CO_2 Emissions from the Nuclear Fuel Cycle

fact sheet
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CO_2 Emissions from the nuclear fuel chain will increase substantially as the limited supplies of high-grade uranium ore are used up and as low-grade ore is mined and milled using fossil fuels.

The recent push for a revival of nuclear energy has been based on its claimed reduction of CO_2 emissions where it substitutes for coal-fired power stations. In reality, only reactor operation is CO_2-free. All other stages of the nuclear fuel chain – mining, milling, fuel fabrication, enrichment, reactor construction, decommissioning and waste management – use fossil fuels and hence emit CO_2. Also the transport between these parts of the fuel cycle can be very energy intensive as they can be in different countries and require shipping, trucking or rail.

These emissions have been quantified by researchers who are independent of the nuclear industry. Early work was published by Nigel Mortimer,[1] until recently Head of the Resources Research Unit at Sheffield Hallam University, UK. In the 2000s a very detailed study was done by Jan Willem Storm Van Leeuwen, a senior consultant in energy systems, together with Philip Smith, a nuclear physicist, both of whom are based in Holland.[2]

These studies find that the CO_2 emissions depend sensitively on the grade of uranium ore used. Following Van Leeuwen and Smith, we define ***high-grade uranium ores*** to be those with at least 0.1% uranium oxide (yellowcake U_3O_8). In simpler terms, for each tonne of ore mined and milled, at least 1 kg of uranium can be extracted. For high-grade ores, such as most of those currently being mined in Australia, the energy inputs from uranium mining and milling are relatively small. However, there are significant emissions from the construction and decommissioning of the nuclear power station, with the result that the station must operate for 2-3 years to generate these energy inputs. (For comparison, wind power requires only 3-7 months.[3])

Low-grade uranium ores contain less than 0.01% yellowcake, i.e. they are at least 10 times less concentrated than the high-grade ores. To obtain 1 kg of yellowcake, at least 10 tonnes of low-grade ore has to be mined. This entails a huge increase in the fossil energy required for mining and milling. Van Leeuwen and Smith find that the fossil energy consumption for these steps in the nuclear fuel chain becomes so large that nuclear energy emits total quantities of CO2 that are comparable with those from an equivalent combined cycle gas-fired power station.

Furthermore, the quantity of known uranium reserves, with ore grades richer than the critical level of 0.01%, is very limited. The vast majority of the world's known uranium resources are low-grade. With the current contribution by nuclear energy of 16% of the world's electricity production, the high-grade reserves would only last several decades. If nuclear energy were to be expanded to contribute (say) half of the world's electricity, high-grade reserves would last less than a decade. No doubt more reserves of high-grade uranium ore will be discovered, perhaps even doubling current reserves, but this would be insufficient for a sustainable substitute for coal.

Recently a physicist, Martin Sevior has produced a critique of Van Leeuwen and Smith's results.[4] Sevior's results for high-grade uranium ore are based on the unpublished data from the Swedish electricity utility, Vattenfall. Unpublished sources have low scientific credibility. The actual results are unbelievable: for instance, based on these data, Sevior claims that the energy inputs to the construction of a nuclear power station are generated in only 1.5 months of its operation. This extraordinarily low result is contradicted by several earlier studies by independent analysts, who find that the energy payback period for the construction of both nuclear and coal fired power stations (which use similar types and quantities of construction materials) is several years.[5]

There can be no doubt that, if uranium ore grade declines by a factor of 10, then energy inputs to mining and milling must increase by at least a factor of 10.[6] As ore grade decreases, there has to be grade at which the CO2 emissions from mining and milling become unacceptably high. However, the exact value of this critical ore grade is still subject to continuing scientific debate.

Are there alternative future pathways for nuclear energy that could have lower CO2 emissions? Although there are vast quantities of uranium oxide in the Earth's crust, almost all exist at very low concentrations, typically 4×10^{-4} %, at which 1000 tonnes of ore would have to be mined to obtain 4 kg of uranium in the form of yellowcake. In this case the energy inputs to extract uranium would be much greater than the energy outputs of the nuclear power station. Sea-water contains uranium at a concentration of about 2×10^{-7} %, meaning that 1 million tonnes of sea-water would have to be processed to extract just 2 kg of uranium.

Future options

A theoretically possible option would be to switch to ***fast breeder reactors***, which produce so much plutonium that in theory they can multiply the original uranium fuel by 50. The world's last non-military fast breeder reactor, the French Superphoenix, was closed in 1998, after many technical problems and costing about A$15 billion. Even if another fast breeder were to be built in the future, large-scale chemical reprocessing of spent fuel would be necessary to extract the plutonium and unused uranium. Since spent fuel is intensely radioactive, reprocessing has its own hazards and costs. At present there is only one 'commercial' plant reprocessing spent fuel in the world, La Hague in France. Three plants were built and shut down in the USA and the British plant was closed temporarily in April 2005 following the discovery that high-level liquid waste, equivalent in volume to half and Olympic swimming pool, had been leaking undetected over the previous 9 months.

Another possible response to the shortage of high-grade uranium arises from estimates that there is about three times as much ***thorium*** in the Earth's crust as uranium. Thorium itself is not fissile (that is,. cannot be split), but, by bombarding it with neutrons, it can be converted into uranium-233, which is fissile. In a conventional approach, the neutrons would be produced by fission of a mixture of uranium-235 and plutonium-239. This would be a complicated system involving a type of breeder reactor, which takes us back to the problems outlined in the previous paragraph. India is attempting to develop such a system. A simpler thorium reactor design would use a particle accelerator to produce the neutrons. This has the advantage that the reactor is fail-safe. Unlike an ordinary uranium reactor, the accelerator-driven thorium reactor can be shut down by simply switching off the particle beam. The nuclear wastes produced by this kind of reactor have much shorter half-lives than from a uranium or plutonium reactor.[7]

None of the above proposed 'solutions' is commercially available and some may be decades away. So, on the basis of present nuclear technology and the small existing high-grade uranium reserves, the potential contribution of nuclear power to the reduction of CO^2 emissions is very limited.

References:

1 Mortimer, N 1991, 'Nuclear power and global warming', *Energy Policy* 19:76-8, Jan-Feb.
2 Van Leeuwen, Jan Willem Storm and Smith, Philip 2005, *Can nuclear power provide energy for the future; would it solve the CO2-emission problem?* www.stormsmith.nl (accessed 4/1/06).
3 E.g. Danish Wind Industry Association 1997, *The Energy Balance of Wind Turbines*, www.windpower.org/. See also www.vestas.com/uk/environment/2005_rev/energybalance.asp.
4 Sevior M, 2006, Energy lifecycle of nuclear power. www.nuclearinfo.net/Nuclearpower/WebHomeEnergyLifecycleOfNuclear_Power
5 e.g. AEA Technology 1998, *Power generation and the environment – a UK perspective*. Vol. 1. AEAT 3776. Report prepared for European Commission ExternE study.
6 "At least" because more than one process is involved. It is quite possible that the efficiency of the other processes decline as ore grade declines.
7 Dean T 2006, New age nuclear. *Cosmos* Issue 8, 40-49.

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