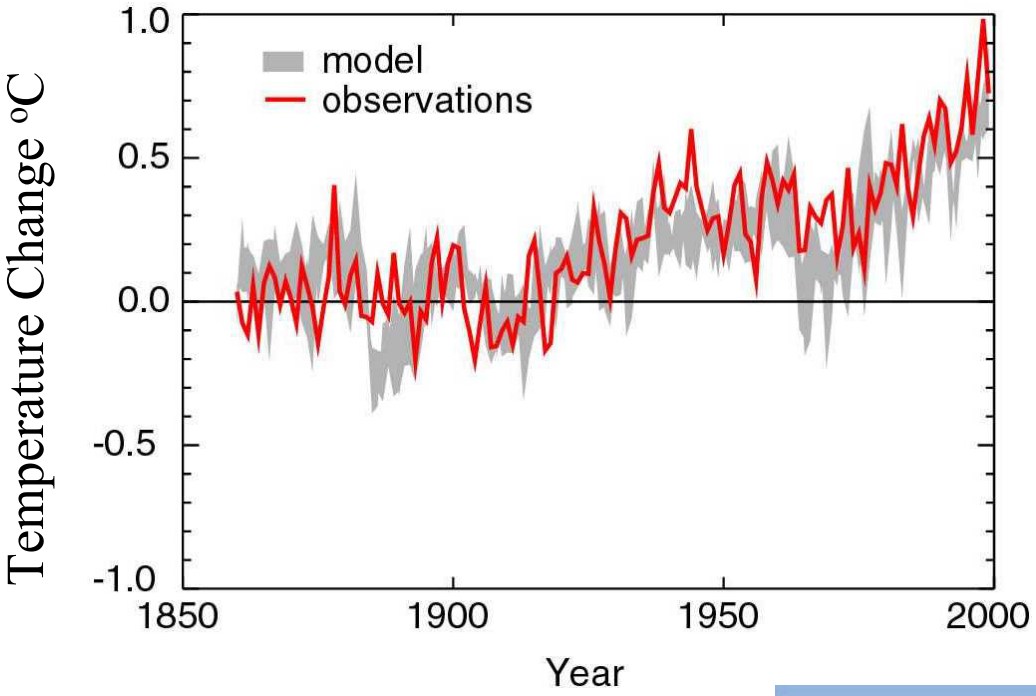
Melting of permafrost

Intense storms

Sequestration of CO_2: First capture CO_2 and then store it

CO_2 & global average temperature

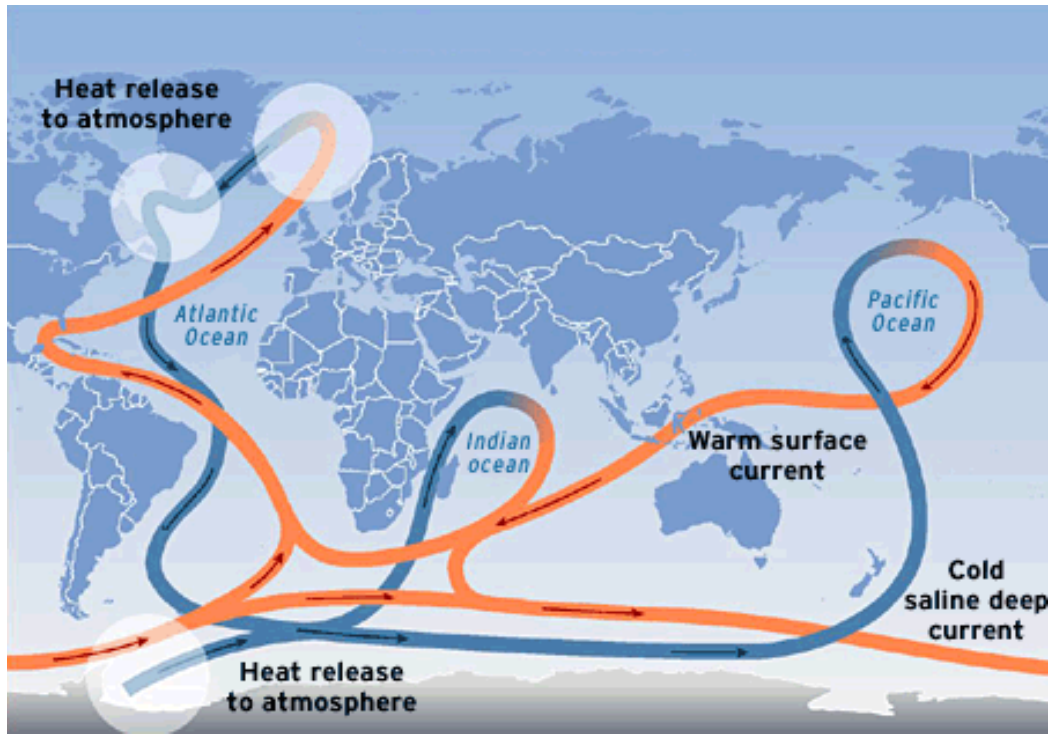




Increasing evidence for temperature rise due to fossil-fuel burning

Possibility of catastrophic change:

Shutdown of the thermohaline in 10s of years

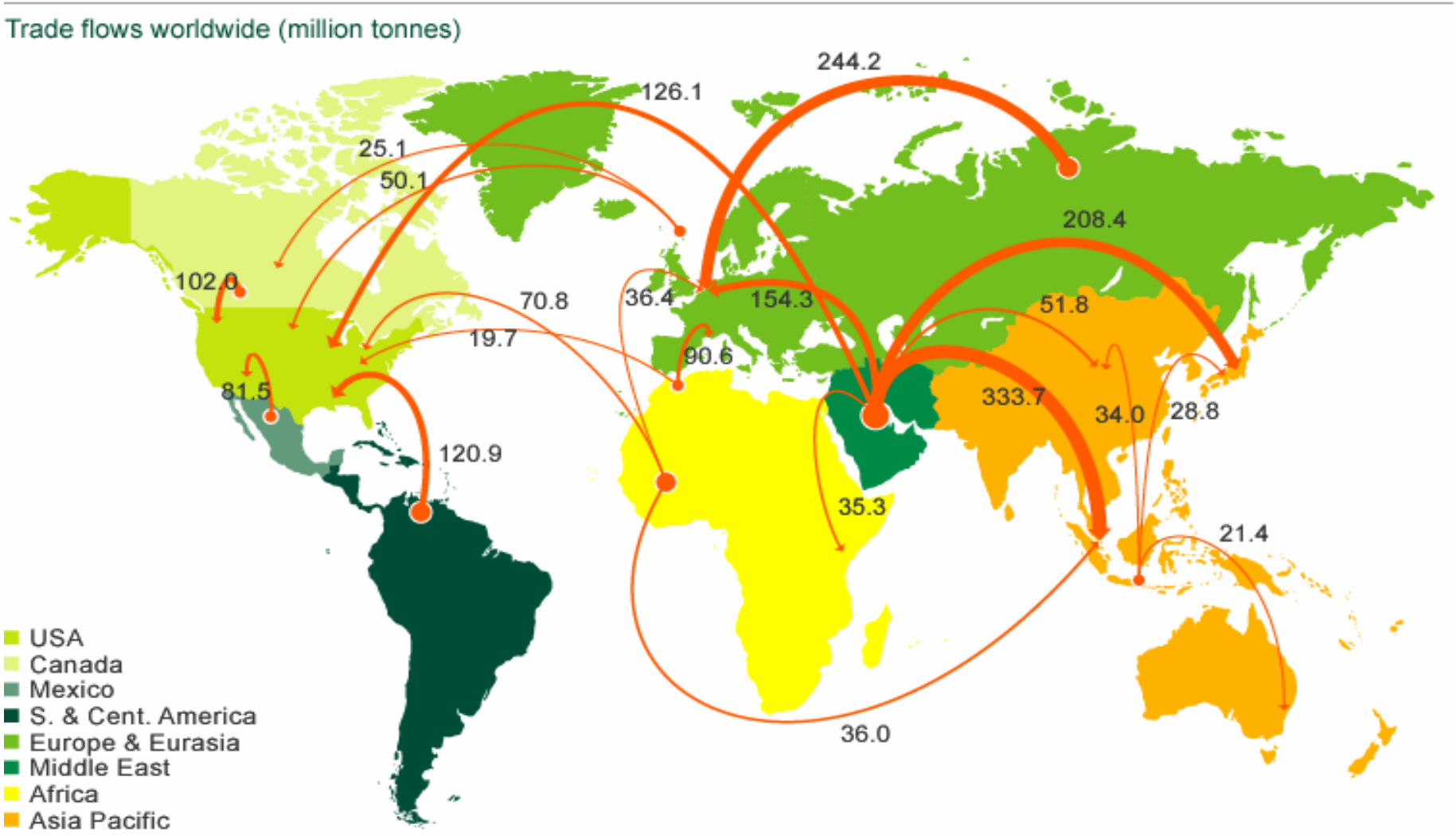


Climate change is the largest, costliest, most dangerous, uncontrolled experiment ever done by mankind

Immediate problems with business as usual

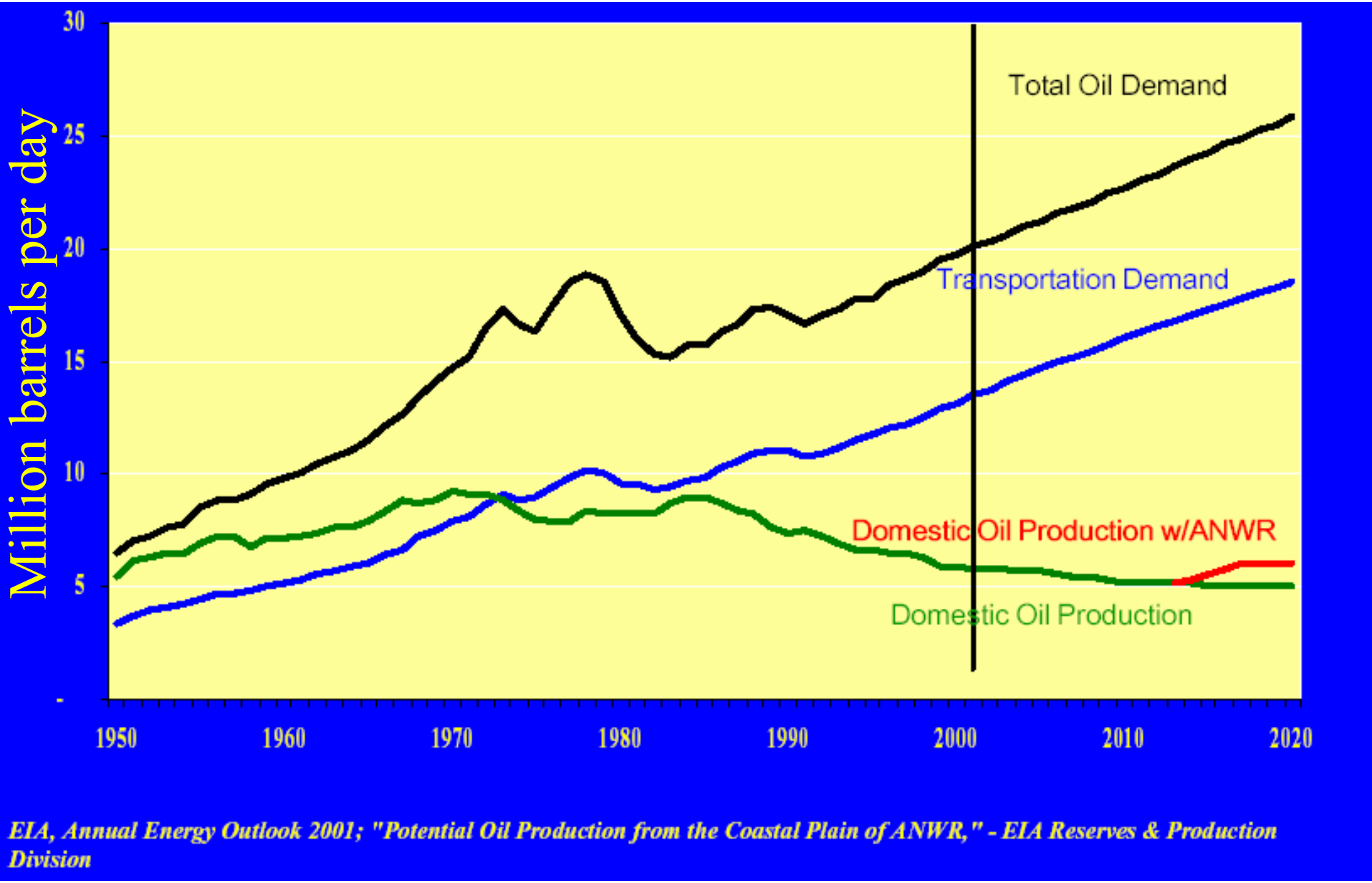
- CO_2 emissions $\rightarrow$ global warming
- USA imports 2/3 of oil used
- Share of imported natural gas (15%) set to increase rapidly
- Market saturated, volatile, unstable

Oil is easy to move and trade



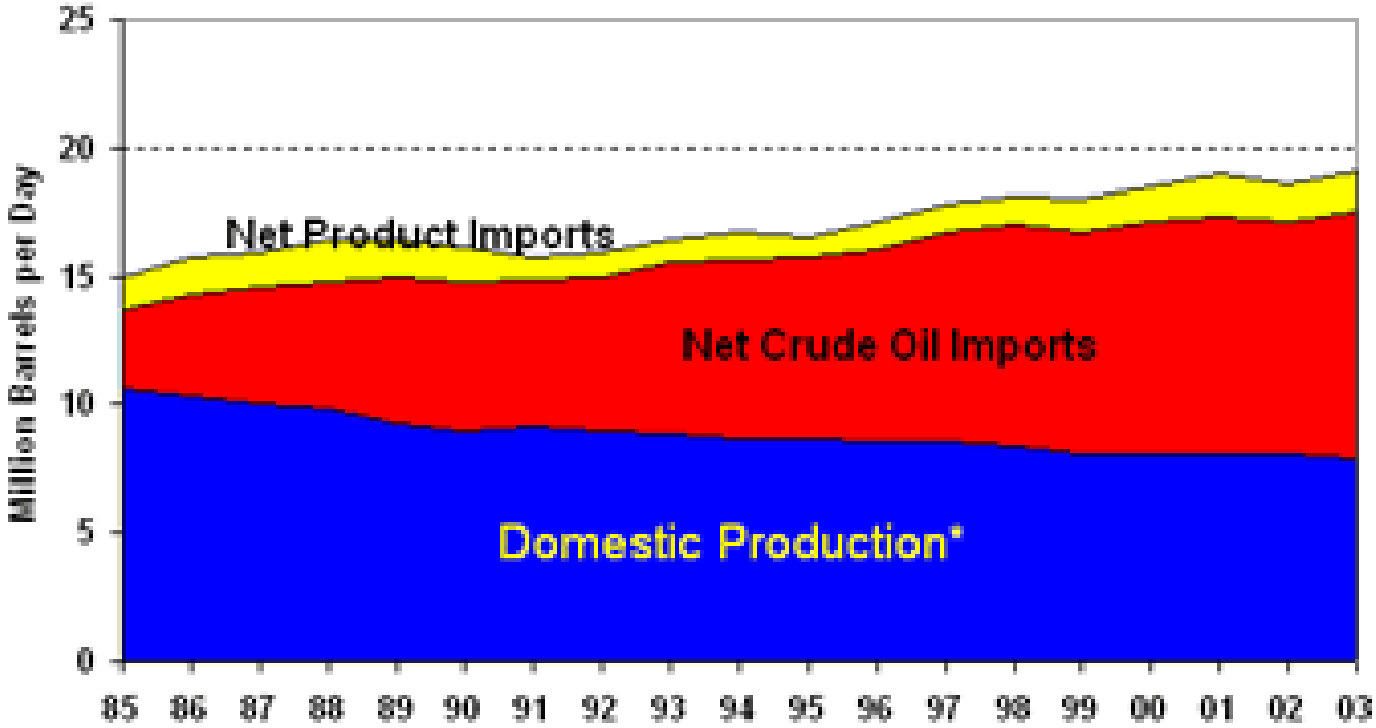
BP 2004

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



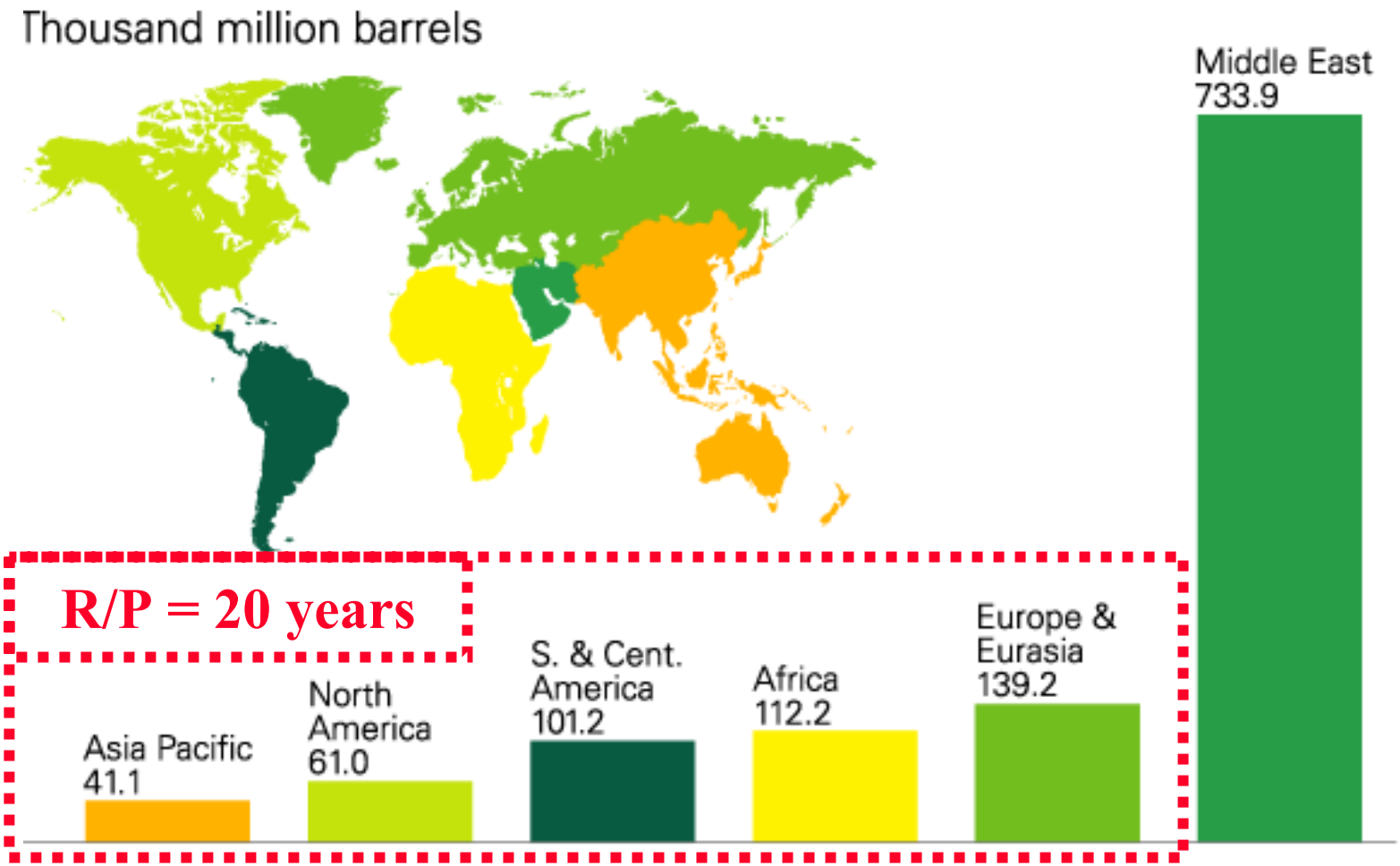
Friendly nations cannot fulfill our oil needs

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

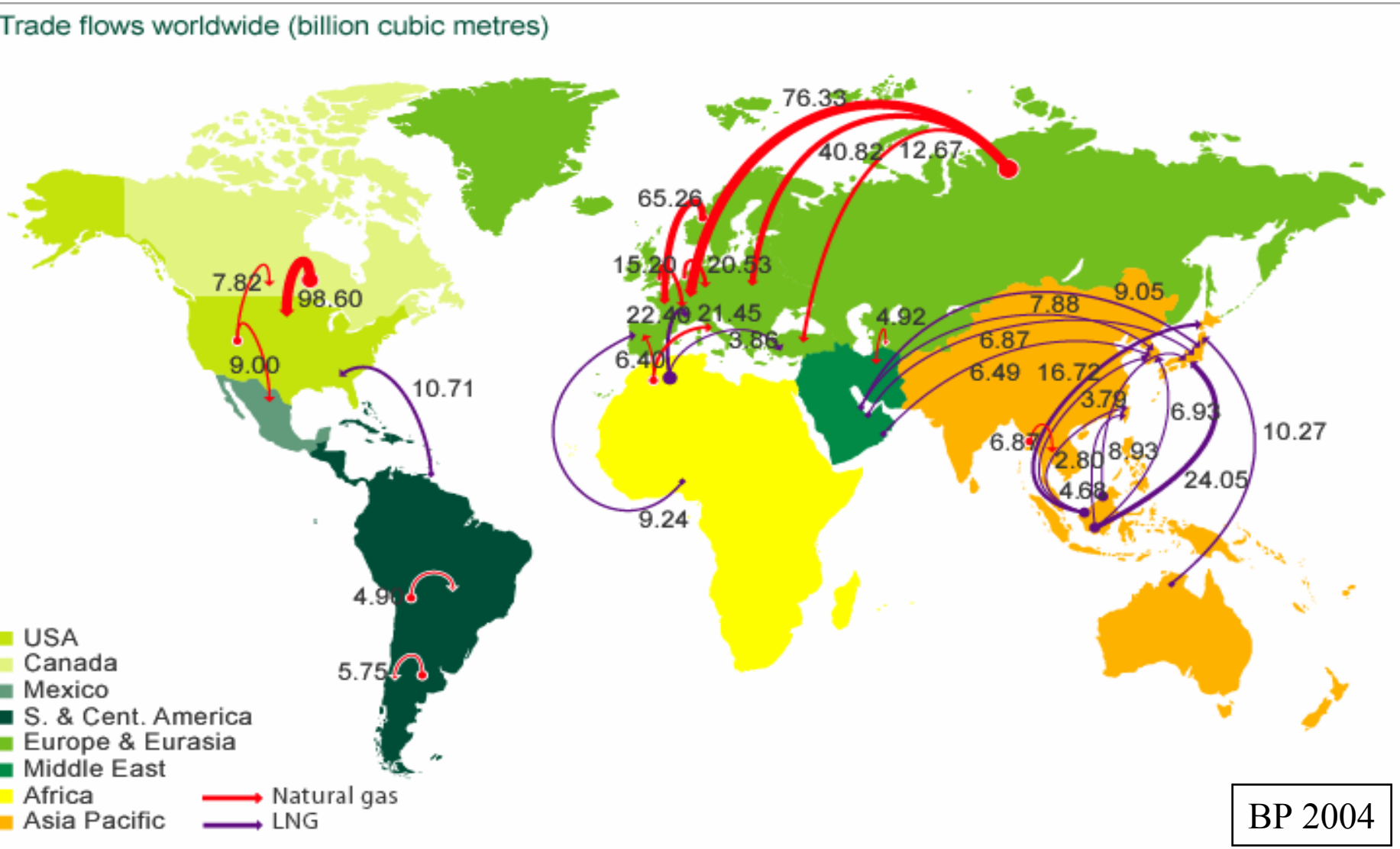


2004 Usage = 31Bbo/year ⇒ R/P = 40 years

Natural Gas

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

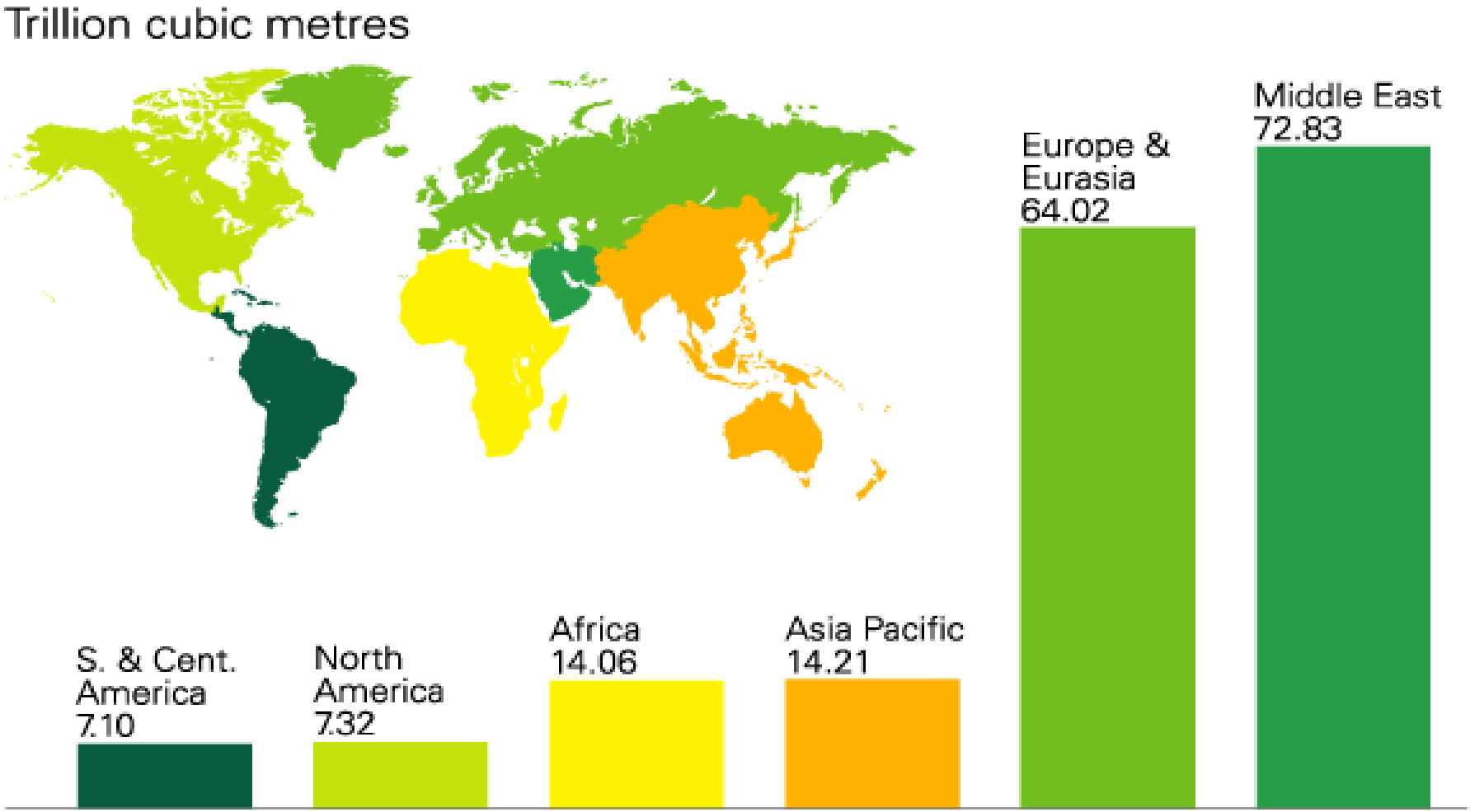
Major natural gas trade movements



BP 2004

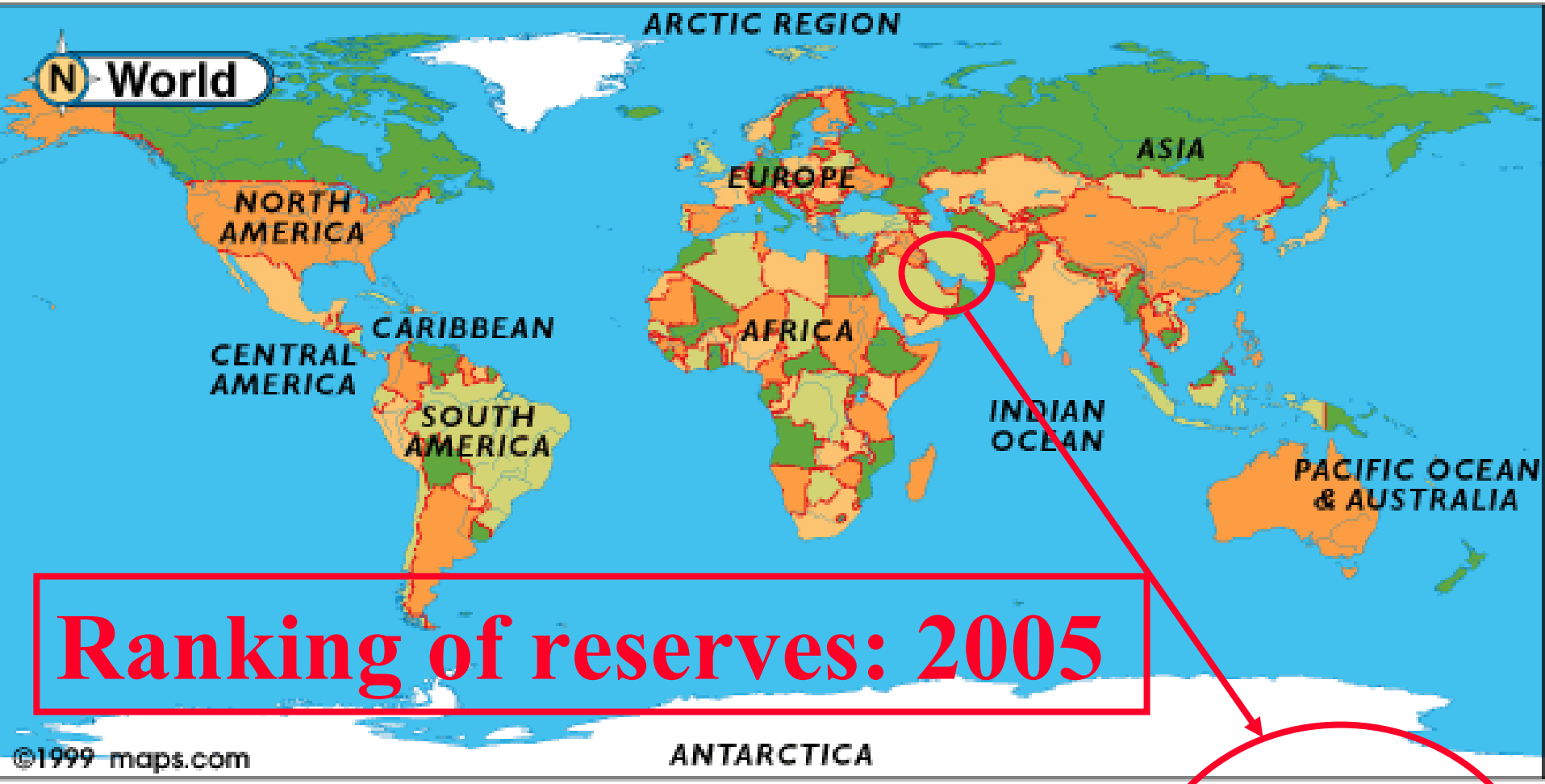
Proven natural gas reserves at end 2004

BP2005



North America uses about 0.8 trillion cubic meters a year

The world has changed, and is changing very rapidly



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

Fast forward to 2020

USA ?,-,1

China -,-,3

EU -, -, 4

Russia ?,1,2

India -, -, 5

AT -, -, -

? → EOR

Persian Gulf

OIL 1,2,3 4,5

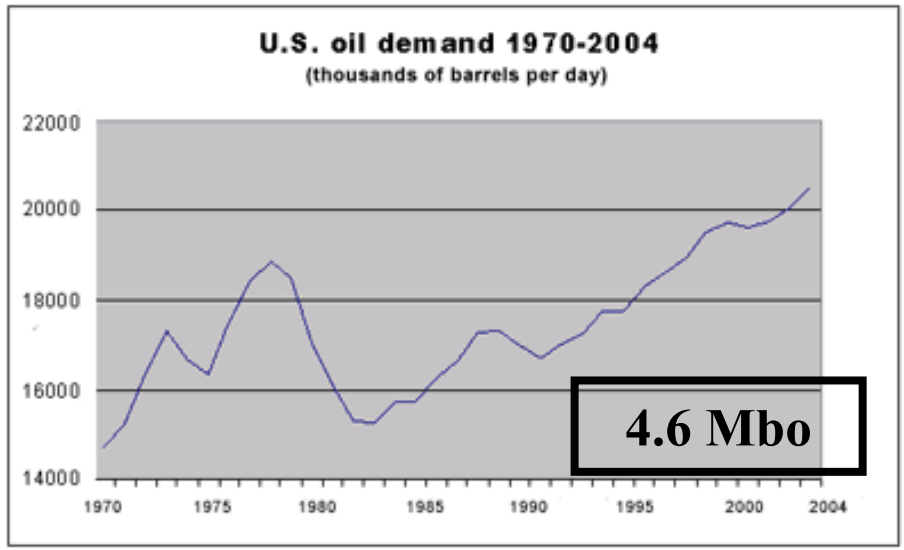
GAS 2,3,4, 5,9

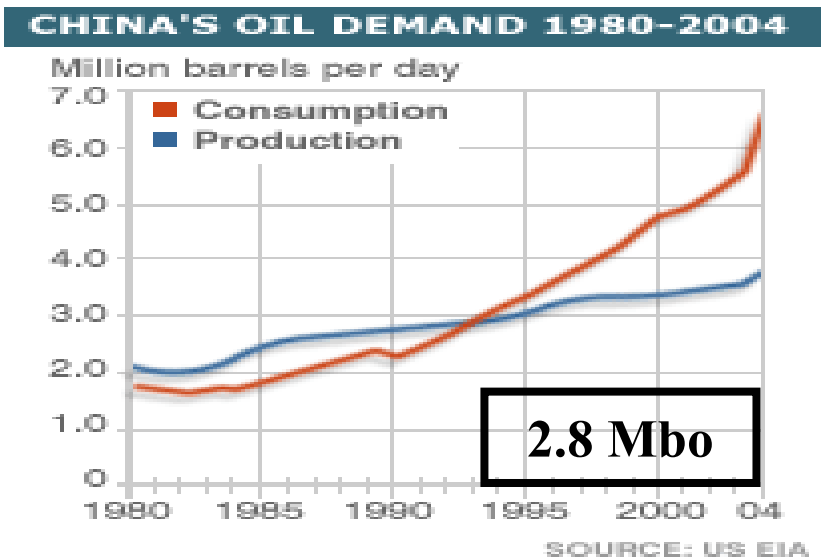
No Coal

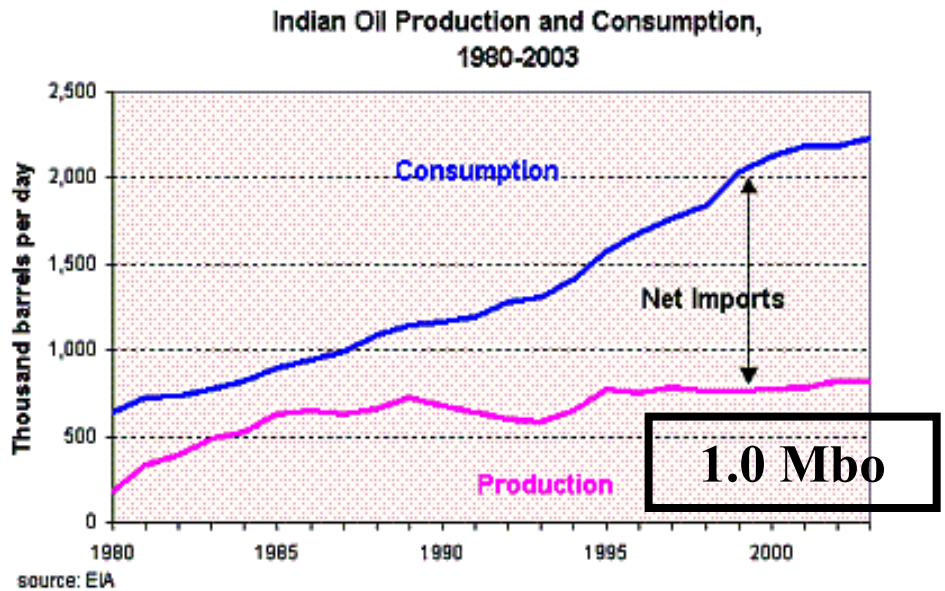
Middle East and Russia control conventional natural gas and oil

Constrains on supply

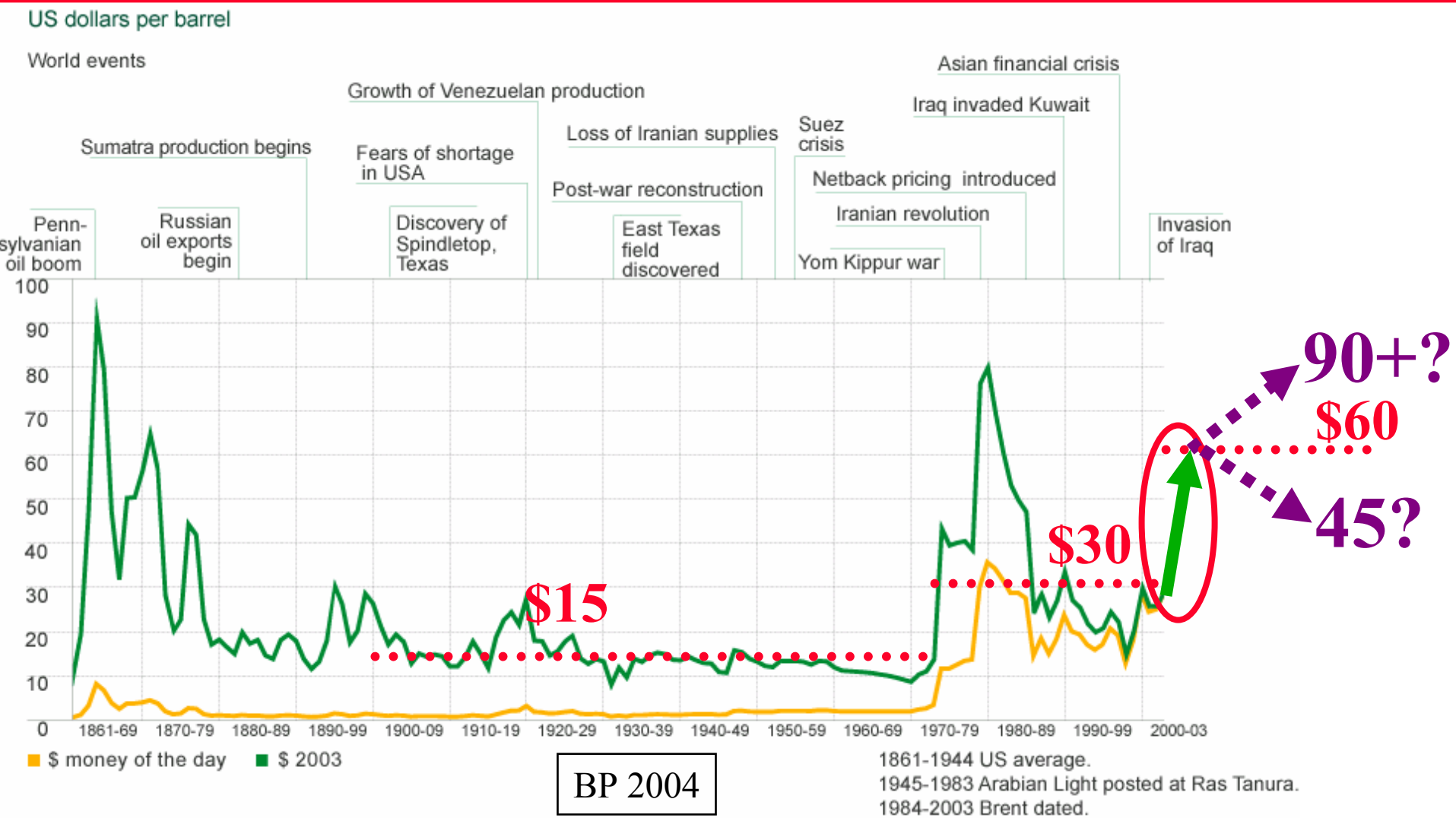
- Competition as a result of growth in demand (USA, China, India since 1990)
- Little excess capacity
- Major disruptions
- Exploration, development and production not in the hands of oil companies







Saturated Market: Increased volatility and high prices post 2004



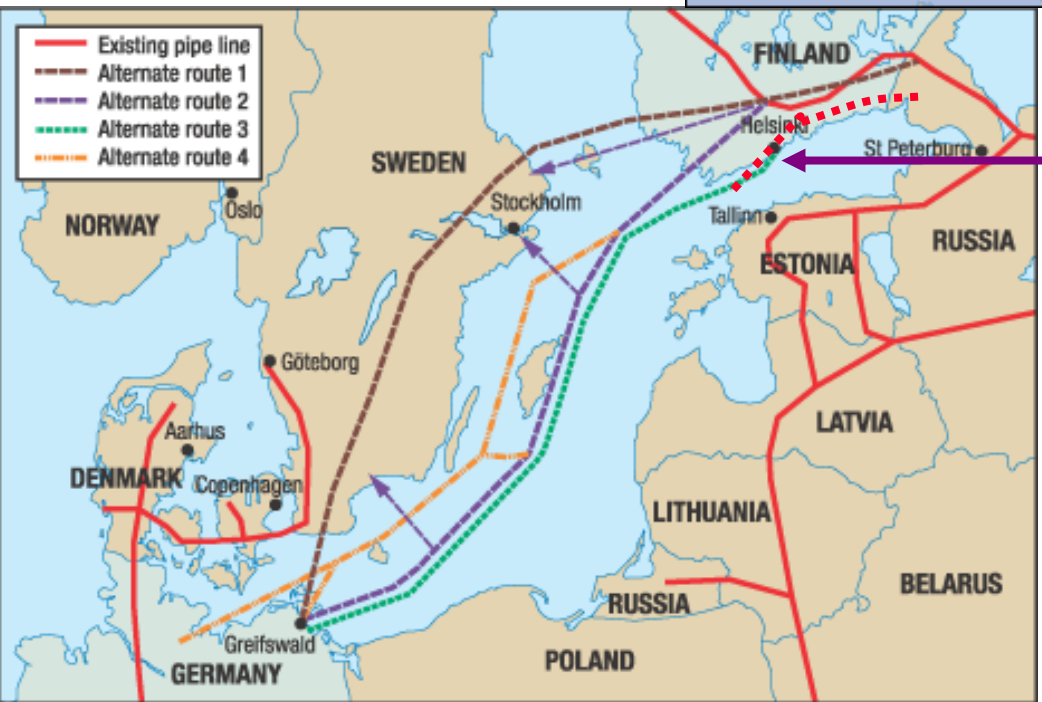
BP 2004

Rapidly changing world – Geopolitics

- Nationalization of oil and natural gas fields (Venezuela, Bolivia, Nigeria, ...)
- New and evolving environmental regulations
- Difficult arrangements between nations with resources and oil companies
- Investments in unstable countries (Nigeria, Chad, Sudan, Angola, Iraq, Iran, Venezuela)
- Disruption of production and supplies (Iraq, Nigeria, Venezuela)
- The emerging role of Russia, Iran

He who owns the pipe lines gets the oil and gas!

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



New pipeline from Vyborg, Russia to Griefswald, Germany bypasses Ukraine and Eastern Europe

Russia has muscle and cash: President Vladimir V. Putin

- (4/26/06 in Tomsk with Chancellor Merkel)
  "Russia should direct future oil and natural gas exports to Asia because *unprincipled competition* had blocked its energy companies from expanding elsewhere"
- (3/10/06 first presidential visit to Algeria)
  A $4-billion arms contract, the biggest in post-Soviet history. Plus contracts worth $1 billion involving natural gas company Gazprom and the oil company LUKoil, …. **(gas cartel?)**

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

Cannot have cheap clean energy for all without some key S&T breakthroughs

- Separation/capture of CO_2 from mixed gas streams
- Secure and effective long-term storage of CO_2.
  - Geologic, mineralization, air extraction, …
- Hydrogen from non-fossil fuels (also fuel cells):
  - Electrolysis of water (inexpensive and efficient electrodes)
  - Photochemical and/or thermo-chemical splitting of water
- Reprocessing of spent nuclear fuel
  - separation of SNF, transmutation, reassembly into fuel
- Photovoltaic cell technology
  - nano and/or bio materials
- Fusion?

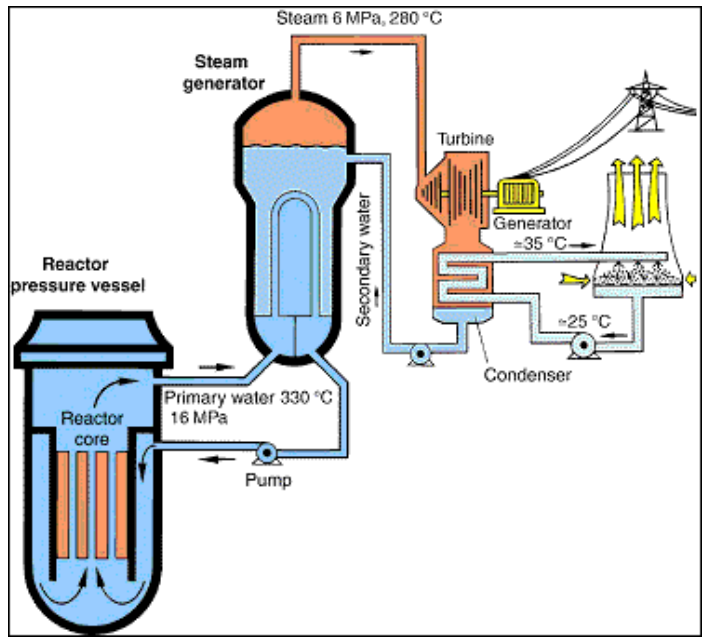
Tipping points reached

- **Excess food crops → ethanol**
  - **Economical at > $40 per barrel**
  - **3-5% solution for the USA**
- **Cellulose (waste) → ethanol**
  - **Economical at > $60 per barrel**
  - **3-5% solution for the USA**
- **Solar (homes and buildings at $10/peak watt)**
  - **Cost recovery over lifetime (25-30 years)**
- **Wind (off-shore & on-shore)**
  - **part of a larger on-demand system**
- **Hybrid cars (35→50 miles per gallon)**
  - **$4K premium recovered over 150K miles @ $3/gallon**

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**
- **SNF reprocessing/management**



Examining energy futures from all three perspectives

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

Be more efficient
Sequester CO_2
Develop alternatives to fossil fuels

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

Questions?

- **Globalized world –**
  - **can free markets create stability in supply and demand?**
  - **Can we come to an agreement on equity?**
  - **Should environmental costs be factored into products?**
- **Can competition in a resource limited world foster co-operation?**
  - **Global identity (transcending family, communal, religious and national interests)**

Questions?

- **Social dynamics**
  - **Changing behaviors**
  - **Changing expectations**
- **Political dynamics**
  - **Exploitation, hegemony, or co-operation**
  - **Environmental impact**
  - **What sacrifices are acceptable**
- **Future demand as countries**
  - **Urbanize**
  - **Develop**
- **Population growth, demographics, migration**
  - **Especially if developing countries fail**

Questions?

- Impact of catastrophic events – resilience in the system?
- Impact of conflicts and wars?
- What happens when cheap oil (2010?) and gas (2035?) production starts declining?

If global energy production is to plateau, will energy be

cheap?

Clean?

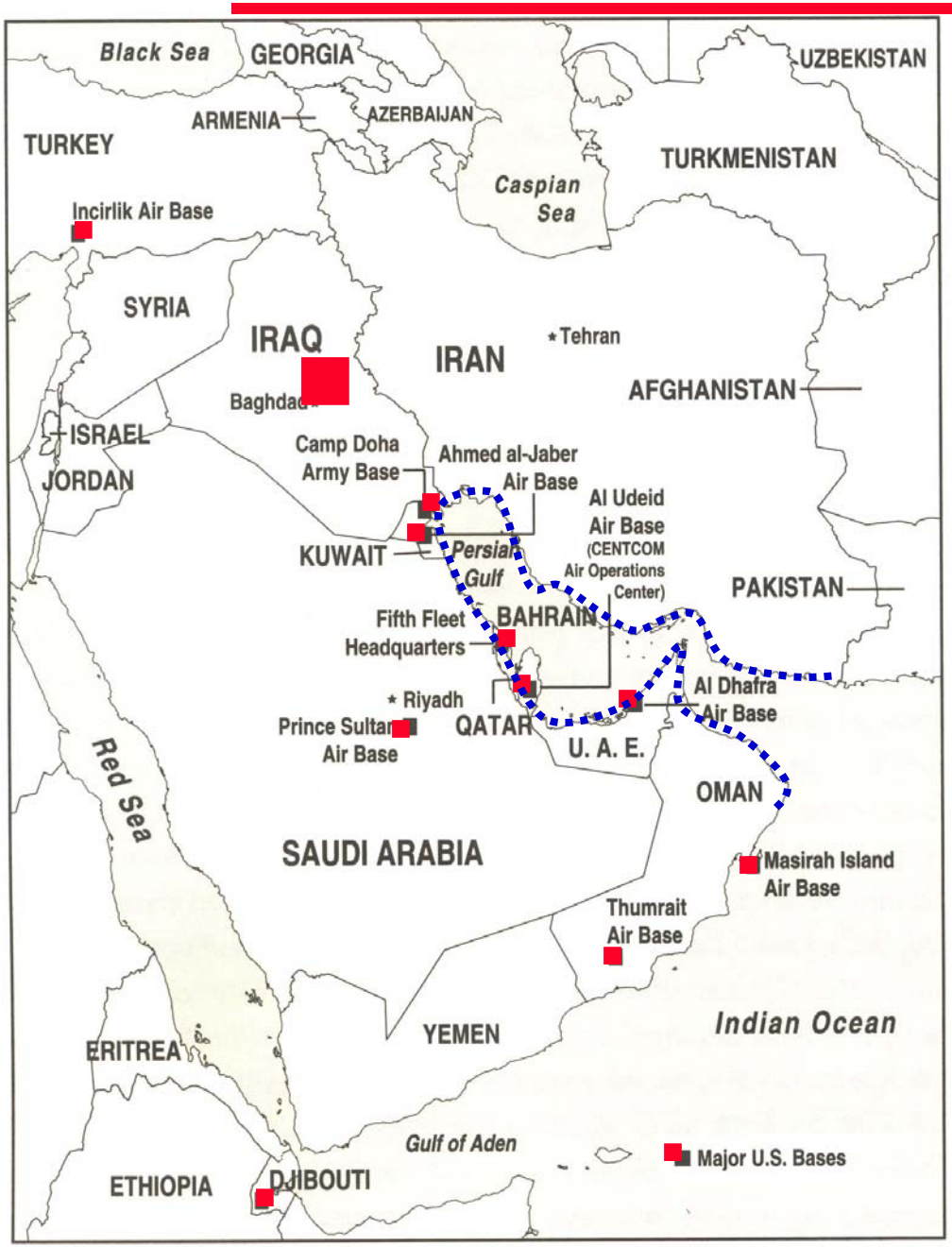
shared by some?

Shared by all?

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?

OR
Renewable Technologies
and
Behavior Change

Energy efficient community: Issues

- **Energy for travel to, and for, work**
- **Shopping (clothes, groceries, household items)**
- **Specialty foods & goods**
- **Education – Schools**
- **Sports**
- **Entertainment and leisure time activities**
- **Health care**
- **Services**

Telecommuting versus relationships and human contact

Some thoughts on urbanization

- **Build compact**
- **Prevent sprawl**
- **Prevent subsidies for services (roads, water, electricity, gas, sewage) to flung out sub-divisions**
- **Promote walking and bicycling as means to commuting. (Healthy too!)**

Good behaviors begin with role models at home

Efficient Public Transport System

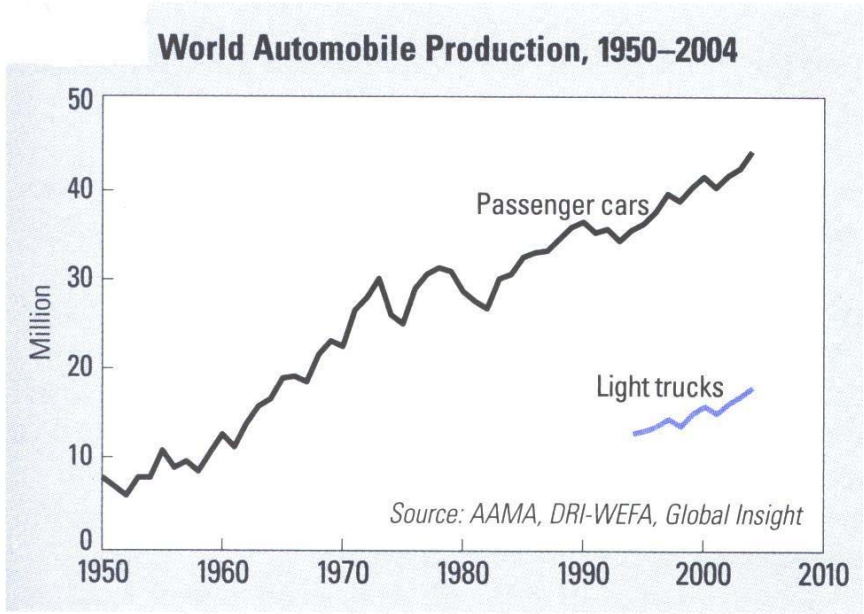
- **In developed countries public transport should match private cars in terms of**
  - **Convenience**
  - **Flexibility**
  - **Stress reduction**
- **Parking: cost and time saving**
- **Enough people have to subscribe to it otherwise need subsidies**

City planning plays a big role in feasibility.

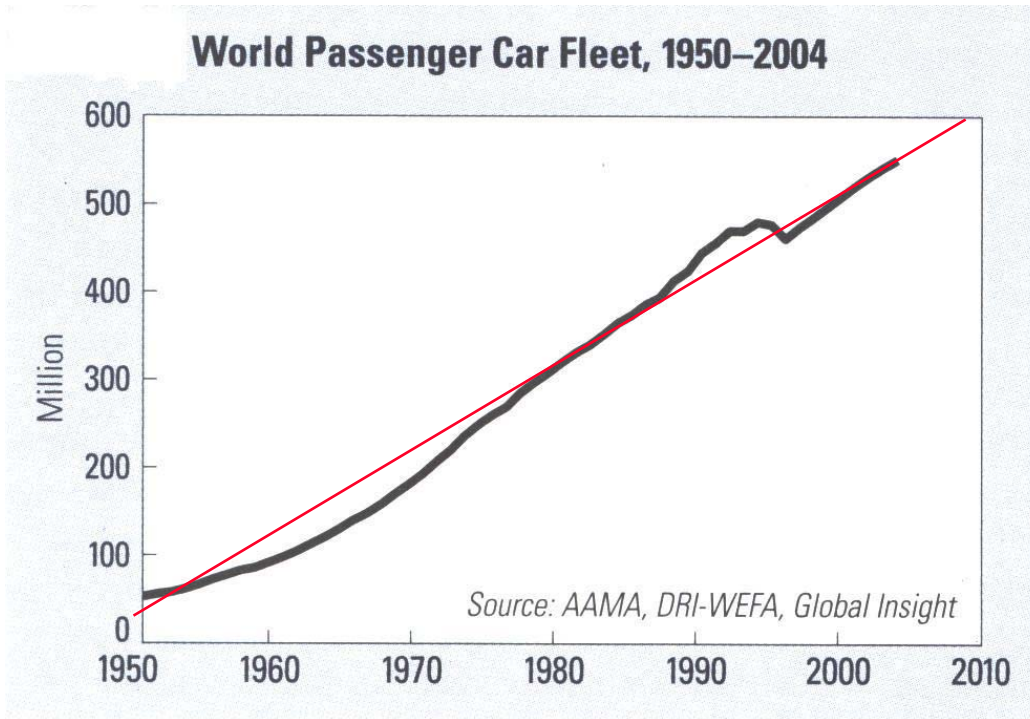
Are our cities being planned appropriately?

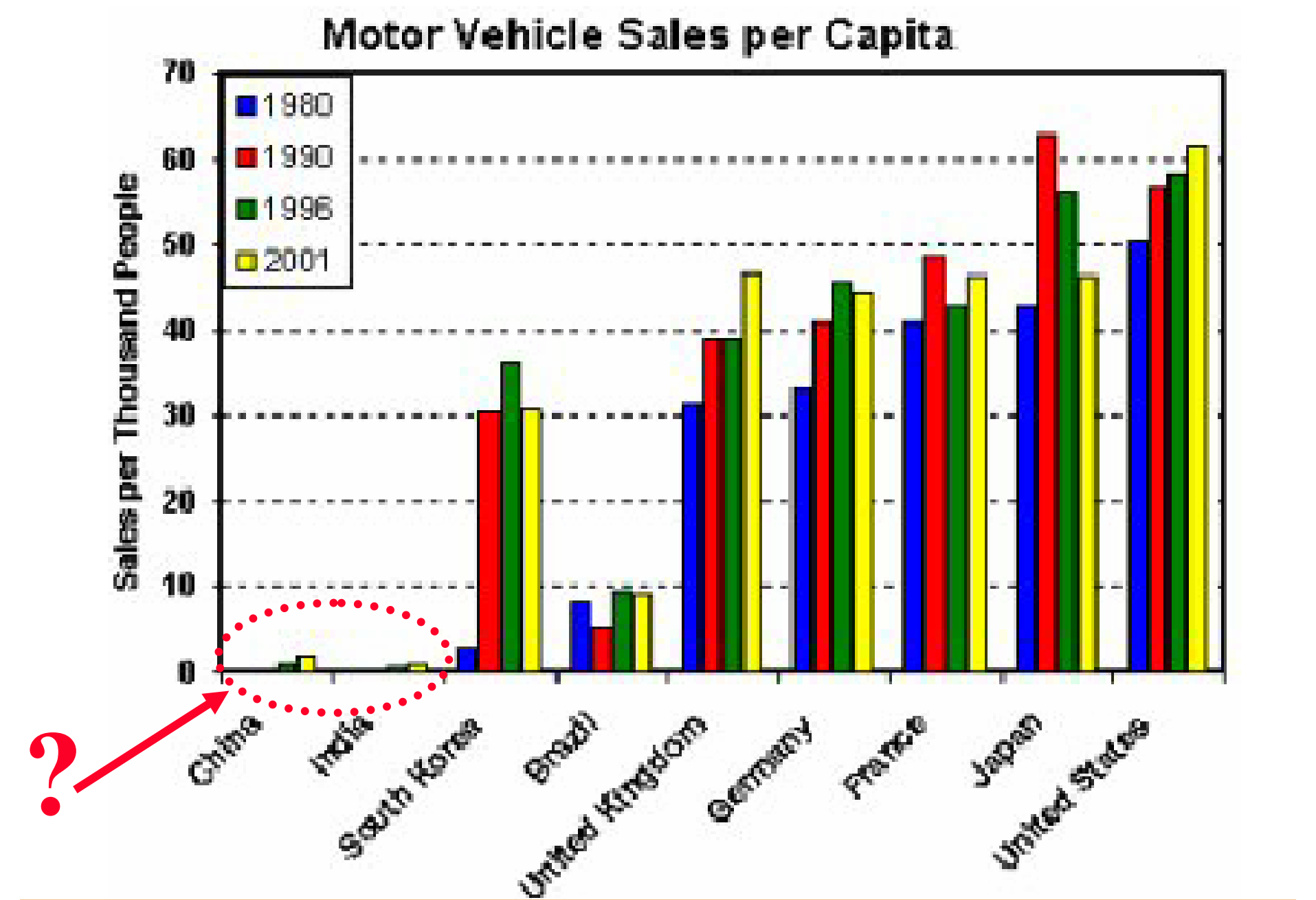
Transport: focus on cars and trucks

- 60 million new cars & light trucks each year
  - Growth: ~700K per year



The world fleet of ~600 million cars and trucks needs liquid fuel





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

Homes and buildings

- **Avoid size creep in fixed family size homes**
- **High insulation rating**
- **Passive/Active solar**
  - **Cool in summer**
  - **Warm in winter**
- **Net zero energy needs**
- **Water and waste management**

Develop homes and places of work in close proximity

Specialty Foods and Goods

- **Specialty foods and goods require time critical**
  - **Packaging**
  - **International scale transport**
  - **Global marketing and distribution chains**
- **External markets drive specialty production over local needs, resources, and capacity**

Understand true cost – include external costs of environment, pollution & waste management

Eat local foods lower in the chain

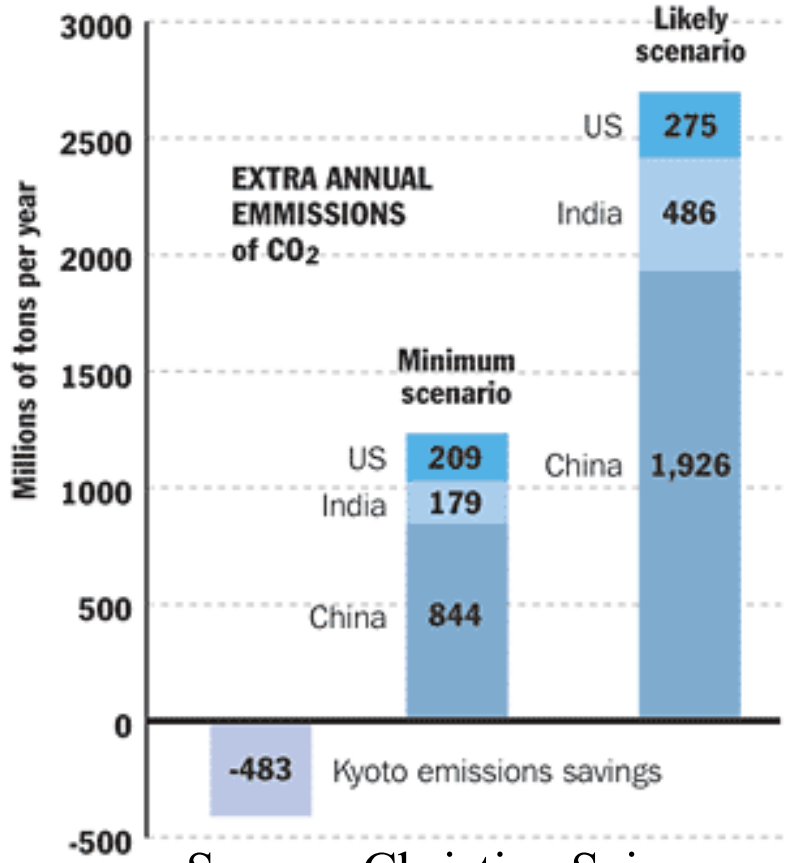
- **Meat requires more energy, fertilizers, pesticides, water, …**
  - **1 kg lean beef = ~33 kg grain = 33,000 kg water**
  - **1 kg chicken meat = ~6 kg grain**
- **Local foods**
  - **Seasonal**
  - **Promote farmers markets**
  - **More control over "organic"**

Rethink food preferences

Energy infrastructure of 2050 is just beginning to be built

- China, India, USA are building a new plant every week (2004-2012)
- Most power plants are coal fueled
  - Coal is abundant
  - Cheap because no CO_2 tax
  - Not zero-emission

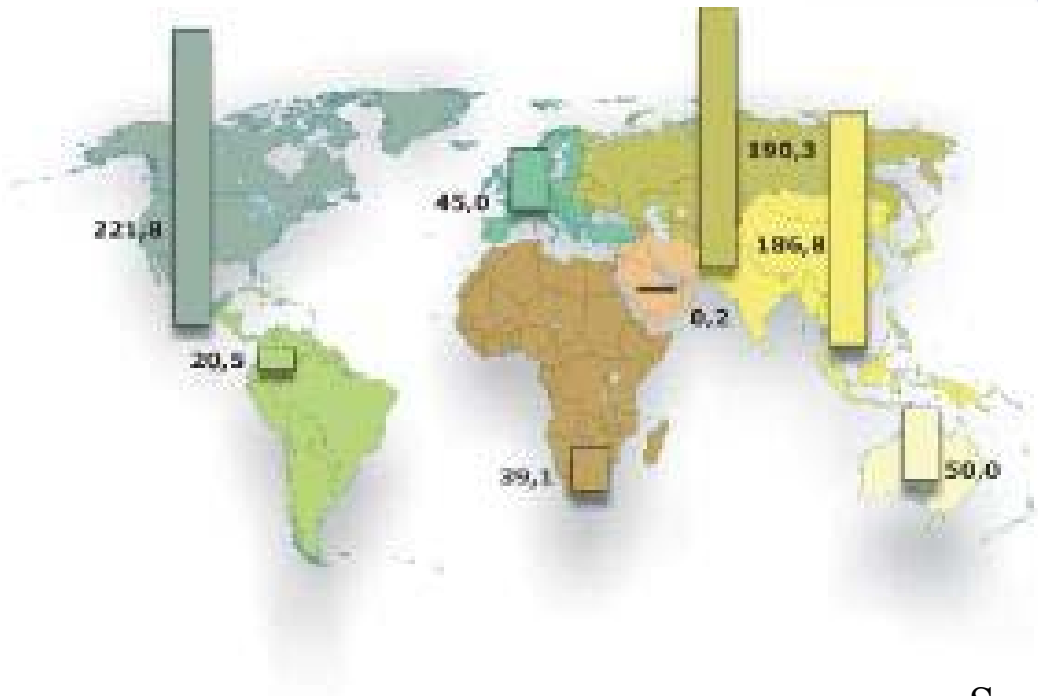
Ask and pay for "renewable" power



Source: Christian Science Monitor 12/24/04

COAL

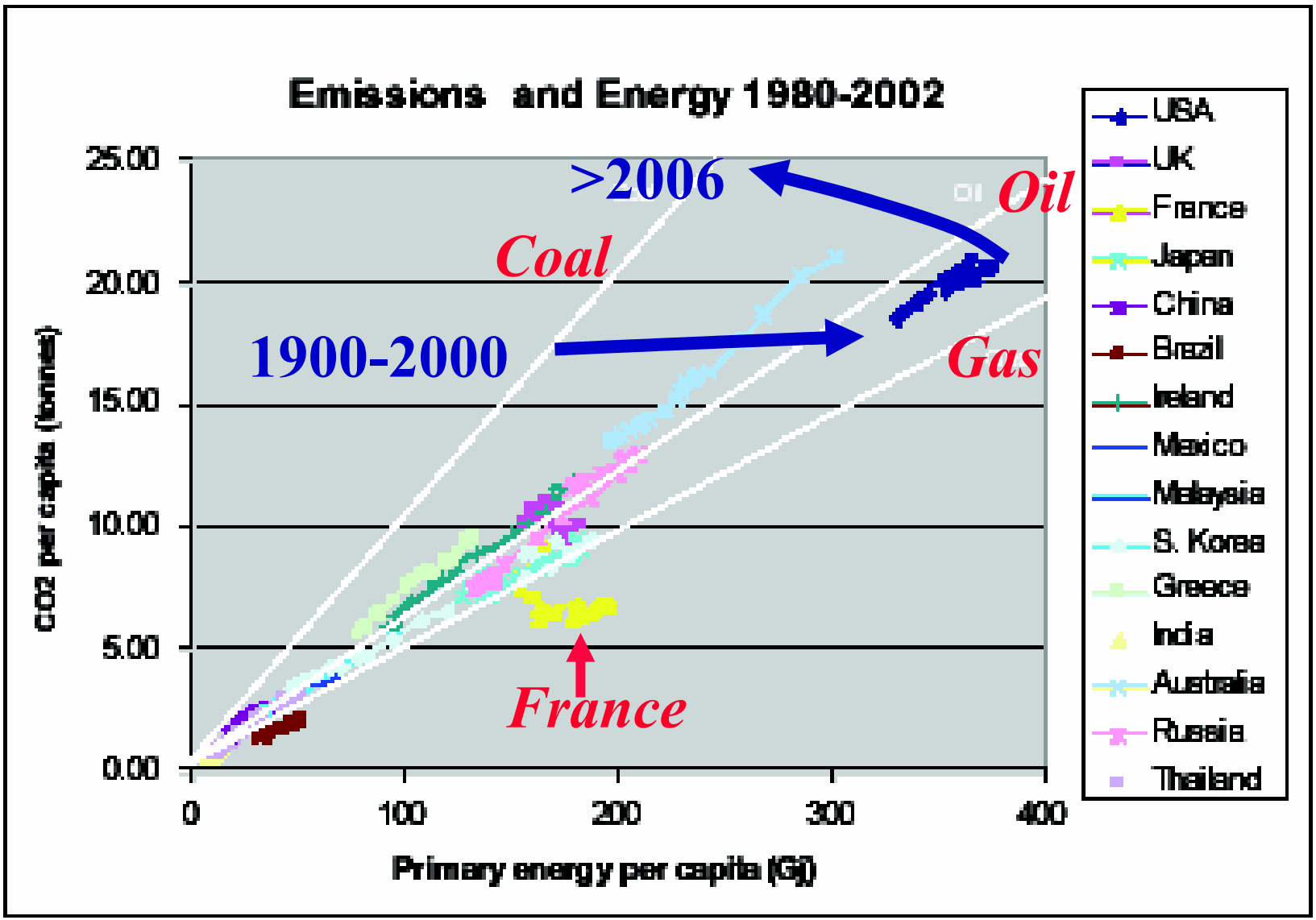
* Cheap
* US has largest reserves
* Pollution



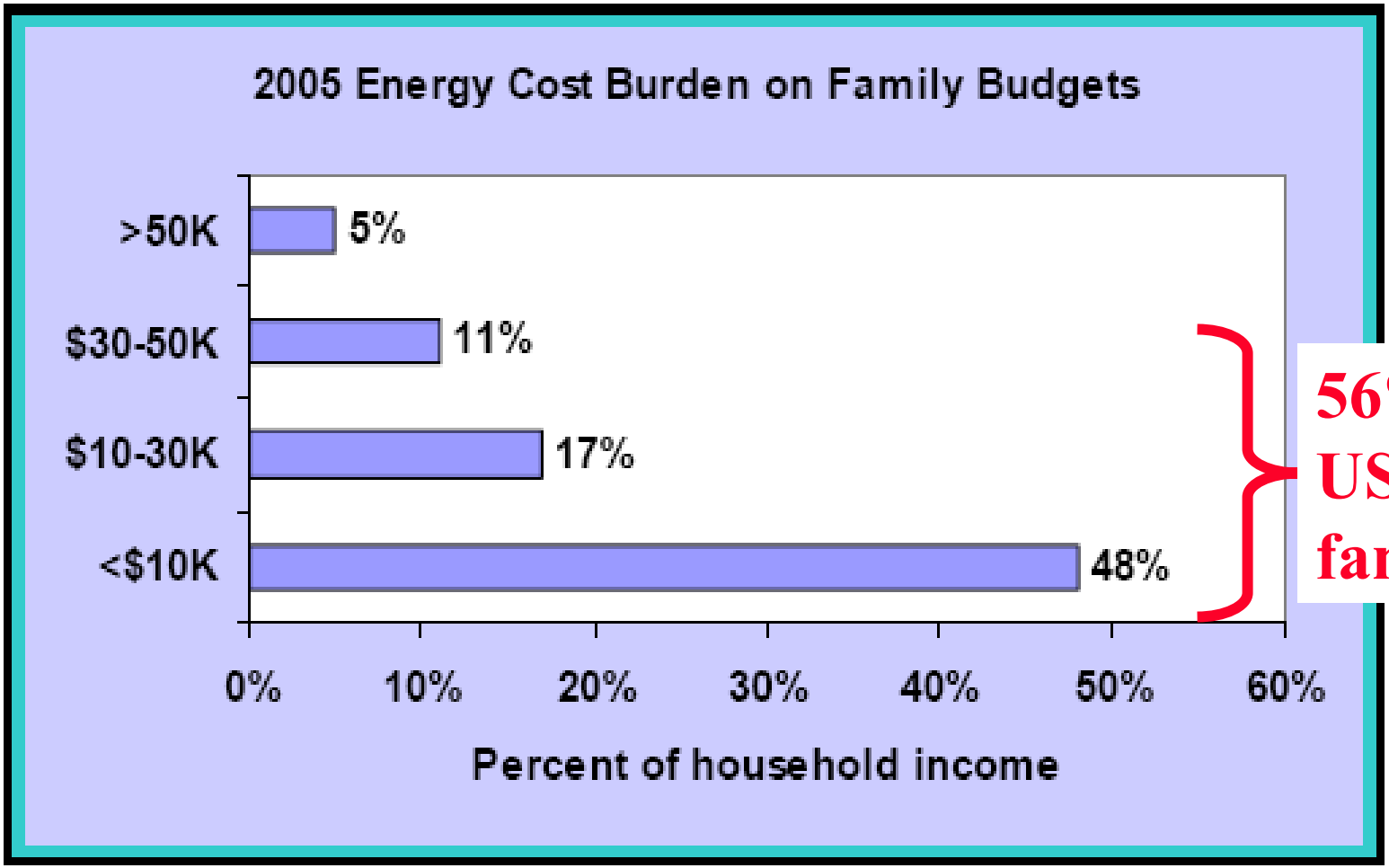
USA also has the largest deposits of oil shale

Source: International Energy Outlook 2004

Using coal/shale → pollution and CO_2



Coal industry lobby for cheap energy



Energy from coal is cheapest if there is no pollution/CO_2 tax

Missing an Economic Opportunity

- **Clean Energy**
- **Low loss electric power grids**
- **Fuel for Transportation**
- **Efficient machines/appliances**

are increasingly value-added products.

32 Terawatts of global power demand translates into a $38 billion/day market at $0.05 kW hour

Education

- Many people would make different choices if educated on options
- Promote wise choices not guilt
- Many environmentally friendly choices make economic sense also
  - Issue: up front cost versus lifetime cost
  - Make them fashionable and cool
- Lead by being good role models

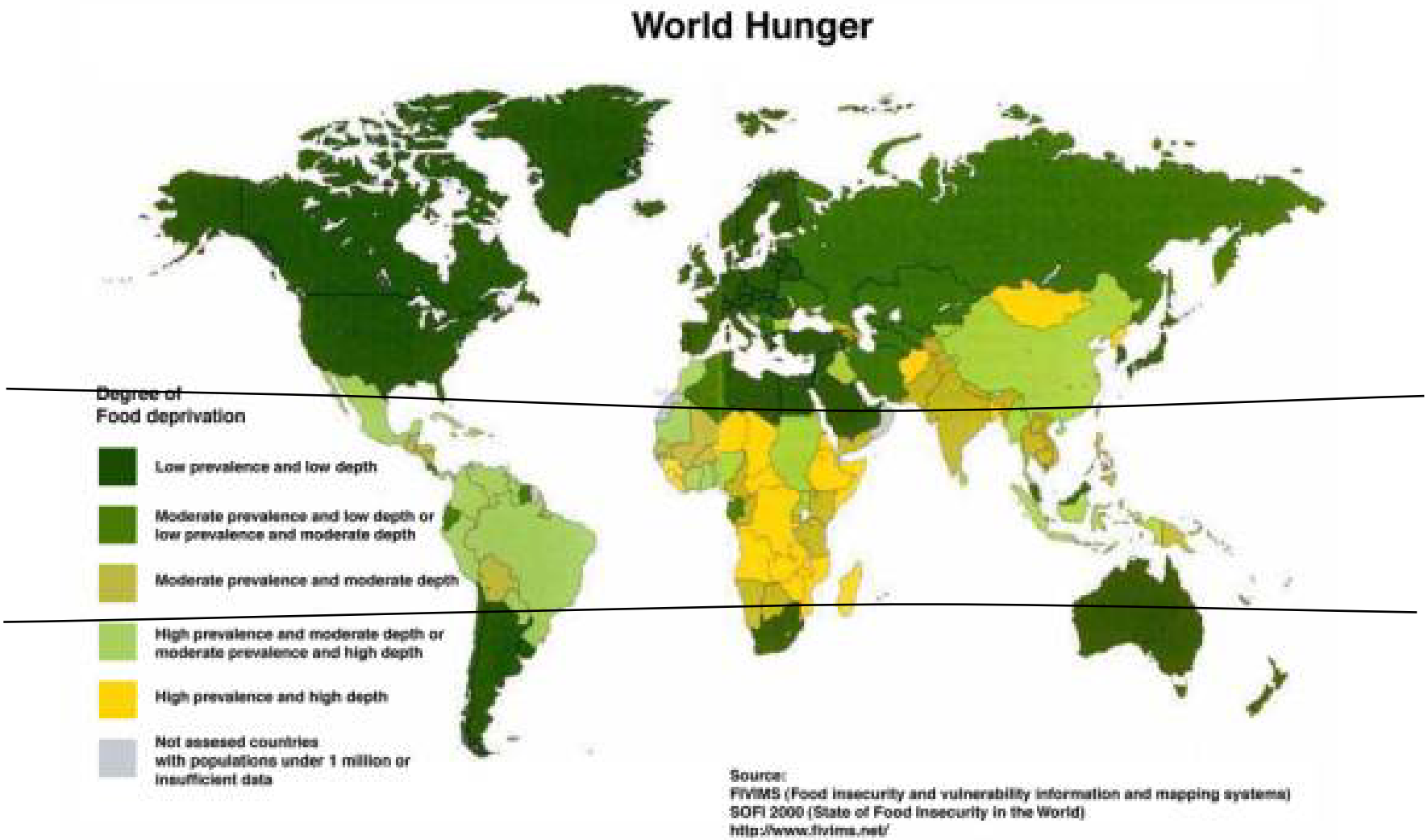
Make New Mexico a Leader

- 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

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 cheap oil and gas, we owe them clean 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/
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