ECN

Energy research Centre of the Netherlands

Climate Change and Technological Innovation

The cases of carbon capture and nuclear energy

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Presentation for the Symposium

"Long-Term Energy Futures and Climate Change Mitigation Strategies"

in Celebration of the 50th Anniversary of ECN

Petten

17-18 November, 2005

ECN

Outline

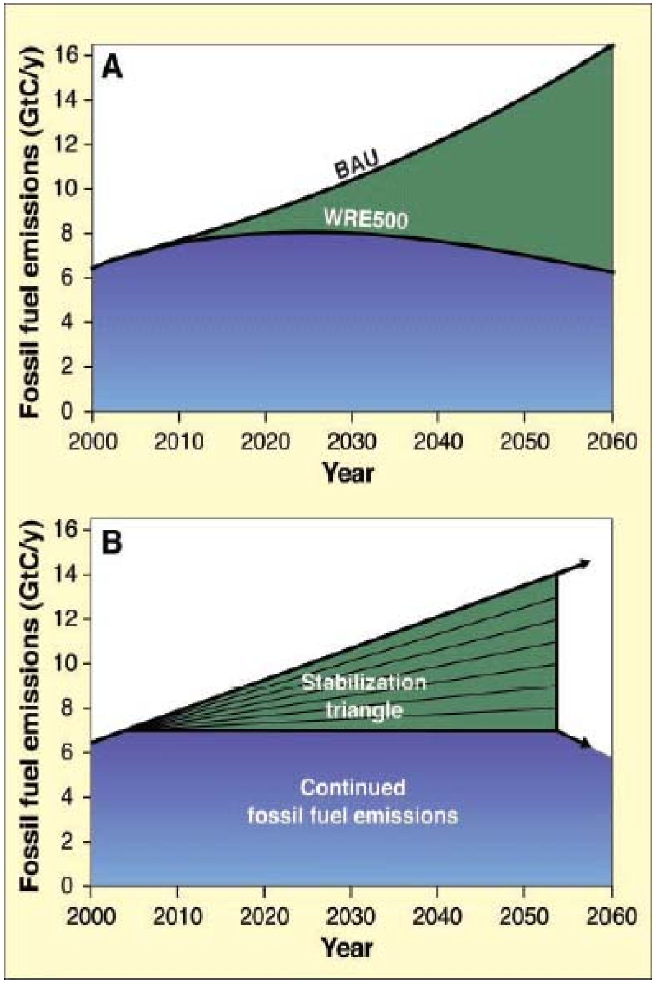
I. Energy innovation: coal and climate change
II. The 'coal paradox'
III. Carbon Capture and Storage (CCS)
IV. Economic modeling of CCS
V. Inducing CCS
VI. Nuclear energy
VII. Conclusions

I. Energy innovation

'Solving the climate change and carbon problem' implies finding the 7 wedges of the stabilization triangle.

Pacala and Socolow (2004) propose 15 possible wedges.

Replacing fossil fuels seems the obvious solution, but retaining them does not need to be precluded.



I. Replacing coal

Of the 15 proposed ‘wedge’ technologies, 4 options replace the use of coal by other (less carbon-intensive) technologies:

- ***Substituting natural gas for coal***: replace 1400 GWe coal with 1400 GWe natural gas plants.
- ***Substituting wind electricity for coal***: replace 700 GWe with 2000 GWp wind.
- ***Substituting PV electricity for coal***: replace 700 GWe with 2000 GWp PV.
- ***Substituting nuclear fission for coal***: replace 700 GWe with 700 GWe nuclear power.

I. Or retaining it?

Of the same 15 proposed ‘wedge’ technologies, 4 alternatives continue the use of coal, but in a different form:

- ***Improved power plant efficiency***: produce twice today’s coal-based electricity at 60% instead of 40% efficiency.
- ***Storage of carbon captured in coal power plants***: install CCS at 800 GWe base-load coal power plants.
- ***Storage of carbon captured in coal-based hydrogen plants***: install CCS at coal-based hydrogen plants producing 250 MtH2/yr.
- ***Storage of carbon captured in coal-based synfuel plants***: install CCS at coal-based synfuel plants producing 30 million barrels per day of synfuels.

II. Global coal consumption

- Global coal consumption is expected to increase at an average rate of 1.7%/yr until 2020.
- Share of coal in world primary energy demand remains stable at about 25% until 2020.
- With a share of 38%, coal is the largest contributor to power production.
- In developing countries, coal consumption will increase at a rate of about 3%/yr until 2020.
- Much of the global coal consumption growth takes place in China and India.

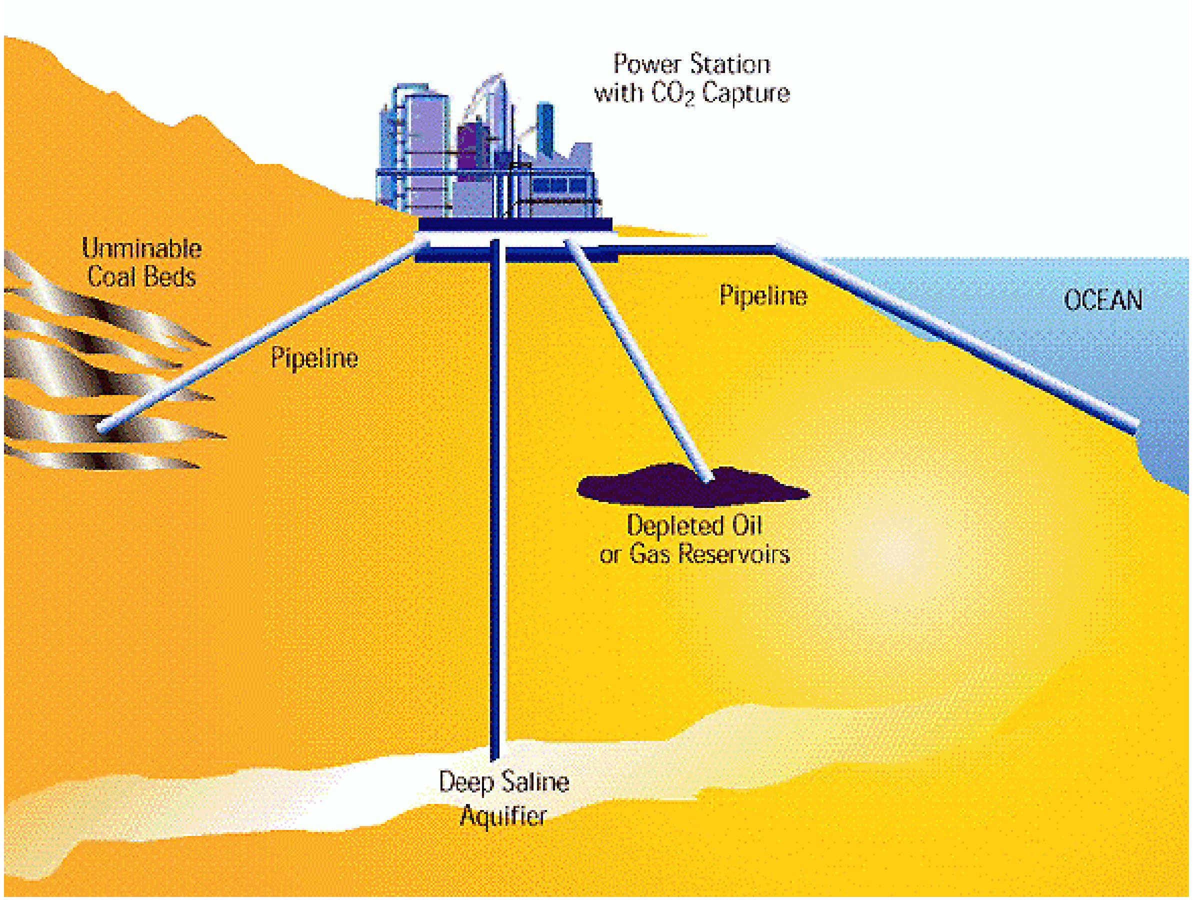
II. Coal resource base

- Global ***coal resources*** amount to at least 6,000 billion tons.
- Perhaps 50% are unlikely to ever become exploitable, since they are too deep underground.
- Still, 3,000 billion tons correspond to 850 yr of coal supply at present production levels.
- Today, proven ***coal reserves*** are close to 700 billion tons.
- Even with an increase of coal use of 1%/yr until 2100, current reserves are enough to cover the 21st century.

II. ‘Coal paradox’

- ‘***Coal paradox***’ can be explained by (1) resource base, (2) technological innovation, (3) advanced technologies, (4) improving economics.
- No technological breakthrough is needed for a resurgence of coal in terms of its contribution to 21st century energy supply: clean coal technologies exist already.
- Their competitivity is continuously increasing.
- The crux is *implementation*: climate and other environmental policies are needed for their large-scale deployment.

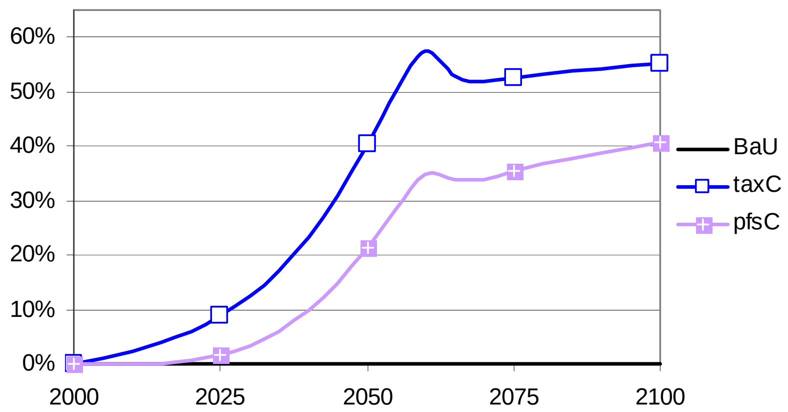
III. CCS options



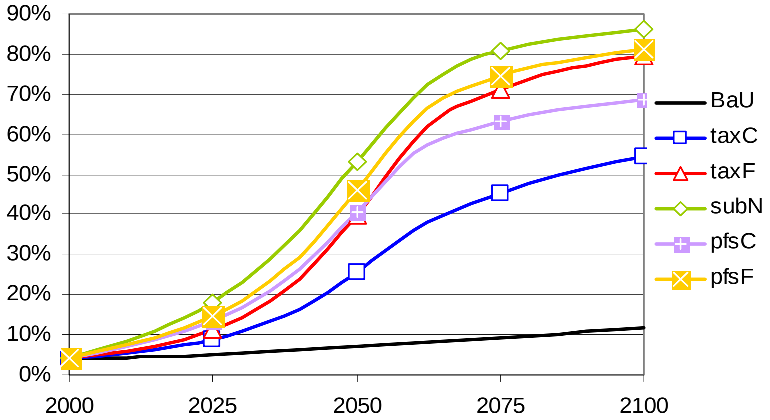
Unlike aquifers, coal-, oil-, and gas-fields have a good history of containment.

Source: IEA Greenhouse Gas R&D Programme.

IV. DEMETER – global results



CCS application to new capacity of fossil energy supply for 450 ppmv climate target.



Share of non-carbon energy source for 450 ppmv climate target.

Source: Gerlagh and van der Zwaan (2005).

IV. DEMETER - conclusions

Carbon taxes (possibly complemented with recycling) prove to be the preferred instrument.

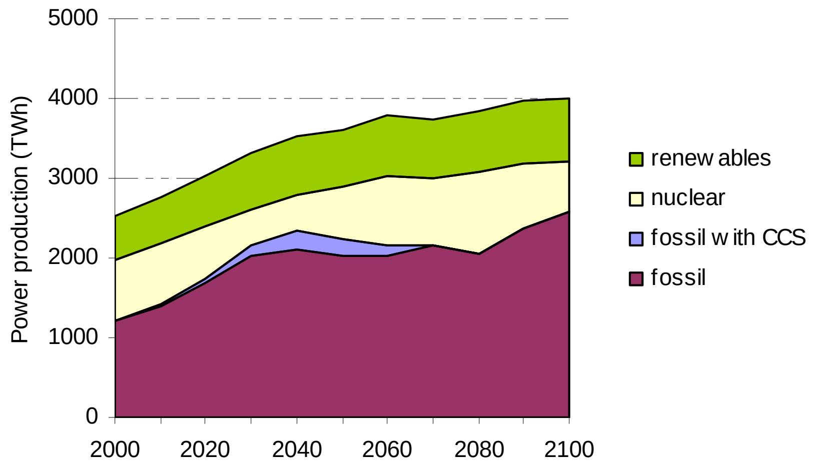
Under 450 ppmv climate stabilization, 30-50% of fossil energy is decarbonised through CCS.

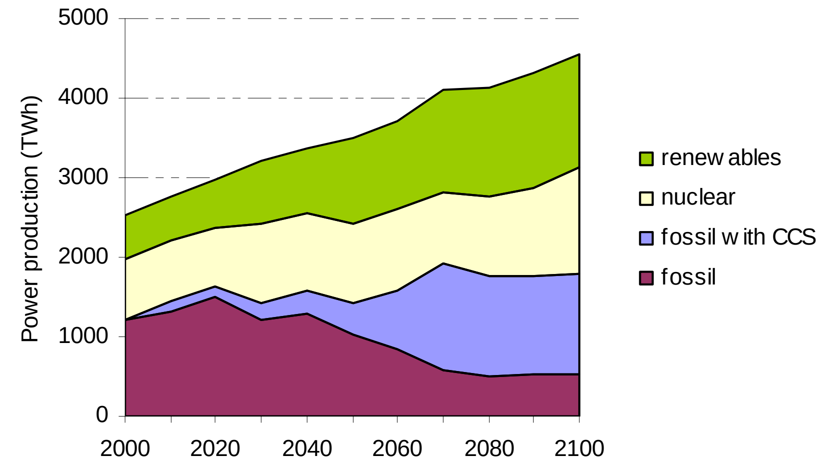
CCS does certainly not obviate the need for the large-scale deployment of renewables.

Without CCS, 80% of the energy system in 2100 needs to be based on renewables.

The use of CCS allows to reduce this share to values between 55% and 70%.

IV. MARKAL – results for the EU





Electricity production (in TWh) until 2100 from renewables, nuclear energy, fossil fuels with CCS, and fossil fuels without CCS (BAU and 550 ppmv, respectively). *Source: Smekens and van der Zwaan (2005).*

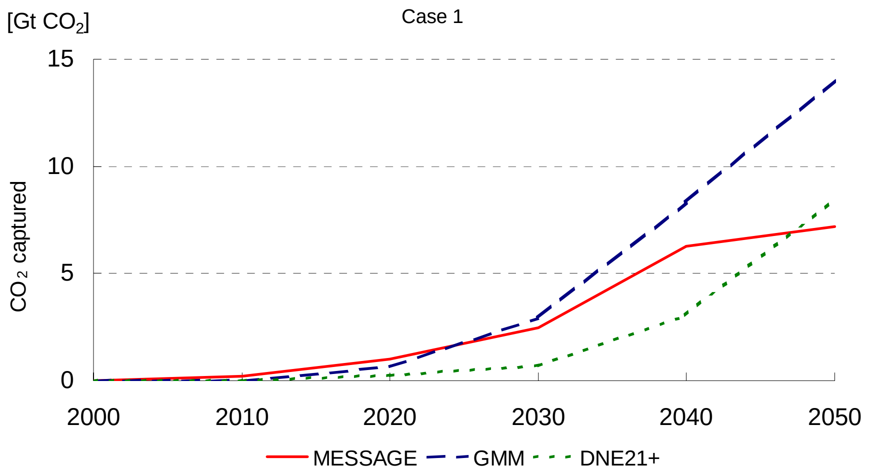
IV. MARKAL - conclusions

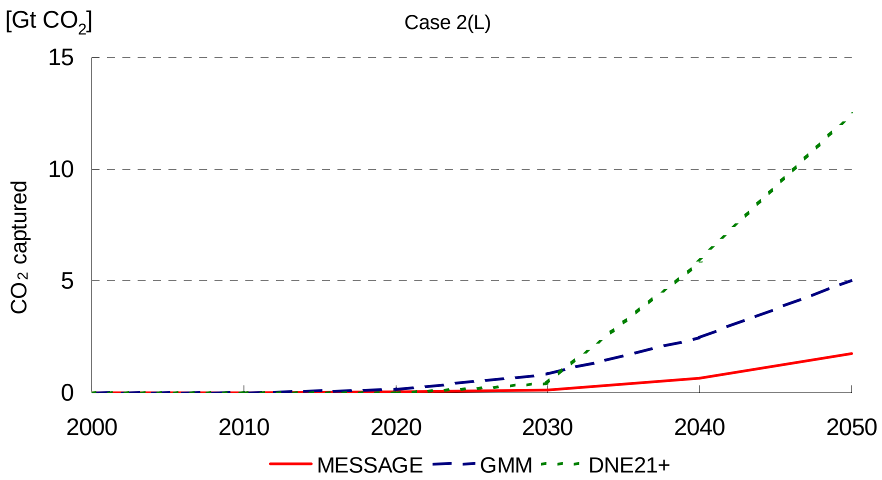
Even without climate change intervention, CCS is likely to be deployed, given the economic benefits of EOR and ECBM.

With (atmospheric *and* geological) CO_2 externality taxation, CCS will only be developed if the global warming damage cost is at least some 100 €/tCO_2 or the CO_2 storage damage cost not more than a few €/tCO_2.

When global warming damage costs are high, CCS applied to biomass-fuelled power plants (while expensive) proves the optimal option to reduce CO_2 emissions.

IV. Cascade-Mints: preliminary CCS results





- Among the three cases analyzed, the CCS standards scenario leads to the largest CCS emission reduction, but even then within the available storage potential.
- Replacing the CCS standards policy by an emissions constraint, reflecting the same emissions reduction scheme, reduces CCS uptake significantly, as well as the overall costs.

V. CCS and ETS

Only preliminary observations can be made regarding CCS in relation to the EU emissions trading system (ETS):

- ***EU emissions trading system is still new***: it will take time before robust predictions can be made regarding its technological impact.
- ***A (premature) impression on the effect of ETS on energy options***: small-scale or expensive options receive little investment stimulus.
- ***Another impression***: CCS is a candidate option to gain under ETS: but e.g. to exploit the 'North Sea *window-of-opportunity*' perhaps less flexible additional CCS-stimulating mechanisms are justified.
- ***CCS is expected to really start 'kicking in' at > 25 euro/tCO2 (IEA 04)***: while currently above 20 euro/tCO2, 'stable' ETS price is possibly lower.

V. Further observations

- For CCS, (slow and sudden) leakage, environmental damages and risks should not be underestimated (storage heterogeneity).
- More R&D but especially multiple demonstration projects are needed in order to prepare for large-scale deployment.
- To what extent can/should taxes be used to stimulate CCS (Norway) and e.g. Shell be involved in applying CCS at the North Sea (à la BP / Statoil)?
- Public acceptance is important: a comparison with nuclear energy in this context is not irrelevant.
- International developments - notably in the US, but also in e.g. China - are fundamentally important for strategies adopted everywhere.

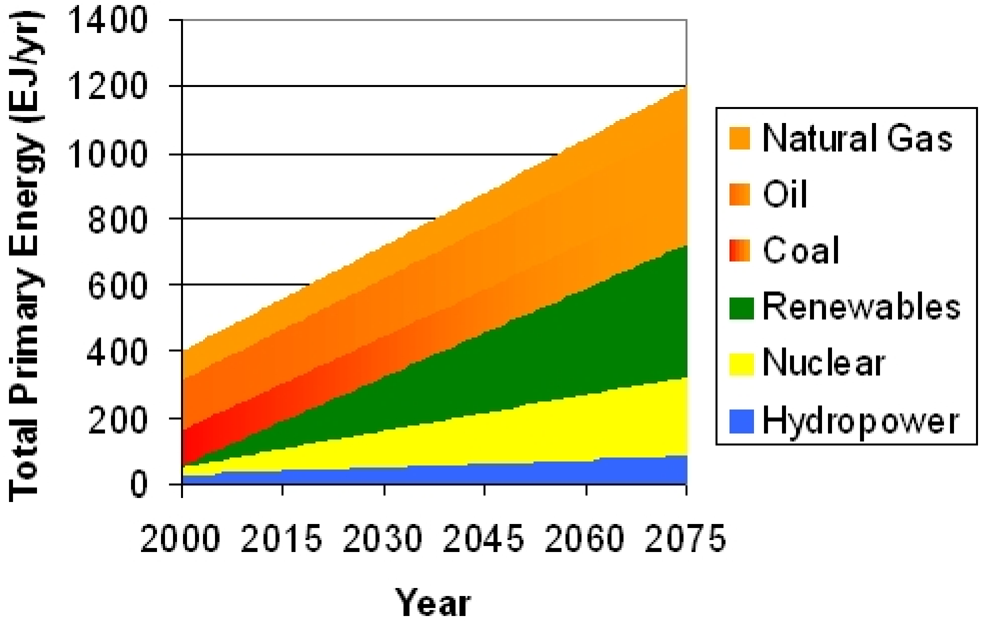
VI. Comparison to nuclear?

- Like in the 1960s for nuclear energy, there is today great optimism about CCS.
- For both CCS and nuclear power, wastes are buried underground.
- In both cases, these wastes may affect human health and have detrimental impacts on the environment.
- Of course, the nature of these wastes is very different (state, toxicity, volume, containment).
- Risks and accidents may not be absent for CCS (incidentally, Lake Nyos occurred, like Chernobyl, in 1986).
- No CCS ‘proliferation’ equivalent, but public acceptance?

VI. Nuclear and climate change

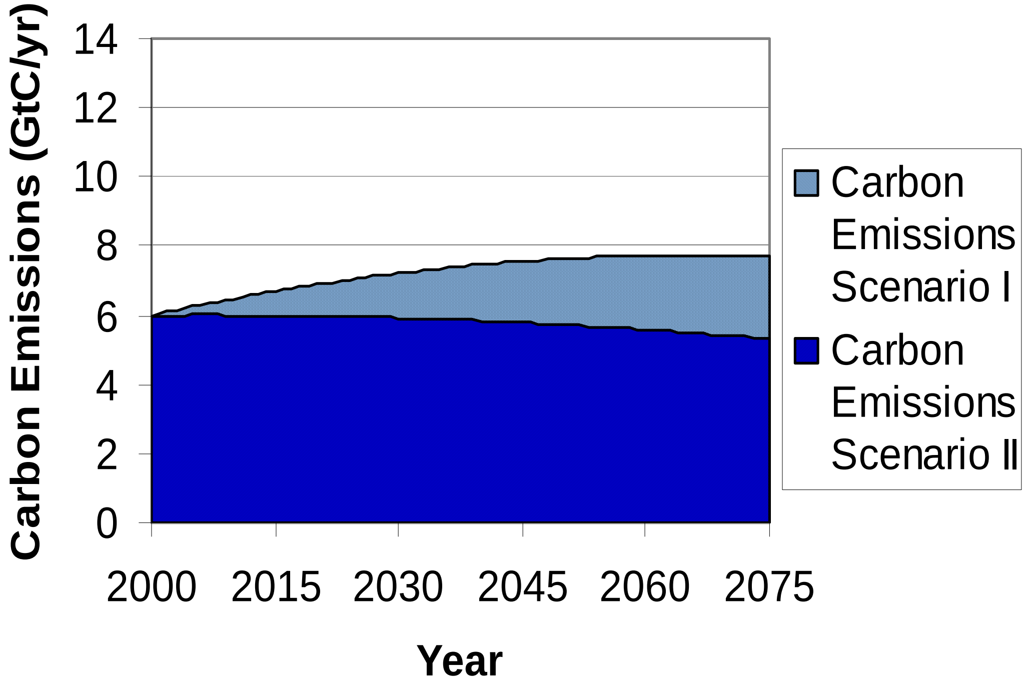
- Should nuclear energy play a role in reducing carbon emissions, thus contributing to climate change mitigation?
- Nuclear energy emits no GHG’s during operation.
- It does emit relatively small amounts of GHG’s during plant construction, and at various stages of the nuclear fuel cycle.
- Today, nuclear power avoids 5-10% of global carbon emissions.
- Whereas even the modest emission reduction goals as formulated in the Kyoto Protocol prove challenging, phasing out nuclear energy today would basically exclude any significant achievements in terms of climate change mitigation the coming decade(s).
- If nuclear energy is expanded 10-fold, what can it contribute to the required reduction of carbon emissions between 2000-2075?

VI. Simple scenario analysis



Energy consumption (in exajoules per year) by resource (2000-2075).

VI. Emissions profile



Energy-related carbon emissions (GtC/yr), from 2000 to 2075.

VI. Uranium resources

- Nuclear energy has a low dependence on resource availability. In terms of weight, about 10^5 more fuel is needed for fossils than for nuclear, to produce a given amount of electricity (based on current LWR technology).
- Uranium resources are abundant; currently known exploitable reserves last >50 years, at current rate of use.
- New exploitable mining sites are likely to be discovered.
- Less profitable mines and ores are also interesting.
- Uranium could be exploitable from seawater (>100$/kgU).

VI. Energy security

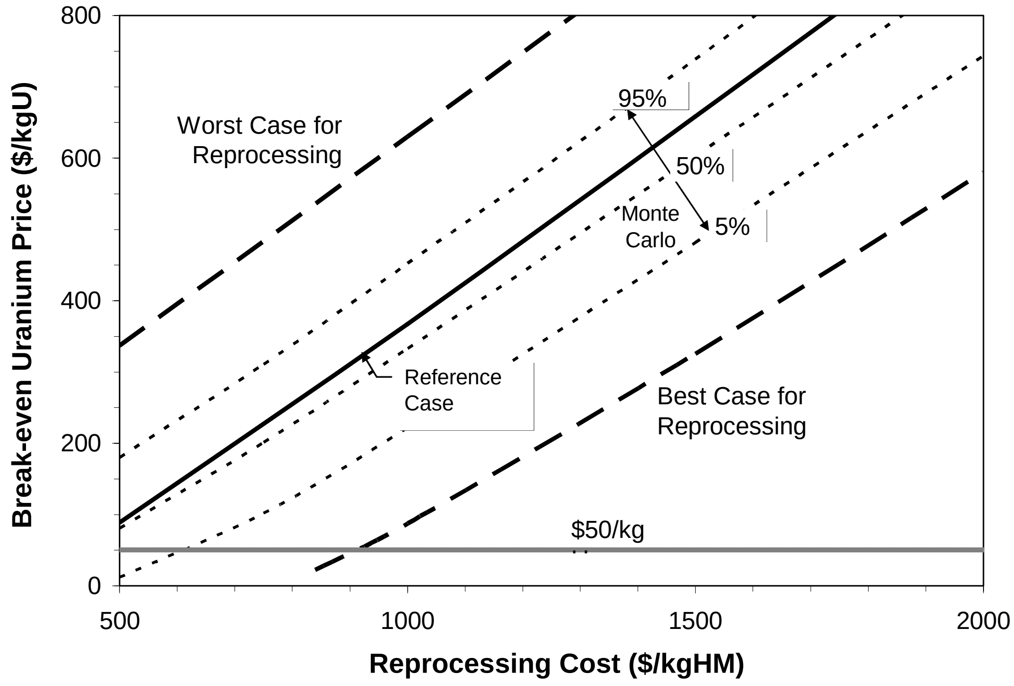
- Nuclear energy has a small dependence on costs and availability of fuel.
- Doubling of natural gas price: ~75% increase kWh price.
- Doubling of uranium price: ~2 à 5% increase kWh price.
- Uranium is widely available and easily storable.
- Arguments of energy supply security will continue to motivate countries, including in the developing world, to develop domestic nuclear power facilities.

VI. Nuclear economics

- ✓ Whereas competitive in principle, its capital intensity makes it increasingly difficult for nuclear energy to compete in a liberalising electricity market.
- ✓ On the other hand, lifetime extension becomes increasingly likely.
- ✓ 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.

VI. 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., *Nuclear Technology*, 2005.

VII. Some conclusions

- Whereas the climate change problem is 'solvable' with currently existing technologies during the coming 50 years, R&D into new technology is required today for the longer run solution.
- Both CCS and nuclear energy may be necessary 'wedges' for addressing climate change until about 2050.
- There is lots of research to be done in the field of CCS, notably regarding how to induce CCS technologies (through e.g. taxes, subsidies, portfolio standards, or emissions trading).
- For CCS, particular attention deserves the classical question how to balance R&D with learning-by-doing through deployment.
- While nuclear energy has so far been unsustainable and may at best only constitute part of the short-term climate solution, it may be rendered more sustainable in the longer run and thus continue to contribute globally to reducing CO_2 emissions.

VII. Publications

Carbon Capture and Storage – R&D Strategies

Stephens, J.C. and B.C.C. van der Zwaan, "The Case for Carbon Capture and Storage", ***Issues in Science and Technology***, Fall, 2005, pp.69-76.

van der Zwaan, B.C.C., "Will Coal Depart or Dominate Global Power Production During the 21st Century?", ***Climate Policy***, 5, 4, 2005.

Sagar, A. and B.C.C. van der Zwaan, "Technological Innovation in the Energy Sector: R&D, Deployment, and Learning-by-Doing", ***Energy Policy***, forthcoming, 2006.

Nuclear Energy

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

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

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

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

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