Prospects for an Alternative Energy Future

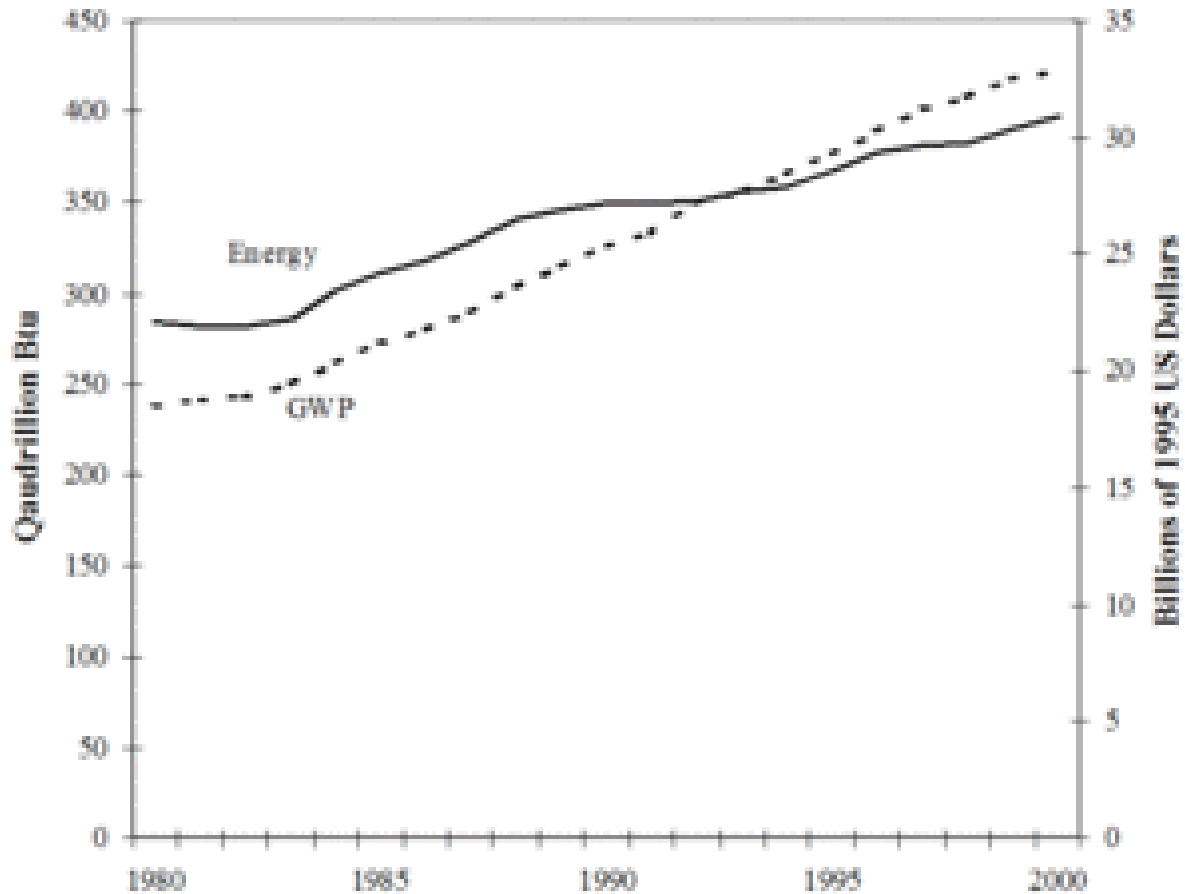
G Cornelis van Kooten

Professor of Economics
Canada Research Chair in Environmental Studies and Climate
University of Victoria

Climate Change and Energy: Issues

1. AGW is model based, not fact based
2. In models, AGW is dangerous only if the very poorest (the bottom) in global society increase their per capita incomes ($1990) from $246 to $1.099-$6,732 by 2050 and $3,832-$49,296 by 2100
3. Any solution to the problem must rely on reducing fossil fuels; technical fixes are not permitted. That is why we focus on energy!

WHY IS IT SO HARD TO DECOUPLE ECONOMIC GROWTH FROM ENERGY?



Global energy use (quadrillion Btu) and Gross World Product (constant US dollars (billions) 1995), from 1980 to 2000. (Source: World Bank, 2002).
http://www.eoearth.org/article/Energy_and_sustainable_development_at_global_environmental_summits

Kaya Identity

$$C = N \times \frac{Y}{N} \times \frac{E}{Y} \times \frac{C}{E}$$

C = CO_2 emissions, N = population, Y = GDP, E = energy use

Ways to reduce emissions of carbon dioxide:

1. Manage population;
2. Limit the generation of wealth (reduce GDP);
3. Generate the same or a higher level of GDP with less energy;
4. Generate energy with less CO_2 emissions; or
5. Some combination of the first four factors.

Ways to reduce CO_2 emissions

Rewrite the Kaya Identity as:

$$Emissions = Y \times C/Y = \text{GDP} \times \text{technology}$$

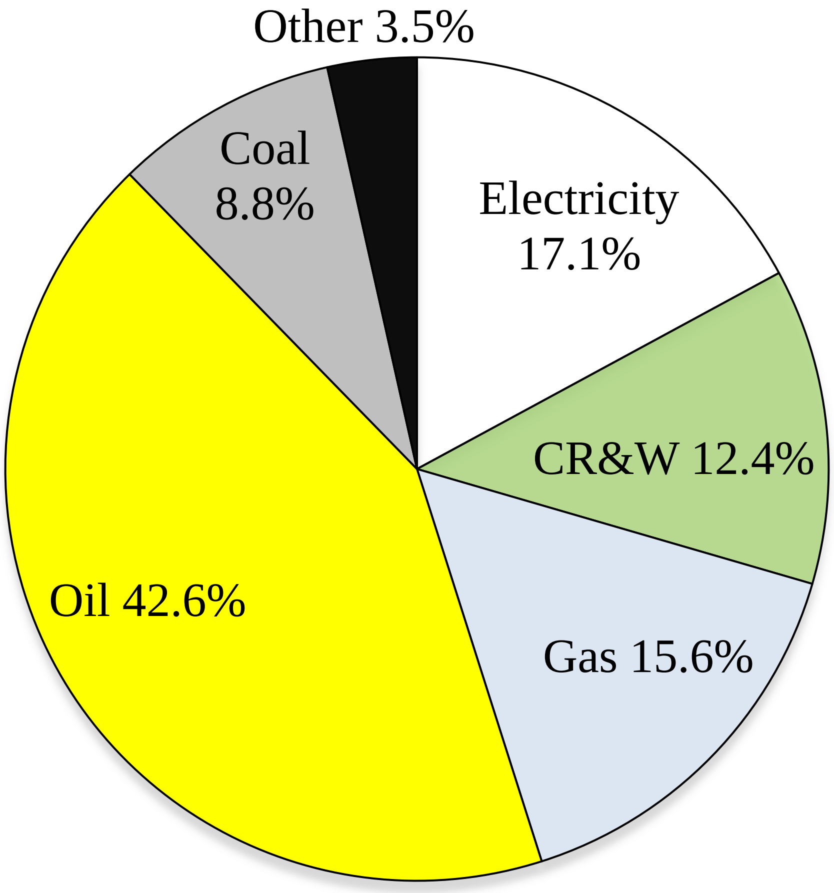
In 2006, global C/Y was 0.62 tCO_2 per \$1000 GDP, down from 0.92 in 1980; France went from 0.42 to 0.30 in 20 years.

For the UK to meet its climate target and go from 0.42 to 0.30 in five years requires 40 nuclear power plants of 1,100 MW capacity.

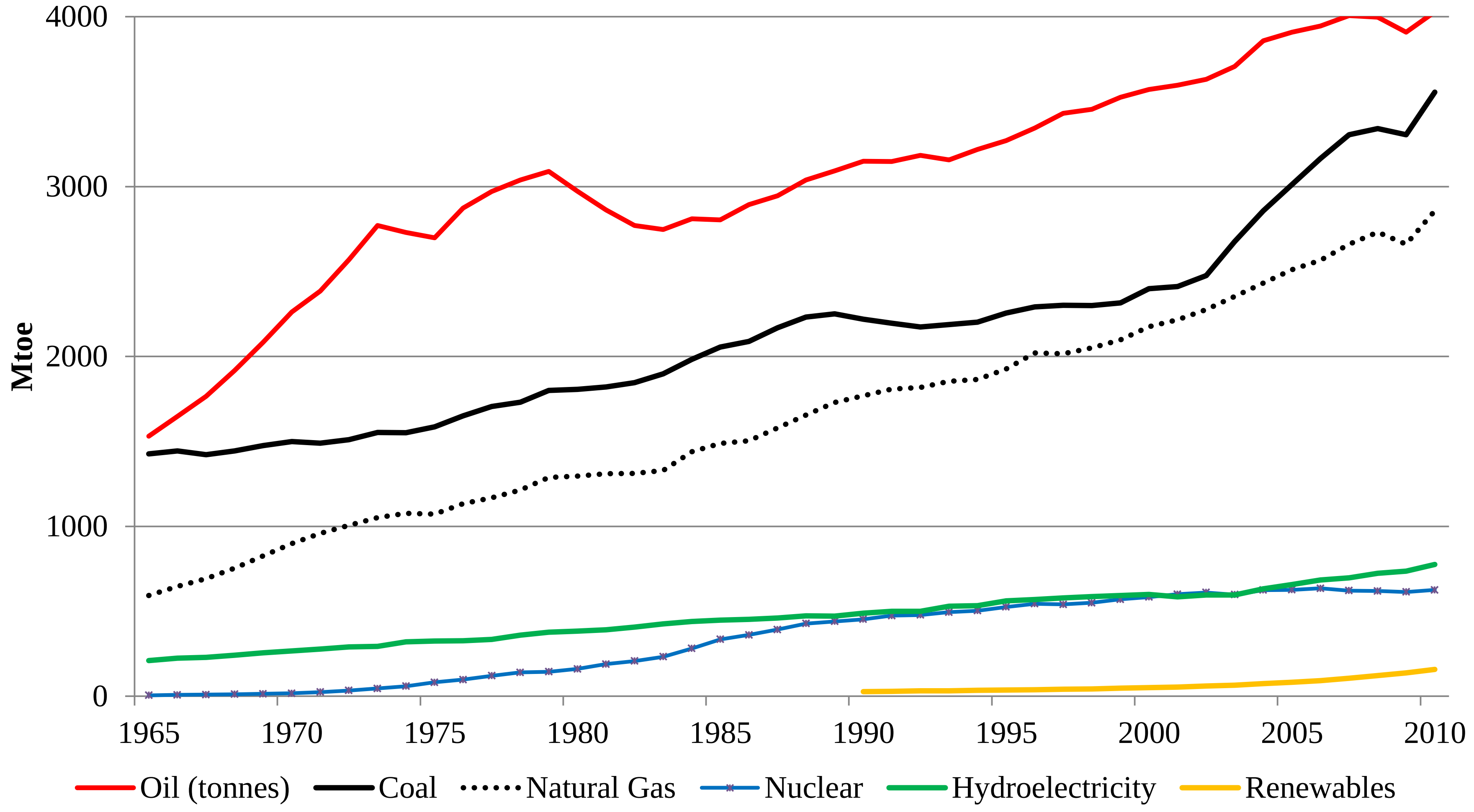
Current Energy Sources

- Petroleum
  - Oil is used primarily for transportation
  - Petroleum products are all around us
  - Very little petroleum used in generating electricity
- Coal
- Natural gas
- Nuclear
- Combustible renewables and wastes (including biomass)
  - Electricity and biofuels; space heating
- Hydraulics
- Other
  - Wind, solar, geothermal, tidal, wave
  - Future: biological organisms, other (?)

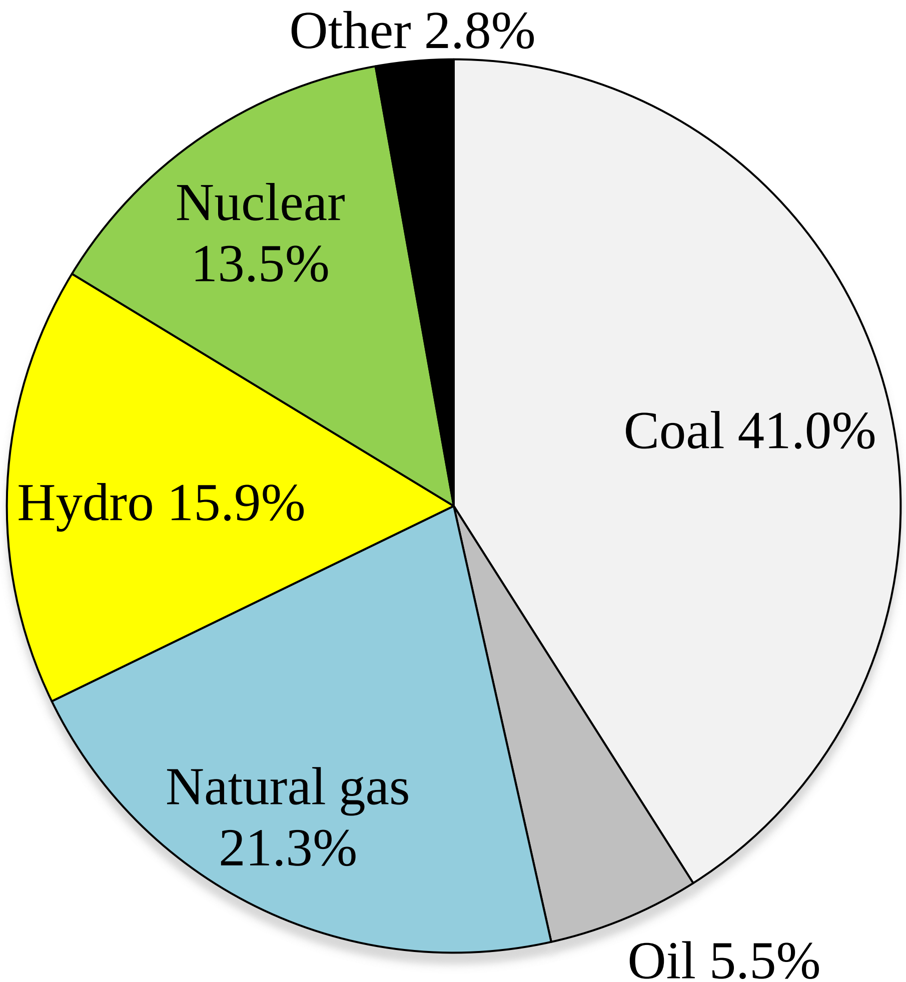
Final Energy Consumption, 2007



Global Energy Consumption by Source, 1965-2010



Fuel Shares of Electricity, 2008



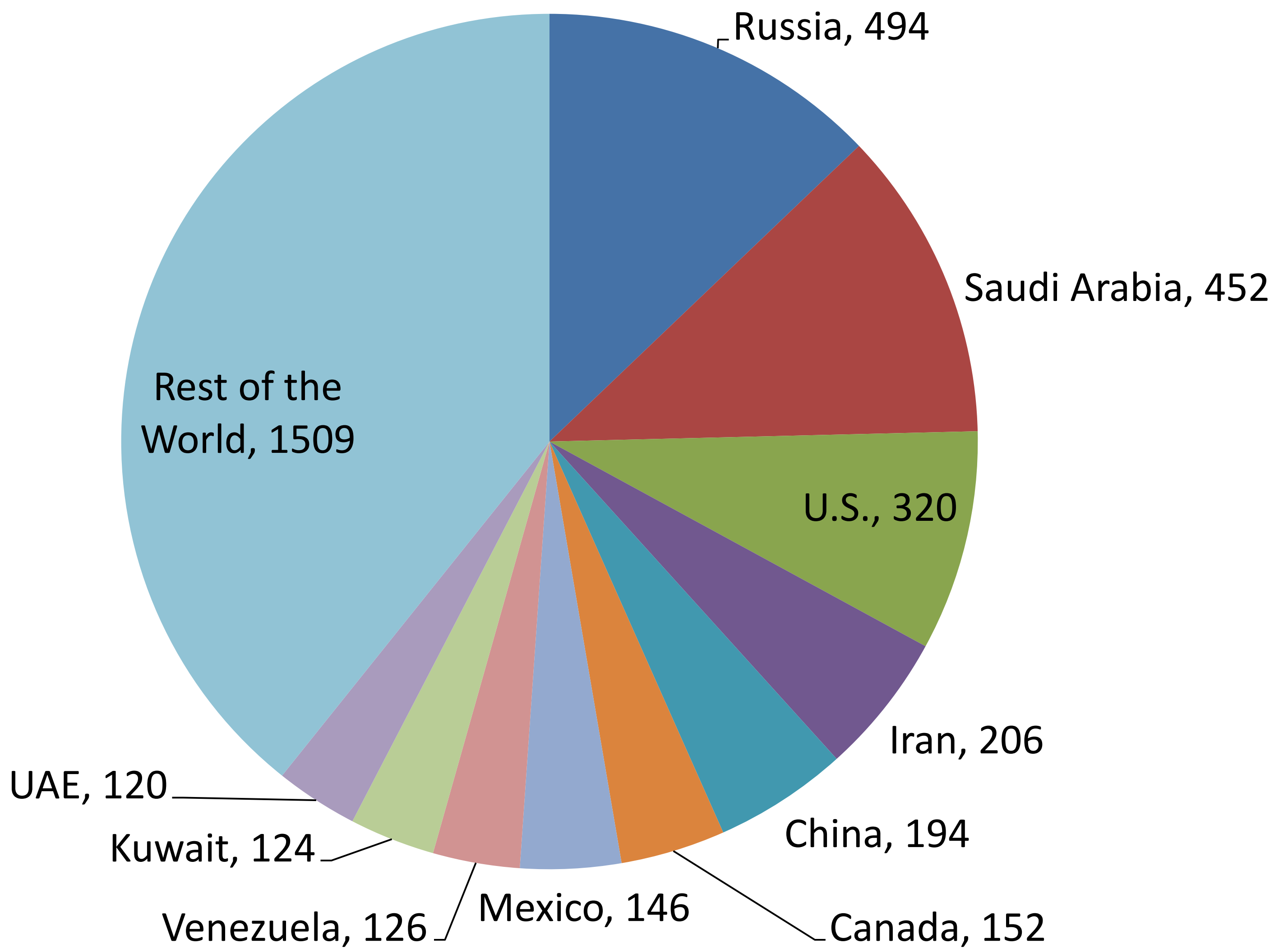
Since 2008, the 'pie' has gotten larger while the share of NG has increased.

Petroleum

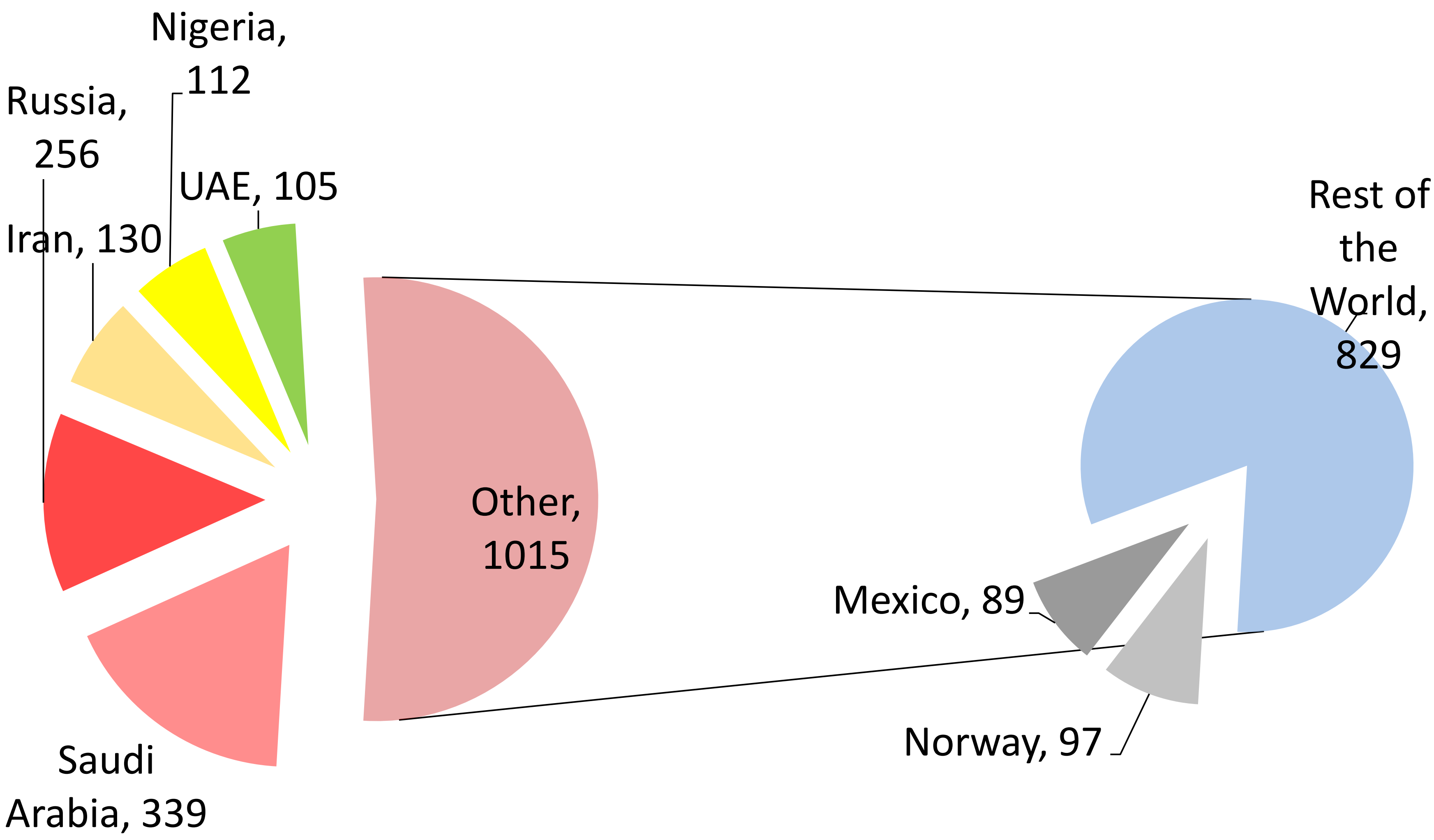
- Location of reserves mainly concentrated in the Middle East, but declining role
- Off-shore drilling
  - Slowed in U.S. due to environmental concerns.
  - U.S. provided $2 billion loan to enable Brazil to exploit its off-shore oil reserves (U.S. to be a preferred customer)
- Oil sands criticized; oil shale development held up for environmental reasons
- Oil needed for transportation and petroleum products (e.g., plastics); wind & solar are promoted on security grounds, but they have nothing to do with oil
- $10/bbl increase in price of oil knocks 0.5 percentage points off global GDP growth

Production of Crude Oil, 2009 (Mt)

Total: 3843 Mt



Oil Exports, 2007, Mt



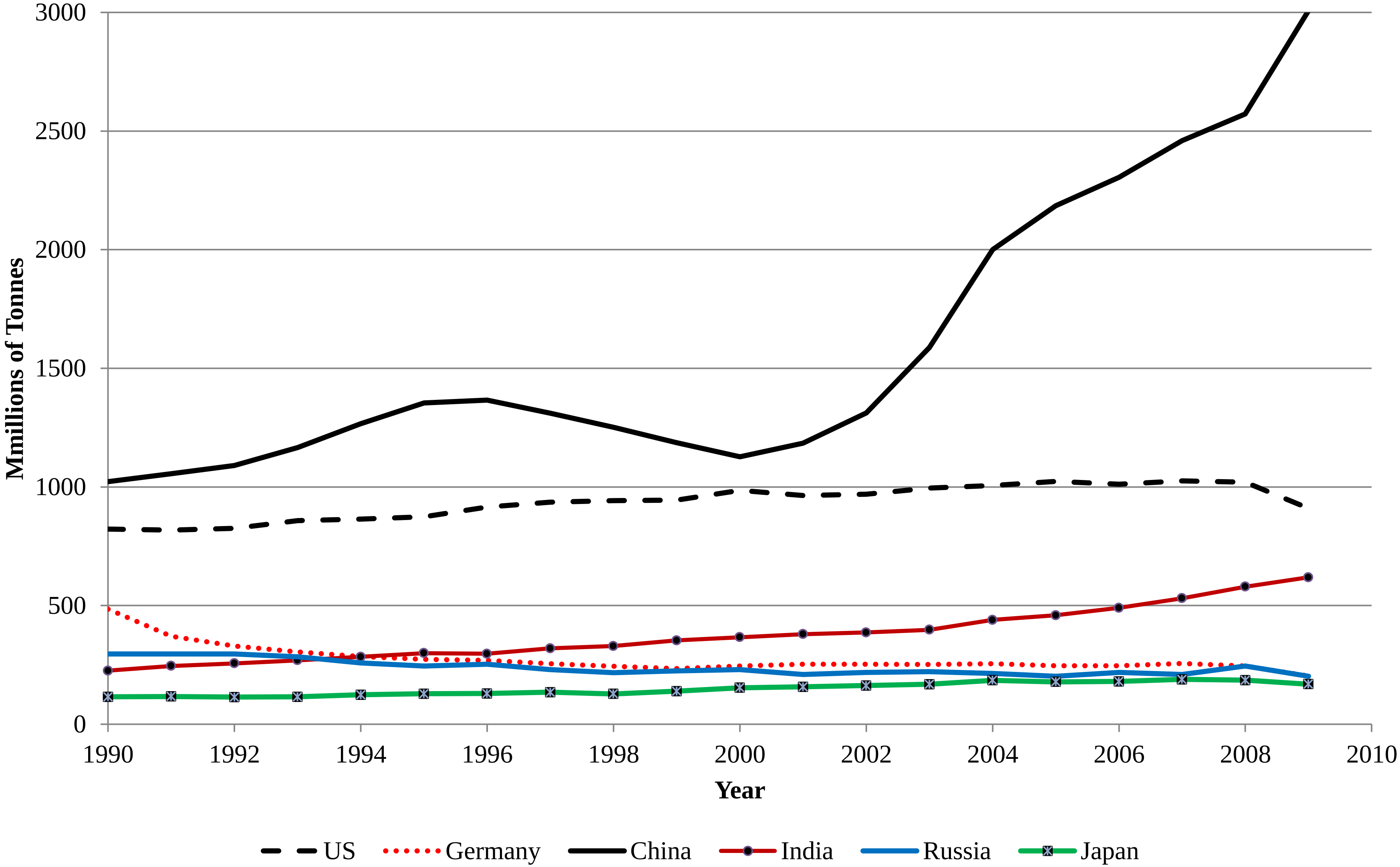
Future of Petroleum

- Unconventional oil includes Alberta's oil sands, Colorado shale and, importantly, 'tight oil' from Bakken Shale in N. Dakota and Saskatchewan and other similar deposits
- Concern for Canada: U.S. might become self sufficient in oil; it is our major export market
- Saskatchewan oil production will soon exceed production of conventional oil in Alberta
- Petroleum resources are not characterized by a Hubbert's Peak ('peak oil') as a result of technology
- Limits on oil production exist because of government restrictions on exploration and technological advances
  - No drilling in ANWR
  - limits on off shore drilling and drilling on public lands
  - Obstacles to fracking, etc. due to environmental concerns about both production methods and CO_2 output from petroleum resources

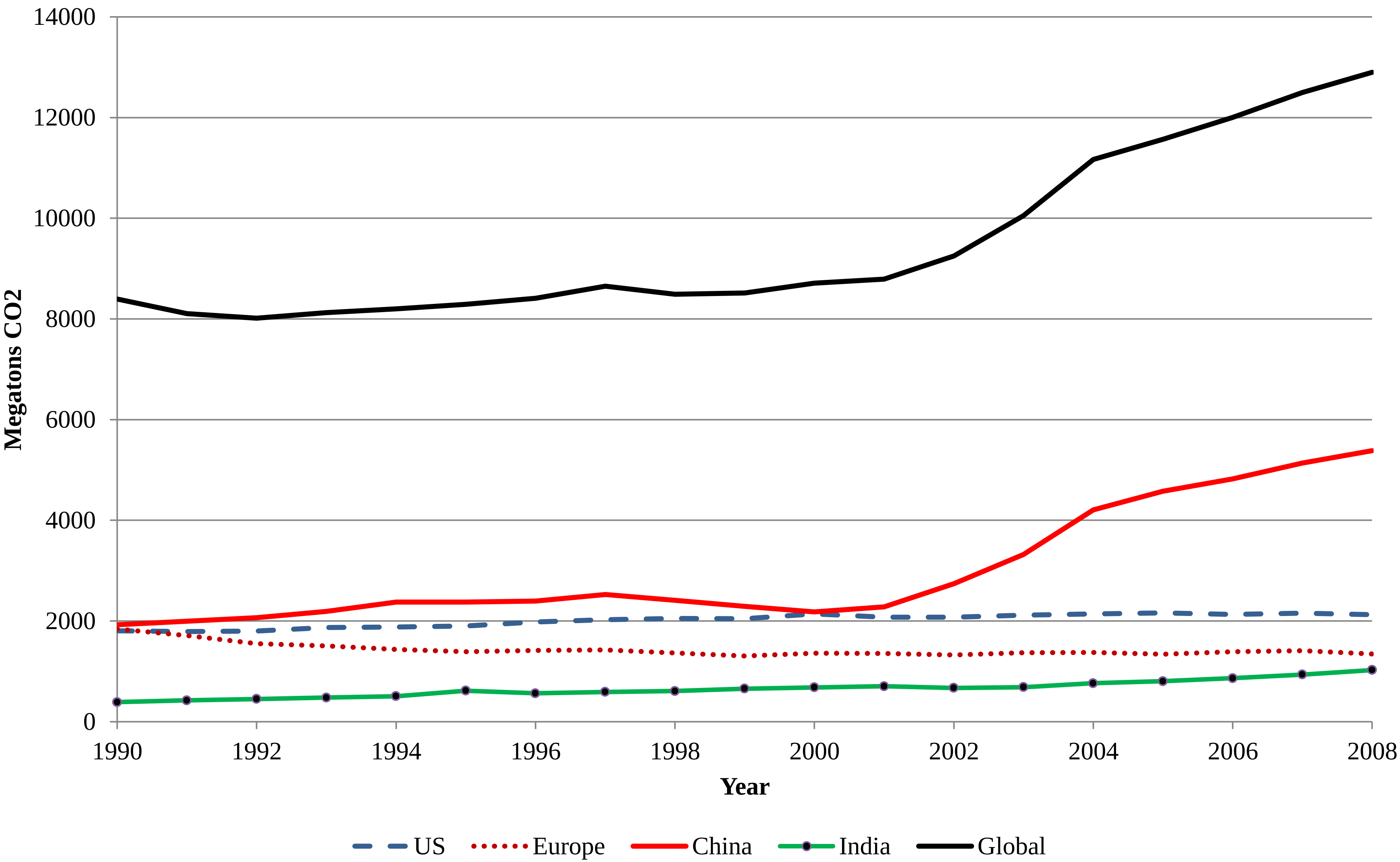
Coal and the Generation of Electricity

- More than 40% of global electricity is generated from coal.
- Coal is ubiquitous, cheap, safe, … but is the largest emitter of CO_2 other than biomass, and some other sources
- Surprisingly, many countries subsidize production of electricity from coal
- Largest exporters are Indonesia, Australia, U.S., Canada, Russia, many developing countries
- U.S. and Canada intend to eliminate all coal-fired generation. Problem: Coal will be exported
  - Coal is currently the single largest commodity exported from British Columbia, ahead of forest products

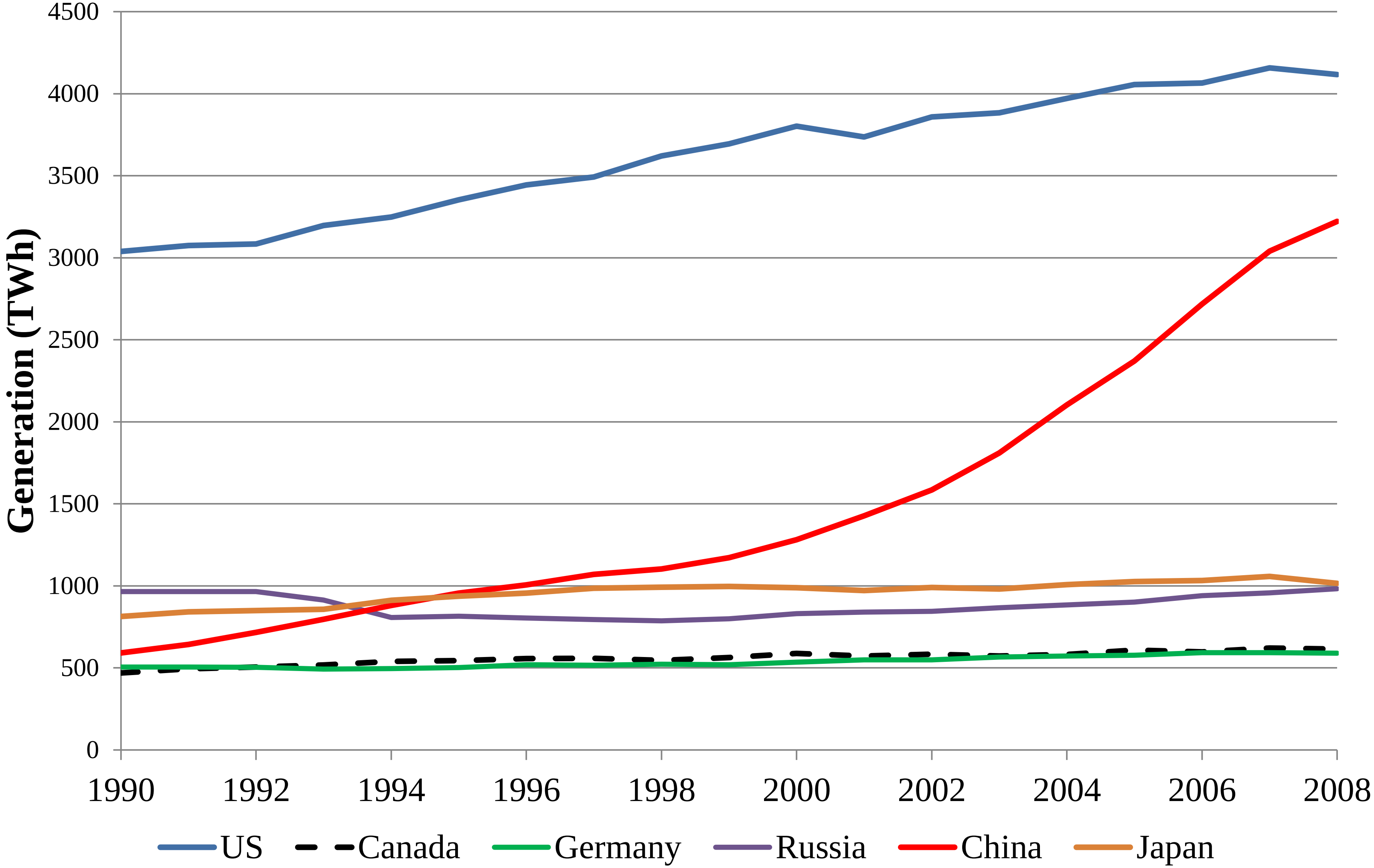
Coal Consumption, Selected Countries, 1990-2009



CO_2 Emissions from Coal by Region & Globe, 1990-2008



Annual Power Generation, Selected Countries, 1990-2008



Clean Coal

- Clean coal refers to up-to-date, coal-fired technology with ability to remove CO_2 from the flue gases – **Carbon Capture & Storage (CCS)**
  - 28% of generated power needed to capture CO_2
- CCS projects and potential projects (not complete listing):
  - Weyburn, SK, annually 1.5 Mt of CO_2 from gasification plant in Beulah, ND, is pumped underground for enhanced oil recovery in field developed in 1954
  - Two projects off Norwegian coast: NG from Sleipner gas field contains nearly 10% CO_2; to avoid paying carbon tax, Norway's Statoil pumps CO_2 into deep underground saline aquifer (1 Mt CO_2 annually since 1996); similar project at Snøhvit gas field, Barents Sea stores 0.7 MtCO_2
  - Algeria, 1.2 Mt CO_2 per year removed from NG and re-injected underground.
  - Project under consideration in Saskatchewan to enable Boundary Dam power station to continue burning coal after recent massive retrofit
  - Alberta oils sands development
  - Germany, U.S., Australia and China looking at clean coal
  - Netherlands, Norway and BC looking at CCS related to CO_2 in NG

CCS: Problems

1. Transportation of CO_2
   - Suppose 10% of global emissions of CO_2 are to be captured, or 3 Gt CO_2.
   - Compress the CO_2 to 1,000 psi leads to an oil equivalent volume of 81.8 million barrels per day
   - 41 supertankers (each holding about 2 million bbls) each and every day
   - Alternatively, a combination of pipelines and ships
2. Risk of release of deadly cloud of CO_2 (NIMBY):
   - Cloud of CO_2 naturally ‘burped’ from Lake Nyos, Cameroon, in 1986, and killed over 1700 people
   - CVM studies suggest compensation demanded could run in the hundreds of billions of dollars annually

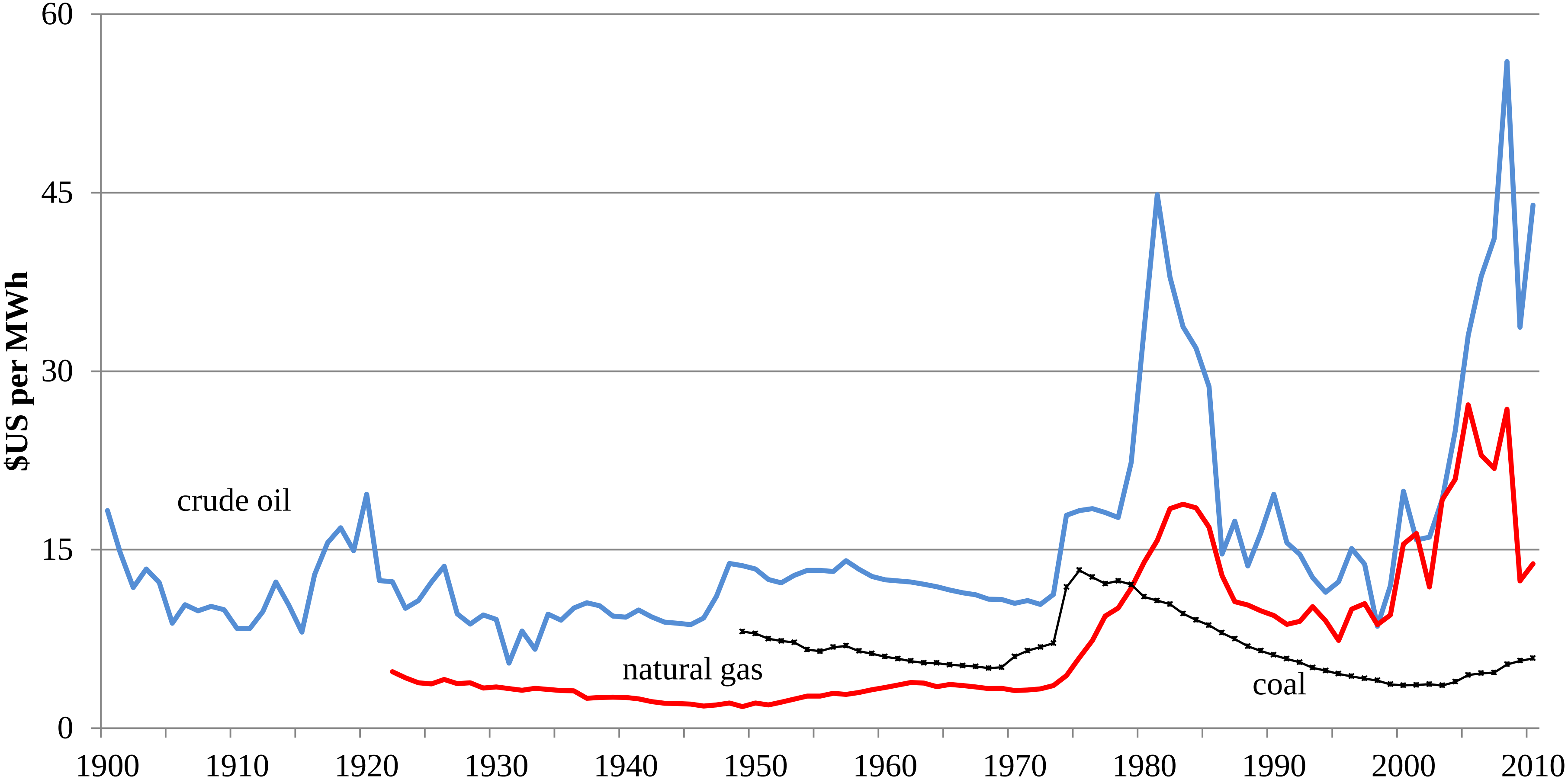
Natural Gas

- In Texas, George Mitchell experimented with methods to get gas to flow from shale deposits. In 1997, he found that water (along with sand and chemicals making up 1% of the mix) injected under extreme pressure caused the gas to flow.
- In 2003, he and his crews also discovered horizontal drilling.
- By ‘fracking’ the pipes every 120 m, they found the two methods led to huge increases in gas flow

Unconventional Gas

- Texas' Barnett shale vaulted into the top ten of the globe's natural gas fields.
  - Recoverable reserves of unconventional (shale) gas estimated at 44 trillion cu feet – an energy equivalent of 8 billion bbls oil
  - East Texas oil field of 1931, then the world's largest, had 6 billion bbls.
- U.S. recoverable reserves of unconventional gas estimated at 649.2 trillion cubic feet
- BC reserves of unconventional gas exceed total U.S. conventional reserves of 1989
- World reserves of unconventional gas are 5 times those of conventional NG

Historical Prices of Fuel in the U.S., $2010



Future Fuels

- Search for alternative fuels starts with a variety of renewables, of which in order wind, solar, biomass, run-of-river, geothermal, tidal and wave appear most promising
- Result: Yes, these can make a significant dent in energy use, but cannot replace coal, oil, gas, large hydro and nuclear

Nuclear Power: Why Not?

- Fukushima Daiichi power plant. What went wrong? How bad is it? Risk of future incidents like this is too great
- Other nuclear accidents have killed people
- Terrorism and nuclear bombs
- Meltdown of a nuclear reactor
- Massive loss of life, wastelands
- Getting rid of nuclear waste

Nuclear Incidents

- Three major accidents
  - Three Mile Island, Pennsylvania, March 1979: Partial meltdown, some radiation released, residents evacuated
  - Chernobyl in the Ukraine, April 1986: result of an unauthorized technical experiment; officially 31 people died (mainly as a result of an explosion), but others suggest that 6000 of the workers involved in cleanup and nearby residents died; several hundred thousand exposed to high radiation; 30 km exclusion zone, about 400 people live inside it, and 3000 workers
  - Fukushima, Japan, March 2011: partial meltdown, residents evacuated, many exposed to radiation
- 16 other incidents/accidents between 1950 and 2000
  - Winter 1957-1958: several hundred may have died of radiation sickness in a Soviet incident; little is known about it
  - January 1961: 3 technicians died at experimental reactor in Idaho
  - July 1961: 8 killed on a Soviet nuclear submarine
  - Other incidents were ‘minor’ involving release of radiation as a result of operator error or breakdowns

Fukushima Daiichi Power Plant

- Combination of massive earthquake and tsunami overwhelmed the power plant's safety mechanisms
  - Earthquake knocked out power from grid
  - Tsunami overwhelmed diesel backup and may or may not have overwhelmed battery backup
- No deaths attributed to it, but release of radiation; residents in a 20-km radius evacuated
  - Generation II (G2) boiling water reactors of GE design; oldest is about 40 years old

Fukushima Daiichi Power Plant (cont)

- Containment:
  - Primary: a concrete and steel structure around the pressure vessel
  - Secondary: thick poured concrete around the primary containment.
  - Thin shell to keep out weather.
- Neutron absorbing rods of boron carbide are placed among fuel rods to control the rate of the nuclear reaction and heat produced. Full insertion of these rods shuts down nuclear reaction, but continuing radioactive decay of the products of the nuclear reaction in fuel rods will continue to give off heat. Thus, need to immerse fuel assemblies in water or other coolant. If coolant is lost, temperature rises and fuel rods could melt.
- Zirconium that coats fuel rods combines strongly with oxygen; oxidation of zirconium produces additional heat. At temperatures of $1000^{o}C$ or higher it can strip oxygen from steam and form hydrogen, which is explosive at 8% concentration or higher when released to the atmosphere. When pressure was released, the thin shell blew up.
- Problem: cooling pools were built above the containment structures.

Good News about Fukushima Reactors

1. The reactors withstood an earthquake significantly above designed strength.
2. Although the primary source of electricity failed, initially the backup systems worked as required.
3. The reactors withstood a tsunami above planned height.
4. The tsunami disabled the diesel generated backup of electricity and the battery backup was either disabled or inadequate.
5. The destruction of the standard communications between the plant operators and corporate and national leaders led to a slow decision to flood the active reactors with sea water, which destroyed them.
6. The observed ‘explosions’ were chemical, probably burning of free hydrogen.
7. Some meltdown of active reactors probably occurred.
8. Some of the cooling pools overheated, probably exposing the fuel rods and giving off hydrogen and radioactive gases.
9. So far, except for the immediate area around the reactors, the radioactivity released has been insignificant.

Nuclear Energy

- Naturally, uranium has about 0.7% of the U-235 isotope, with the balance of U-238 isotope. U-235 can support a fission chain reaction, but U-238 cannot.
- Uranium in power plant is 3-5% U-235; for weapons it needs to be 90% or more
- Nuclear waste can be recycled and used again as a fuel source:
  - U.S. laws enacted under Jimmy Carter prevent recycling
  - Sweden and France do recycle nuclear material
  - Actual waste from all nuclear power plants in the U.S. would fill no more than a small room
- How dangerous is exposure to radiation? (see Peter Gale & Eric Lax 2012)

Nuclear Energy (cont)

- As of 2009, 44 nuclear power plants were under construction globally:
  - 11 in China
  - 8 in Russia
  - 6 in India
  - 5 in Korea
  - 2 in the Ukraine, Bulgaria, Taiwan and Japan
  - 1 in Argentina, Finland, France, Iran, Pakistan and the U.S.
- Life-cycle costs of production:
  - Nuclear energy: 8.4¢ per kWh (6.6¢/kWh if added risks of capital used in building nuclear reactors were eliminated, so carrying costs same as for coal and gas plants)
  - Coal: 6.2¢/kWh (8.3¢/kWh under carbon tax of $25/tCO_2$)
  - Natural gas: 6.5¢/kWh (7.4¢/kWh under carbon tax of $25/tCO_2$)

Chinese Nuclear Energy

- Estimated 28 plants under construction (viewed March 28, 2011: http://www.world-nuclear-news.org/):
  - 18 advanced designs of the French Generation II pressurized water reactors (PWR) of 900 MW capacity
  - 5 Westinghouse AP 1000 Generation III modular reactors
  - Two Areva EPR (European Pressurized Reactor) are Generation III+. Only Finland and France have an Areva EPR under construction, but are experiencing delays and cost overruns
  - 3 Chinese CNP-600 reactors
- In April, construction to start on 1st full-sized pebble bed, modular, nuclear power plant, the HTGR, that uses inert helium, rather than water, for a coolant. China refers to this as a beginning to Generation IV plants.
- Generation III+ reactors have passive safety features – no operators, external power or pumps, etc. needed to control cooling in case of an emergency

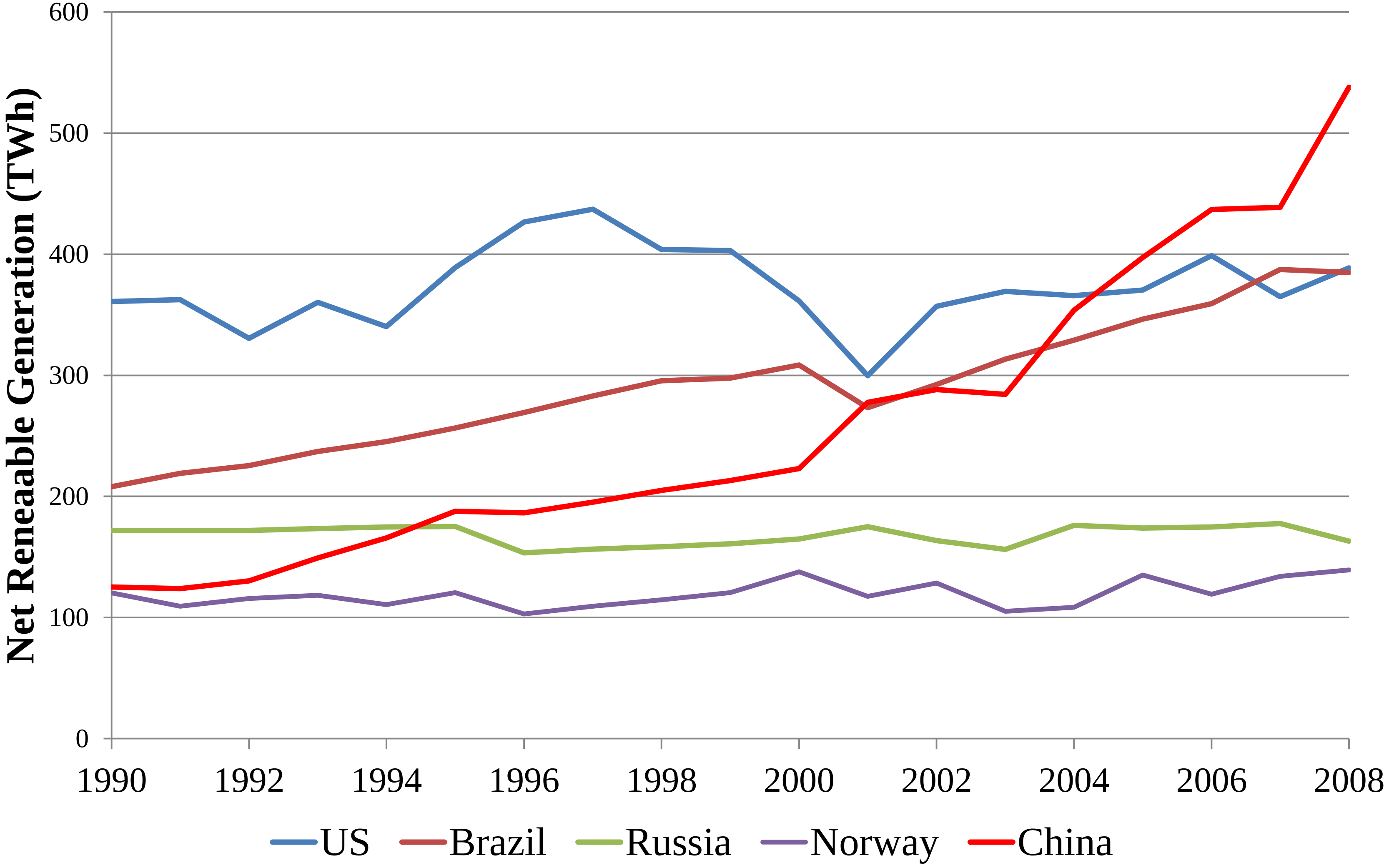
Nuclear Power Production and Capacity, Top Ten Producers, 2007

Country	Production (TWh)	Capacity (GW)	% of domestic consumption
United States	837	106	19.4
France	440	63	77.9
Japan	264	49	23.5
Russia	160	22	15.8
Korea	143	18	33.6
Germany	141	20	22.3
Canada	93	13	14.6
Ukraine	93	13	47.2
Sweden	67	9	45.0
United Kingdom	63	11	16.1
Rest of World	418	48	6.6
WORLD	**2719**	**372**	**13.8**

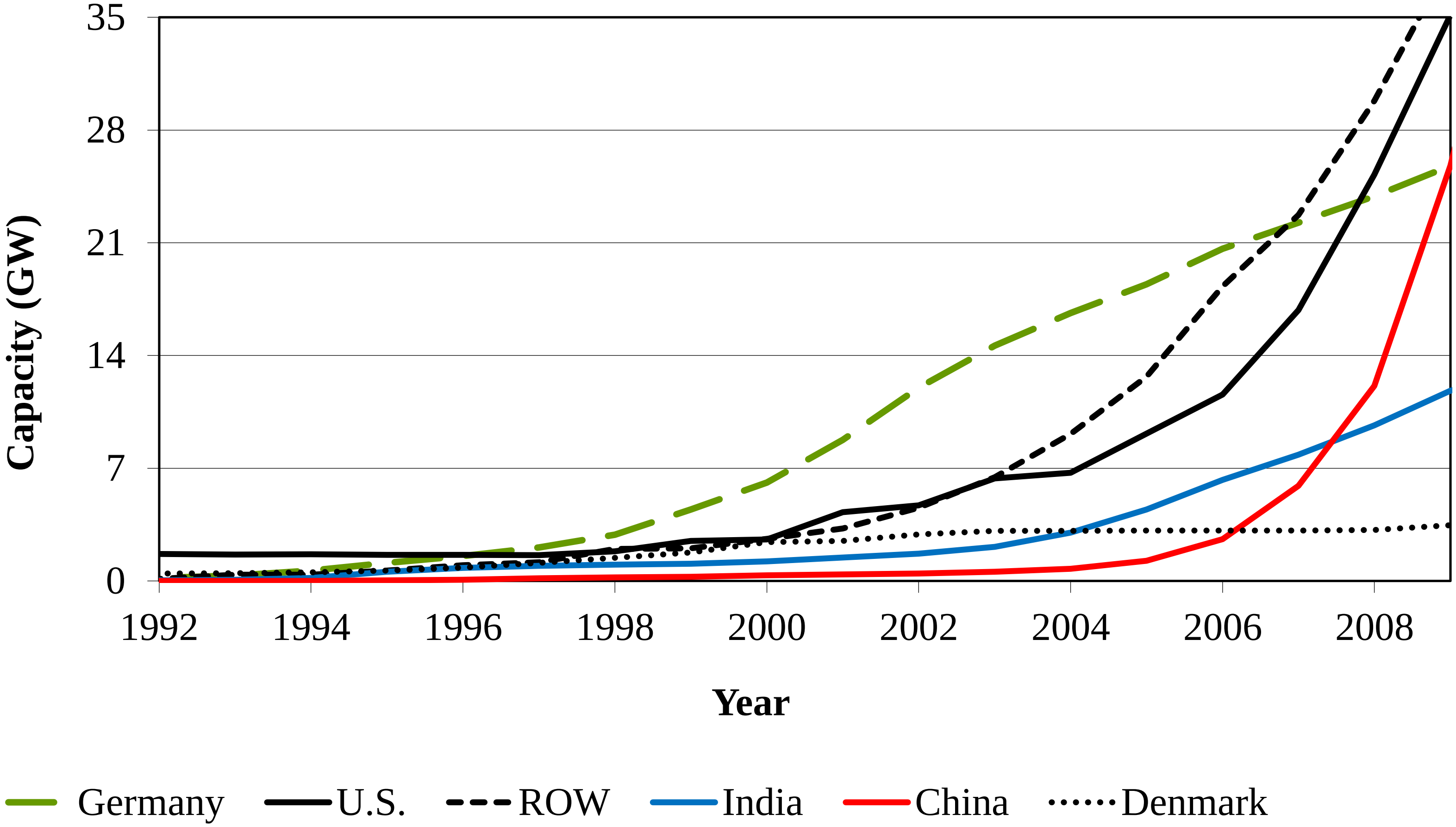
Renewable Energy

- Consider again the hydrogen economy
  - Need fuels for transportation and space heating
  - Need energy for electricity: A great variety of energy sources can be used to generate electricity
    - Think of the electric car: but it still needs an energy source
- For transportation, outside of fossil fuels, the only options are batteries, hydrogen & biofuels, or combinations
- For electricity, there is more flexibility and countries are increasing generation from renewables, including hydropower

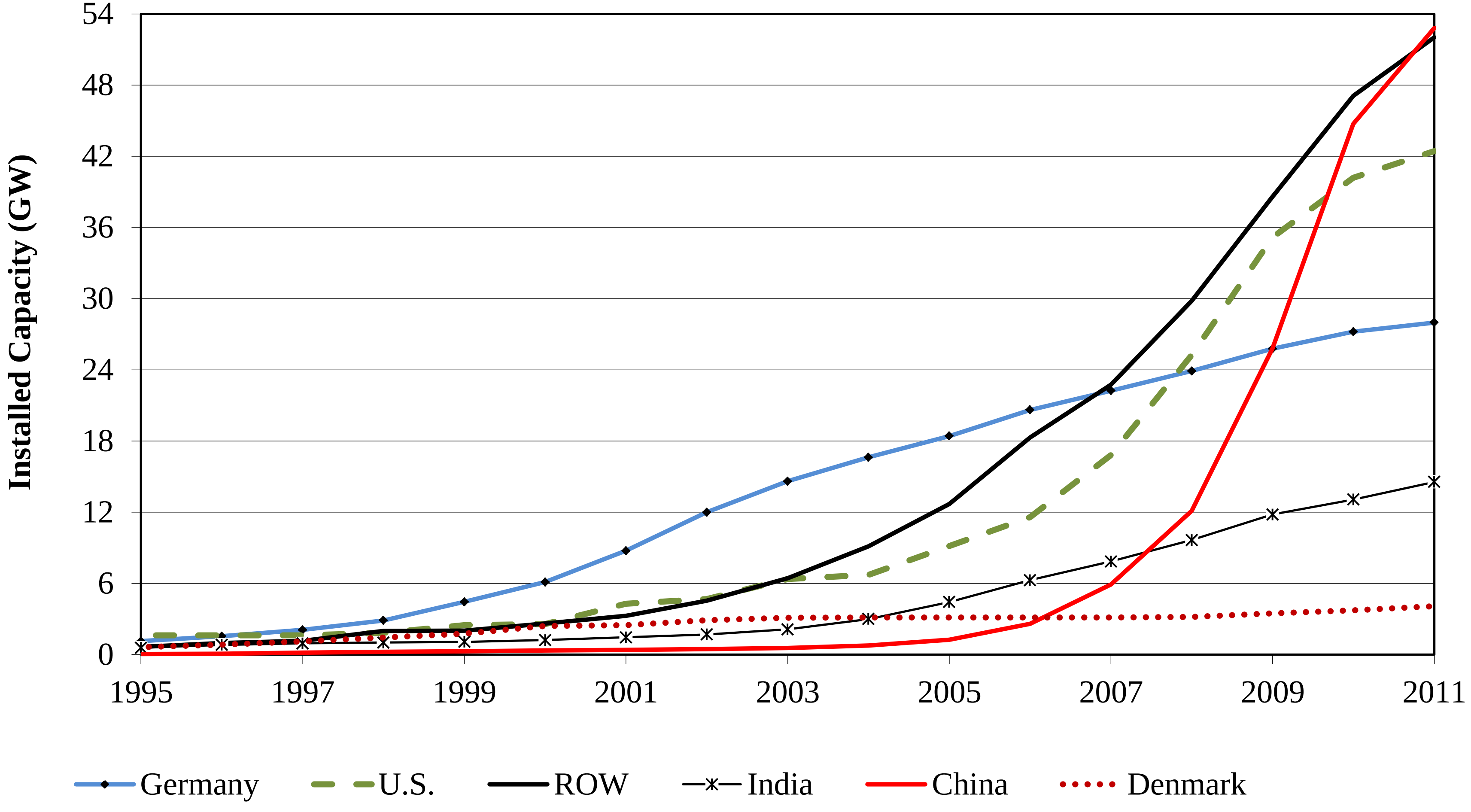
Renewable Electricity, 1990-2008



Installed Wind Electrical Generating Capacity, Selected Countries, 1992-2009



Installed Wind Capacity to June 2011, MW



ENERGY EFFICIENCY

"I think we have to have a strong push toward energy efficiency. **We know that's the low-hanging fruit, we can save as much as 30 percent of our current energy usage** without changing our quality of life."

(Obama, June 28, 2009)

http://www.nytimes.com/2009/06/29/us/politics/29climate-text.html

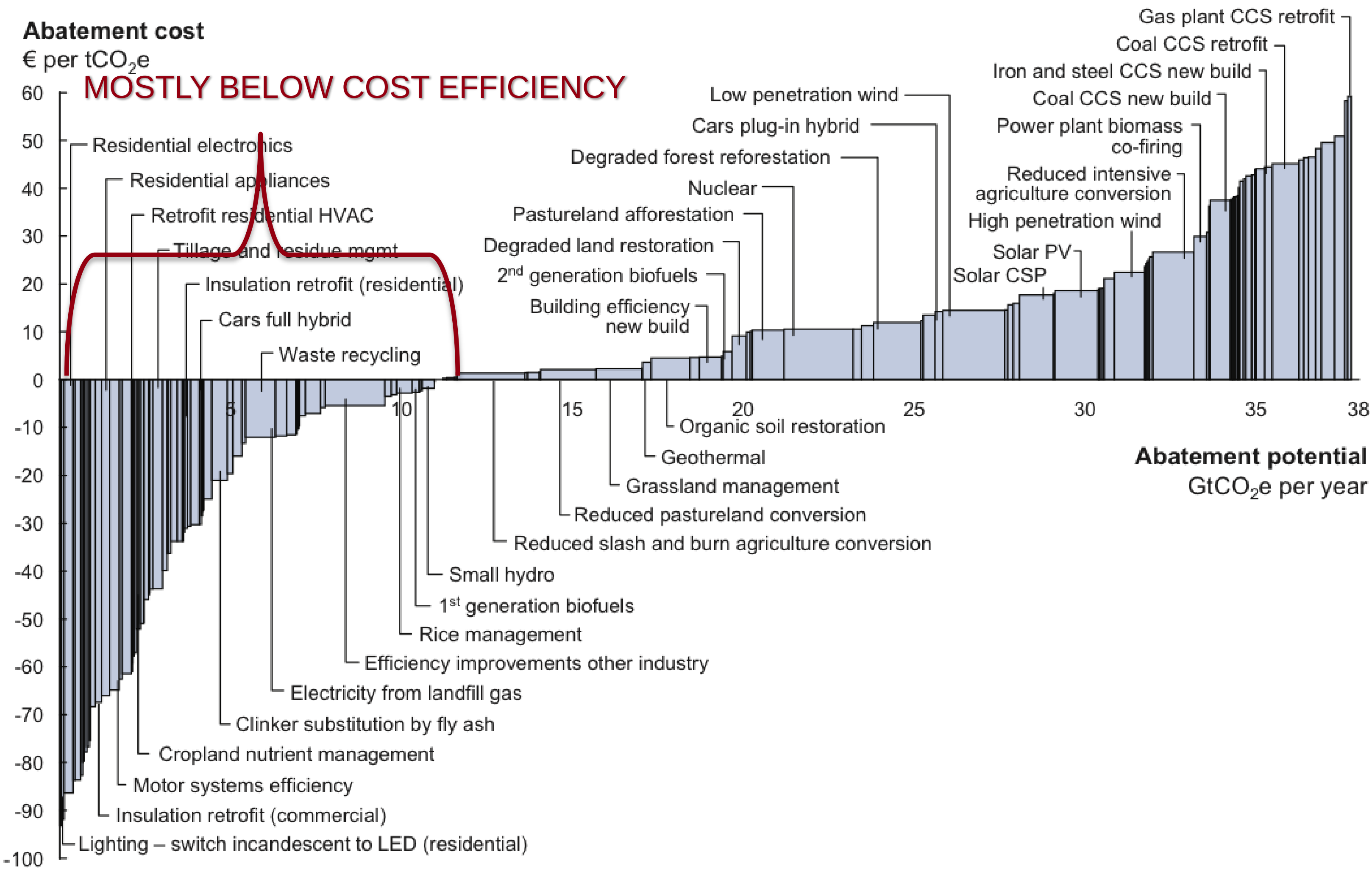
Very naïve statement for two reasons:

1. Failure to recognize the **rebound effect**
2. Failure to recognize the role of markets

ENERGY EFFICIENCY

MCKINSEY AND CO. "PATHWAYS TO A LOW-CARBON ECONOMY"

Global GHG abatement cost curve beyond business-as-usual – 2030



Note: The curve presents an estimate of the maximum potential of all technical GHG abatement measures below €60 per tCO_2e if each lever was pursued aggressively. It is not a forecast of what role different abatement measures and technologies will play.

Source: Global GHG Abatement Cost Curve v2.0

SO HOW BIG IS REBOUND?

REBOUND: DIRECT EFFECTS

ROUGHLY 10-30% FOR CONSUMERS IN RICH NATIONS

TABLE 2.1:

Scale of Direct Rebound for Consumer Energy Services in Developed Nations – Summary

Energy Service	Range of Estimates	Best Guess	Degree of Confidence (Notes)
Automotive transport	5-87%	10-30%	HIGH (*Unmeasured in these studies are changes in automotive attributes, particularly heavier vehicles and more powerful engines.*)
Space heating	1.4-60%	10-30%	MEDIUM (*Unmeasured in these studies are increases in the space heated and an increase in thermal comfort.*)
Space cooling	0-50%	1-26%	LOW (*Unmeasured in these studies are increases in the space cooled and an increase in thermal comfort.*)
Water heating	<10-40%	??	VERY LOW (*Unmeasured in these studies are reports of increased shower length or purchase of larger water heating unit.*)
Other consumer energy services	0-49%	<20%	LOW

REBOUND: DIRECT EFFECTS

MUCH LARGER IN DEVELOPING NATIONS

40-80% (?)

TYPICAL VALUES FOR INDUSTRY MAY BE 20-70%

REBOUND: DIRECT EFFECTS

TYPICAL VALUES FOR INDUSTRY MAY BE 20-70%

TABLE 2.2: Scale of Direct Rebound for Producing Sectors

Sector	Long-term rebound	Share of rebound due to substitution	Share of rebound due to output	Long-term rebound from substitution	Long-term rebound from output
Electric utilities	120%	75%	25%	90%	30%
Transportation	59%	57%	43%	34%	25%
Services	25%	90%	10%	23%	3%
Chemicals	53%	38%	62%	20%	33%
Construction	58%	94%	6%	55%	3%
Primary Metals	66%	84%	16%	55%	11%
Agriculture	39%	47%	53%	18%	21%
Financial Industries	61%	95%	5%	58%	3%
Government Enterprises	40%	87%	13%	35%	5%
Food & Kindred Products	40%	98%	2%	39%	1%
Paper & Allied Products	44%	80%	20%	35%	9%

REBOUND: INDIRECT EFFECTS

1. Savings result in re-spending throughout the economy (probably small to moderate)
2. Macro growth effects due to efficiency enhancement
3. Price effects: efficiency lowers price of energy causing more to be used

Various studies indicate that, when indirect effects are included, the rebound could be anywhere from 15% rebound (Holland) to as much as 350% Kenya), with anything over 100% deemed a BACKFIRE effect.

BACKFIRE RISK: MULTI-FACTOR PRODUCTIVITY GAINS

"**Improved energy efficiency, especially end-use efficiency, often delivers better services.** Efficient houses are more comfortable; efficient lighting systems can look better and help you see better; efficient motors can be more quiet, reliable, and controllable; efficient refrigerators can keep food fresher for longer; efficient cleanrooms can improve the yield, flexibility, throughput, and setup time of microchip fabrication plants; ... retail sales pressure can rise 40% in well-daylit stores ... **Such side- benefits can be one or even two orders of magnitude more valuable than the energy directly saved. ...[With] efficient buildings,** ... labor productivity typically rises by about 6-16%. Since office workers in industrialized countries cost ~100x more than office energy, a 1% increase in labor productivity has the same bottom-line effect as eliminating the energy bill – and **the actual gain in labor productivity is ~6-16x bigger than that**."

(Amory Lovins, 2005)

WHERE DOES THIS LEAVE US?

- REBOUND EFFECTS ARE REAL, SIGNIFICANT, AND CAN NOT BE IGNORED.
- COMBINE TO ERODE MUCH – AND IN SOME CASES ALL – OF PROJECTED ENERGY SAVINGS FROM BELOW-COST EFFICIENCY MEASURES.

WHERE DOES THIS LEAVE US?

- EFFICIENCY IS STILL GOOD ECONOMIC POLICY, AND PLENTY OF REASONS TO CONTINUE TO PURSUE TRULY COSY-EFFECTIVE EFFICIENCY

- **BUT** CONVENTIONAL CLIMATE MITIGATION STRATEGIES (WHICH IGNORE REBOUND) ARE **DANGEROUSLY OVER-RELIANT ON EFFICIENCY**

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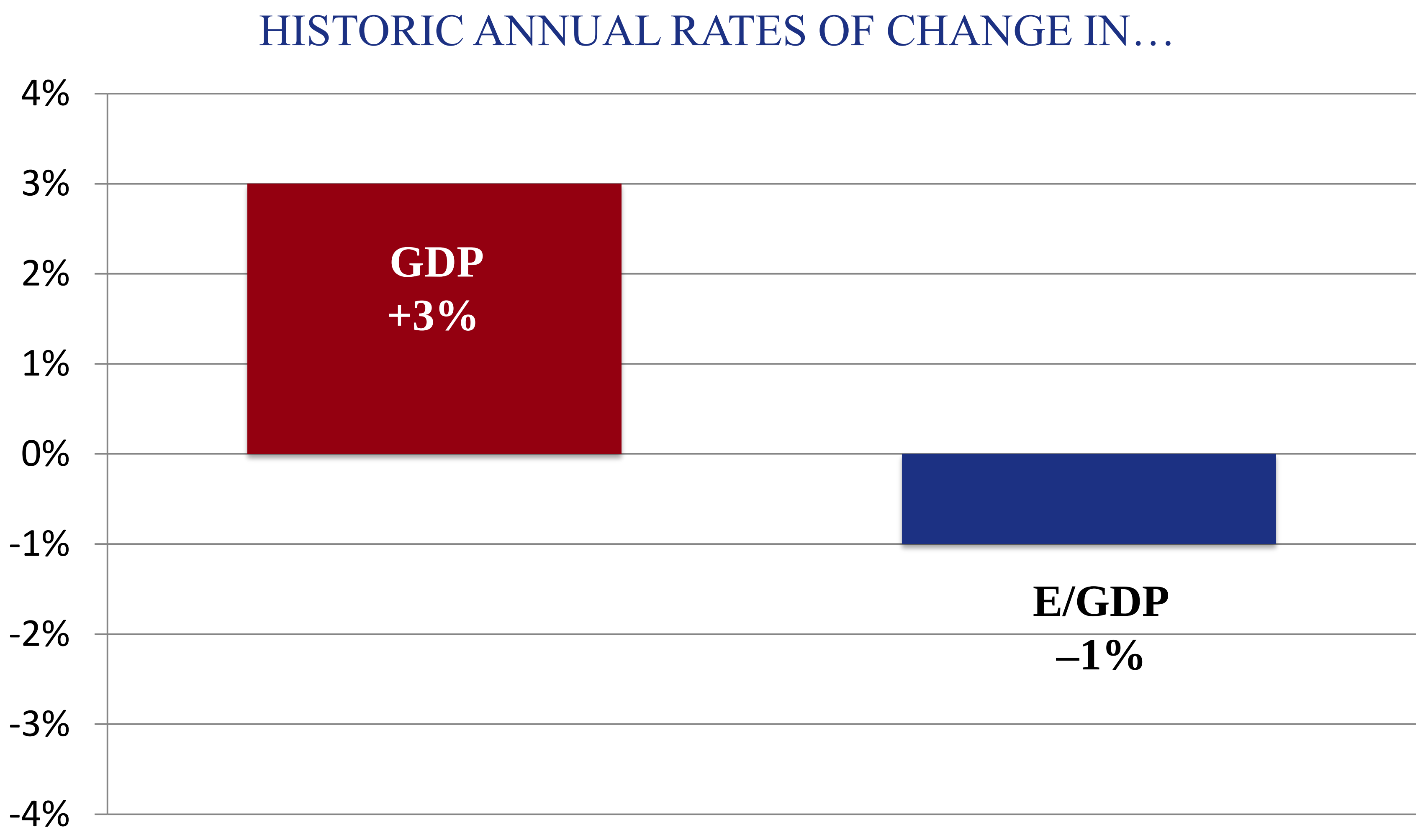

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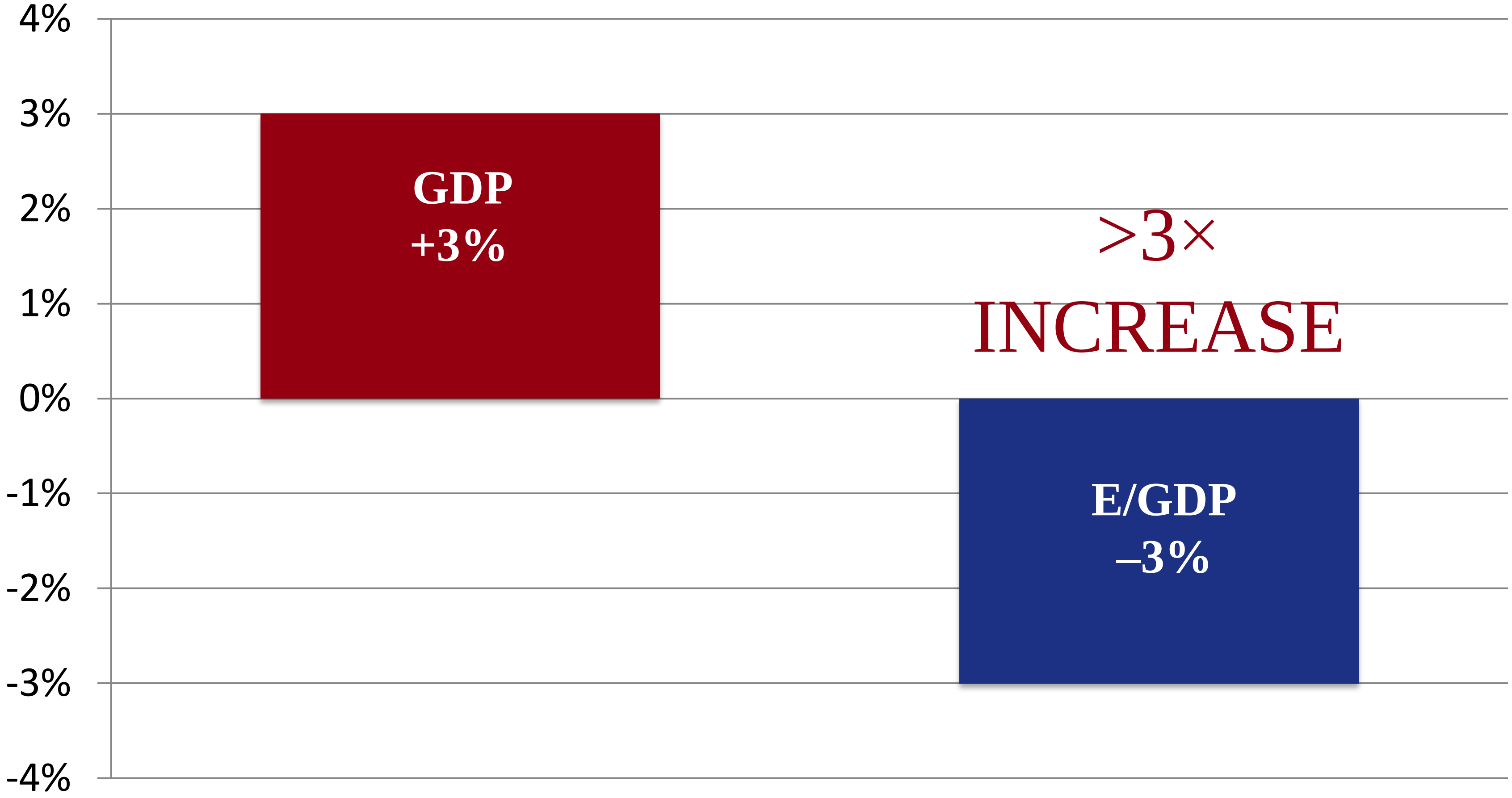
HISTORIC ANNUAL RATES OF CHANGE IN…



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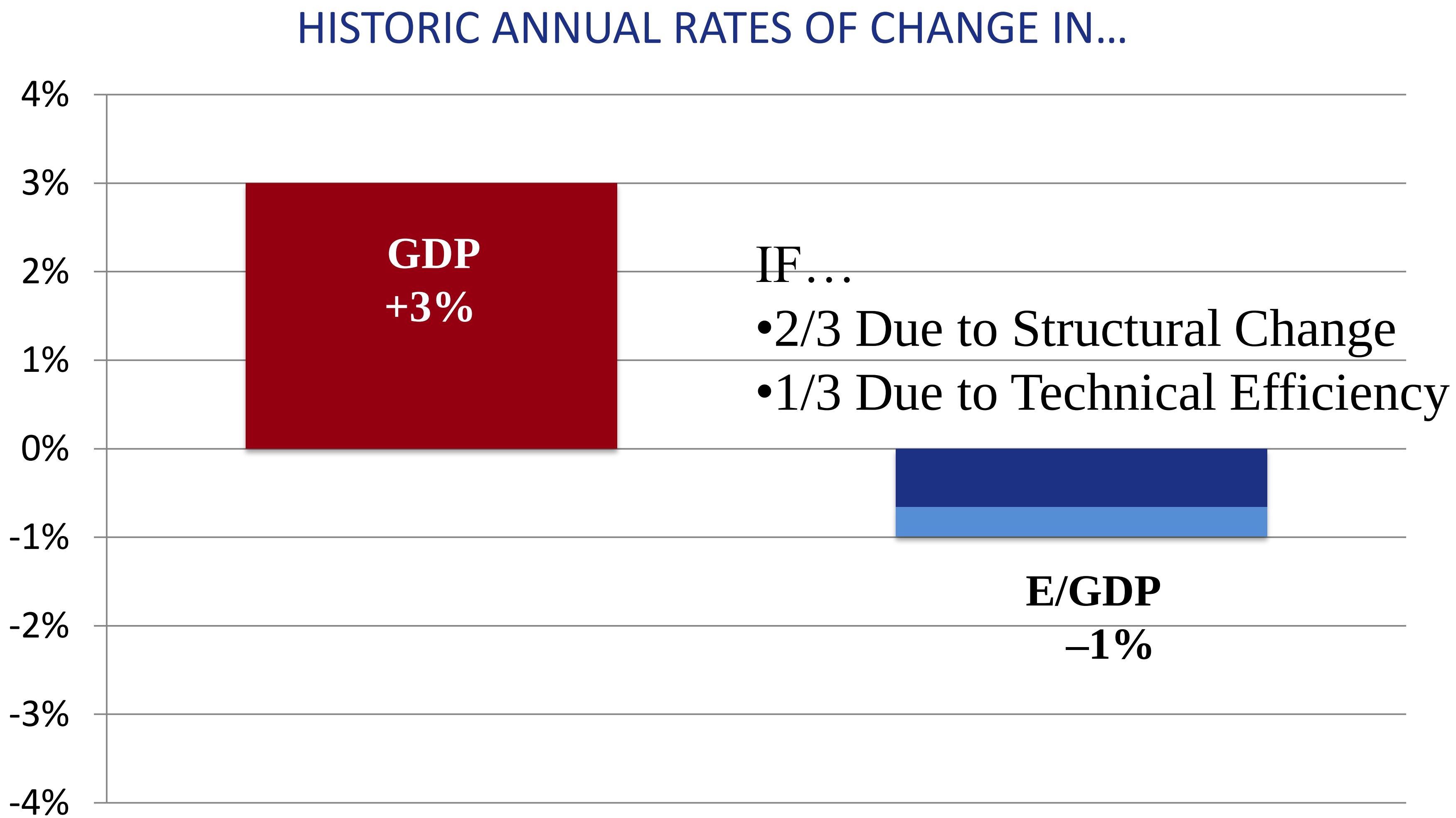

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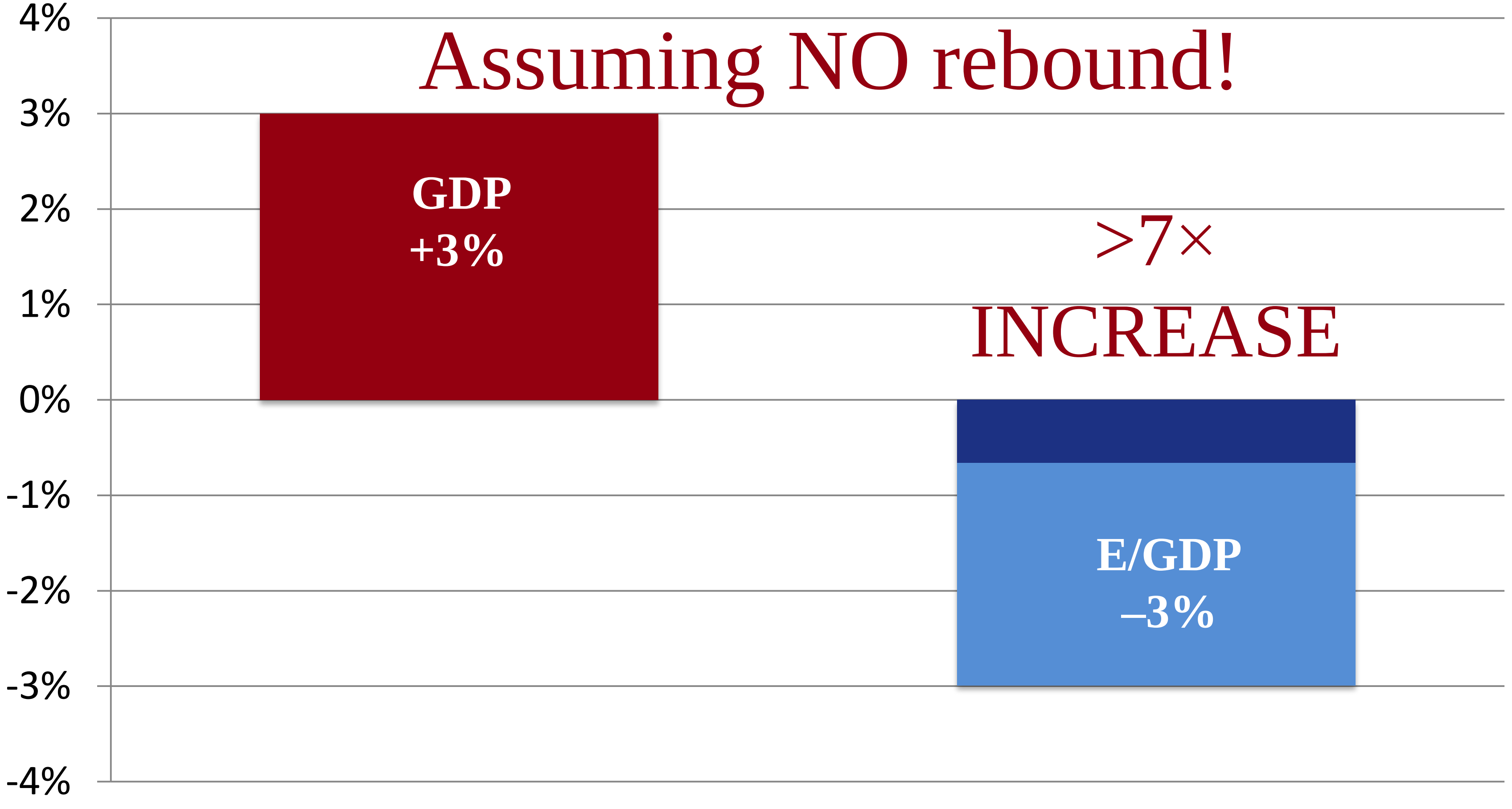


FINAL THOUGHTS

- There is always this concern that human activities have a negative impact on the environment.
- The following quote illustrates this better than any I know

“Everything has been visited, everything know, everything exploited. Now pleasant estates obliterate the famous wilderness areas of the past. Plowed fields have replaced forests, domesticated animals have dispersed wild life. Beaches are plowed, mountains smoothed and swamps drained. There are as many cities as, in former years, there were dwellings. Islands do not frighten, nor cliffs deter. Everywhere there are buildings, everywhere people, everywhere communities, everywhere life. … Proof [of this crowding] is the density of human beings. We weigh upon the world; its resources hardly suffice to support us. As our needs grow larger, so do our protests, that already nature does not sustain us. In truth, plague, famine, wars and earthquakes must be regarded as a blessing to civilization, since they prune away the luxuriant growth of the human race.”

Source of preceding quote:

Tertullian (c.a. 200)

Sustainable Development

Development that ***"…meets the needs of the present without compromising the ability of future generations to meet their own needs."***

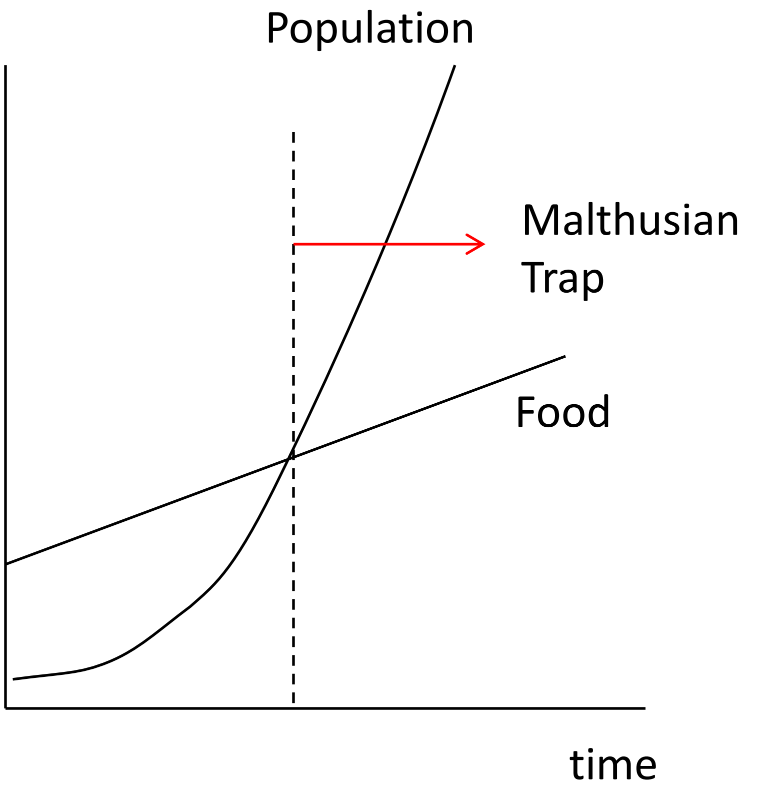
(World Commission on Environment & Development, Brundtland Commission,1987)

Definitions have in common:

1. Concern with long-term health of the environment
2. Worry about welfare of future generations
3. Condemnation of a large global population and rapid population growth
4. Concern about continued economic growth in the face of scarcity
5. Guilt about the gulf between rich and poor
6. Call for government action

Resource Scarcity

- Thomas Malthus argued in 1798 that population growth was geometric (exponential) and agricultural output expanded at an arithmetic (linear) rate, leading to a (poverty/ subsistence) trap



Resource Scarcity (cont.)

- Malthus was likely preceded by the Chinese intellectual Hong Liangji, who in 1790 made a similar argument, but actually pointed to a more complex prospect: “The continual need to increase yields … would lead to an ecological catastrophe, which would cause social dysfunction – and with it massive human suffering” (Charles Mann, *1493*, p. 180).
- This is the view of the Malthusian Trap taken by today’s ecologists and environmentalists.

Environmental Disaster

- How has the view on the previous slide played out?
- Jay Forrester at MIT invented ‘Systems Dynamics’ – a computer language called ‘dynamo’ that could make projections of the future
- Club of Rome sponsored studies by Donella Meadows et al. beginning in 1972 (again in 1992, 2008) initially used Forrester’s modeling approach to predict ecosystem collapse, class conflict and large-scale warfare
  - Models were easy to debunk
  - simply by changing the assumptions (parameters in the models) slightly, totally different conclusions followed

Environmental Disaster (cont)

- The environmental picture of eminent disaster is painted in what has become an industry
  - Rachel Carson's *Silent Spring*
  - Paul Ehrlich et al. publications fearing population growth
  - E.O. Wilson & others regarding loss of species and biodiversity
- Countering this literature was solid research indicating that the projections did not accord with empirical evidence
  - Julian Simon, *The Ultimate Resource*
  - Bjorn Lomberg, *The Skeptical Environmentalist*
  - Mann and Plummer, *Noah's Choice*
  - Jeffrey Foss, *Beyond Environmentalism*

THE ENVIRONMENTAL TRUMP CARD

- Climate modeling is the latest installment in the environmentalist arsenal
  - Complex computer models can only be understood by a small group of … well … computer programmers. Thus, it is difficult for those unfamiliar with the computer code to modify parameters – to ‘play’ with the models.
  - Climate models can only be run on super computers that are beyond the reach of many scientists
- Climate models provide an appearance of scientific authority to a greater degree than earlier models
  - Easier to convince the media and public of the veracity

Two Concerns

- The UN has a dilemma: Development goals such as the Millennium Development Goals require rapid economic growth and convergence (i.e., attainment of the incomes underlying the emission scenarios), but the UN's climate program requires that the impoverished remain impoverished
- Environmentalists look to government – to global government – for solving environmental problems. World history indicates that this is likely the worse place to look: It will only lead to loss of individual freedom, increasing poverty and an environment that is worse than what was seen before.