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Energy research Centre of the Netherlands

Energy Technology Innovation: Is Nuclear an Option?

Prospects for Nuclear Energy in Europe

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Outline

I. Introduction: nuclear power in Europe

II. Climate change and air pollution

III. Resource availability and energy security

IV. Costs and economic competitiveness

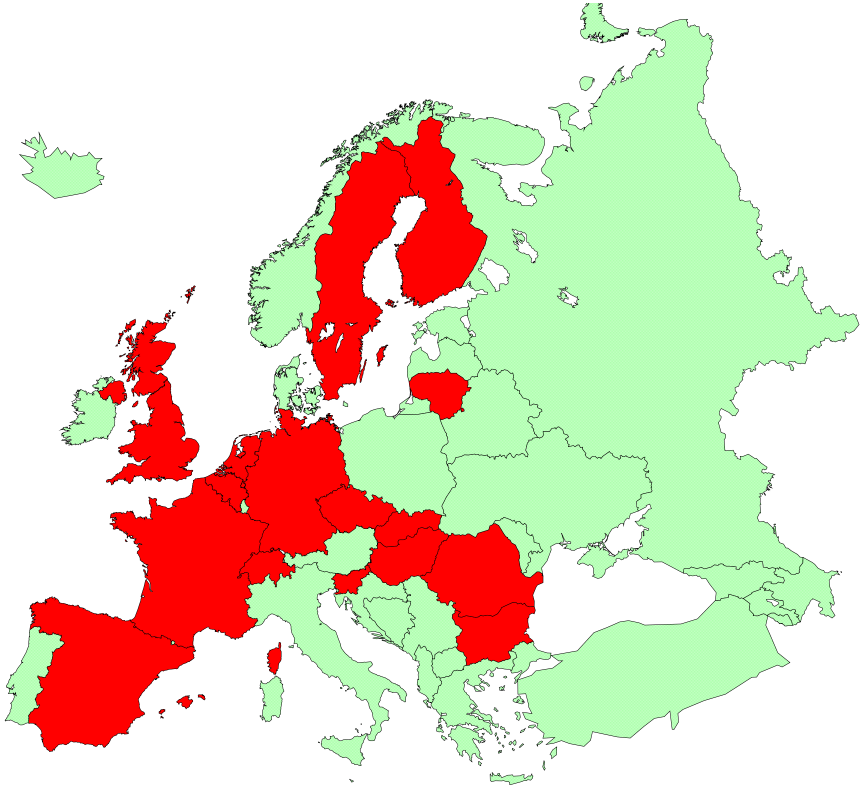
V. Radioactive waste, nuclear proliferation, reactor accidents

VI. Prospects for nuclear power in Europe

VII. Conclusions

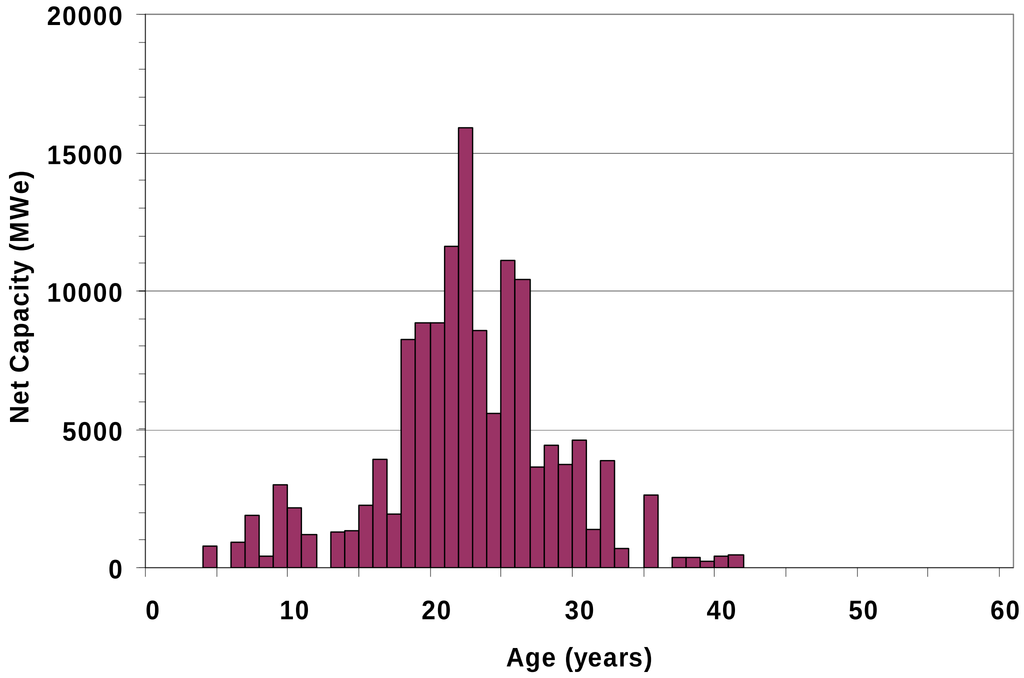
Partly based on a contribution to a Special Issue on the Prospects of Nuclear Energy of the *International Journal of Global Energy Issues* (Eds. Hans-Holger Rogner and Ferenc Toth).

I. Nuclear power in Europe



Nuclear power in Europe: 16 countries today produce nuclear energy domestically and 20 countries do not. *Source: van der Zwaan, forthcoming*.

I. Nuclear capacity in Europe



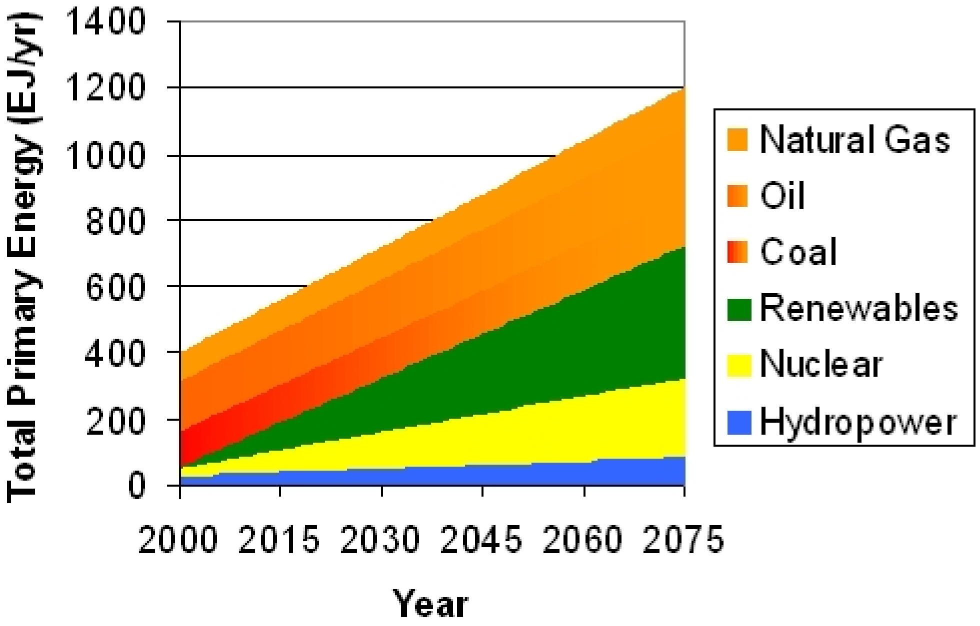
Aggregated net capacity of nuclear power in Europe per age in operation years.
Source: van der Zwaan, forthcoming; *Data from IAEA, PRIS.*

II. Climate change and air pollution

- The expected growth in global energy consumption will lead, in a BAU scenario, to steady increases of GHG emissions.
- Nuclear energy emits essentially no GHG's, even when considering the entire fuel cycle and power plant construction.
- Nuclear power is today the only non-carbon energy source that is deployed on a large scale and can still be significantly expanded.
- Nuclear energy cannot be the panacea to the problem of climate change, but may need to be part of the solution.
- With 137 GWe installed capacity, Europe has the potential to expand the role of nuclear power for climate change control.
- Such an expansion would simultaneously reduce emissions of SO_2, NO_x, Hg, and particulates.

II. Simple scenario analysis

How does a nuclear status quo (scenario I) compare to a tenfold expansion of nuclear power (scenario II), in emission reduction terms?

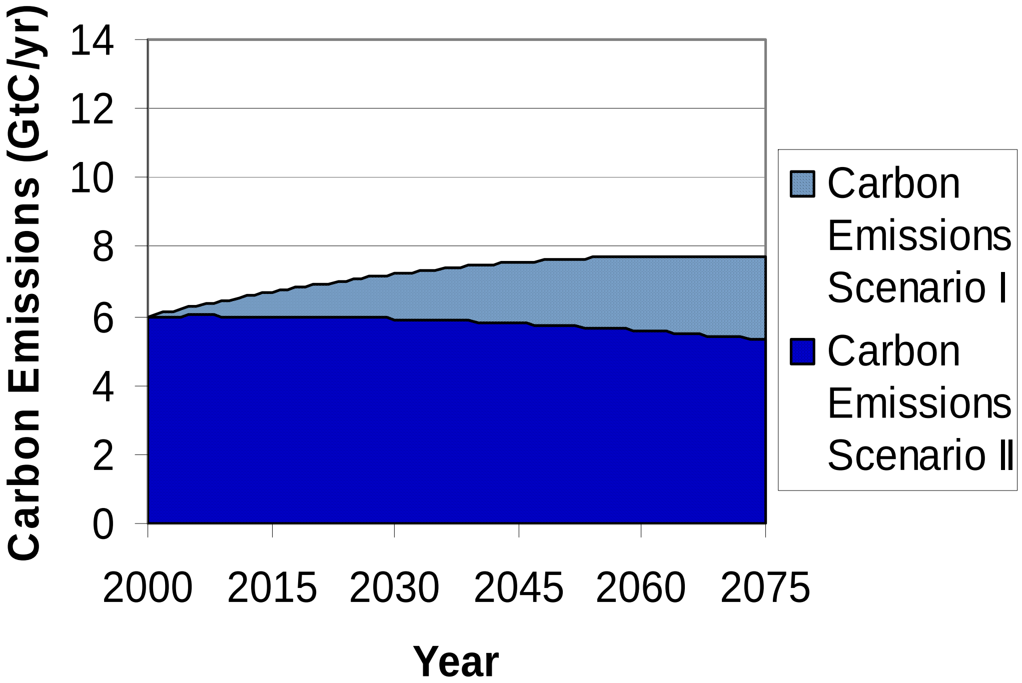


Energy consumption (in EJ/yr) by resource.

Source: van der Zwaan, 2002.

II. Emissions profile

Even in the extraordinarily challenging scenario II, nuclear power can at best be a significant contributor to achieving emission reductions.



Energy-related carbon emissions (GtC/yr).

Source: van der Zwaan, 2002.

III. Energy security

- Under BAU, the EU's dependency on imported energy would increase from 50% today to about 70% in 2030.
- Nuclear energy can be instrumental in reducing this dependency, even while Europe does not possess large uranium resources.
- Uranium is (I) widely available, (II) easily storable, and (III) cheaply acquirable.
- A diverse roster of stable uranium producers exists, and strategic reserves can easily be built.
- Nuclear energy has a low dependence on resource availability, as required amounts of uranium are small.

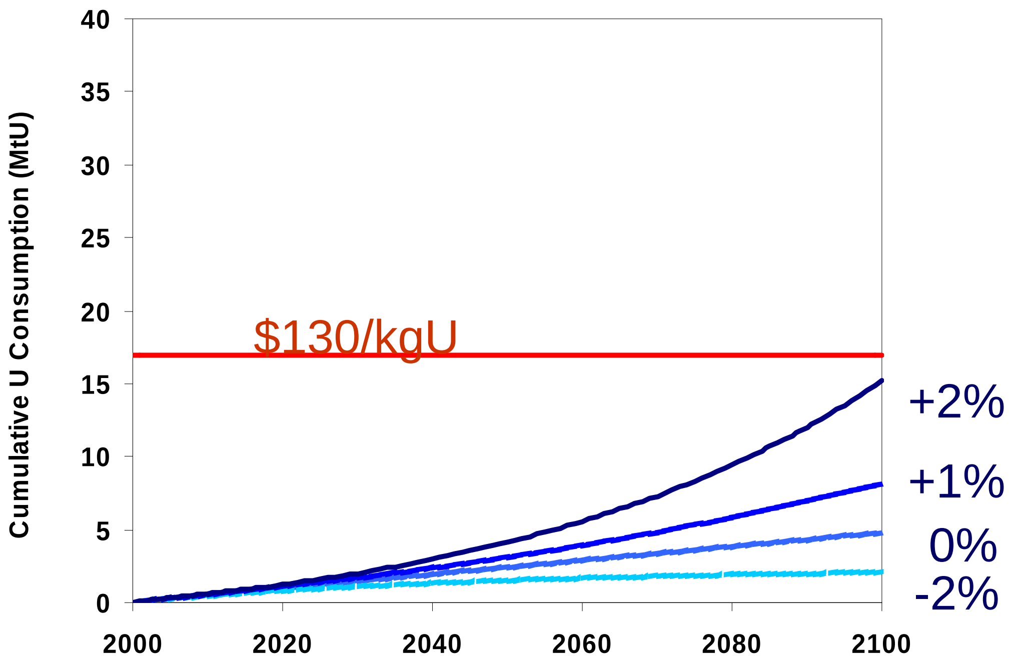
III. Resource price sensitivity

- The costs of nuclear power are little sensitive to fluctuations or even significant increases in the price of uranium.
- Doubling of natural gas price: ~75% increase kWh price.
- Doubling of uranium price: ~2 à 5% increase kWh price.
- Arguments of energy supply security will continue to motivate countries, including in the developing world, to develop domestic nuclear power facilities.

III. Uranium resources

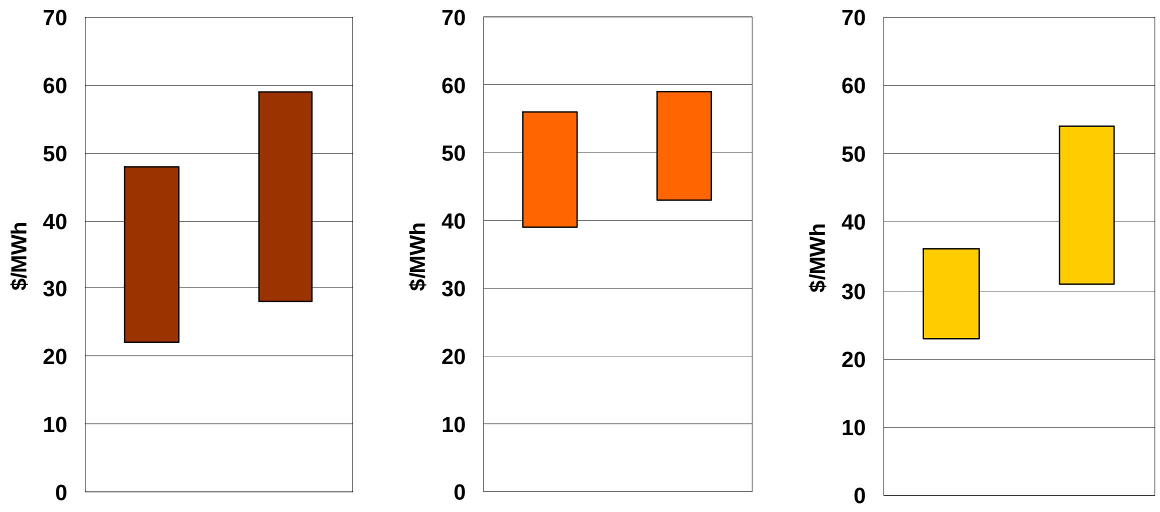
- Uranium resources are abundant: current exploitable reserves last >50 years, at current rate of use and prices.
- New exploitable mining sites are likely to be discovered.
- Less profitable mines and ores are also economical.
- Uranium could be produced from seawater (>>100$/kgU).

III. Resource availability



Scenarios of cumulative uranium consumption under annual nuclear electricity production growth rates of -2%, 0%, +1%, and +2% (once-through fuel cycle, 19 tU/TWh, 2500 TWh in 2000). *Source: van der Zwaan, forthcoming*.

IV. Levelised costs



(a) Coal: 5% and 10% **(b) Gas: 5% and 10%** **(c) Nuclear: 5% and 10%**

Figure 4. Range of total levelised electricity generation costs (in US$/MWh) for (a) coal, (b) natural gas, and (c) nuclear power plants for two values of the discount rate (left bar 5%, and right bar 10%). *Data from: OECD, 2005.*

Nuclear power is well able to compete with its two main counterparts (oil and gas prices prior to 2005). *Source: van der Zwaan, forthcoming*.

IV. Economic competitiveness

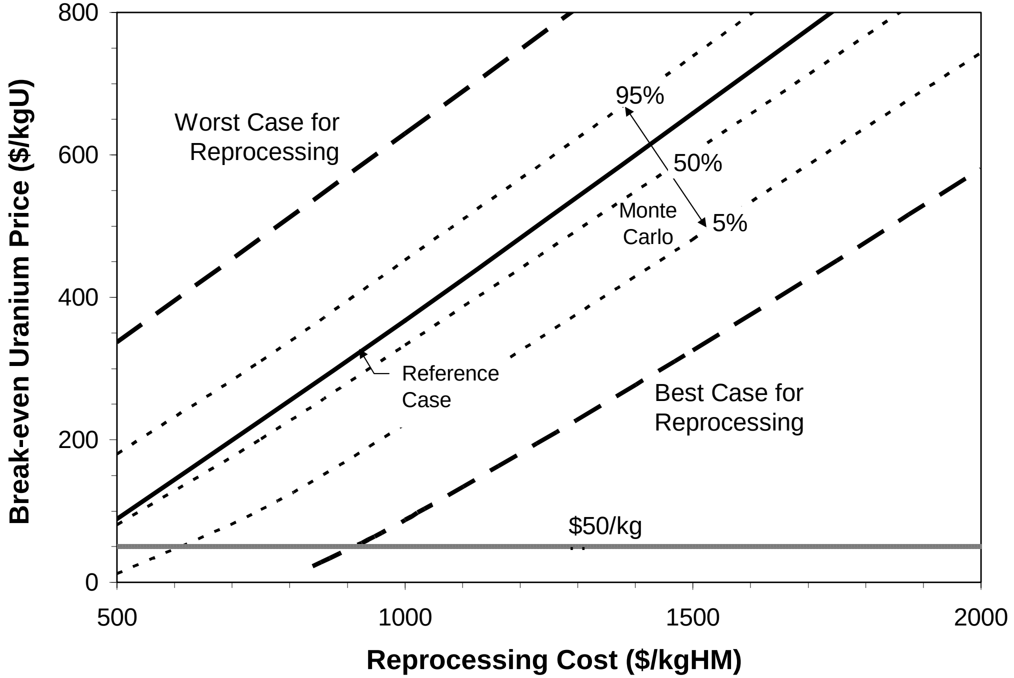
- High capital cost requirements for nuclear power plant construction often impede investments in nuclear energy.
- Regulatory, legal, and political incertitude, as well as market liberalisation, disadvantage new investments in the nuclear sector.
- An active role of government is indispensable, as recently demonstrated by Finland and France.
- Plausible reductions in power plant construction costs may reduce the investment gap between nuclear and fossil-based power.
- CCS application, economic valuation of CO_2 abatement, and the EU ETS may benefit investments in new nuclear power plants.

IV. Nuclear economics

- Lifetime extension of most existing nuclear power plants becomes increasingly likely, in Europe as elsewhere.
- The internalisation of externalities in energy prices would reinforce the competitiveness of nuclear energy.
- Enhancing security against potential terrorist attacks to nuclear power plants and spent fuel cooling ponds increases costs.
- Reprocessing and recycling of plutonium is more expensive than direct disposal of spent fuel.
- The economics of reprocessing remains a relevant subject of study, especially now that some countries face major decisions regarding the future management of spent nuclear fuel.

IV. Break-even uranium price

Break-even uranium price as a function of the cost of reprocessing, for various sets of assumptions about the cost of other fuel-cycle services.



Source: Bunn et al., 2005.

V. Radioactive waste, nuclear proliferation, and reactor accidents

- The problems related to these three intrinsic nuclear drawbacks are real, significant, and will never be solved entirely.
- Still, they are dynamic: they have evolved substantially over the past decades, and more progress can be made.
- The waste problem can be mitigated through e.g. lifetime reduction (transmutation) and regional disposal options (IMWRs).
- The proliferation problem can be reduced by new reactor types (Gen-IV) and expanded mandate of supranational means (IAEA).
- Accident risks can be reduced by use of passive safety features and reactor operation improvement and coordination.

V. Current and new reactors

	Today	Short to medium term	Long term
Generation	**I and II**	**III**	**IV**
Reactor type	PWR (92) WWER (22) BWR (19) AGR (14) GCR (8) LWGR (1) PHWR (1) FBR (1)	EPR (PWR) AP1000 (PWR) WWER (PWR) ABWR (BWR) ESBWR (BWR) HTR (pebble bed)	GFR LFR MSR SFR SCWR VHTR

Nuclear reactor types in Europe: currently deployed, deployable in the short-medium term, and possibly developed in the long term. *Sources: van der Zwaan, forthcoming*; *IAEA-PRIS, 2006; NERAC/GIF, 2002.*

V. Natural nuclear power

The oldest nuclear reactor is natural: Oklo, Gabon.

V. The Oklo natural nuclear reactor

- 2 billion yrs ago, the concentration of U-235 in natural uranium deposits was around 3% (0.7% today), as the half-life of U-235 (700 million yrs) is shorter than that of U-238 (4.5 billion yrs).
- In the Oklo area, the presence of water constituted a natural moderator for the slowing down of neutrons produced during the fission of U-235 nuclei.
- The resulting reactor(s) operated at an average power of 100 kW, producing a total of 15 GW-yr of energy, with self-regulatory cycles of 0.5-2.5 hours.

The Oklo reactors show how 'natural' nuclear power is, and how well radioactive waste can be contained for billions of years.

VI. Prospects for nuclear power in Europe

- For the short run (2025), Europe’s nuclear energy capacity is unlikely to be very different from that of today.
- For the medium run (2050), the relative weights attached to its benefits and drawbacks will determine its future in Europe.
- For the long run (2100), the extent to which nuclear power can contribute to sustainable development is the determinant factor.

My guess:

World-wide until 2050 nuclear power contribution is likely to remain between lower bound of constant capacity (in absolute terms) and upper bound of constant share (in relative terms).

VII. Conclusions

The future of nuclear power will significantly be determined by the extent to which the public will accept:

- the current solutions for the treatment and disposal of radioactive waste,
- the inherent risks associated with the proliferation or terrorist diversion of nuclear technologies and materials,
- the non-zero probability for the occurrence of reactor incidents and accidents,

and the further progress booked in these areas, in perspective of the risks / disadvantages of other energy resources.

Will all countries fulfill their NPT obligations, and are we able to fairly and transparently internationalise the nuclear fuel cycle?

VII. Publications

Sailor, W.C., D. Bodansky, C. Braun, S. Fetter and B.C.C. van der Zwaan, 2000, A Nuclear Solution to Climate Change?, *Science*, Vol. 288, 19 May, pp. 1177-1178.

Bruggink, J.J.C. and B.C.C. van der Zwaan, 2002, “The role of nuclear energy in establishing sustainable energy paths”, *International Journal of Global Energy Issues*, vol.18, 2/3/4.

van der Zwaan, B.C.C., 2002, “Nuclear Energy: Tenfold Expansion or Phaseout?”, *Technological Forecasting and Social Change*, 69, 287-307.

Rothwell, G. and B.C.C. van der Zwaan, 2003, “Are light water reactor systems sustainable?”, *Journal of Energy and Development*, vol.29, no.1, pp. 65-79.

Bunn, M., S. Fetter, J.P. Holdren and B.C.C. van der Zwaan, 2005, “The Economics of Reprocessing vs. Direct Disposal of Spent Nuclear Fuel”, *Nuclear Technology*, 150, pp. 209-230.

van der Zwaan, B.C.C., “Prospects for nuclear energy in Europe”, *International Journal of Global Energy Issues,* forthcoming.