Energy Options for the Future

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Introduction

- My presentation will be structured as follows:
  - The thirst for energy
  - The choice of the best energy options
  - The most important energy sources
  - The particular case of Nuclear Energy
  - Innovation in the energy sector
  - The issue of financing energy investments
  - Local vs. Global Governance

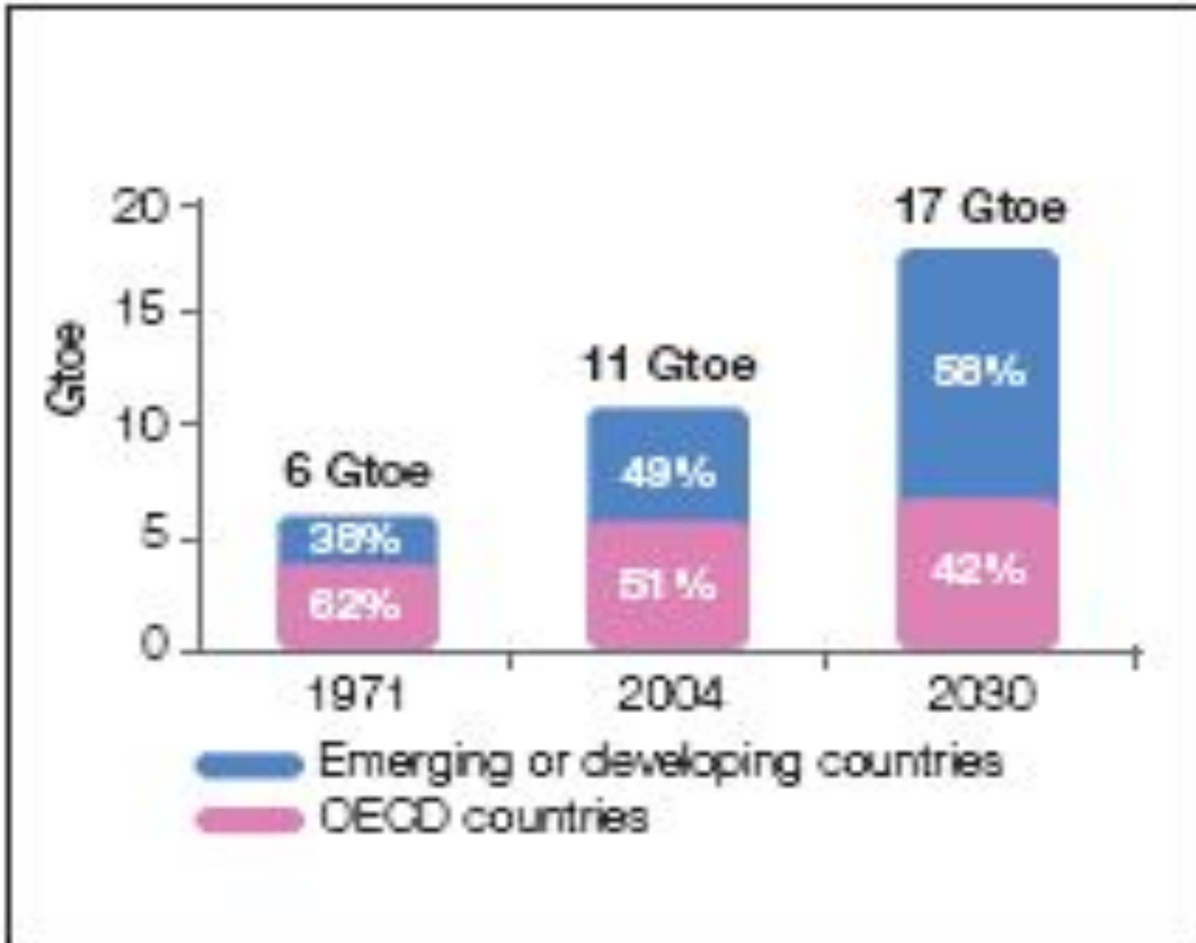
The Thirst for Energy

The Thirst for Energy (1)

- The IEA World Energy Outlook 2007 predicts that, with no change in current policies, the world's primary energy needs would grow by 55% between 2005 and 2030, in a scenario still dominated by fossil fuels
- Why current energy policies can't be changed fundamentally?:
  - The (welcomed?) growth of the world population
  - The welcomed growth in well being, indicated by a growth in GDP, leading to the need to reduce existing large disparities in energy consumption

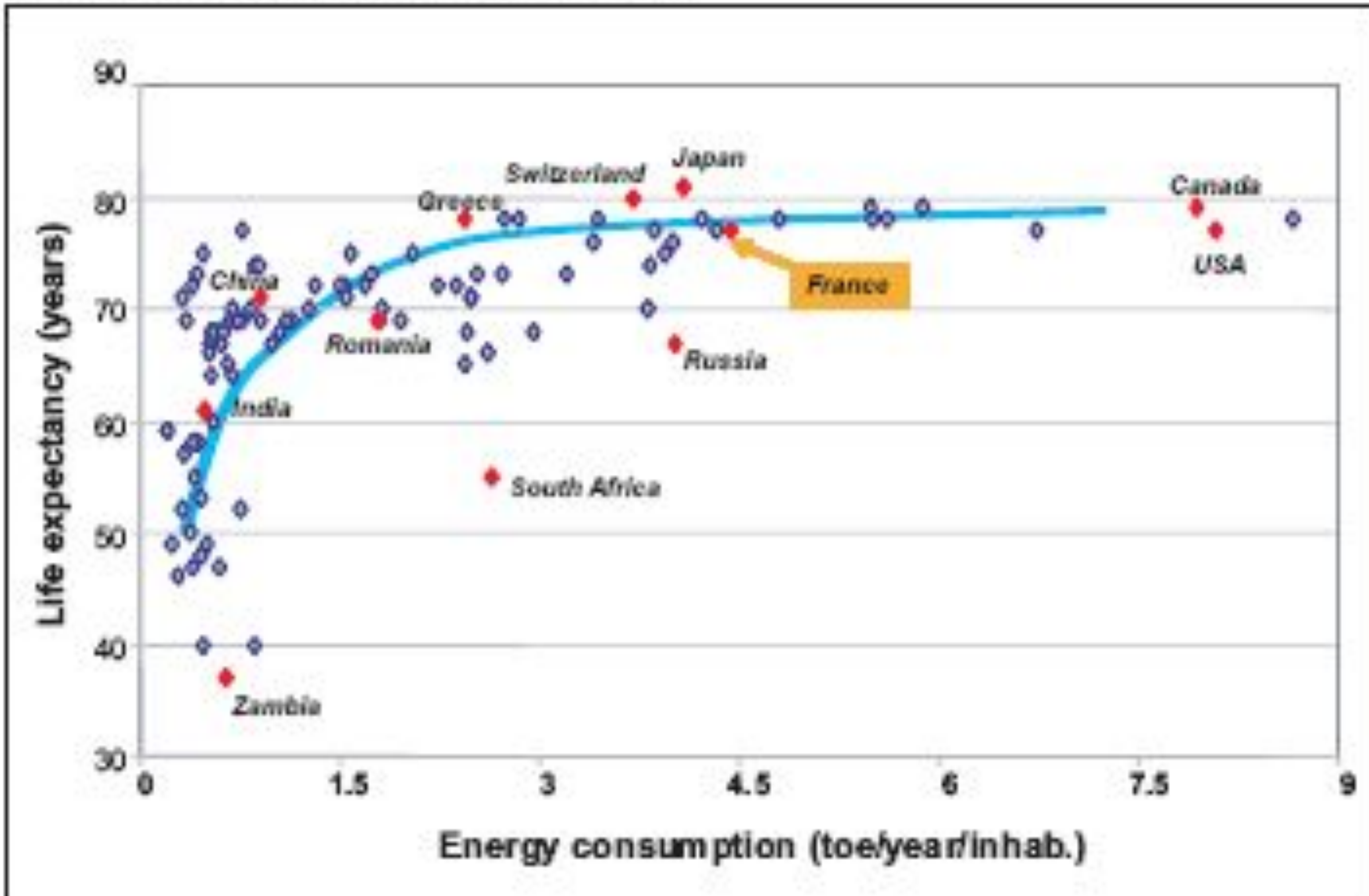
World – Forecast Trend of Primary Energy Consumption ("Business As Usual" Scenario)

(In rounded figures based on IEA's "World Energy Outlook", 2006)



World - Correlation Between Energy Consumption and Life Expectancy

(Source: United Nations Development Program, "World Energy Assessment: Energy and the Challenge of Sustainability", 2001, and "Overview 2004 Update")

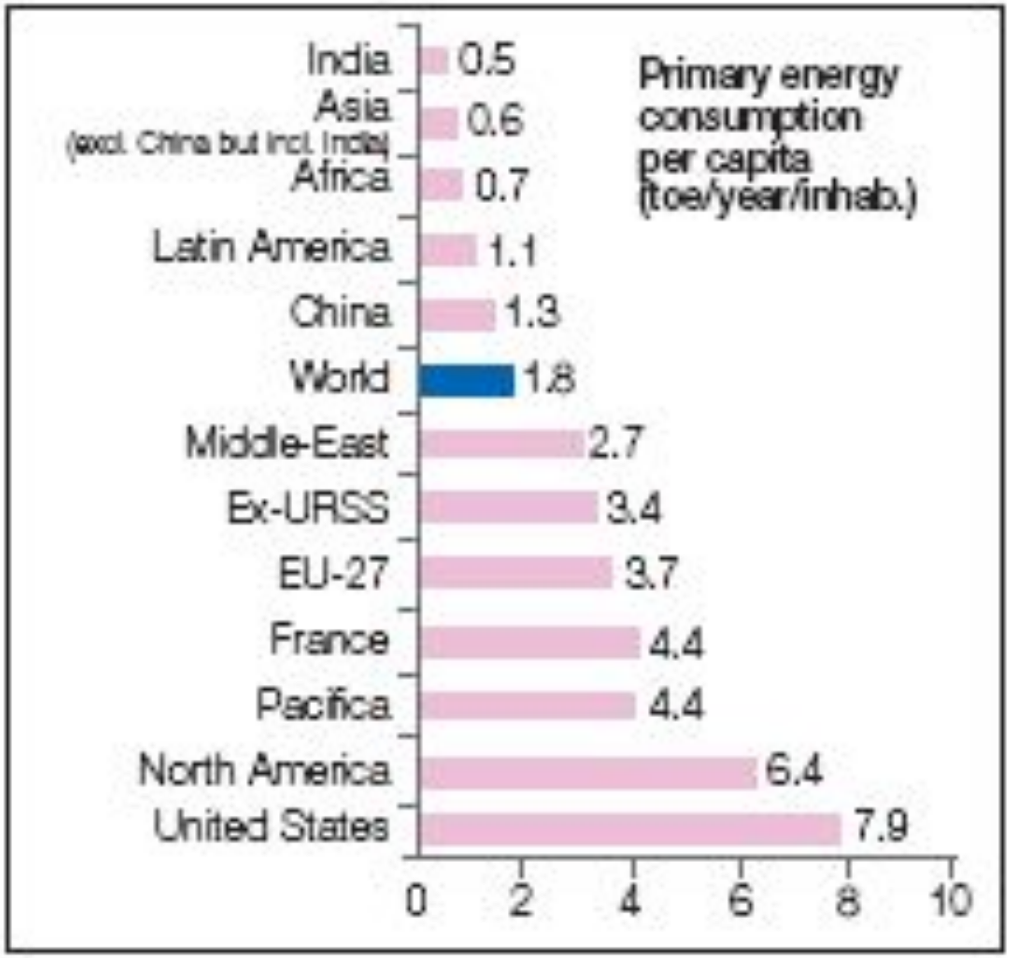


The Thirst for Energy (2)

- The gap in energy consumption per capita between the high income/high human development countries and the low income/low human development countries is striking, as exemplified by data on electricity consumption in kWh in 2002:
  - High human development 8586 kWh
  - Low human development 133 kWh
  - High income 10198 kWh
  - Low income 399 kWh
  - (Malaysia 2883 kWh, China 988 kWh)

World - Differences in Primary Energy Consumption in 2005

(In rounded figures based on IEA's "Key World Energy Statistics", "Energy Balances of Non-OECD Countries", "Energy Balances of OECD countries" 2007)



The World by Night (Source: Composite picture, NASA, 2005)
The major electricity-consuming regions are visible on this map.

The Thirst for Energy (3)

- Energy resources are unevenly distributed around the world. Our globalized economy requires the trading of this precious commodity, oil and gas being the most eloquent examples. This reality constitutes an interactive factor for the political instability to be deplored in several areas of the World

The Thirst for Energy (4)

- The race for energy impacts on the economic and social development of the less favored countries through higher oil prices and the wild development of bio-fuels which increases the price of food
- The latter development has reinforced the perception of the strong coupling between energy and agriculture

The Thirst for Energy (5)

- The interaction between energy and climate change is quite high on political agendas. The conclusions of the IPCC Fourth Assessment Report published in November 2007 indicate that, in order to limit the global average temperature increase below 3˚C, the peaking year for CO² emissions should be realized before 2030. Such requirement has a strong impact on energy options of the future

The Thirst for Energy (6)

- Future energy options must be seen also against the background of an incomplete fulfillment of the Millennium Development Goals. Global issues such as poverty, hunger, lack of education, diseases, poor drinking water, missing sanitation, still require urgent action. Energy constitutes an important factor for their mitigation

The Thirst for Energy (7)

- In summary, global growth in energy demand can’t be negated. For ensuring the greatest possible compatibility with sustainable development, a truly holistic approach, combining in the most appropriate way all possible aspects of energy options, is clearly needed

The Choice of the Best Energy Options

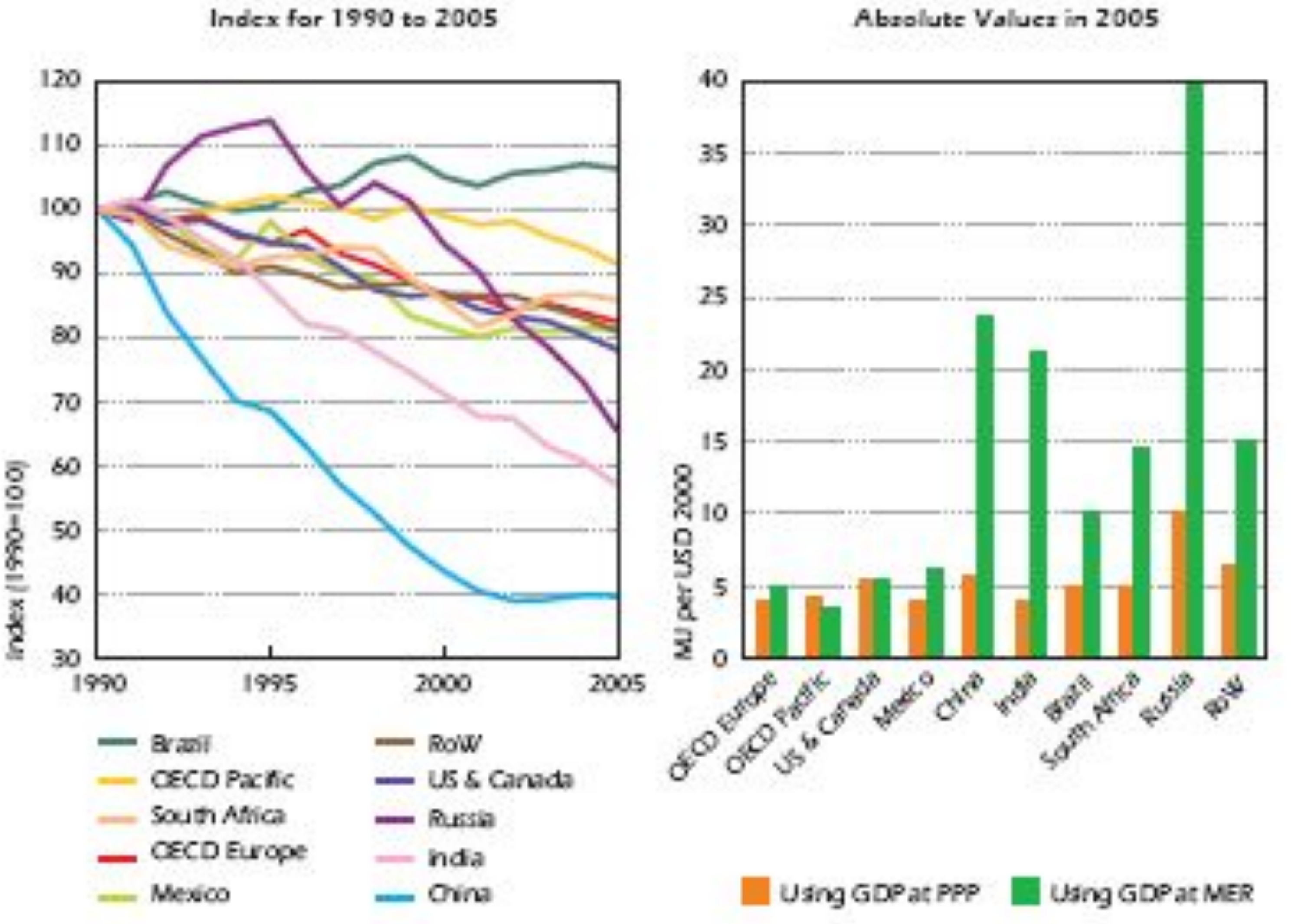
Choosing the Best Energy Options

- There is no single optimum energy option applicable to all regions, to all countries. What are the criteria for establishing the best option responding to the local specificity?
- Any option should contain two components:
  - A strategy for *energy conservation*, increasing energy efficiency, reducing energy consumption. This should be a universal preoccupation, for developed and emerging countries
  - An adequate mix of *energy sources*, ***diversification is a keyword for users in the energy field***

Energy Conservation

- There has been good progress in energy efficiency, as shown by the energy use elasticity with regard to GDP. For all countries in recent years, a growth of around 0.80% in energy use for 1% growth in GDP has been experienced (K.S. Parikh). Efforts should be enhanced in this direction
- Contrary to what is sometimes asserted, emerging economies have participated so far successfully to the progress in energy efficiency

Figure 2.5 ▶ *Total Final Energy Consumption per Unit of GDP*



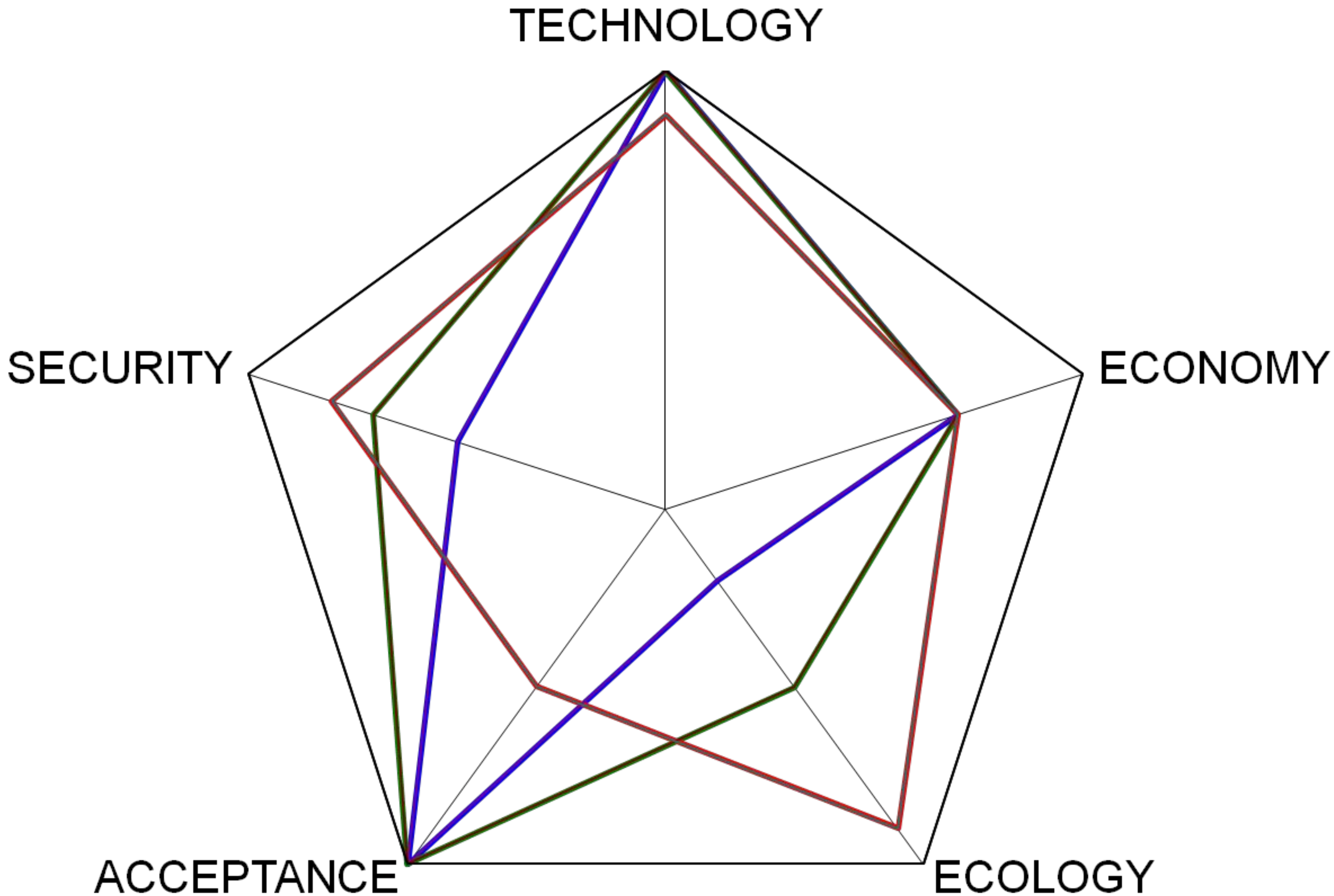
Sources: IEA, 2007 c; IEA, 2007 d; IEA estimates.

Figure 19. Energy Intensity by Region, 1970-2025

Sources: **History:** Energy Information Administration (EIA), *International Energy Annual 2002*, DOE/EIA-0219(2002) (Washington, DC, March 2004), web site www.eia.doe.gov/iea/. **Projections:** EIA, System for the Analysis of Global Energy Markets (2005).

The Best Mix of Energy Sources (1)

- Five criteria should be used for selecting an adequate mix of energy sources:
  - *Being technologically mature TECHNOLOGY*
  - *Demonstrating economical competitiveness ECONOMY*
  - *Respecting the Environment ECOLOGY*
  - *Guaranteeing a stability of supply SECURITY*
  - *Being perceived as presenting a low physical risk ACCEPTANCE*



TECHNOLOGY
ECONOMY
ECOLOGY
ACCEPTANCE
SECURITY

The Best Mix of Energy Sources (2)

- What are the energy sources to be considered under such criteria?
- In a first group:
  - Oil, gas and coal, aiming at improved forms of utilization, notably, for liquid fuels, moving to gas-to-liquids and coal-to-liquids
  - Hydropower when available; small hydropower is an opportunity
  - Geothermal energy, when available
  - Wind power, already a mature technology

The Best Mix of Energy Sources (3)

- In a second group:
  - Solar power, emphasis on solar thermal and solar refrigeration, large scale photovoltaic systems still too expensive
  - Bio-fuels, second generation liquid bio-fuels not competing with food production, bio-gas from organic refuses
  - Wave power, the wild card of renewable energies, might carry a lot of promises
  - Hydrogen, an energy vector, not a primary source of energy, its future depending on the evolution of various primary energy sources

The Best Mix of Energy Sources (4)

- Energy from thermonuclear fusion is a very objective, engineering feasibility is still a question mark
- It remains nuclear energy which should enjoy a strong growth in certain regions of the world but requires specific conditions for its use

World - Total Primary Energy Supply in 2005

(In rounded figures based on IEA's "Key World Energy Statistics", 2007)
Total: 11.5 Gtoe, including 80% fossil fuel energy (oil, coal, gas)

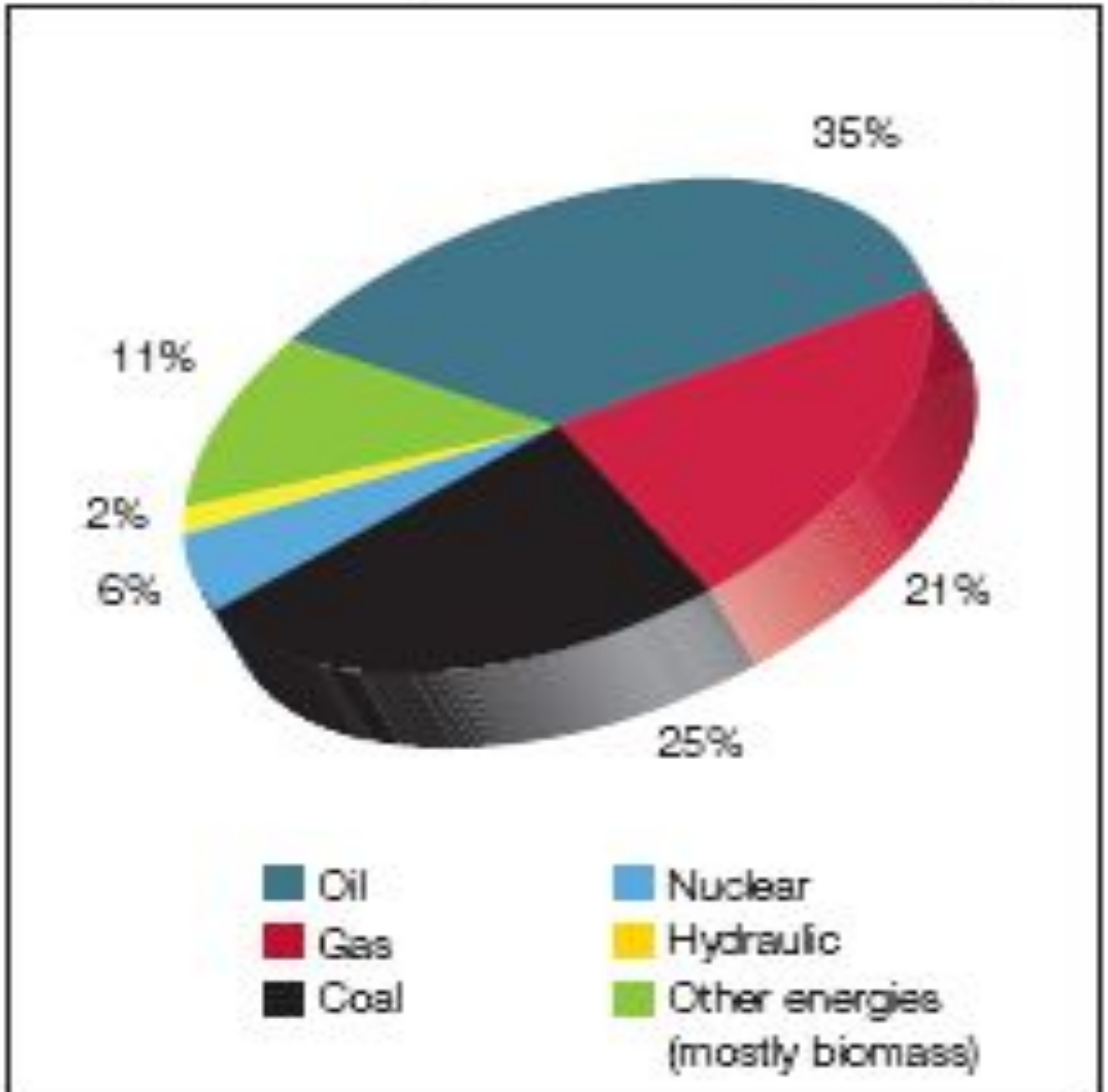
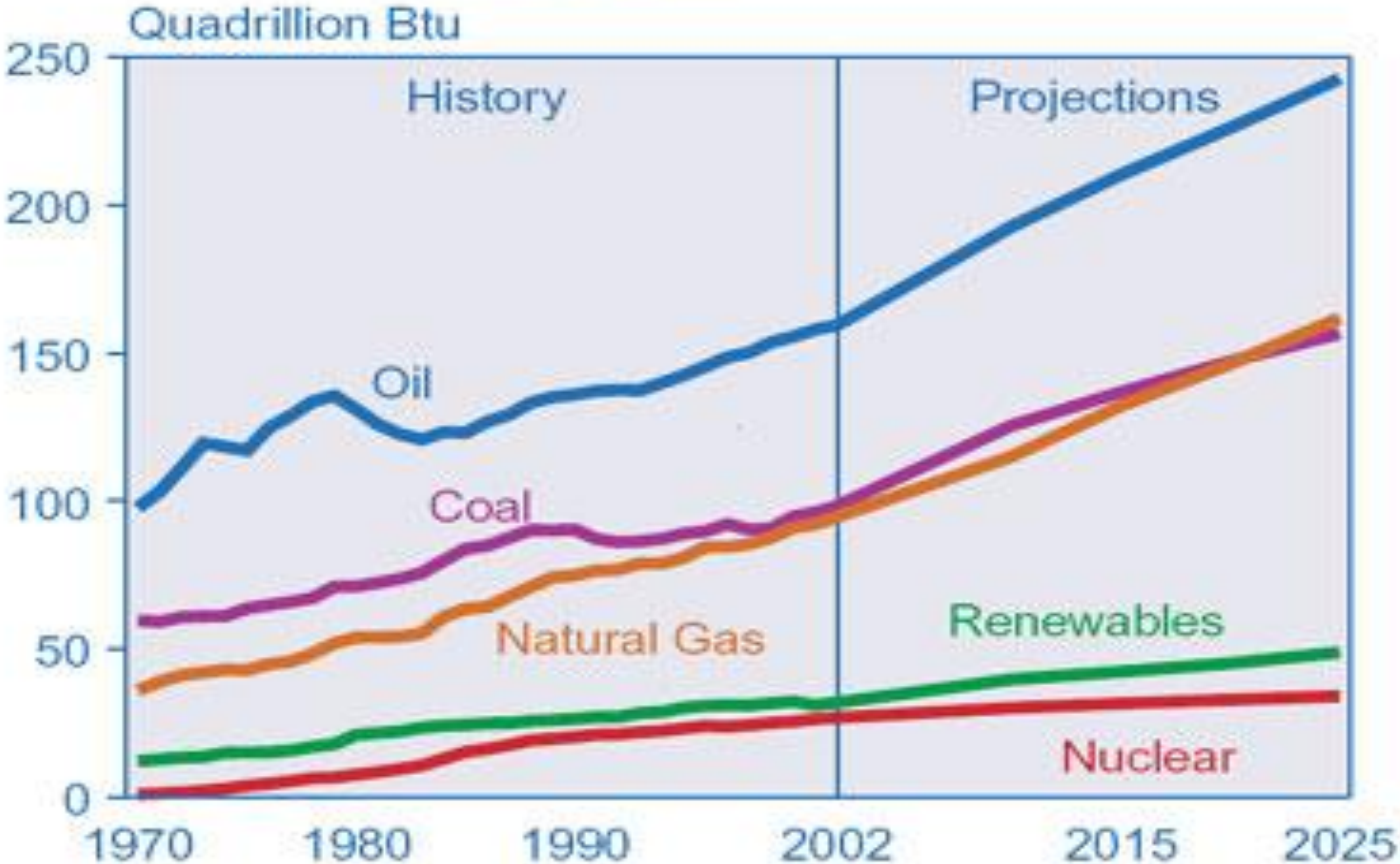


Figure 10. World Marketed Energy Use by Fuel Type, 1970-2025



Sources: **History:** Energy Information Administration (EIA), *International Energy Annual 2002*, DOE/EIA-0219(2002) (Washington, DC, March 2004), web site www.eia.doe.gov/iea/. **Projections:** EIA, System for the Analysis of Global Energy Markets (2005).

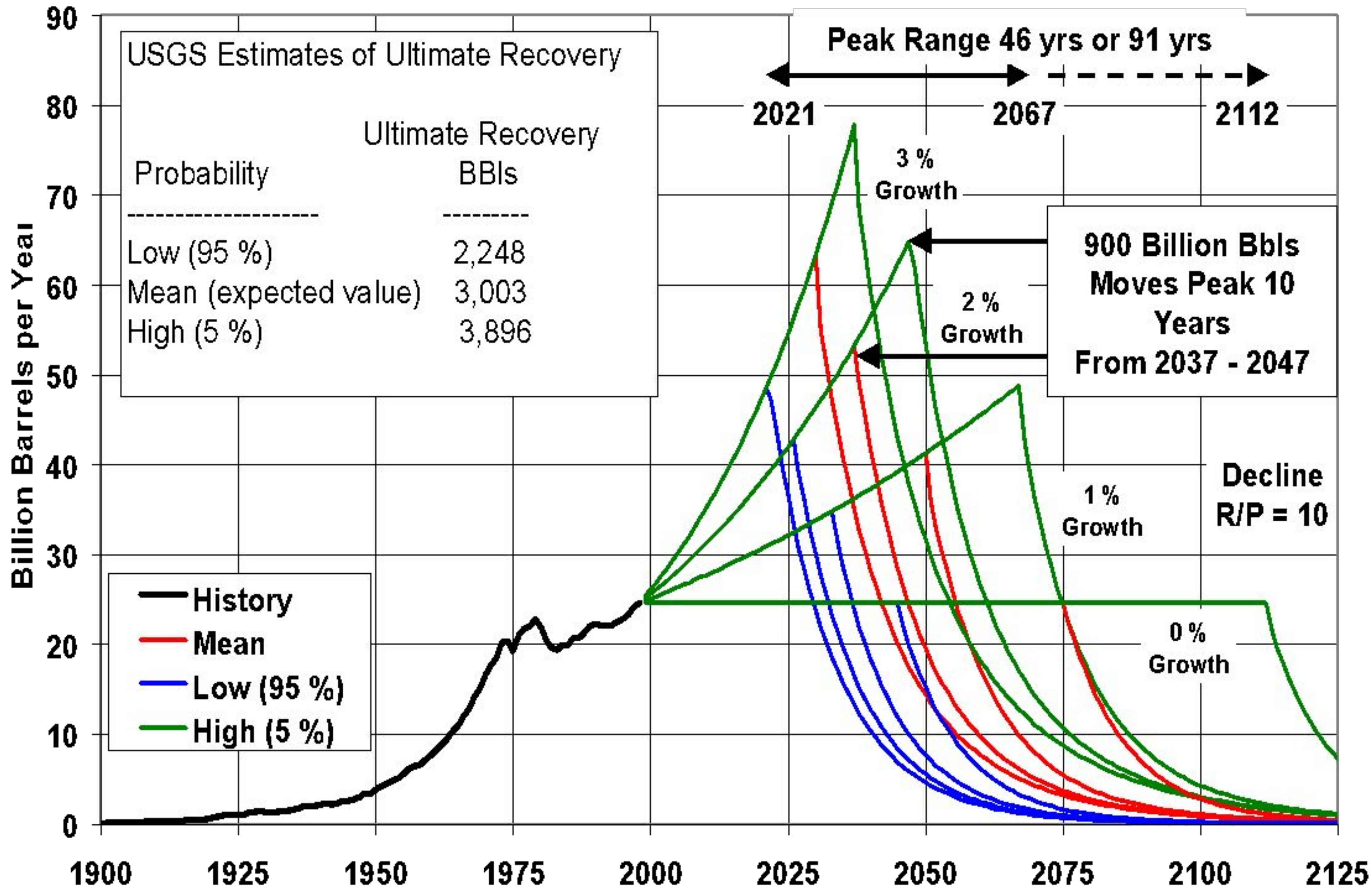
The Most Important Energy Sources

Oil in its current forms of utilization (1)

Currently, the most important form of energy

- *Technology:* fully mastered
- *Security:* beyond the issue of political stability, the main interrogation relates to the date of the peaking of its production due to the exhaustion of the oil fields. Globally, the peak would lie between 2035 and 2075 but with great differences among countries: the reserve-to-production ratio was, in 2005, 7 years for UK as opposed to 110 years for Kuwait. For Kazakhstan, it would amount to 23 years (EIA/DOE). The opening of the Arctic reserves and the recent discoveries off Brazil could postpone globally the peaking point

12 EIA World Conventional Oil Production Scenarios



Note: U.S. volumes were added to the USGS foreign volumes to obtain world totals.

Oil in its current forms of utilization (2)

- *Acceptance:* largely accepted in terms of physical risk but perceived as a political risk due to its geographical concentration
- *Ecology:* with coal, the main source of greenhouse gases. Carbon capture and sequestration could mitigate the issue but this technology is still uncertain and definitely costly
- *Economy:* prices are volatile with extremely large variations in very short times. With a price stabilizing at around 60 US$/barrel, remains competitive for electricity production when no heavy CO^2 tax is included

Oil in its current forms of utilization (3)

- *Economy (cont.):* for electricity production, there is a wide range depending on local conditions, and financial assumptions but taking into account the basic costs (capital, fuel, operation and maintenance), oil-fired power plants present a total basic cost of 40-50 US$/MWh. With an emission trading at 30 US$/t$CO^2$, the increase would lead to 65-80 US$/MWh; alternatively, carbon capture and sequestration would add to the basic cost from 10 to 50 US$/MWh (IPPC, 2005)

Gas in its current forms of utilization (1)

The form of energy which came at the forefront in a dazzling short time

- *Technology:* mature except for the recuperation of gas flares. The World Bank estimates that over 100 Billion cubic meters of natural gas are flared or vented annually, an amount worth approximately 30 Billion US$, equivalent to the combined annual gas consumption of Germany and France, twice the annual gas consumption of Africa! Russia has announced (September 2007) that it will stop the practice of gas flaring and is making a big effort in this respect

Russia’s recuperation of gas flares (1)

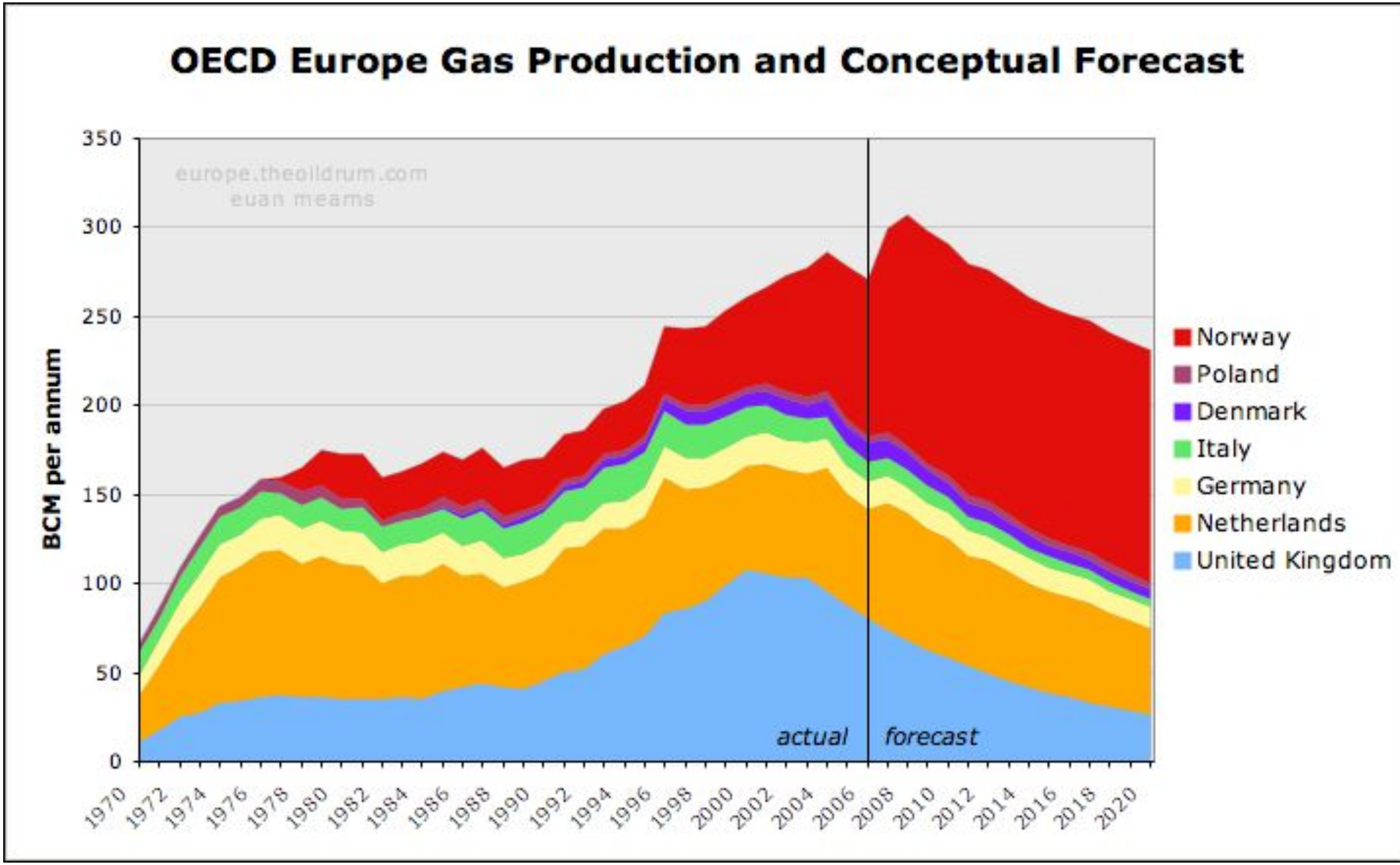
- For Russia, gas flared by oil companies represents about 20 millions cubic meters per day. Rosneft has submitted to the Russian government a proposal for a pilot project consisting of a 315 MW gas turbine power plant at the Priobskoye field (Khanty-Mansiisk autonomous district) fed from the surrounding fields spewing out 2 billions cubic meters of gas per year. The power plant would use about a fourth of this volume. Rosneft plans to spend 2.7 Billions $ over the next 5 years to reduce wasteful gas flaring

Russia’s recuperation of gas flares (2)

- The problems currently faced with gas recuperation are:
  - The electricity production is far geographically from consumption centers
  - The price of the electricity produced by gas turbines power plants are uncompetitive under current conditions

Gas in its current forms of utilization (2)

Security: production already peaking in most OECD countries. Proven reserves amount to 172,000 Billions Cubic Meters (BCM); world's annual consumption was 2,900 BCM in 2005, with a projected increase in 2030 to 4.5 BCM. World's reserves are predominantly in Siberia, Iran and Qatar. Intercontinental transport might be an issue in the future, the liquefied form is the only available for maritime transport



OECD Europe Gas Production and Conceptual Forecast
europe.theoildrum.com
euan mearns
BCM per annum
350
300
250
200
150
100
50
0
1970
1972
1974
1976
1978
1980
1982
1984
1986
1988
1990
1992
1994
1996
1998
2000
2002
2004
2006
2008
2010
2012
2014
2016
2018
2020
actual
forecast
Norway
Poland
Denmark
Italy
Germany
Netherlands
United Kingdom

Gas in its current forms of utilization (2)

- *Acceptance:* as for oil, largely accepted in terms of physical risk but perceived as a political risk due to its geographical concentration
- *Ecology:* gas combined cycles are better than oil and coal in terms of greenhouse gases emission
- *Economy:* price linked so far to the price of oil, hence following with some attenuation the variations of the latter. Even with a moderate increase in price, gas remains competitive, thanks to the conversion efficiencies that it achieves in power production

Gas in its current forms of utilization (3)

- *Economy (cont.):* for electricity production, basic costs of gas combined cycle power stations are in the range of 35-45 US$/MWh. With an emission trading at 30 US$/t$CO^2$, this would increase to 45-65 US$/MWh, lower than for oil and coal (EC, 2007). Alternatively, as for other fossil fuels, carbon capture and sequestration would add to the basic cost from 10 to 50 US$/MWh (IPPC, 2005)

Coal in its current forms of utilization (1)

The energy of the 19th Century enjoying a revival

- *Technology:* mature, well known
- *Security:* reserves present in all continents. Large reserves in the US and China, also in Kazakhstan
- *Acceptance:* in spite of all the accidents in coal mines and radioactivity released when burned, no great problem
- *Ecology:* serious drawback due to CO^2 emission when used

Coal in its current forms of utilization (2)

- *Economy:* prices are soaring due to the recent demand. Nevertheless, still quite competitive for electricity production when no large CO^2 tax included. The basic cost for coal pulverized fuel plants with flue desulphurization could be as low as 30 to 40 US$/MWh. With an emission trading at 30 US$/t$CO^2$, this would increase to 50-70 US$/MWh, lower than oil, higher than gas. Alternatively, as for other fossil fuels, carbon capture and sequestration would add to the basic cost from 10 to 50 US$/MWh (IPPC, 2005)

Renewable Energies (1)

A significant component of the future

The most promising forms of renewable energies:

- Hydropower
- Wind

Hydropower (1)

The engineering success of the 20th Century

- *Technology:* fully mastered
- *Security:* potential of mountainous areas not fully exploited; same applies to Greenland and in many countries for small units along rivers
- *Acceptance:* with nuclear, the most contested form of energy production

Hydropower (2)

- *Ecology:* no impact on climate change but, on the contrary, climate change could impact on the implantation of hydropower due to an increase in droughts, e.g. in the Mediterranean area or Central Asia
- *Economy:* quite attractive, basic cost could be currently as low as 30 US$/MWh but also as high as 100 US$/MWh. Impact of CO^2 tax would be negligible

Wind (1)

A most promising technology for the 21st Century

- *Technology:* reaching maturity, improvements still possible
- *Security:* wind exists in most places of the globe, careful implantation could boost the production, off shore installations are attractive, even if more costly

Wind (2)

- *Acceptance:* some problems at local level due to the "Not In My Back Yard" syndrome
- *Ecology:* no impact <u>on</u> climate change
- *Economy:* quite attractive, basic cost could be in a near future between 40 and 70 US$/MWh. Impact of a CO² tax would be negligible

Renewable Energies (2)

The renewables with a question mark in spite of their appeal:

- Solar
- Biomass

Solar (1)

A lot of appeal, notably among political decision-makers but not without problems

Three conversion processes are mainly utilized:

- Low enthalpy solar thermal conversion for producing hot water or hot air at small scale. Largely utilized in areas with important solar flux (e.g. Mediterranean). Renewed interest for large floating solar thermal farms producing electricity

Solar (2)

- High enthalpy solar thermal conversion using focused mirrors for high temperature electricity production. A few experiments, not very promising
- Photovoltaic conversion. The most promising option:
  - *Technology:* much improvement still possible, nanotechnologies could help
  - *Security:* suffers from the night/day cycle, problem of sufficient solar flux above 55 degrees latitude

Solar (3)

- *Acceptance:* no real problem
- *Ecology:* limited impact on climate change
- *Economy:* the real sore point; the prospect of becoming competitive even in a distant future appears remote. For medium to large scale electricity production, costs could be currently as high as 100 to 500 US$/MWh with a prospect in several decades to go down to 60 to 250 US$/MWh (EC 2007, Deju and Holmes, AIST). Only, for limited power production at remote places, such costs could be justified

Biomass (1)

As for solar energy, a lot of appeal, notably among political decision-makers but not without problems

- Biomass raises the basic issue of the utilization of land either for food or for energy: as an example, 50 liters of ethanol (250 km with a SUV) require 200 kg of maize (1 year of food for one person in developing countries)
- Also, in certain cases, a positive energy balance is not guaranteed

Biomass (2)

- 2008 world bio-fuels production is estimated at 1.4 millions of barrels per day, rising annually by about 300,000 barrels per day
- More than half of the production is concentrated in two countries, about 30% from the US and 25% from Brazil
- The demand has led to a sharp increase in the price of corn and other bio-fuel crops and creates environmental problems due mainly to deforestation

Biomass (3)

- The future of biomass as an energy source depends very much from the possibility in the future to produce bio-fuels from waste (e.g. wooden chips) or from crops grown on marginal land (e.g. jastropha in India, miscanthus in Britain) or from algae

Biomass (4)

An example of the pressure on arable land: Virgin Atlantic and other airlines testing bio-fuels for their flights:

- One return flight London:New York consumes 170 000 liters of fuel. With two flights a day, this means about 122 millions liters of fuel; one m^2 of arable land can produce 0.05 l of bio-fuel in US/European conditions. Hence two transatlantic flights a day during a year would require the constant use of about 2500 km^2 of cultivated land under good production conditions!

Renewable Energies (3)

The renewables with a limited potential due to their dependence on geography:

- Geothermal
- Wave

Geothermal

- Very dependent from the geological structure of the site, limited site availability
- Used for combined production of heat and electricity
- 8 GWe currently installed. The growth initiated several decades ago should continue: the objective for 2020 is multiplying by 7 the current electricity production and by 4 the heat production
- Local environmental degradation is an issue

Wave

- High theoretical potential as wave energy could be applied around most of the world's coastal zones
- Technologies are still at the experimental stage. Transport of produced energy is an issue in the marine environment
- Foreseeable costs about an order of magnitude above those of wind energy
- Problems linked to compatibility with fishing and navigation
- Worth continuing the demonstration efforts

Synthetic Fuels

- Oil has been utilized mainly in the form of liquid fuels, notably in transport. The other fossil fuels, gas and coal, which should have a longer life cycle, look for an access to the large liquid fuel market by using chemical conversion, hence the appearance of synthetic fuels, gas-to-liquids and coal-to-liquids, stimulated by their environmental friendliness. This conversion has the additional advantage of creating added-value industries at the production sites. Aviation has started utilizing them operationally; hopefully, their utilization will grow because there are few alternatives in this case

Gas-To-Liquids (GTL's)

- Conversion of natural gas into ultra clean fuels replacing notably diesel fuels
- Offer the possibility of utilizing gas reserves either too important for the conventional market or too remote for the traditional exploitation methods
- Limited cost of introduction when substituting for conventional oil derived liquid fuels
- Qatar is the world capital of GTLs, but the process is also developed in other parts of the world
- Still consuming too much energy for its production but the appeal is great

Coal-To-Liquids (CTL's) (1)

- Process developed in Germany during the 1920s (Fischer-Tropsch and Bosch-Bergius) and used extensively during World War II. Know-how improved subsequently in South Africa: SASOL provides now 30% of South African fuel consumption
- Offers the possibility of utilizing coal reserves while limiting the impact on the environment, resulting fuels are very clean but CO^2 emission in the process is still too high. Also the process is extremely resource-intensive, notably for water
- Limited cost of introduction when substituting for conventional oil derived liquid fuels but production cost still high

Coal-To-Liquids (CTL's) (2)

- Important effort of China in this field. China wishes to pursue the exploitation of its coal reserves which cover currently 75% of its domestic energy needs
- China plans to invest some 15 Billions US$ over the next few years, notably in the provinces of Ningxia et Shaanxi. Beginning 2008, conclusion of a development project with SASOL (6 B$) and undergoing negotiations with Royal Dutch/Shell for further projects
- China's objective is production in the future of 30 millions tons per year

What about Hydrogen? (1)

- Hydrogen is an energy vector, not a primary source of energy. Its development depends in great part from the future development of different primary energy sources.
- Hydropower is the prime candidate for its production. The development of large scale high temperature nuclear reactors could create a viable alternative

What about Hydrogen? (2)

- Its production from natural gas is technologically mature and economically sound but the process releases CO² which mitigates the interest of going to hydrogen
- It could be an attractive way of storing energy from renewables such as wind, solar and wave
- Collective urban transport and decentralized production of electricity, notably for emergencies, appear to be the most immediate applications

What about Hydrogen? (3)

- In spite of the so-called « Hindenburg Syndrome » (the Zeppelin Accident in NAS Lakehurst, USA, on May 6, 1937), its utilization does not appear to raise acceptance problems. The experiments with H^2 buses in various European cities, notably in Bavaria, and their planned use for the 2010 Winter Olympics in Vancouver substantiate this view

What about Nuclear Fusion?

- Still at the stage of scientific and technological experiments.
- Too early to predict its introduction in future energy scenarios

What about Nuclear Fission?

- Even after nearly six decades of nuclear power production, there is still, at world level, a controversy about the future of nuclear energy. In some European countries, no technological innovation, with the exception of Genetically Modified Organisms, has ever created such an emotional opposition. In view of the potential offered by this form of energy, it deserves a detailed presentation

The Particular Case of Nuclear Energy

The Position of Nuclear Energy (1)

- With regard to the other forms of energy, how nuclear energy can be rated?:
  - *Technology*: established for most types of reactors, including 3rd generation systems. For most of the 4th generation systems, technological advances are still needed

The Position of Nuclear Energy (2)

- *Economy:* it concerns essentially electricity production. There is a wide range of data depending on local conditions, financial assumptions and types of reactors but in average, LWRs and advanced LWRS present a total basic cost (capital, fuel, operation and maintenance) of 40-50 US$/MWh. The cost of waste treatment and decommissioning would increase it by about 3 US$/MWh when externalizing costs. A CO^2 tax would a have a negligible impact
- As shown by the following table, this cost is currently matching total basic costs of coal- and oil-fired power plants while somewhat higher than the cost of gas combined cycle plants

The Position of Nuclear Energy (3)

- *Economy (cont.)* : Hydropower is quite advantageous in certain circumstances as wind generators could be in the near future. Other renewable energies are not cost competitive, except in particular circumstances
- If an emission trading (CO^2 tax) would be introduced or if Carbon Capture and Sequestration (CCS) would be applied, the related added costs for all fossil forms of energy would bring them away from being competitive with nuclear energy which would keep in this case as competitors hydropower and wind energy

Electricité: Coûts de Production

Type	Total basic cost US$/MWh	With CO^2 tax of 20$/t$CO^2$	With CCS
OIL	40 to 50	65 à 80	+ 10 à 50
GAS	35 to 45	45 à 65	+ 10 à 50
COAL	30 to 50	50 à 70	+ 10 à 50
NUCLEAR	40 to 50 WASTE/DEC + 3	+ 0.15-1.0	X
HYDRO	30 to 100	+ 0.10-1.1	X
Wind	40 to 150	+ 0.30-1.1	X

Economie (1)

- Basic values used in the comparison of the costs of various energy sources:
  - US$/€ 1.30
  - Oil at 60 US$/barrel
  - Natural gas at 6.50 US$/GJ (46.5 US$/barrel oil equivalent)
  - Coal at 60 US$/Tonne
- Sensitivity to price variation is given in the following diagram

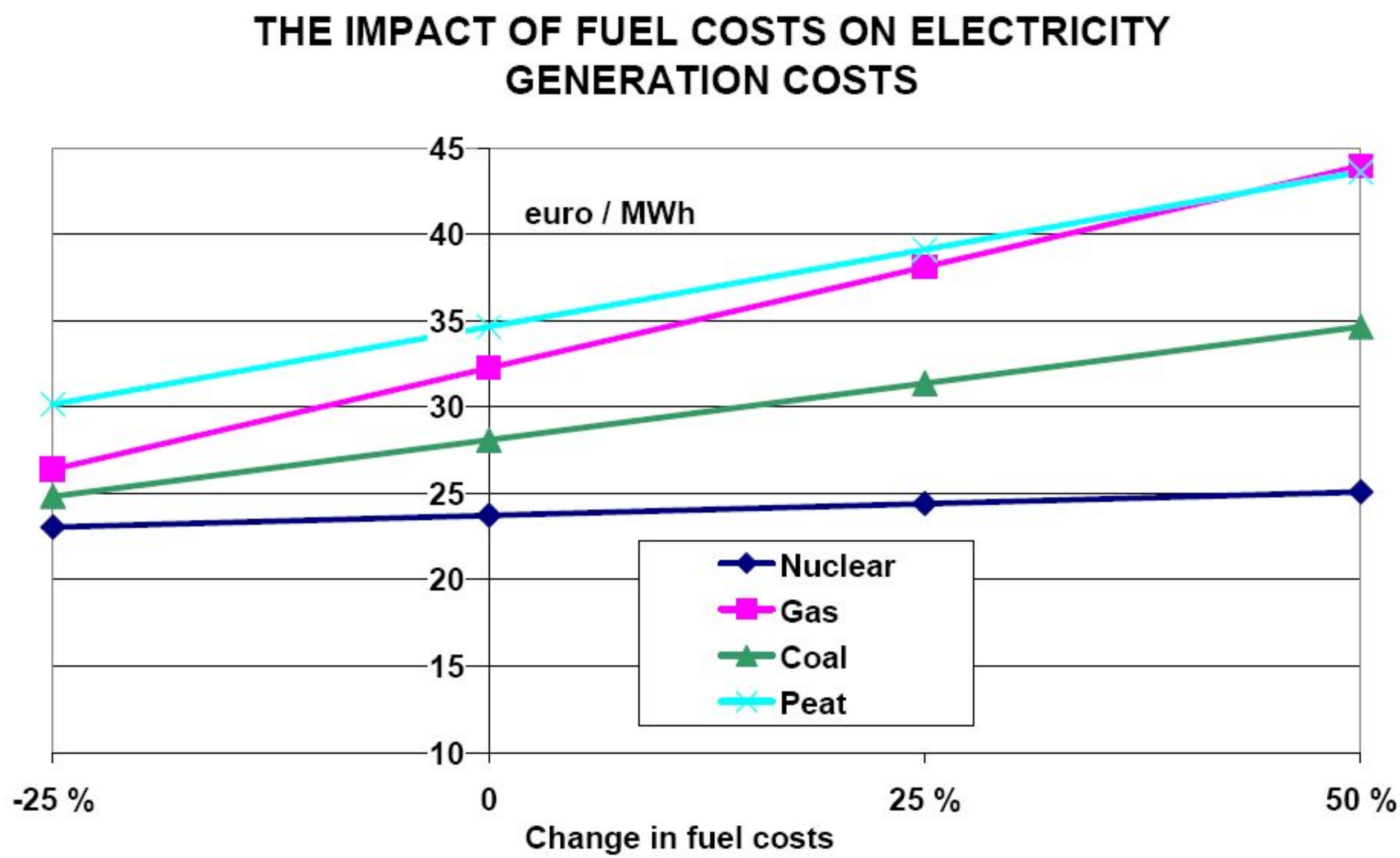


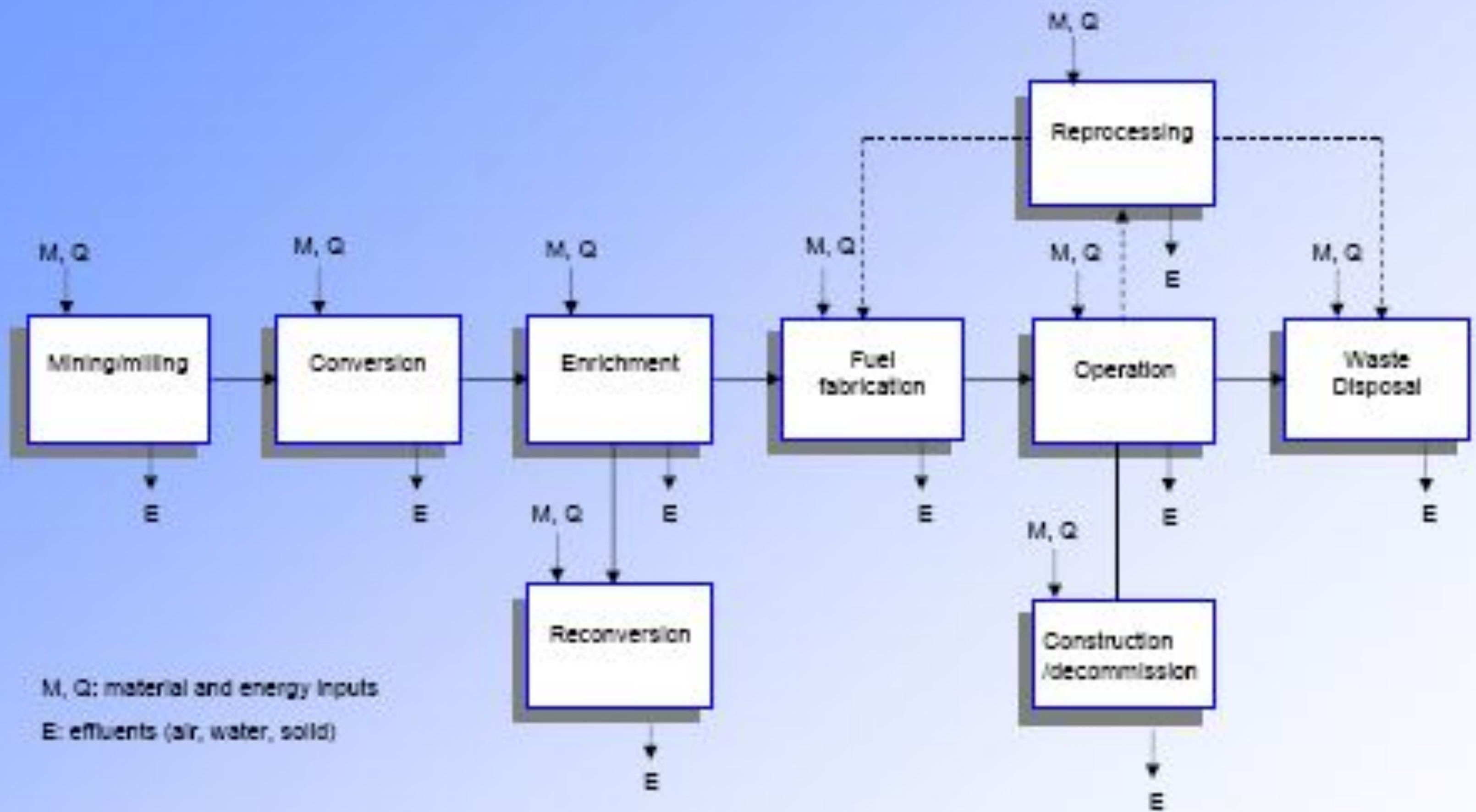
Fig. 4. The impact of fuel costs on electricity generation costs (without emission trading).

The Position of Nuclear Energy (4)

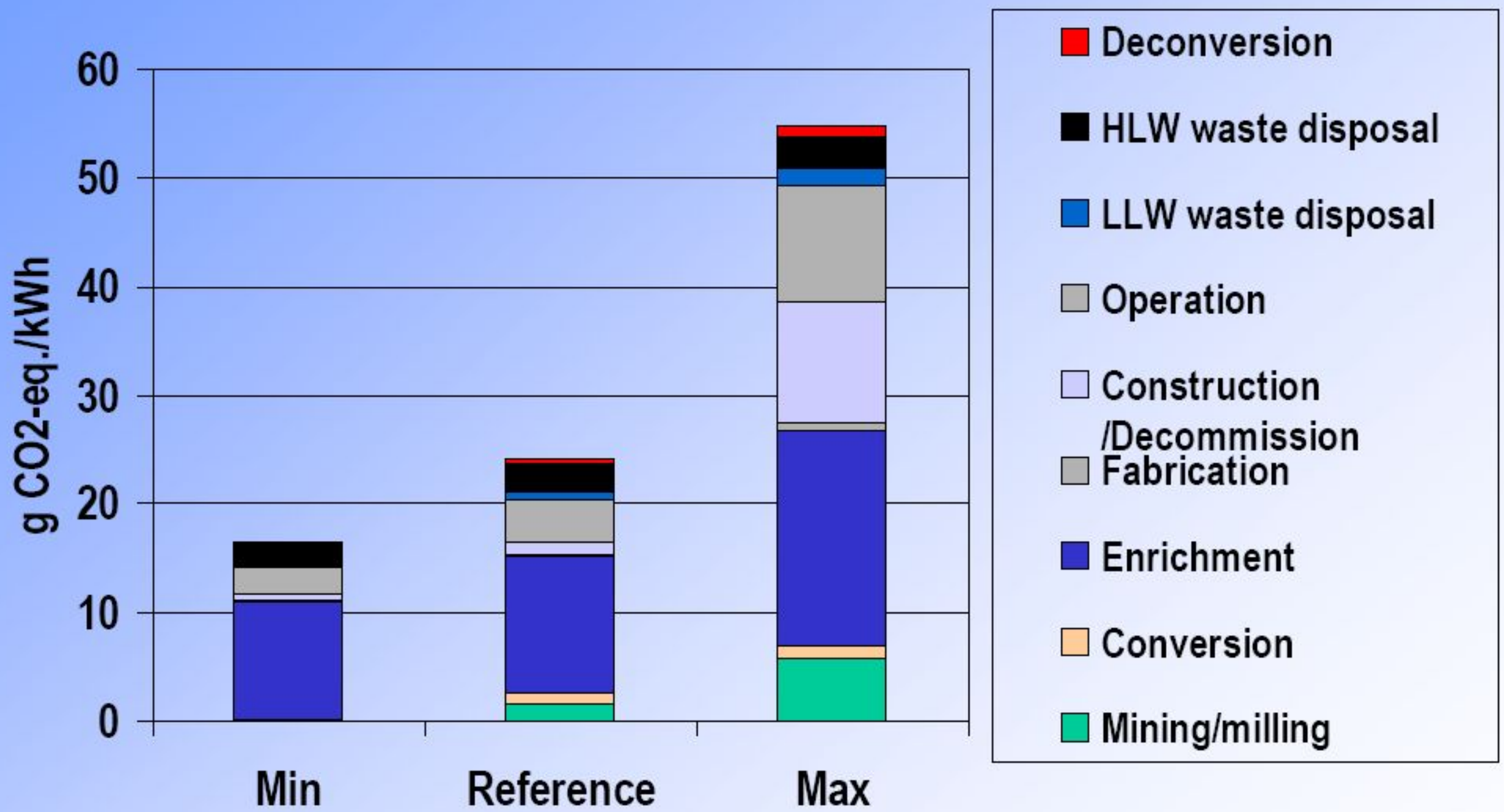
- *Ecology:* nuclear energy together with the renewables present the best performance in terms of greenhouse gases emission, even taking into account life cycle assessment. Combined gas cycles are the best among the fossil based sources, as shown in the following diagrams and tables

  The issue of nuclear waste disposal is probably the most serious one for nuclear energy.

The Nuclear Fuel Cycle



BNL Study -US Nuclear Fuel Cycle: GHG Emissions

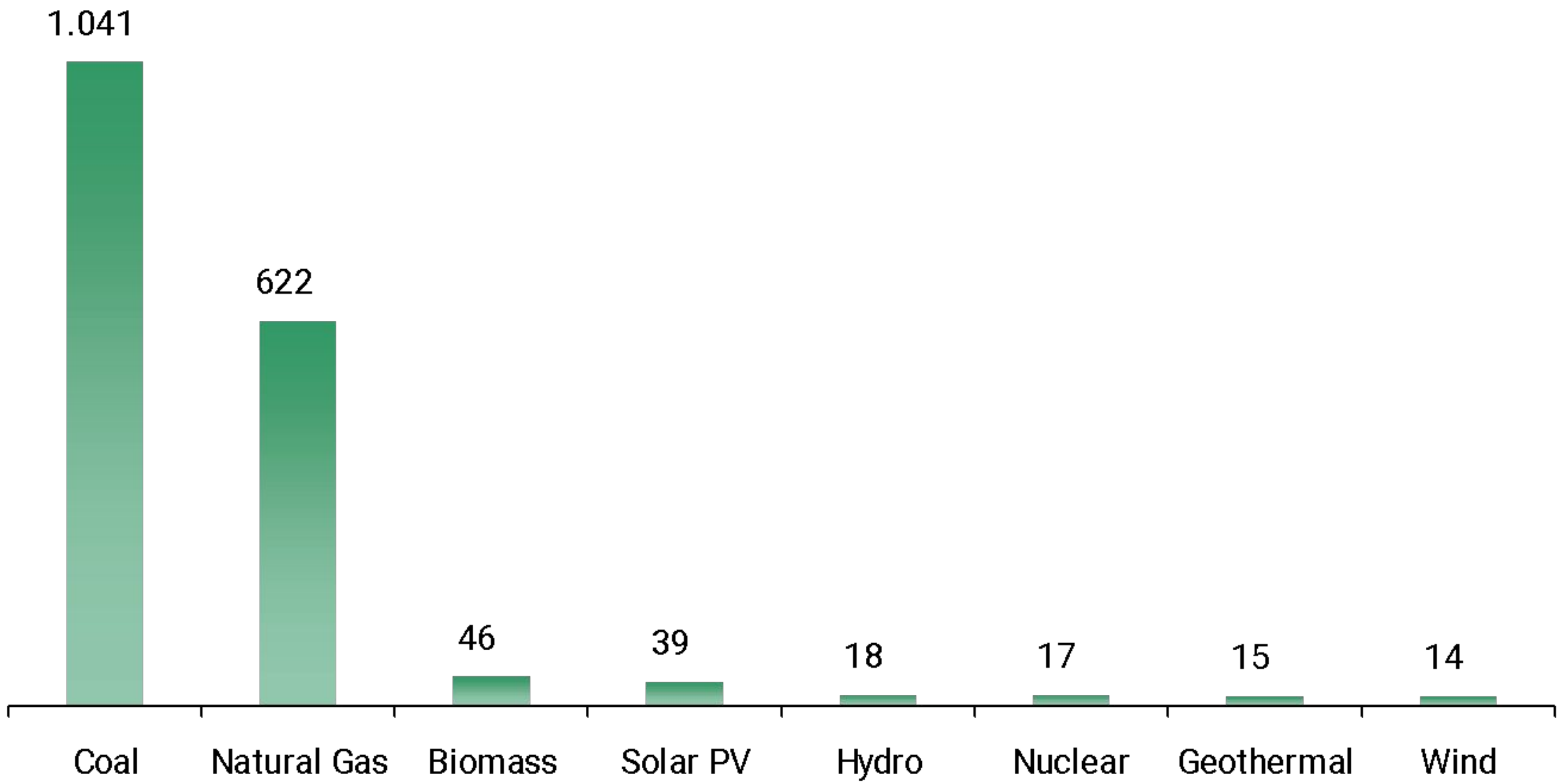


MRS LCA Symposium, Nov. 2005

Energy Policy 35 (2007) 2549-2557

Comparison of Life-Cycle Emissions

Tons of Carbon Dioxide Equivalent per Gigawatt-Hour



Source: "Life-Cycle Assessment of Electricity Generation Systems and Applications for Climate Change Policy Analysis," Paul J. Meier, University of Wisconsin-Madison, August 2002.

Table Seven. Life-cycle Emissions from Selected Generating Technologies
Grams emitted per kilowatt-hour of output (g/kWh)

Technology / Emission	Coal[A]		Biomass[B]	PV[C]		Wind[D]	Geothermal[E]	Nuclear[F]
	Average current system	New source performance standard	Gasification combined-cycle	Grid-tied rooftop PV	Stand-alone rooftop PV w. battery		Flashed steam *(Reservoir emissions only!)*	Light water reactor
Particulates	9.21	9.78	0.04	Unk.	Unk.	Unk.	0	0.09
SO_2	6.70	2.53	0.30	Unk.	Unk.	Unk.	0.03	0.16
NO_X	16.1	14.6	0.69	Unk.	Unk.	Unk.	0	0.11
Carbon monoxide	1.3	1.5	0.08	Unk.	Unk.	Unk.	0	0.01
Non-CH_4 hydrocarbons	1.0	1.3	0.60	Unk.	Unk.	Unk.	0	Unk.
CO_2 from mining or cultivation	9	8	28	NA	NA	NA	0	Unk.
CO_2 from transportation	17	16	6	NA	NA	NA	0	Unk.
CO_2 from power generation	996	917	12	0	0	0	45-81	Unk.
Total CO_2	1,022	941	46	Unk.	Unk.	Unk.	45-81	36.6
Methane	4.4	5.2	0.005	Unk.	Unk.	Unk.	0.09-0.75	0.12
Total CO_2 equivalent[G]	1,114	1,050	46	60-150	280-410	7-74	47-97	39.1

The Position of Nuclear Energy (5)

- *Security:* nuclear energy, coal and some renewables present a greater stability against political risk, when compared with oil and gas, nuclear energy benefiting from a wide geographical distribution of uranium producers.

The Position of Nuclear Energy (6)

- *Security (cont.)* : there is a certain controversy on the availability of uranium resources, a preoccupation which is not reflected in the latest edition (2006) of the OECD-NEA “Red Book”, indicating that the uranium resources are plenty to sustain growth of nuclear power

The Position of Nuclear Energy (7)

- *Security (cont.)* :By 2025, world nuclear energy capacity is expected to grow to between 450 GWe (+22%) and 530 GWe (+44%) from the present generating capacity of about 370 GWe; this will raise annual uranium requirements to 80 000-100 000 tonnes, to be compared to “identified resources” of 4.7 Million tonnes and “total conventional resources” of 14.8 Million tonnes.

  The possible recourse in Generation IV reactors to the Thorium cycle and to breeding in fast reactors would further relieve any constraint. The use in civilian reactors of existing demilitarized fissile material could also extend the resources

Use of existing fissile materials

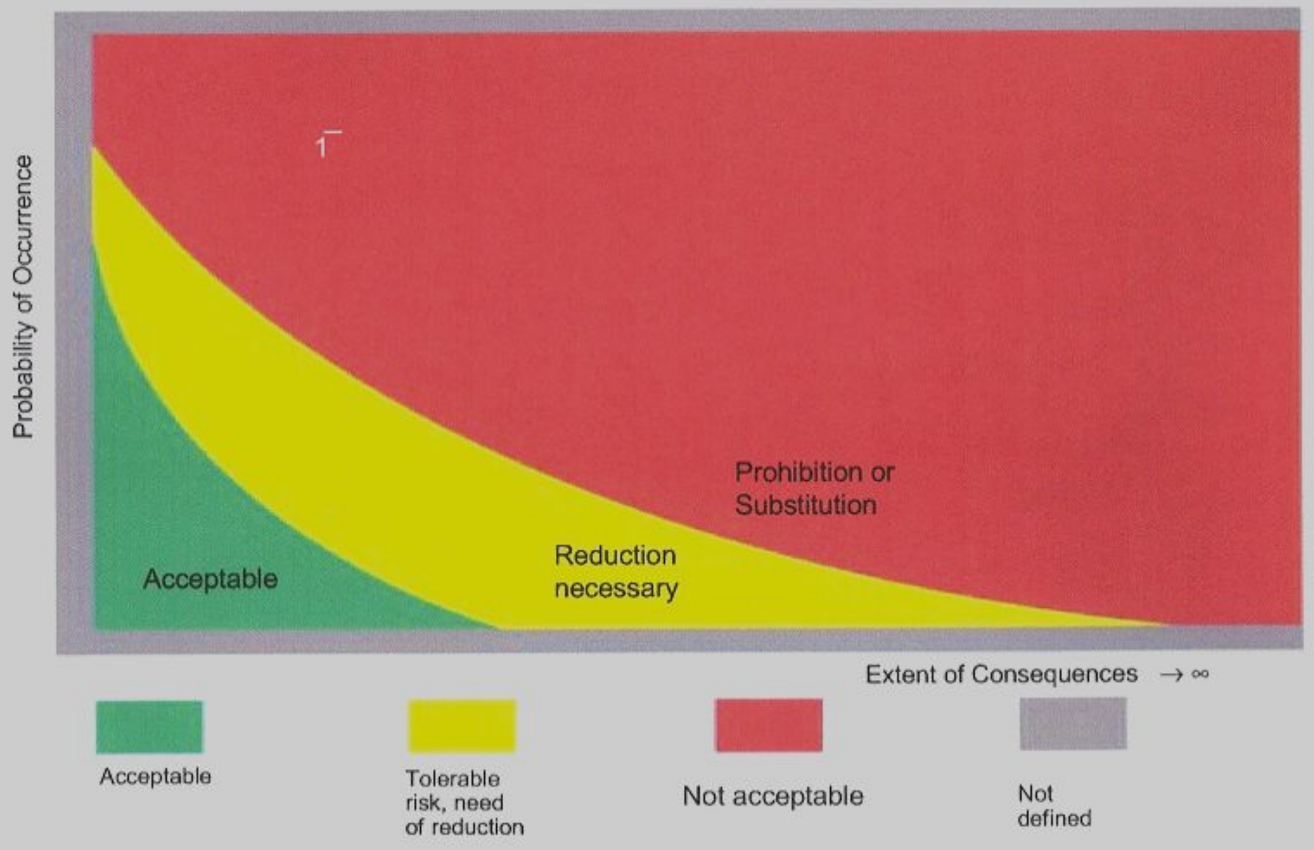
- The development of new nuclear power generation capacity would enable to reduce usefully the very large quantities of weapon grade fissile materials currently stored, originating from partial nuclear disarmament programs. Declared surplus are:
  - In Highly Enriched Uranium (HEU); 174T US, 500T RF
  - In Plutonium (Pu): 53T US, 34T RF
- Furthermore, it exists a stock of more than 200T of separated Pu from civilian operations and, in used nuclear fuels, not reprocessed, lies a very large amount of Pu, about 17 000T, which will continue to grow!

The Position of Nuclear Energy (8)

- *Acceptance* : this is clearly the most critical factor for nuclear energy; all other energy sources, with the exception of hydropower and in some places wind, are widely accepted in terms of physical risk. Hydrogen, as an energy vector, experiences also problems within certain segments of society

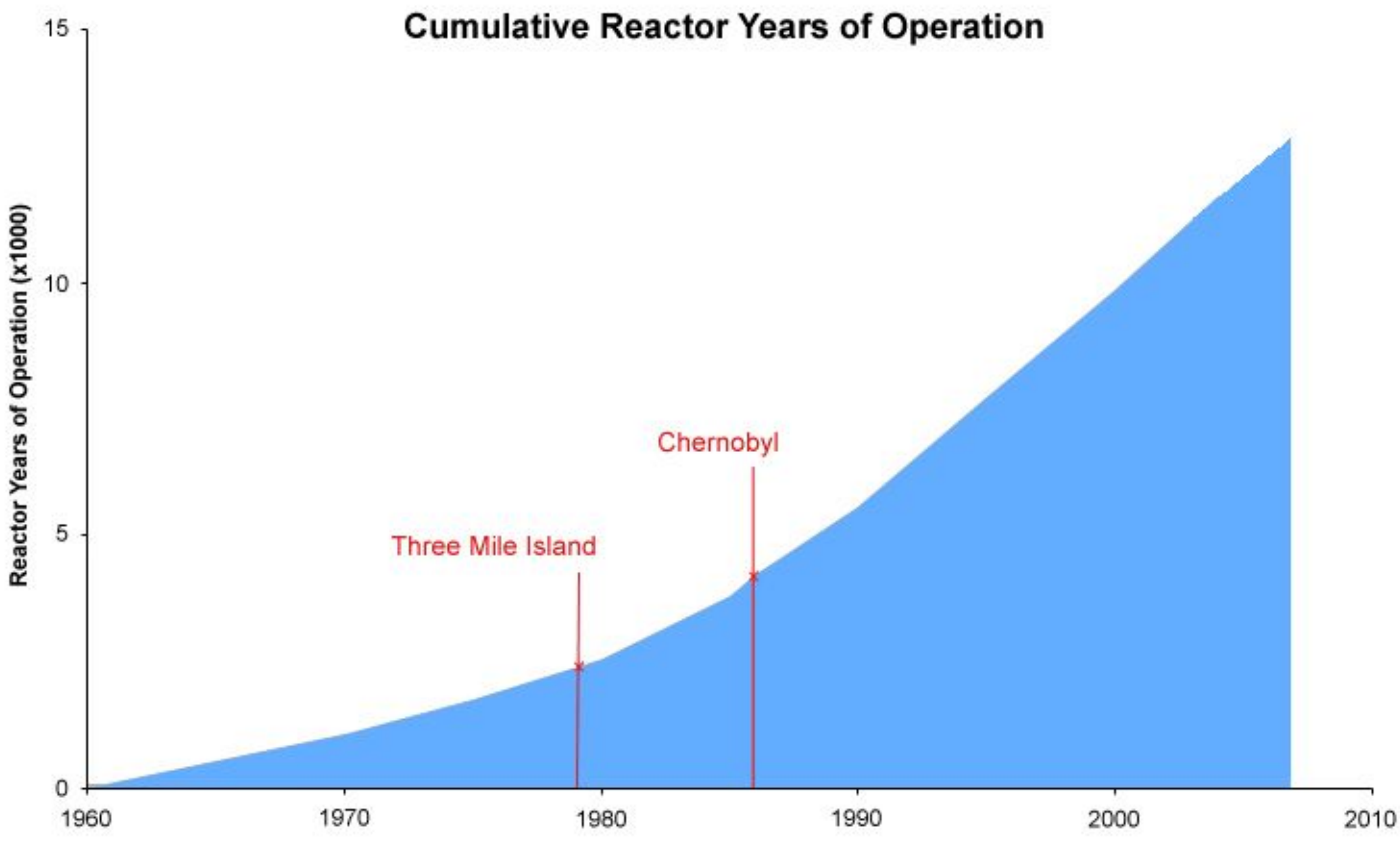
  Perception of the risk, rather than the risk itself is the issue. On a strictly scientific basis, no energy source in its present utilization could be rejected

Acceptable, Tolerable and Not-Acceptable Risks (Traffic Light Model)



The Position of Nuclear Energy (9)

- *Acceptance (cont.)* : for nuclear energy, the attention is mostly focused on the issue of the ultimate fate of radioactive waste, followed by the risk of a major accident. The exceptional character of the Tchernobyl accident is mostly recognized; the tightening of safety rules and the safety record of all currently running power plants should contribute to the reinforcement of the trust in safe operation of nuclear plants


Cumulative Reactor Years of Operation
Reactor Years of Operation (x1000)
15
10
5
0
1960
1970
1980
1990
2000
2010
Three Mile Island
Chernobyl

The Position of Nuclear Energy (10)

- *Acceptance (cont.)* : for nuclear waste, two solutions are currently considered at IAEA level:
  - Extended surface storage with possible reconditioning of the waste. Such approach should not become perpetual, it requires active surveillance and management and raises the issue of institutional control, i.e. continuity of government policy. Significant operational cost
  - Disposal in geological formations with possibility of retrieval of emplaced material for a certain period. It constitutes a lesser issue for institutional control and presents better features in terms of surveillance and management. High capital cost

The Position of Nuclear Energy (11)

- *Acceptance (cont.)* : Storage encounters less opposition than disposal. Better communication with stakeholders should promote the acceptance of any of the two solutions. In the future, new types of reactors should reduce fairly significantly the radioactive inventory of the waste produced

  Nuclear proliferation is not mentioned so frequently in the debate over the acceptance of nuclear energy; this shows the difference between risk and perception of risk.

Nuclear Energy vs. Other Sources

In summary, there are objective reasons for justifying the renaissance of nuclear energy as part of a wider scenario, associating efforts for energy conservation, a greater recourse to renewables and a cleaner utilization of coal and gas

Current World Nuclear Park

- At the end of 2007, 439 commercial NPPs;
  - 215 PWRs and 50 VVERs
  - 94 BWRs
  - 44 PHWRs
  - 18 gas-cooled reactors
  - 16 RBMKs
  - 2 FBRs
- Additionally, about 220 reactors powering 150 ships and submarines worldwide
- Finally, 56 countries operate a total of 284 research reactors

Nuclear Energy: a Renaissance? (1)

- In the very recent years, an evolution in national plans for nuclear power is noticeable (WAN, 2008) with 32 plants under construction {C} and 88 planned {P}
  - Argentina: 1C, 1P
  - Belarus: 2P
  - Brazil: 1P
  - Bulgaria: 2P
  - Canada: 2C, 4P
  - China: 5C, 30P
  - Finland: 1C

Nuclear Energy: a Renaissance? (2)

- France: 1 C
- India: 6C, 10P
- Iran: 1C
- Japan: 2C, 11P
- Korea: 3C, 5P
- Pakistan: 1C, 2P
- Romania: 2P
- Russia; 7C, 8P
- Slovakia: 2C
- South Africa; 1P
- Ukraine: 2P
- USA: 7P

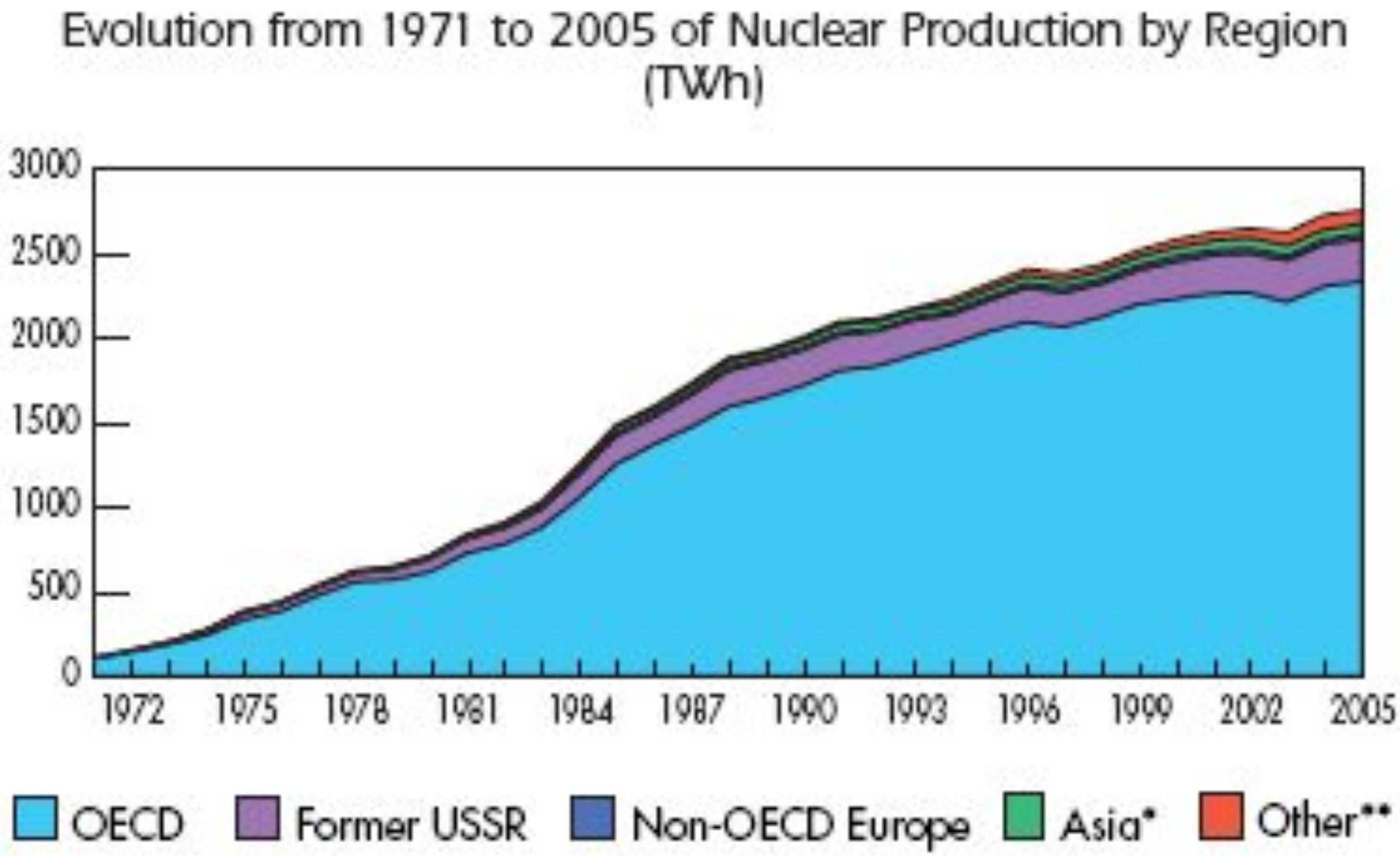
Nuclear Energy: a Renaissance? (3)

- Is it a renaissance? Yes, or rather a rebound in the sense of the acceleration of its growth, particularly in terms of new orders, but one should remind that the world net nuclear electric power generation, expressed in TWh, has never stopped to grow between 1980 and 2005, with some slowdown after 1990:

  1980 : 685, *1985* : 1425, *1990* : 1910,
  1995 : 2210, *2000* : 2450, *2005* : 2625

  The following diagram extracted from the IEA Key World Energy Statistics 2007 illustrates this point:

Nuclear Production



Conditions for a Renaissance (1)

- This renaissance should be accompanied by unrelenting efforts for maintaining the highest level of safety, tackling the issue of the end of the fuel cycle by minimizing the inventory of radioactive waste and guaranteeing zero tolerance to proliferation. This one of the essential objectives of 4th Generation power reactors

4th Generation Power Reactors (1)

- Main drivers for innovation in reactor systems and fuel cycles:
  - Sustainability focused on enhanced fuel utilization and optimal waste management: recycling or once-through, enhanced breeding, homogeneous recycling, minor actinides bearing fuels
  - Economics focused on minimization of costs of MWe installed and MWh generated: plant management and higher thermodynamic efficiency
  - Safety and reliability focused on robust safety architecture and enhanced reliability requirements
  - Proliferation focused on impractical separation of plutonium and reinforced physical protection

4th Generation Power Reactors (2)

- Forum for studies:
  - Launch of Generation IV International Forum (GIF) in January 2000; GIF Charter signed in July 2001; 13 members in November 2006. Technical secretariat at OECD/NEA
  - 6 systems selected for GIF studies: three fast spectrum systems (SFR,GFR, LFR), two thermal/fast spectrum systems (SCWR, MSR) and one thermal spectrum system (VHTR)

4th Generation Power Reactors (3)

- Sodium cooled Fast Reactor:
  - Electricity production and full actinide management, enhanced fuel utilization
  - Core outlet temperature of 550˚C, efficiency close to 40%
  - Reference power: modules of 50-150 MWe or plants of 600-1500 MWe

4th Generation Power Reactors (4)

- Gas cooled Fast Reactor:
  - Cogeneration of electricity and process heat, enhanced fuel utilization, full actinide management
  - Core outlet temperature of 850°C, efficiency close to 45%
  - Reference power: 1000 MWe

4th Generation Power Reactors (5)

- Lead cooled Fast Reactor:
  - Cogeneration of electricity and process heat, full actinide management
  - Core outlet temperature of 800˚C, efficiency close to 45%
  - Reference power: batteries of 10-100 MWe reactors and plants of 300-600MWe

4th Generation Power Reactors (6)

- Super Critical Water cooled Reactor:
  - Electricity production at high temperatures, no actinide management, once-through cycle with high fuel burn-up
  - Core outlet temperature of 1000˚C, efficiency 45-50%
  - Reference power: 600 MWth/300 MWe

4th Generation Power Reactors (7)

- Molten Salt Reactor:
  - Cogeneration of electricity and process heat, full actinide management, Thorium Cycle possible
  - Core outlet temperature of 800˚C, efficiency close to 45%
  - Reference power: 1000 MWe

4th Generation Power Reactors (8)

- Very High Temperature gas cooled Reactor:
  - Cogeneration of high temperature process heat and electricity production and, full actinide management, Thorium cycle possible
  - Core outlet temperature of 800°C, efficiency close to 45%
  - Reference power: 1000 MWe

4th Generation Power Reactors (9)

- Currently, there is not really a winner emerging from the comparison between the 6 types of systems. SFRs and VHTRs have some lead due to previous experience but it is not determining. The choice of one (or two?) system(s) will depend on the emphasis on economics or fuel cycle management. Conversion Ratio (ratio of fissile material produced to fissile material destroyed) will be an important factor. Date of availability is not a decisive factor as all possible systems could be introduced in the bracket 2020-2025

Conditions for a Renaissance (2)

- The recourse to nuclear energy remains the choice of sovereign nations and there can't be an international ruling on such issue. This does not mean that there is no role for multilateral mechanisms in this area and new initiatives should be taken in this respect

The role of multilateral mechanisms (1)

- At international level, multilateral mechanisms can contribute in reinforcing such responsibility through good governance, an essential measure for accompanying the renaissance of nuclear energy
- Several avenues for action should be explored; they relate to non proliferation, safety of nuclear installations, financial instruments, multilateral cooperation in the fuel cycle, training, knowledge preservation and developing countries

The role of multilateral mechanisms (2)

- Maintaining strict control procedures for guaranteeing *non proliferation*, based on the best performance of monitoring and verification regimes. Verification of compliance is a crucial issue, relying on efficient monitoring. The International Atomic Energy Agency remains the fundamental pillar for this process, assisted by regional collective systems

The role of multilateral mechanisms (3)

Measures for guaranteeing non-proliferation should go beyond physical security of installations and verification of the flow of fissile materials, they should cover also the stabilization of weapons scientists and the monitoring of sensitive technologies contributing to weapons production and delivery. Research reactors and installations with low inventory of nuclear materials should receive greater attention in view of the emergence of terrorist groups

The role of multilateral mechanisms (4)

- Reinforcing *nuclear safety* governance. How could the optimal level of safety of nuclear installations be ensured? Though developing adequate standards and guaranteeing safety management. Standards developed by IAEA in conjunction with the regulators of its member states are of high quality. Organizations at regional level such as WENRA have complemented them with additional norms such as “Reference Levels”.

The role of multilateral mechanisms (5)

- Further harmonization, especially for new designs, is required for avoiding obstacles to trade
- The way safety is managed is the most critical issue. International cooperation could reinforce safety management through pooling knowledge, sharing best practices, exchanging experience feedback, exchanging personnel, etc. Existing efforts through WANO and OSART among others should be taken into account

The role of multilateral mechanisms (6)

- Discussing new concepts of *Public-Private Partnership* for achieving the best financing options, including possible leasing arrangements for power plants in a way comparable to the “wet lease” of aircrafts to airlines. This formula could relieve the local actors from operational tasks while maintaining overall control. The banking sector should be involved

The role of multilateral mechanisms (7)

- Reviewing once again the issue of *multinational fuel cycle centers* for reducing the burden of small- and medium-sized nations, for optimizing the number of enrichment and reprocessing facilities, balancing diversification of supply against non-proliferation and cost reduction

The role of multilateral mechanisms (8)

- Developing plans for countering the potential *lack of nuclear engineers and scientists*, reinforcing the educational and training capacities through international cooperation. Joint efforts are also required for *knowledge preservation*, merging the past with the future. IAEA is already going in this direction with its Fast Reactor Knowledge Preservation Initiative

The role of multilateral mechanisms (9)

- Reflecting on the energy problems of the *least developed countries*. Nuclear energy should not be the most adequate solution for these countries at this time, but the increased recourse by industrialized countries to nuclear energy and renewables, both capital intensive forms of energy, could lower the market pressure on oil and gas, allowing for a certain period an easier access of least developed countries to these more traditional forms of energy

Innovation in Energy Systems

Most Pressing Needs in Innovation (1)

- Several areas require enhanced innovative efforts, not only for new products and processes but also for new systems, new services and new organizational schemes

Most Pressing Needs in Innovation (2)

- Beyond progressing in performance and cost of the various new forms of energy, transport, distribution and storage of energy require extensive improvements. Energy conservation needs also increased efforts at system level to avoid unwanted effects on the environment (Mercury in low consumption light bulbs)

Most Pressing Needs in Innovation (3)

- Examples of needed innovation advances:
  - Electric grids with higher degree of autonomy, active grid control (Adam Smith vs. Gustave Kirchhoff), DC transport and distribution networks
  - Improved energy storage: batteries using nanotechnologies, superconducting rings, capacitors
  - Improved energy conversion: high performance, low cost fuel cells from μW to MW, efficient gas turbines
  - Recuperation of gas flares
  - “Green” industrial processes

Most Pressing Needs in Innovation (4)

- Examples of needed innovation advances (cont.):
  - Second generation bio-fuels (liquid, gas) production processes
  - Passive architecture, solar cooling
  - Carbon capture and sequestration, enhanced oil recovery
  - Improved photovoltaic systems
  - High efficiency Fischer Tropsch conversion processes for synthetic fuels

What about Kazakhstan? (1)

- Kazakhstan enjoys the privilege of being a producer of oil, gas, coal and uranium ore
- Kazakhstan is joining countries in Annex 1 to the Kyoto Protocol, i.e. accepting GHG emission limitations
- In terms of renewables, Northern latitudes do not favor solar applications but there is a lot of wind

What about Kazakhstan? (2)

These factors should influence innovation in energy systems:

- Energy conservation, better efficiency of existing production and distribution systems
- Recuperation of gas flares
- Synthetic fuels from coal and gas (price sensitive)
- Wind and small hydropower
- Carbon Capture and Sequestration (in exhausted gas fields)
- Wave power on the Caspian sea

The Issue of Financing Energy Investments

What about financing (1)

- When selecting energy options and in particular moving towards innovative solutions, the financial burden of new investments should be taken into account. Securing enough capital for energy development is a real issue
- The total investment requirement for energy supply infrastructure over the period 2001-2030 is over 16 Trillions US$ for replacing and expanding supply facilities. It corresponds to 1% of global GDP and 4.5% of all investments (IEA World Energy Investment Outlook 2003 Insights)

What about financing (2)

- For Africa, it means allocating 4% of its GDP to this sole purpose. The alternative for Africa is the continuation of power outages which cost African economies as much as 2% of their GDP (The Wall Street Journal, April 18, 2008)
- Mobilizing the investment depends on the ability of the energy sector to compete against other sectors of the economy for capital. The electricity sector alone needs about 10 Trillions US$, 60% of the total energy investment. Half of the energy investment will have to take place in the developing world

What about financing (3)

- The competition for investment comes from two very important areas: the fulfillment of the Millennium Development Goals and the mitigation of, and adaptation to, climate change
- Defining the right priorities for financing the required investments will be a difficult exercise

What about financing (4)

- Achieving the Millennium Development Goals is hampered by the lack of funding. A plausible level of overall ODA for the MDGs should be 135 Billion$ in 2006 increasing to 195 Billion$ in 2015, including co-financing and “graduation”. These figures have to be compared to the overall level of ODA. Total ODA from OECD countries was 103.6 Billion$ in 2007, compared to 104.4 in 2006 and 106.7 in 2005. This reduction is slightly compensated by India’s pledge to double its assistance to African countries which was 2.15 Billion$ over the last 5 years. The total ODA does not even cover the current MDGs needs

What about financing (5)

- What about adaptation to, and mitigation of, climate change effects? They require also new investments amounting again to hundreds of billions of $. Even if the long term impact of such investments will be fairly moderate, i.e. a slowdown of about 0.1% in the average annual growth of global GDP, money has to be found for the required work, notably for Less Developed Countries

An Example of Energy Investment

For illustrating the magnitude of investments, one could use the example of the investment required for installing a generating capacity delivering 50 TWh annually (approximately the electricity consumption of Portugal):

- Nuclear at overnight capital cost of 1500$/kW and annual production of 7.5TWh per GW installed yields a figure of 10 B$
- Wind at 1500$/kW (peak) and annual production of 2.7TWh per GW installed yields a figure of 28 B$
- Solar photovoltaic at 10000$/kW(peak) and 0.85 TWh per GW installed (50° latitude) yields a figure of 580 B$

What about financing (6)

- A lot of wisdom and solidarity will have to be exercised in the financing of our World's pressing needs. External financial assistance is required. The five-year "Cool Earth Partnership" fund announced by Japan at the World Economic Forum in 2008 is a welcomed move in this direction

Local vs. Global Governance

Local vs. Global Governance (1)

- 1. In the energy sector, the priority should be given to local governance in the view of the disparities in the global energy scene and the links to other local issues. Doing as much as one can for implementing the energy options most suited to the local situation is essential. Think and act locally in the first instance. Globalization should not erase local specificities

Local vs. Global Governance (2)

- 2. This does not mean isolation and selfishness. Those countries which benefit from substantial energy resources should give an helping hand to the less favored ones, notably by leaving the more traditional forms of energy to those which can’t afford moving to more innovative solutions

Local vs. Global Governance (3)

- 3. A true international governance is required in terms of protection of the environment (post-Kyoto, biodiversity), in terms of intellectual property rights (access to innovative technologies) and in terms of financial assistance to the large investments required. Global solidarity should not remain an abstract concept

Local vs. Global Governance (4)

- 4. The intermediate level of regional cooperation should be used for sharing material and intellectual resources, for reinforcing the impact of local measures and for increasing the political weight in international negotiations

Conclusion

Conclusion (1)

- In summary, in the short term, the volatility of oil and gas prices and the recurrent problems of the developing world do not lead to a real global energy crisis. What we need is a clear medium term strategy based on
  - The selection of the best options using a mix of several criteria
  - The recourse to technological innovation as a powerful tool

Conclusion (2)

- A careful attitude towards the financial investment is required
- Decision makers should implement a policy of thinking and acting locally in the first instance, complemented by global action when needed, not neglecting the regional dimension

Thank you for your kind attention!