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Nuclear Power: Status and Trends

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Nuclear Power: Status and Trends

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Introduction

Nuclear Energy **- energy released during the splitting or fusing of atomic nuclei.**

- **1905 Einstein's theory of special relativity.**
- **1932 English physicist and Nobel laureate James Chadwick discovers the neutron.**
- **1932 Atom split by John Cockcroft and Ernest Walton.**
- **1939 Otto Hahn, Fritz Strassman, Lise Meitner, and Otto Frisch demonstrate fission.**
- **1942 Enrico Fermi and colleagues at the University of Chicago achieve the firstcontrolled, self-sustaining nuclear reaction.**
- **1945 Atomic bombs dropped on Hiroshima and Nagasaki, Japan.**

Introduction(2)

- **1946 Oak Ridge facility ships first nuclear reactor-produced radioisotopes for civilian use to Barnard Cancer Hospital in St. Louis.**
- **1951 Experimental Breeder Reactor 1 (EBR-I) produces the world's first usable amount of electricity from nuclear energy.**

- **1954 United States launches the U.S.S. Nautilus, the world's first nuclear-powered submarine.**
- **The first nuclear power plant began operating in 1954 in Obninsk, Russia. Subsequently, several other countries followed.**
- **1957 The International Atomic Energy Agency is formed with 18 member countries to promote peaceful uses of nuclear energy. Today it has 130 members.**

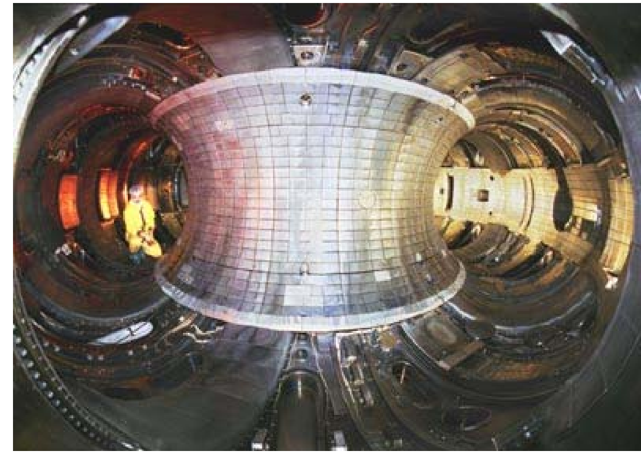
Though controversial, the engineering achievements related to nuclear technologies remain among the most important of the 20th century.

Nuclear Power Reactors

- Light-Water Reactors (LWR)
  - Pressurized-Water Reactor (PWR)
  - Boiling-Water Reactor (BWR)
- Heavy-Water Reactors (HWR)
  - CANadian Deuterium-Uranium reactor (CANDU)

In the United Kingdom and France the first full-scale power reactors were fueled with natural uranium metal, were graphite-moderated, and were cooled with carbon dioxide gas under pressure.

Nuclear Power Reactors (2)



- **Propulsion Reactors (cargo ships, icebreaker)**
- **Research Reactors**
- **Breeder Reactors**
  - **Liquid-Metal Fast Breeder Reactor (LMFBR)**
- **Thorium High Temperature Reactor (THTR)**
- ***Nuclear Fusion (JET and the Tokamak)***

Nuclear Power Status

- 441 nuclear power plants (NPPs) in operation worldwide
- 359 GW(e) of generating capacity (some 10% of total generating capacity)
- Six new NPPs first connected to the grid in 2002 – China (4), Czech Republic, Dem. P. R. Korea
- Two new connections in 2001, six in 2000
- One retirement in 2000 – Chernobyl-3 in Ukraine – no retirements in 2001 and four in 2002 – 2 in Bulgaria and 2 in United Kingdom.

Source: RDS-1 and PRIS

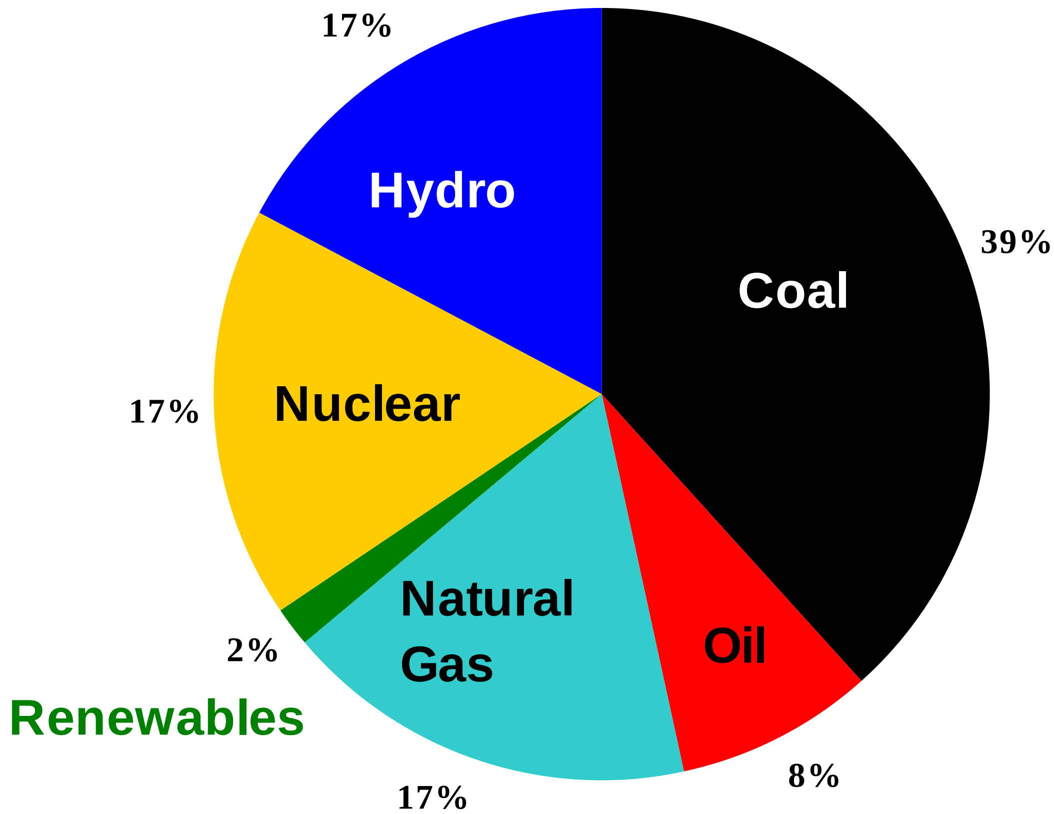
Nuclear Power Status

- Five new construction start-ups in 2000 – China, India (2) and Japan (2).
- One construction start-up in Japan in 2001 and seven in 2002 - India (6) and Dem. P. R. Korea.
- Altogether there were 32 NPPs under construction worldwide at the end of 2002.
- Most current construction is in Asia or the economies in transition.
- Nuclear power contributes 16% to global electricity supply in 2002.
- More than 10,000 reactor years of operating experience
- Excellent safety record – despite TMI and Chernobyl

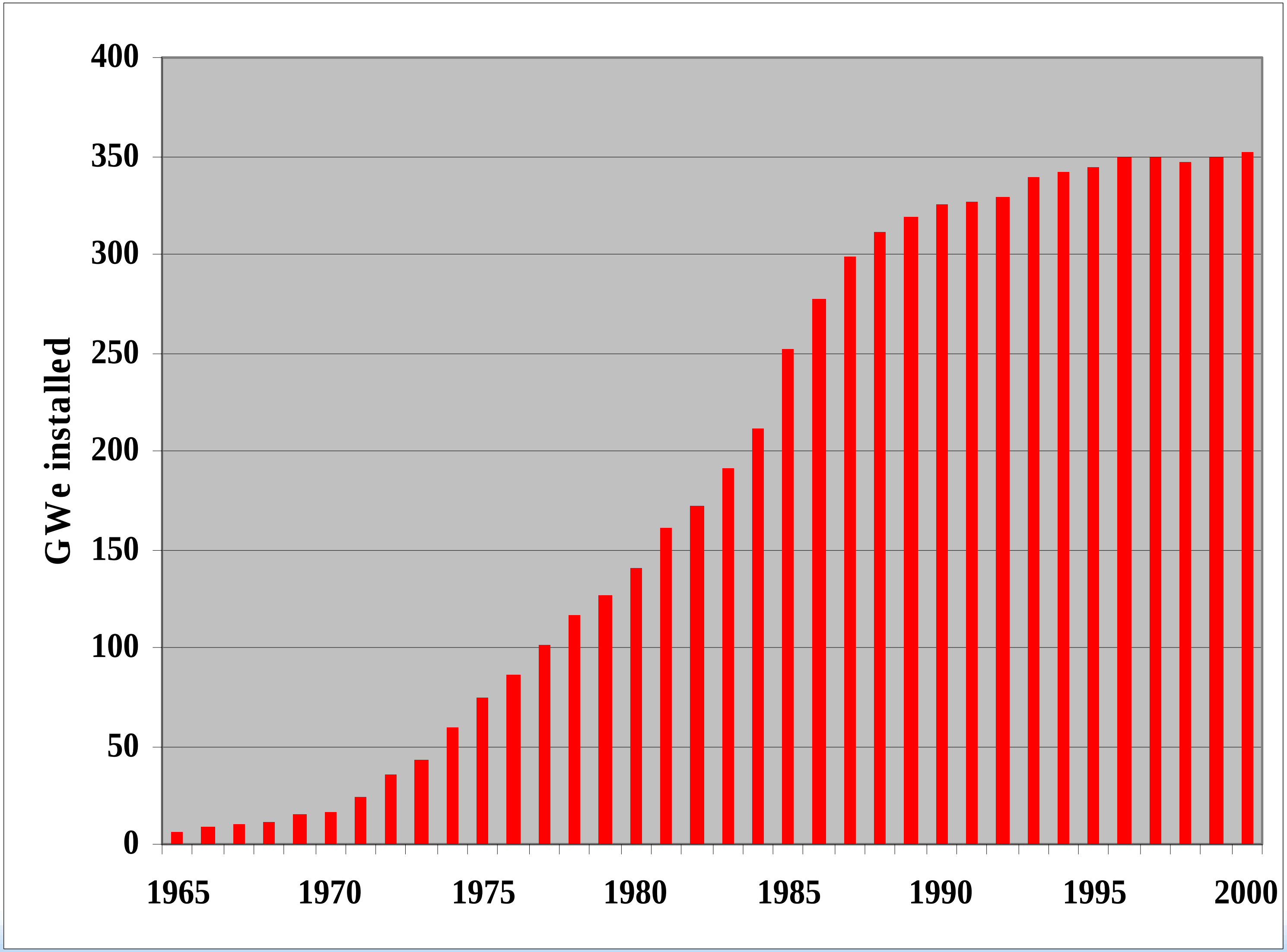
Source: RDS-1 and PRIS

Global Electricity Supply Mix, 2000

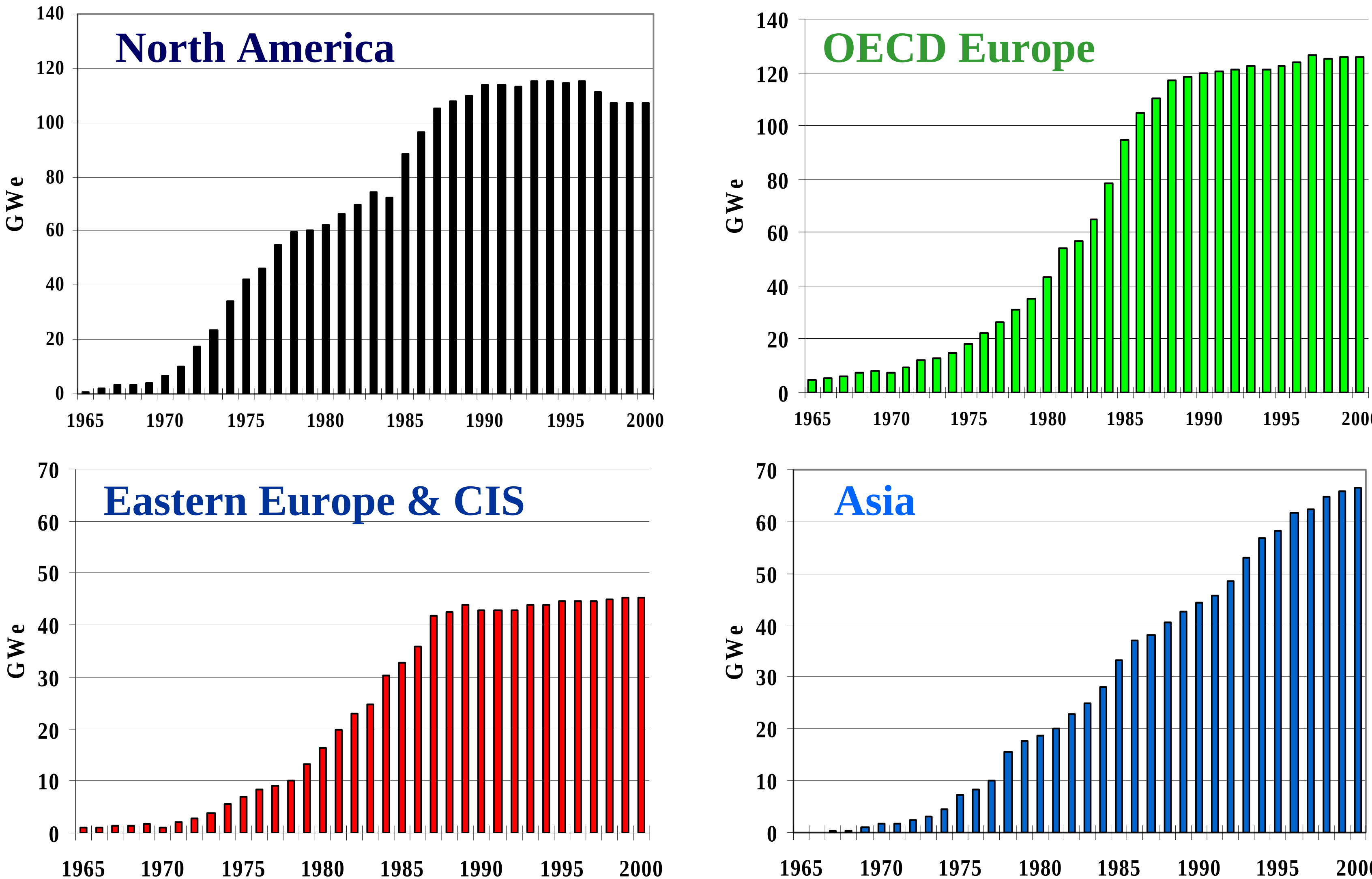
Total production: 14,900 TWh



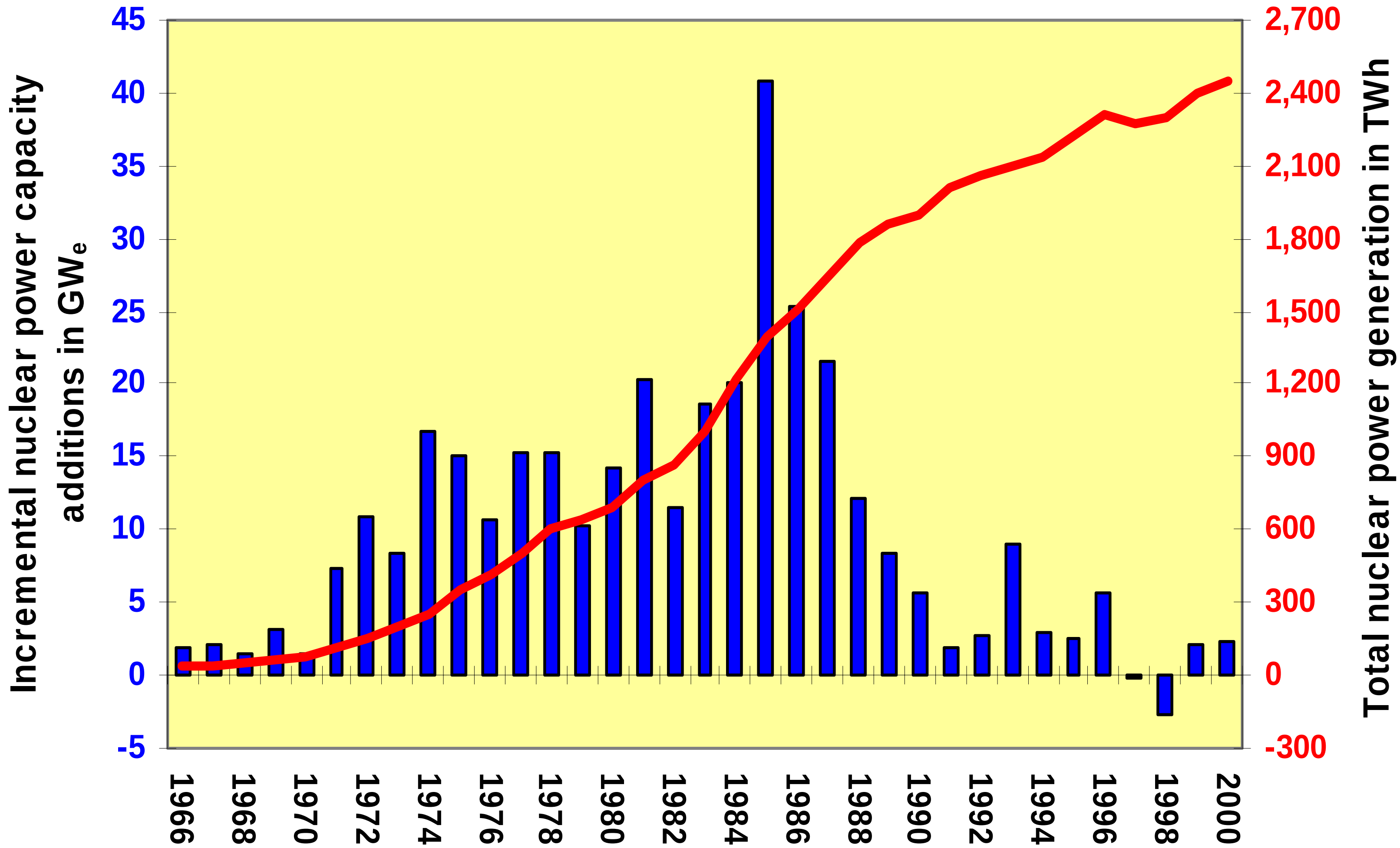
Evolution of Global Nuclear Power Capacity 1965 - 2000



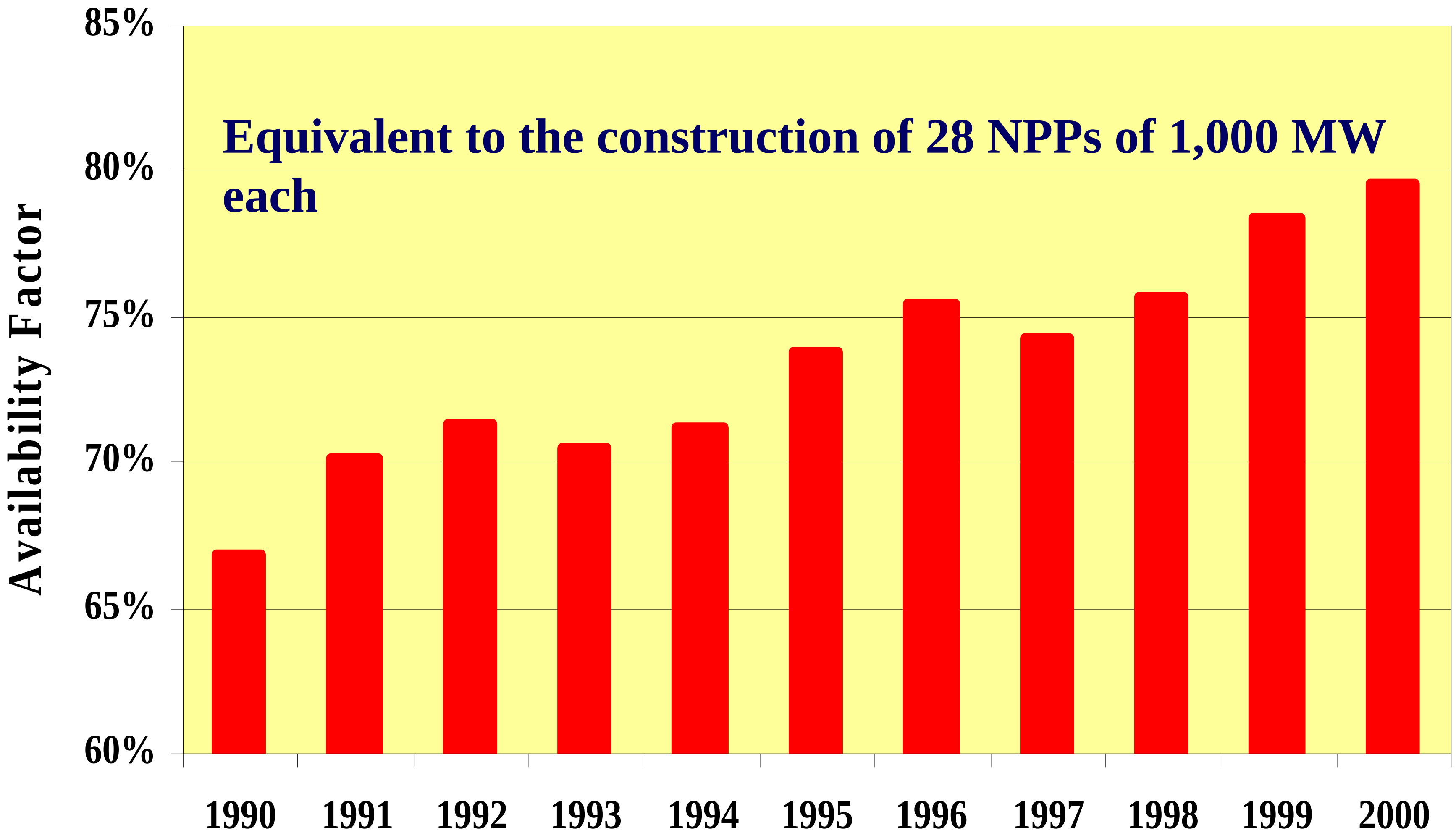
Development of Nuclear Generating Capacities



Annual Incremental Capacity Additions and Total Nuclear Electricity Generation



Global Availability Factor of NPPs



The Future of Nuclear Power: The Short-term Outlook

- Clear distinction between existing capacities and new nuclear power plants.
- Contrary to common belief, deregulation and privatization have not “grounded” the bulk of nuclear power plants.
- Rather, deregulation has stimulated (or forced) the nuclear industry to become innovative in a proactive manner.
- Depreciation, improvements in availability and other cost curbing efforts enable nuclear power operators to operate successfully in the most competitive markets.
- While existing plants thrive - new plants wait.

The Economics of Investing in Nuclear Power:

- High up-front capital costs and long amortization periods are adversely affecting competitiveness.
- Investments in nuclear are viewed as too risky especially in indecisive political settings.
- Deregulation/privatization is likely to raise the capital barrier further.
- Open-ended liabilities are not conducive for private investors.
- Regulated markets that allowed factoring into the rate the cost of safety improvements requested by the nuclear regulator no longer exist.

The Economics of New Electricity Generating Capacities

Capital costs & construction times for different electricity generating options

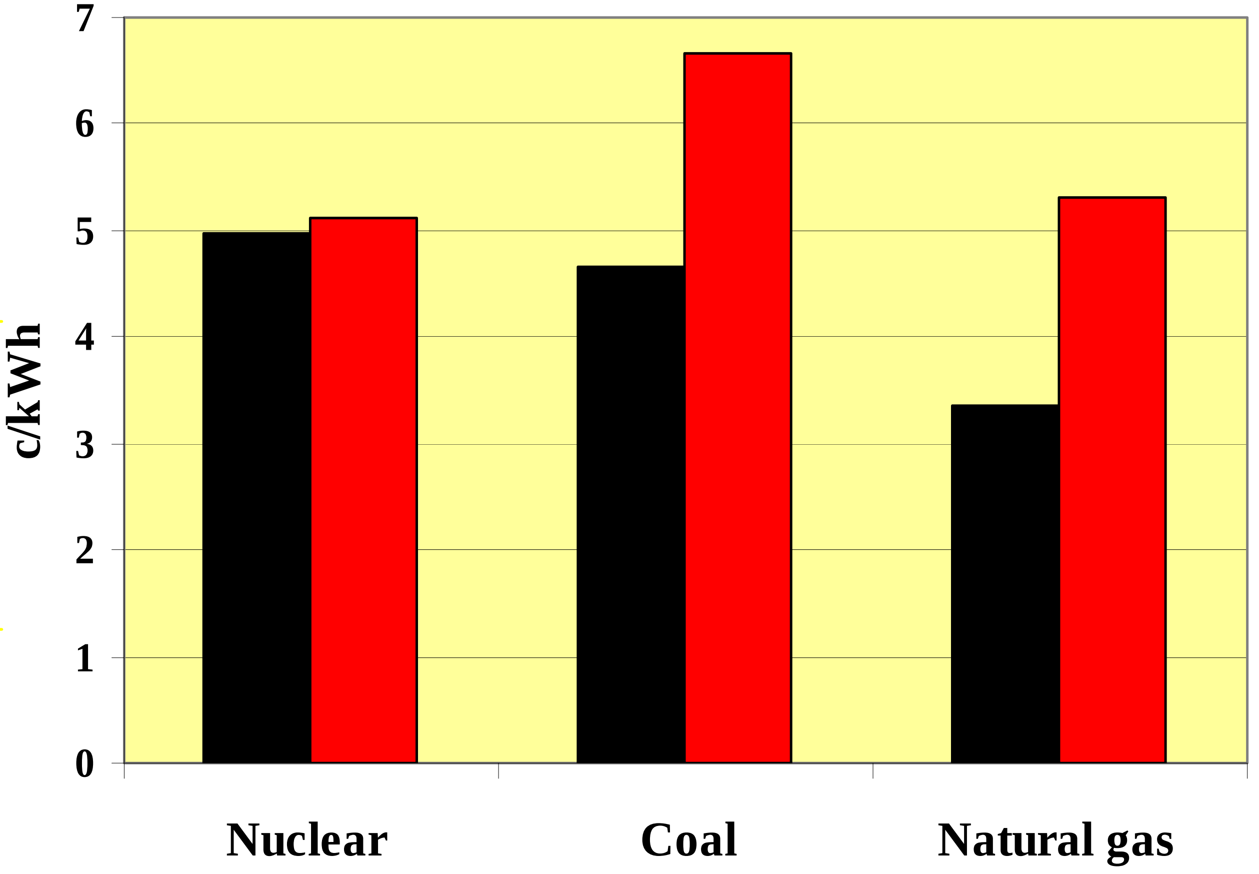
	Cost per kWe installed US $ [a]	Total cost for 1,000 MW capacity Billion US $	Construc-tion period Years	Typical plant size MW	Typical plant turn key costs Billion US $	Indicative generating costs[b] US c/kWh
Nuclear LWR	2,100 – 3,100	2.1 – 3.1	6 - 8	600 – 1,750	1.5 – 4.2	4.9 – 6.8
Nuclear, best practice	1,700 – 2,100	1.7 – 2.1	4 - 6	800 – 1,000	1.3 – 2.1	4.0 – 4.7
Coal, pulverized, ESP	1,000 – 1,300	1.0 –1.3	3 – 5	400 – 1,000	0.5 – 1.3	3.2 – 4.5
Coal, FGD, ESP, SCR	1,300 – 2,500	1.3 –2.5	4 - 5	400 – 1,000	0.6 – 2.5	3.6 – 6.3
Natural gas CCGT	450 – 900	0.45 – 0.9	1.5 - 3	250 -– 750	0.2 – 0.6	2.6 – 4.8
Wind farm	900 – 1,900	0.9 – 1.9	0.4	20 –- 100	0.03 – 0.12	3.5 – 9.2

ESP= Electrostatic precipitator; FGD = Flue gas desulphurization; SCR = Selective catalytic reduction

[1] Includes interest during construction, [2] Not firm supply, i.e., without storage or back-up [a] Including IDC

[b] 10% discount rate, 20 payback, $1/GJ - $2/GJ for coal, $2/GJ - $5/GJ for gas, mean wind speeds and availability factors

Impact of Doubling of Fuel Prices on Generating Costs



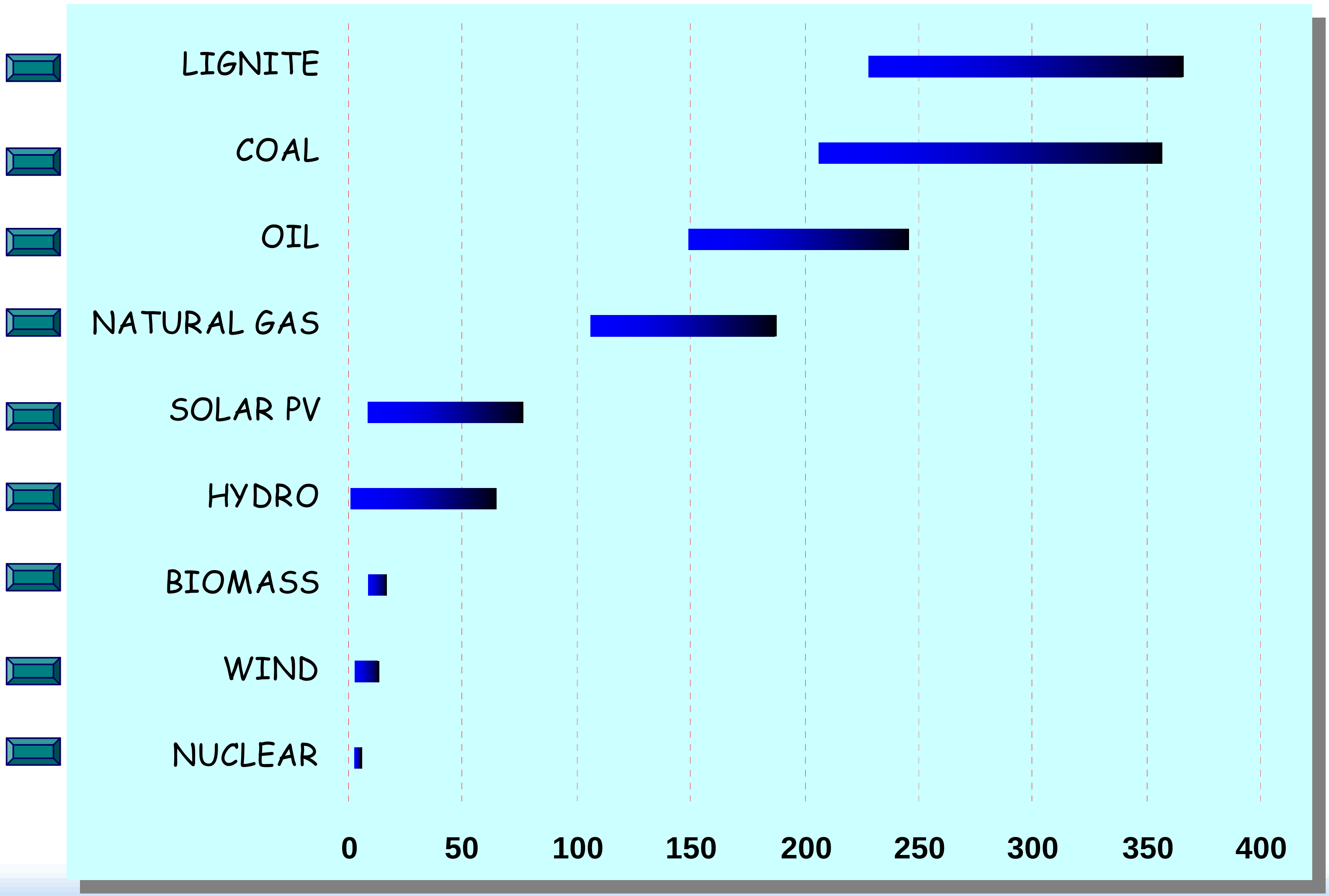
Nuclear Power and Environmental Protection

- Along the a full source-to-electricity chain including indirect emissions, nuclear power generates two order's of magnitude less CO_2 and virtually no air pollutants responsible for local and regional environmental degradation.

- Currently avoids some 8 percent of CO_2 emissions (some 0.6 GtC) globally.

- A significant *potential* environmental impact could arise from abnormal events, the probability of which is (negligibly) small in modern nuclear power plants.

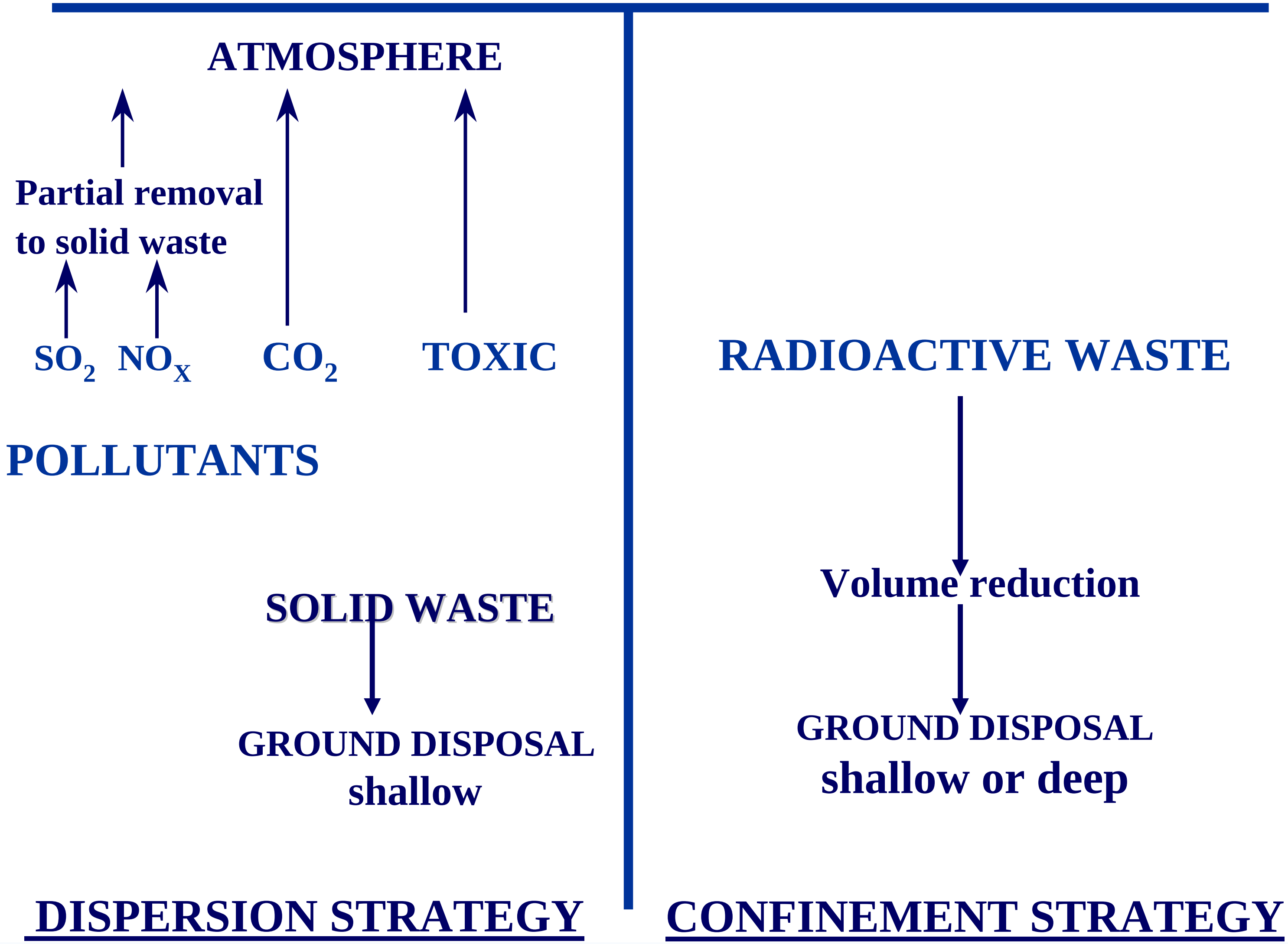
Greenhouse Gas Emissions (gC_{eq} per kWh)



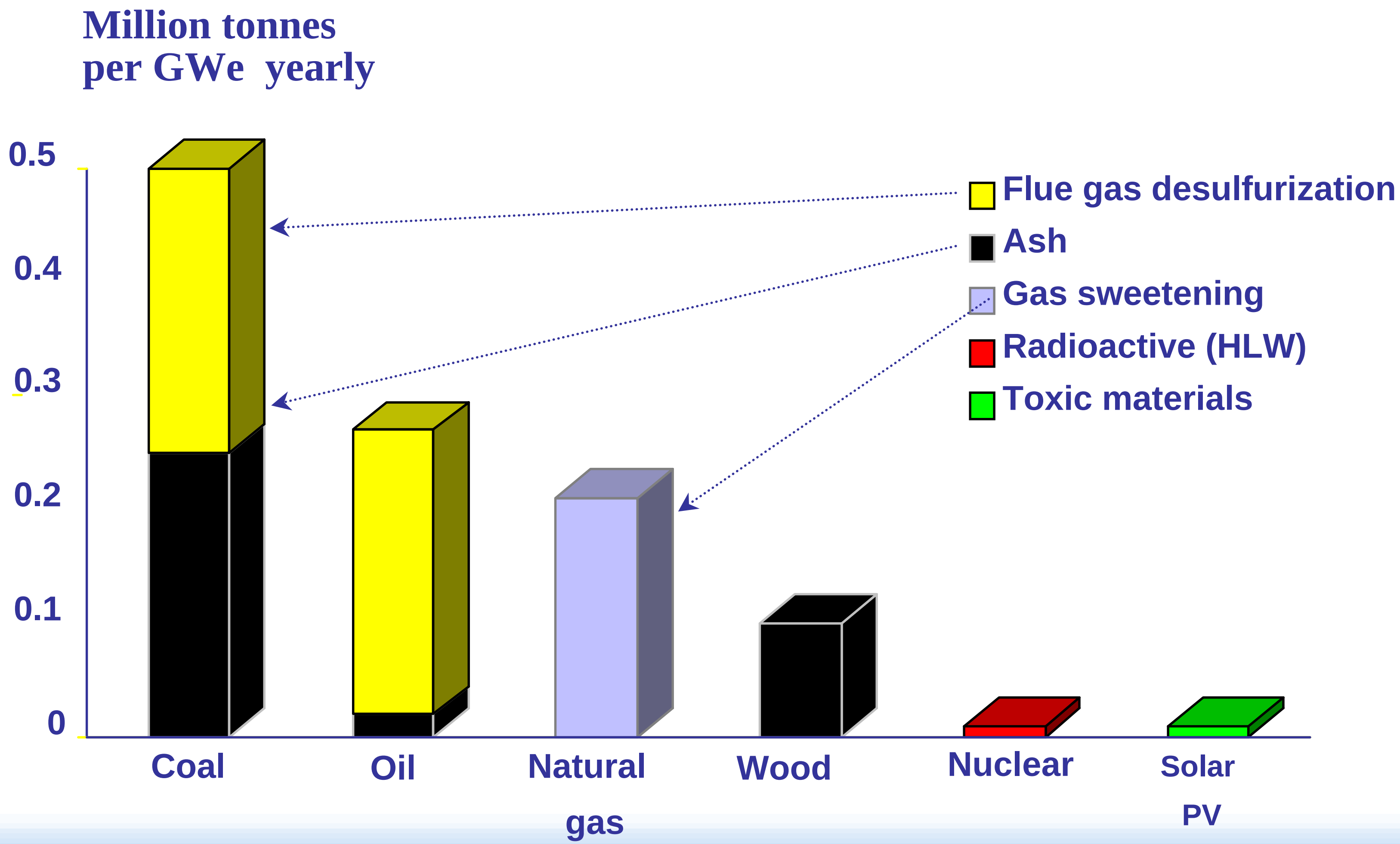
Nuclear Power and the Environment
The Waste Issue

- A 1,000 MWe nuclear power plant produces annually
  - some 30 tonnes of high level radioactive spent fuel
  - 800 tonnes of low and intermediate level radioactive waste.
- Significant reductions in the volume of low level waste can be made through compaction.
- A 1,000 MWe coal fired power plant generates annually some 320,000 tonnes of ash containing about 400 tonnes of heavy metals and *radioactive material* from combustion alone without considering energy chain activities such as mining and transportation.

Two Alternative Strategies



Wastes in Fuel Preparation and Plant Operation



Source: IAEA, 1997

EXTERNAL COSTS

	Costs (mEcu/kWh)	Equivalent lives lost (per GWa)
Coal	5.3 – 15.0	37
Lignite	10	27
Oil	12	32
Gas	0.4 – 1.0	2
Wind	0.8 - 2.2	0.3
Hydro	2.3	0.8
Nuclear	0.4 - 2.5	1

Note: Externalities of greenhouse gas (GHG) emissions, i.e., of climate change not included

Source: Adapted from European Commission (1995)

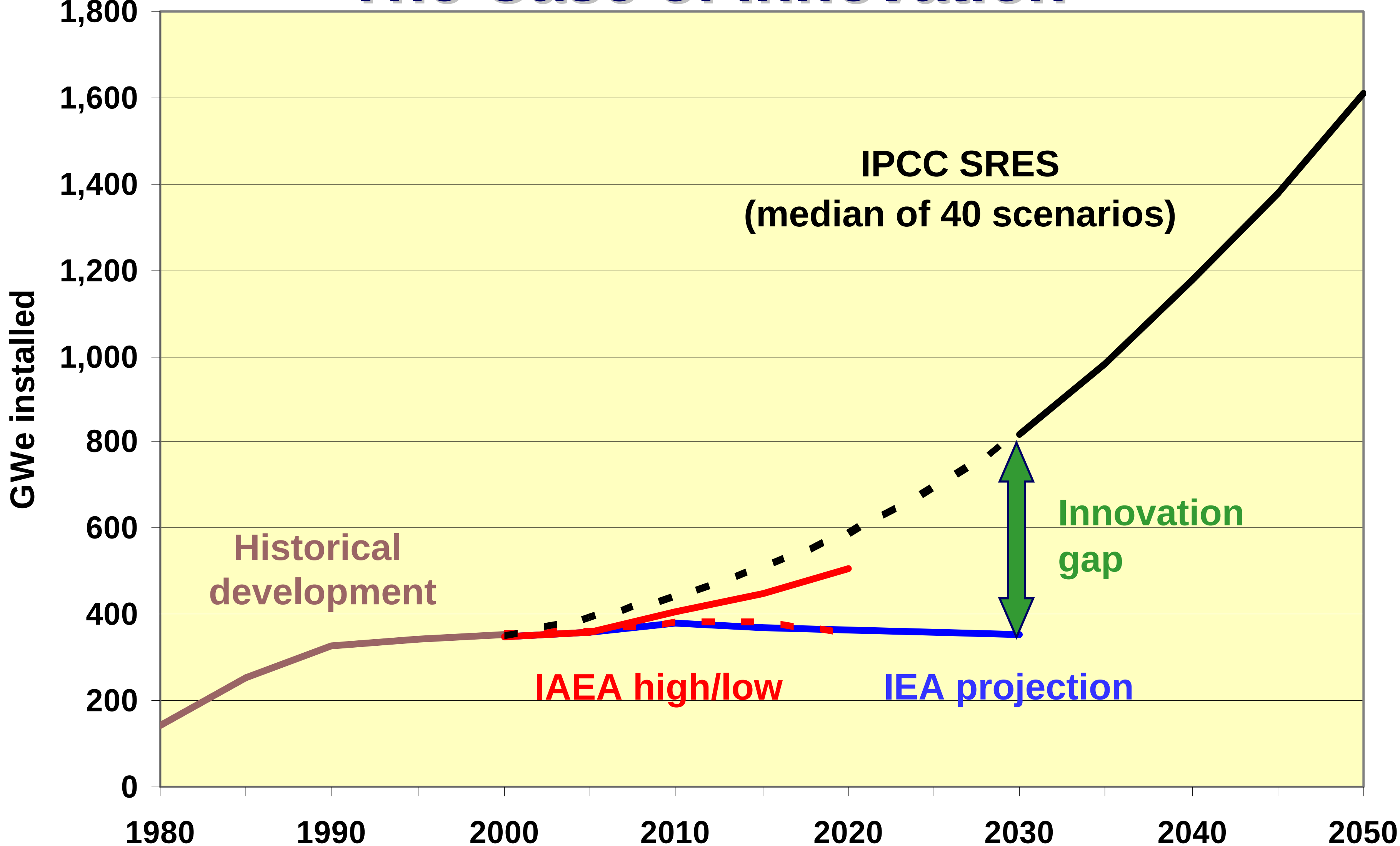
Nuclear Power Outlook

- Nuclear power is economically competitive in many places around the world
- Developing countries experiencing rapid economic development need even faster growing electricity supplies
- All options are needed including nuclear power
- Nuclear power contributes to supply security
- Nuclear power virtually avoids air pollution and the emissions of gases threatening climate stability

Nuclear Power Outlook (2)

- Still nuclear power has to innovate in order to reduce costs and serve a wider market spectrum
- Considerable innovation activity ongoing around the world
- Nuclear power is a cheap insurance against surprise
- Nuclear power alone is not the solution – but for sure it is integral part of any solution

A Discontinuity for Nuclear Power: The Case of Innovation

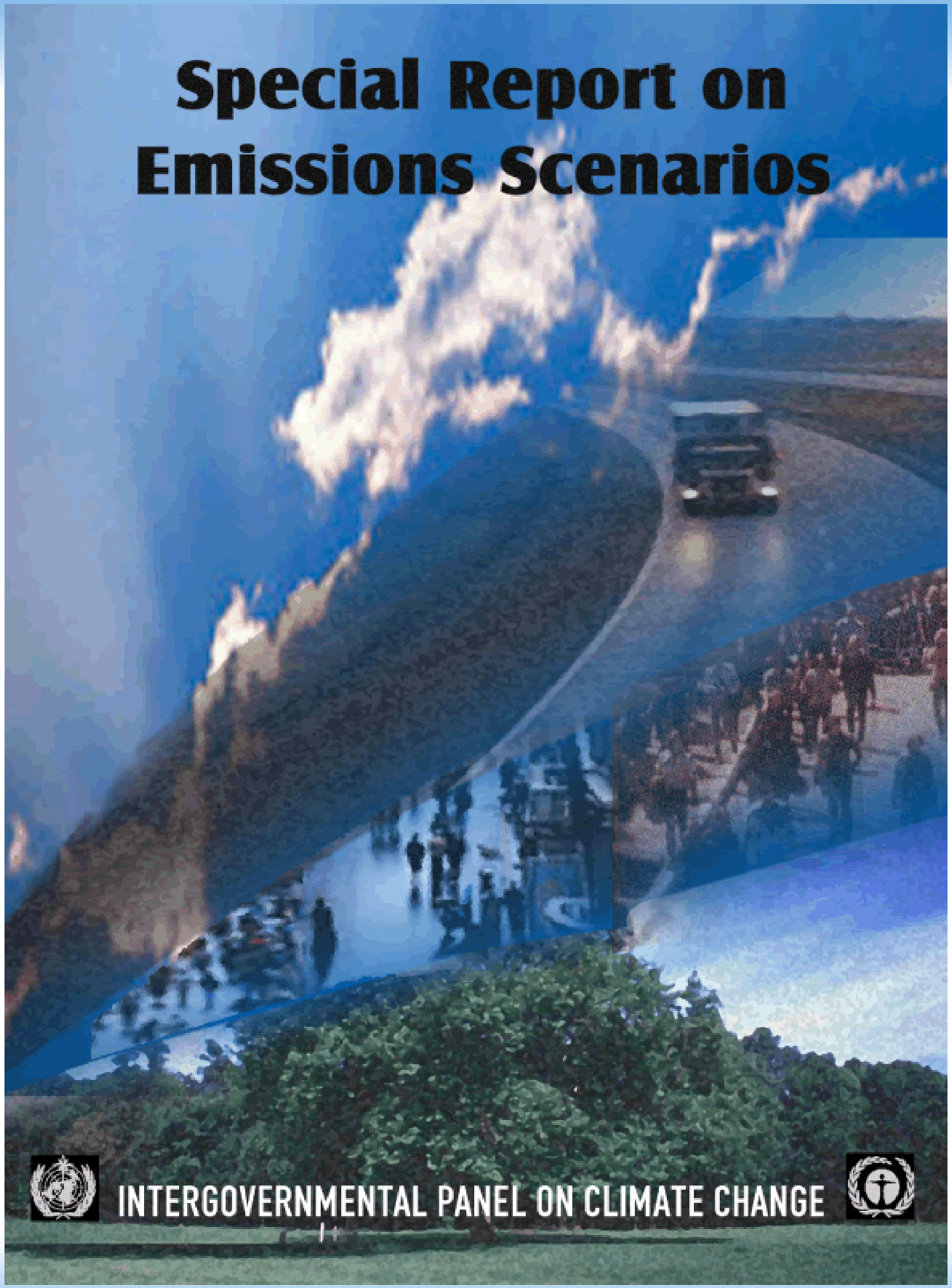


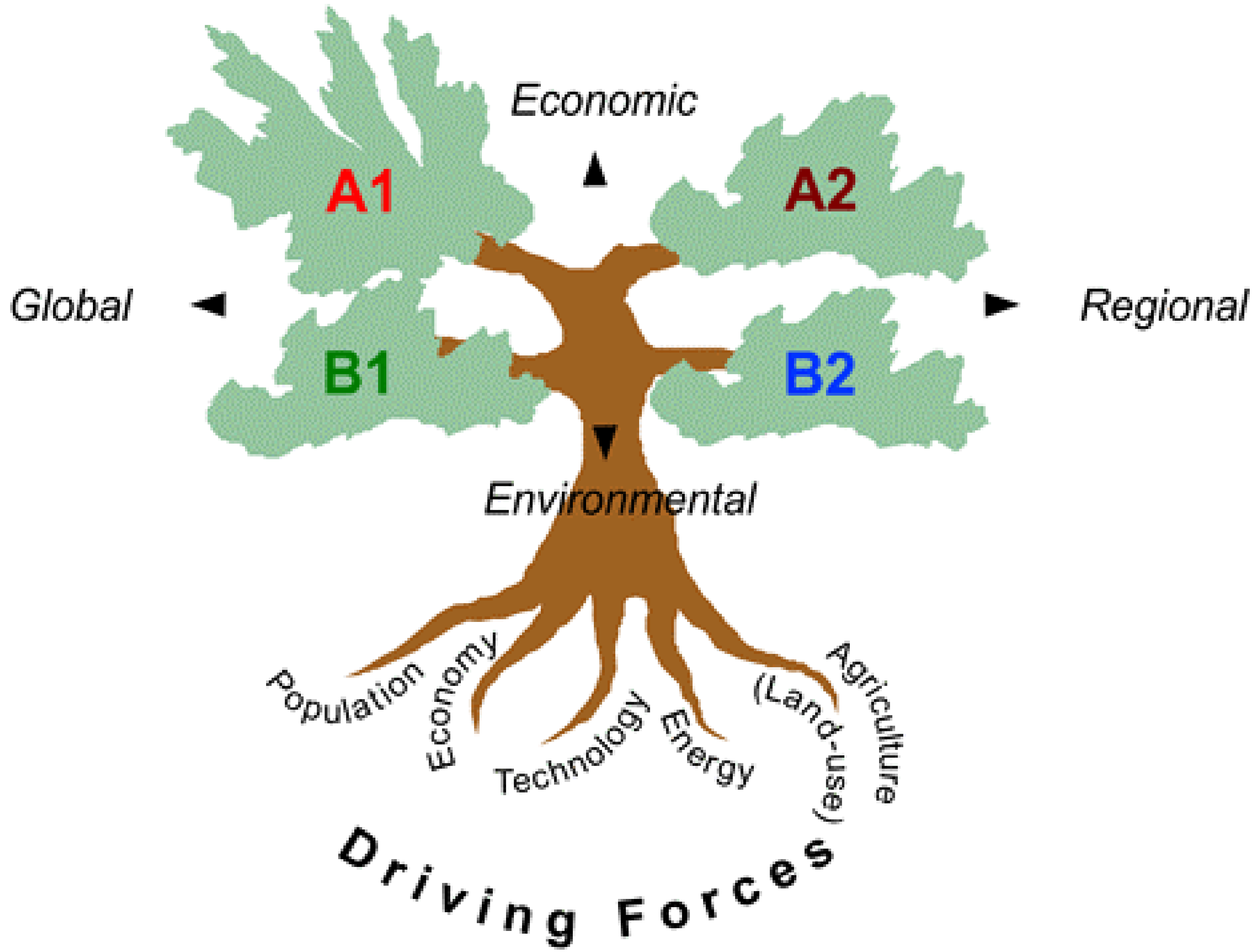
Nuclear Power Outlook (3)

- Political and public resistance to its use in some countries
- Political support and at least public tolerance in others
- No consensus on the future role of nuclear power in the short to medium run
- Credible longer-term energy demand and supply analyses consistently foresee a growing role for nuclear power

Scenarios

- Are internally consistent images of alternative futures (not prophecies)
- Explore uncertainties based on broad “what if” and “how” questions
- Help identify discontinuities
- Encourage to think the unthinkable


Special Report on
Emissions Scenarios
INTERGOVERNMENTAL PANEL ON CLIMATE CHANGE

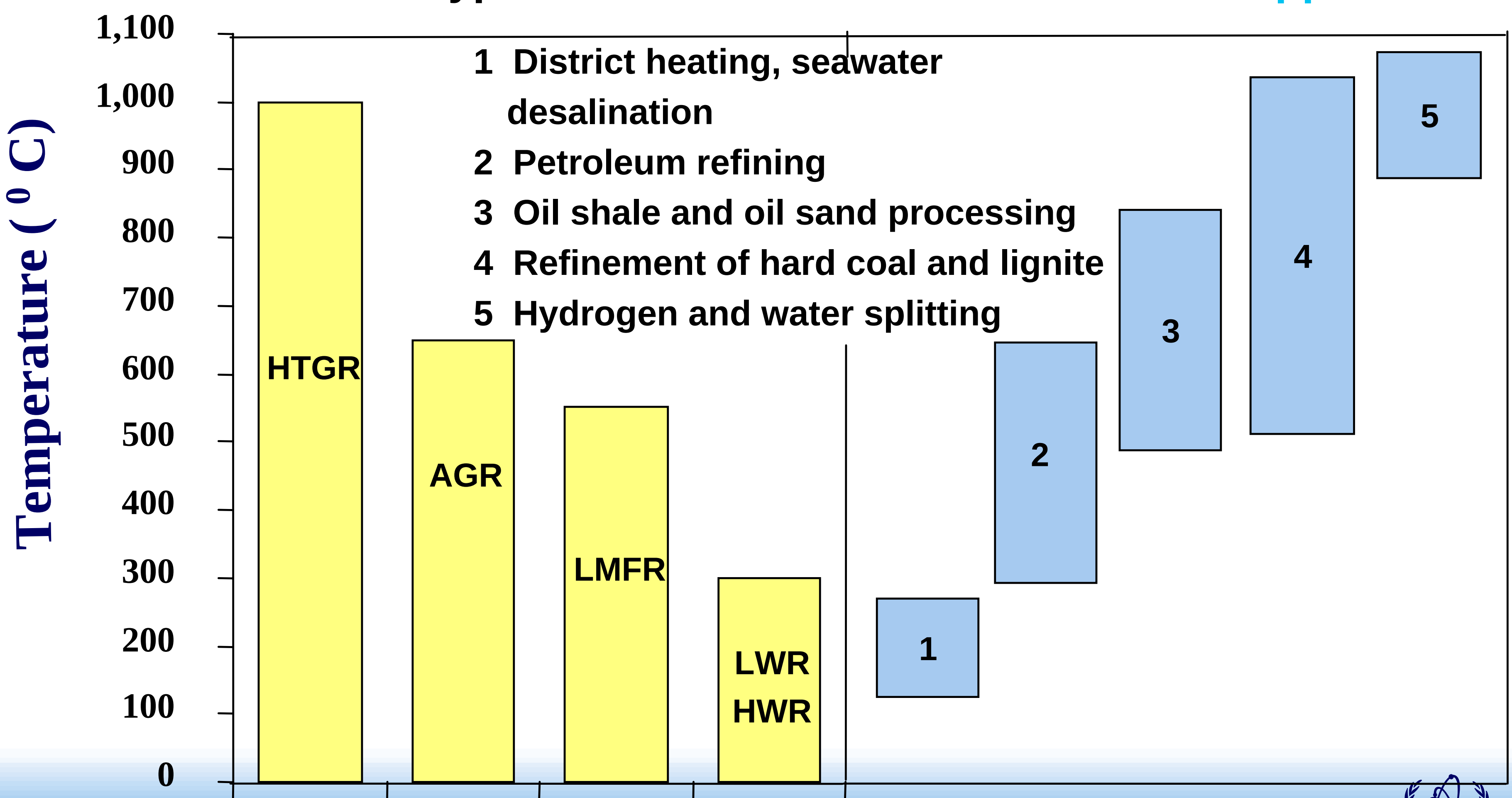

Economic
A1
A2
Global
Regional
B1
B2
Environmental
Population
Economy
Technology
Energy
(Land-use)
Agriculture
Driving Forces

Technology Options Towards a Sustainable Energy Future

- **Improved Energy Efficiency throughout the energy system**
- **More Renewable Energy**
- **Advanced Energy Technologies:**
  - **clean fossil fuel technologies**
  - **next generation nuclear technologies**

NUCLEAR POWER: More than just electricity generation:

Reactor type **Use / Application**



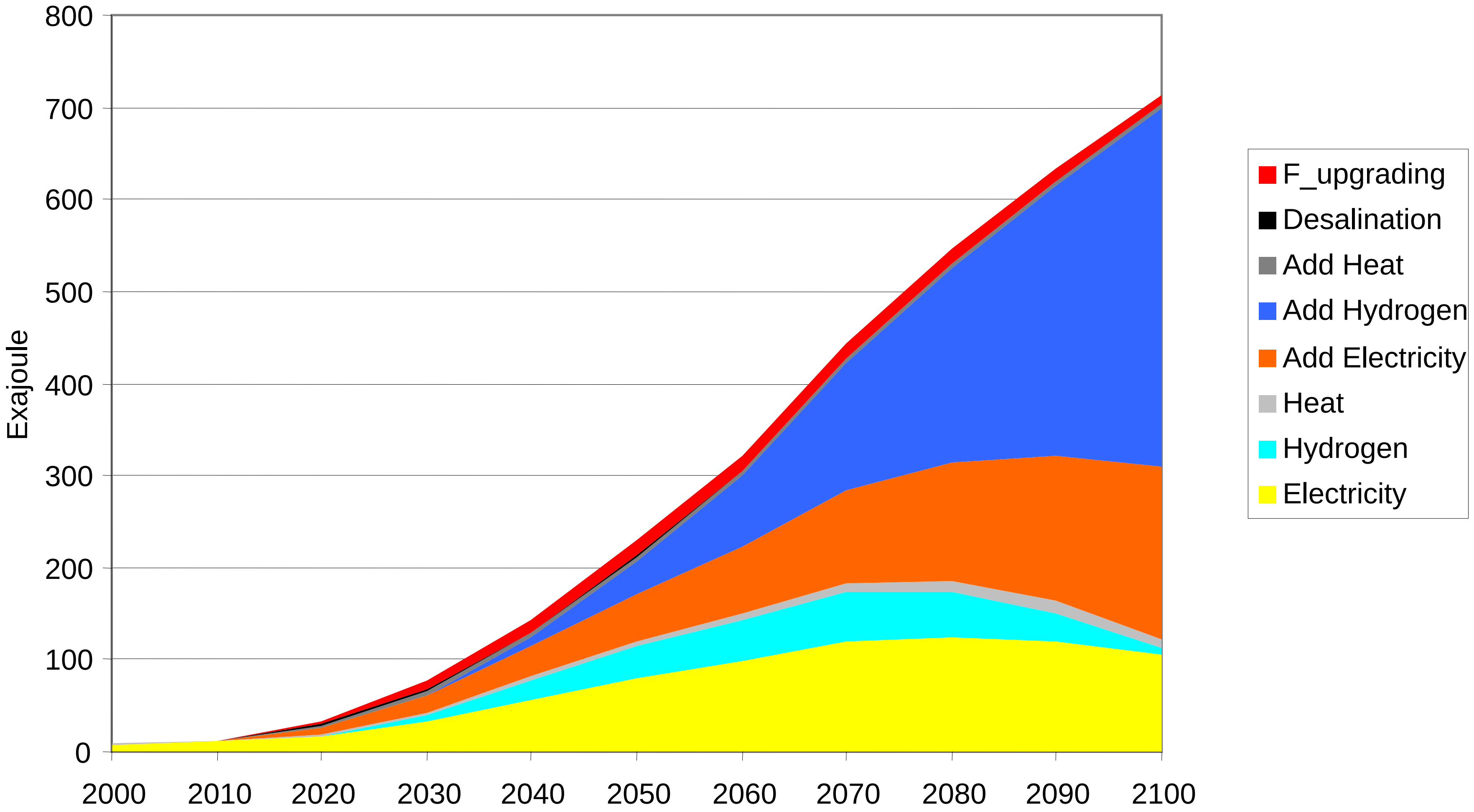
Nuclear Variations on SRES

- SRES results are indicators, not constraints
- Add desalination & fossil fuel upgrading
- Postulate innovation driven “accelerated nuclear expansion”
  - identify key competitors
  - identify vulnerable market shares

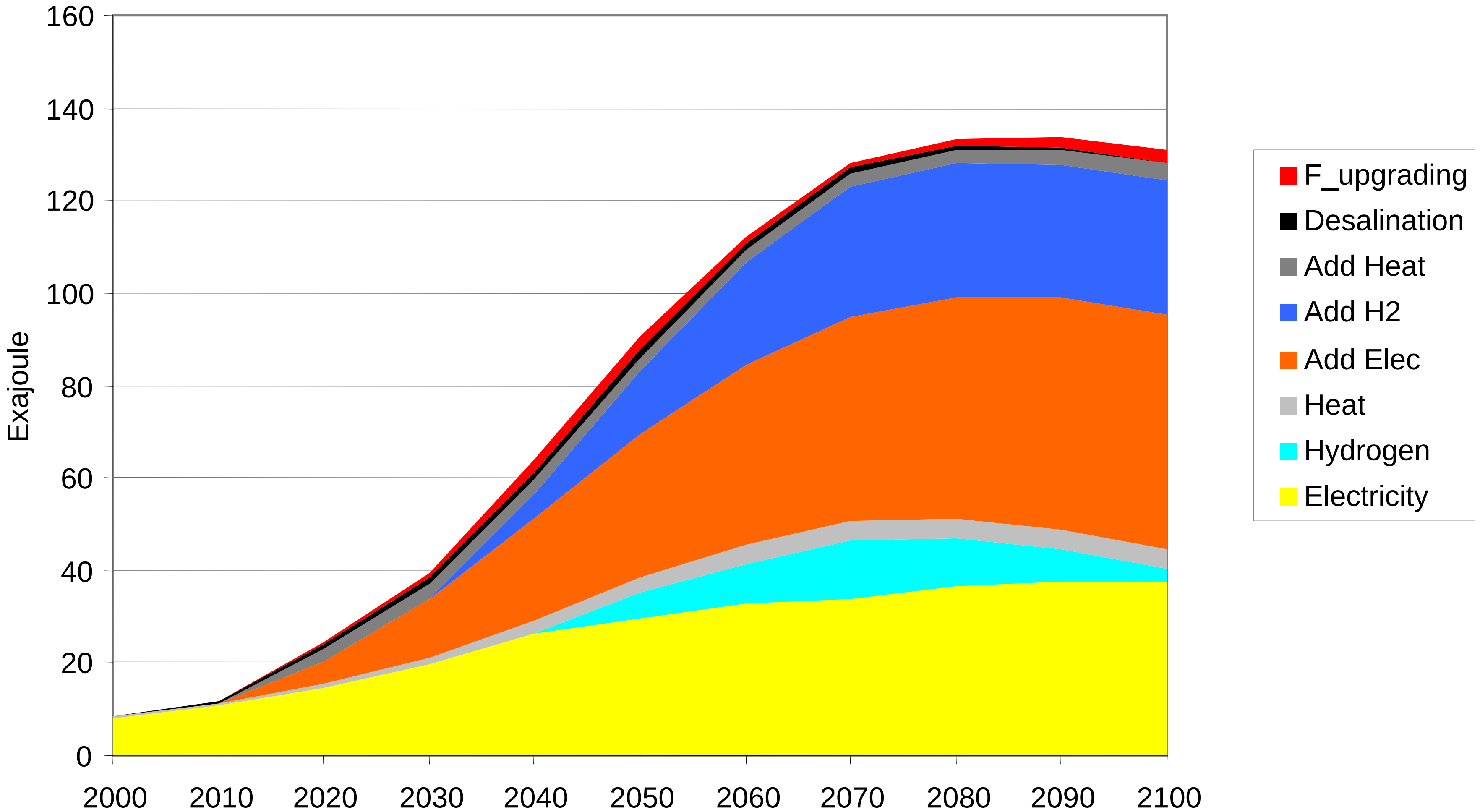
Assumptions

- Innovative nuclear technologies capture
  - 50% of electricity from expensive coal categories
  - 50% of electricity from expensive natural gas categories
  - biomass/waste electricity exceeding 60% of potential
  - 50% of high-cost hydro in OECD & REF (33% in Asia & ROW)
  - 50% of centralized solar
  - 25% of wind & geothermal

A1T World: Nuclear Power Markets and Potentials



B1 World: Nuclear Power Markets and Potentials



Why Nuclear Power?

- There is no technology without wastes and risks
- On factual balance, nuclear compares well with alternatives
- It is readily available at large scale
- Nuclear power alone is not the solution to climate change and sustainable development – but for sure it can be an integral part of any solution

Summary

- Nuclear prospects for the 21st century are bright.
- Alternative development paths can result in very different implications for nuclear power.
- Nuclear power performance profiles must match overall energy system needs.
- Innovation along the full nuclear source-to-waste disposal chain is key throughout the 21st century.
- ????.....?