Uranium-fuelled nuclear power: too little, too late, to no useful end

> Recent greenhouse gas (GHG) emissions place the Earth perilously close to dramatic climate change that could run out of our control, with great dangers for humans and other creatures. … Only intense simultaneous efforts to slow CO_2 emissions and reduce non-CO_2 forcings can keep climate within or near the range of the past million years. (Hansen et. al. 2007, 1925)
>
> I think we have a very brief window of opportunity to deal with climate change … no longer than a decade, at the most. (James Hansen, quoted in McCarthy & Usborne 2006)

Less than a decade remains to enact solutions that can effectively avoid truly dangerous anthropogenic climate change. Among many others', James Hansen's recent statements attest to that[1]. Nuclear power has been pushed strongly in recent years as an effective means to reduce global greenhouse gas (GHG) emissions. But viewed holistically, such reductions are simply not possible due to three fundamental weaknesses: inherent limitations in the uranium resource; the time required to commission nuclear power facilities; and the emission of greenhouse gases at *every stage* of the nuclear fuel cycle due to the heavy dependence on fossil fuels.

There are myriad other concerns with nuclear power. Long-term (millennial) storage of a range of radioactive wastes, the risks of nuclear weapons proliferation and terrorism, or the monumental costs required, to name but some. All are important and all oblige rigorous, critical scrutiny. Yet none are directly relevant to the problem of climate change, so I will not discuss them here.

Clear and present danger

The opening quotations above, and the volumes of science behind the IPCC's Fourth Assessment Report, make clear that there is little time left to act if we are to avoid dangerous global climate change. A temperature rise of 2°C above pre-industrial times is widely regarded as the point at which such impacts could become inevitable. Research released in 2007 has shown that an increase of 1°C from *today* may trigger an '*albedo flip*' feedback mechanism, causing — among other impacts — sea level rise of 4 ±2m from melting ice sheets (Hansen et. al 2007). This research claims that there is 'little doubt that projected warmings under [Business As Usual (BAU) GHG emission scenarios] would initiate albedo-flip changes as great as those that occurred at earlier times in the Earth's history', and that if current BAU trends continue, in *10 years* emissions will be 40% above those estimated as the necessary level for climate stabilisation (emphasis added, pp. 1936-1938).

The threat to the Earth and to human civilisation from anthropogenic climate change is *urgent*, and any policy aimed at GHG emission reductions must be robustly evaluated in that context.

---

[1] Dr James Hansen is current director of NASA's Goddard Institute for Space Studies and a leading expert and sometimes-activist on the subject of climate change and humanity's contribution to it. See http://www.columbia.edu/~jeh1/ and http://www.giss.nasa.gov/about/.

A nuclear solution

Mark Diesendorf has observed that, beginning in 2000, the nuclear industry has 'mounted a massive international media and lobbying campaign to promote nuclear energy as a solution to the enhanced greenhouse effect' (2007, 247). Nuclear power is promoted as being rapidly deployable and as emitting either *no or only negligible* CO_2. Those two assertions are crucial. If true, then nuclear power may indeed be necessary for GHG mitigation, despite its manifest problems. However, before addressing these claims, there is another facet to the nuclear proposition that demands attention — does the uranium exist?

In short supply

To be a viable long-term energy provider, nuclear power based on the fission of uranium isotopes (largely ^{235}U) requires[2] a reasonably secure supply of uranium ore. Without a fuel source, it truly matters not whatever GHG benefits nuclear power might have. In December 2006, the German-based Energy Watch Group (EWG) released a detailed report analysing the world uranium resource and the question of future supply capacity. Their findings do not favour a nuclear future.

EWG concludes that uranium reserves are sufficient for guaranteed supply of *only 30 years*; ie, 'proved reserves' at current annual demand and below US$40/kgU extraction cost (EWG 2006, 4). Further: 11 countries have already exhausted their domestic reserves; only Canada has ore grades greater than 1% (around 400kt U, and up to 20% grade); 90% of world reserves are below 1% grade and two thirds are below 0.1%.

Moreover, only 42kt of the current 67kt annual demand is actually sourced from new production — the remainder is taken from (largely military) stockpiles that were made before 1980 (EWG 2006, 4). Only around 10 years of those stocks remain, and uranium production capacity must therefore increase by *50%* to match demand *at current reactor capacity* (emphasis added, pg. 4). EWG claims that 'severe uranium supply shortages become likely' after about 2020 (pg. 6).

The following figures illustrate these fundamental uranium resource limits.

[2] Reprocessing and plutonium breeder cycles are discussed shortly.

Figure 1 shows production forecasts based on reasonably assured resources (RAR) below US$40/kgU (approximates 'proved reserves') in red, below US$130/kgU (approximates 'probable reserves') in orange area, and inferred resources (approximates 'possible reserves') in light-blue. The black lines indicate fuel demand trends for currently-operating reactors, together with the IEA's 2006 World Energy Outlook scenarios.

Figure 2 shows EWG's analysis of world uranium resources, as reported by the Nuclear Energy Association in 2006. Importantly, EWG argues that the so-called undiscovered resources are 'highly speculative' and, more likely than not, will never be produced (pg. 7).

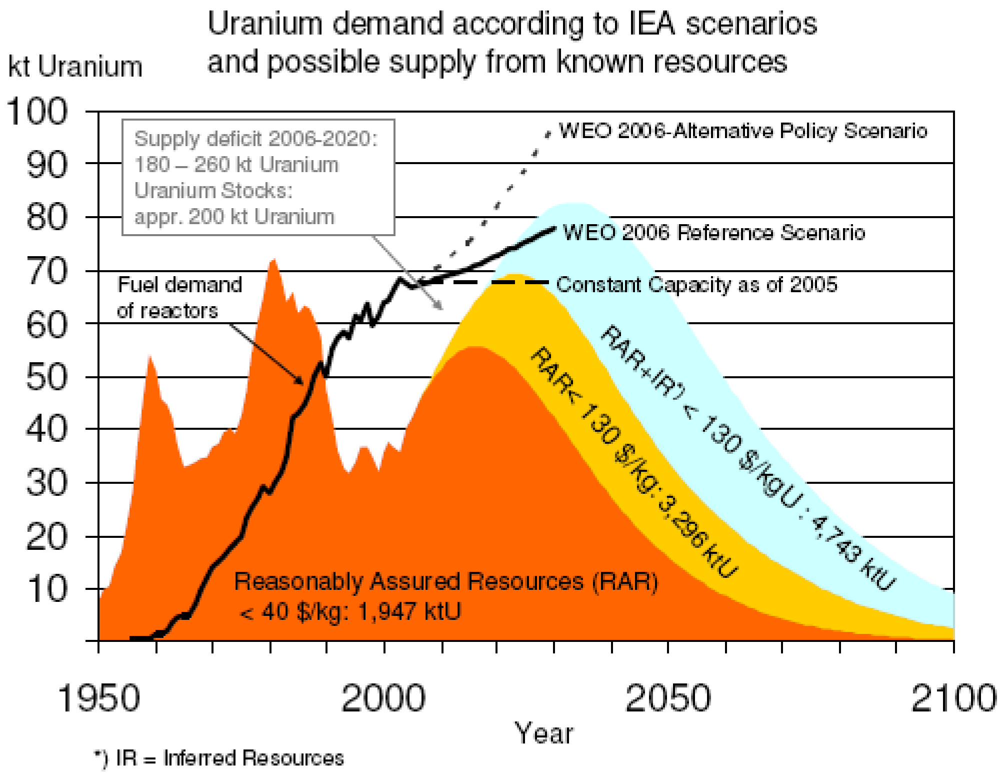

Figure 1 - Past and projected uranium production (EWG 2006, 5)

Resource category		Cost range	Resource [kt]		Data reliability
				cumulative	
Reasonably Assured Resources (RAR)		< 40 $/kgU	1,947	1,947	high
		40 – 80 $/kgU	696	2,643	↑
		80 - 130 $/kgU	654	3,297	
Inferred Resources (IR) - former EAR I		< 40 $/kgU	799	4,096	
		40 – 80 $/kgU	362	4,458	↓
		80 - 130 $/kgU	285	4,743	low
Undiscovered Resources	Prognosticated	< 80 $/kgU	1,700	6,443	↓
		80 - 130 $/kgU	819	7,262	
	Speculative	< 130 $/kgU	4,557	11,819	
		unassigned	2,979	14,798	

Figure 2 - World uranium resources[3] (EWG 2006, 8)

Supplying even the current 67ktU annual consumption would exceed RAR reserves below US$40/kgU by 2030 to 2035; RAR reserves below US$130/kgU would last to around 2050; and inferred resources below US$130/kgU would be exhausted by around 2070 (EWG 2006, 13). So, far from uranium being the source of a nuclear golden age, it is rather ‘very unlikely that beyond 2040 even the present nuclear capacity can still be supplied adequately' (EWG 2006, 15).

What of other forms of nuclear generation or fuel? Unfortunately, ‘… neither nuclear [plutonium] breeding reactors nor thorium reactors will play a significant role [within the next 25 years] because of the long lead times for their development and market penetration’ (EWG 2006, 4). Fast plutonium breeder reactors have yet to operate successfully, at least on a commercial scale, and even a recent pro-nuclear MIT study does not foresee commercial operation within 30 years (Diesendorf 2007, 254). Despite original intentions, spent fuel reprocessing to extract fissile plutonium has not happened to any significant degree (pg. 249). And the much coveted hydrogen fusion simply does not yet exist in any useful sense, nor is it likely to in any relevant timeframe (pg. 256).

[3] Approximately 2.3Mt uranium has been produced since 1945, compared with between 1.9 and 3.3Mt of RAR remaining. Australia has by far the largest uranium resources — RAR up to 747ktU, inferred up to an additional 396ktU — but 90% of these have an ore grade <0.06% (EWG 2006, 10-11).

Out of time

The planning and construction phase for commissioning a nuclear power plant (NPP) takes between 8 and 10 years (Diesendorf 2007, 256). This claim is supported by the IAEA's own data (EWG 2006, 18). EWG 'can forecast with great certainty that at least by 2011 total capacity cannot increase due to the long lead times' (pg. 6). And further, the skilled labour necessary for any increased NPP construction programme is not currently available (pg. 22).

Contrast these timelines with those for large wind farms — less than 1 year — and for small bioenergy plants — less than 2 (Diesendorf 2007, 256).

As of 2000, approximately $303GW_{el}$ of NPP capacity was available. That is around 6.3% of 2005 world primary energy and 15.2% of world electricity supply (IEA 2007). EWG claims maximum operational capacity is 367GW by 2011, and that even the 391GW projected for 2015 by the WEO2006 IEA reference scenario is 'simply not possible' (pg. 17, 20). Due to the rate of decommissioning balanced with current construction, 'just to maintain the present capacity would require much more ambitious investments into nuclear power [than] can be observed today' (pg. 21). In fact, 'maintaining *present capacity* until 2030 seems to be an ambitious goal even when assuming a revival of nuclear projects' (emphasis added, pg. 22). The World Nuclear Association's data shows that net NPP capacity could increase at best 13% (50GW) by 2021 (pp. 21-22). These trends are illustrated in Figure 3.

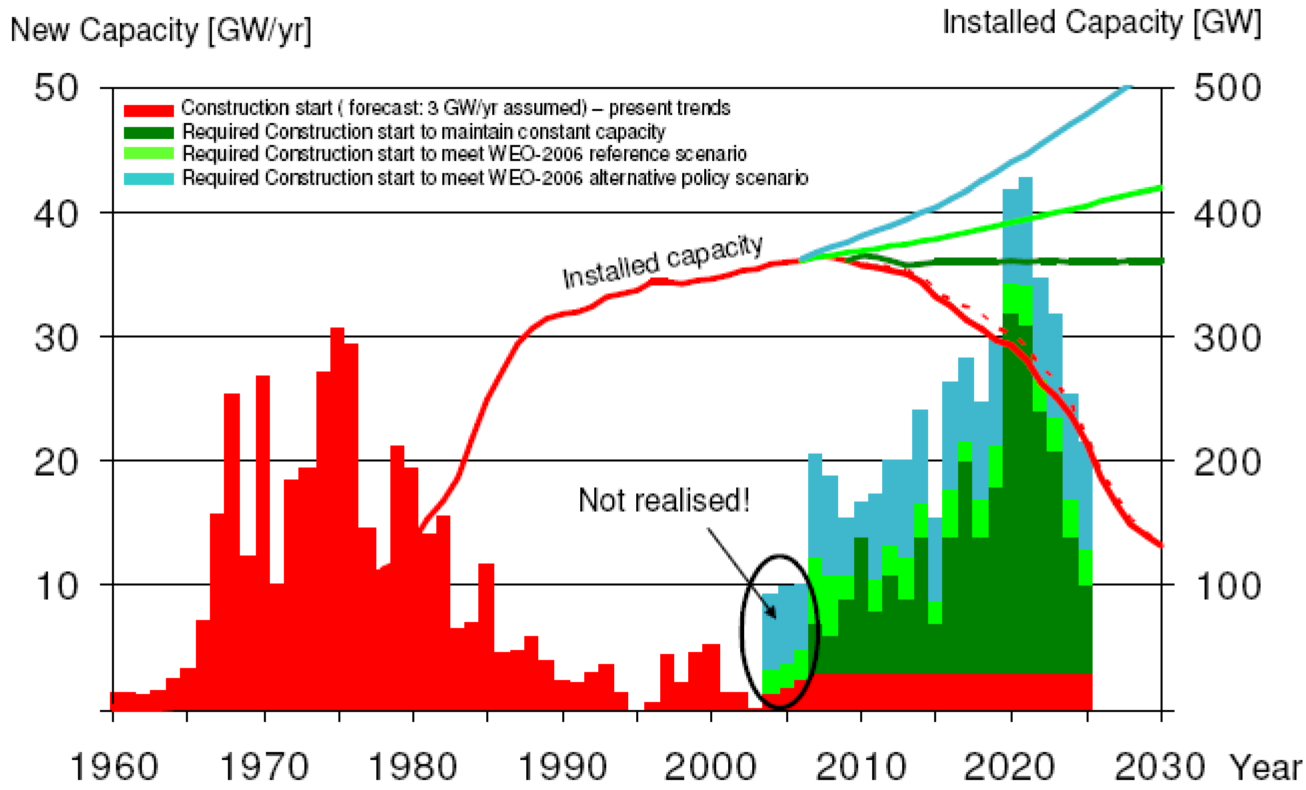

Figure 3 - NPP capacity present and future (EWG 2006, 23)

A long way from 'green'

And now to the central claim of the nuclear push: nuclear power emits little to no CO_2. To assess this assertion, a full and systematic *life cycle analysis* (LCA)[4] of the nuclear fuel chain is required. LCA studies show that 'in reality, only reactor operation is CO_2-free' — mining, milling, fuel fabrication, enrichment, reactor construction, reactor decommissioning, and waste management: all stages use fossil fuels, and all emit CO_2 (Diesendorf 2006, 252). Enrichment in particular can require massive electricity inputs; gaseous diffusion uses *40x* more energy than gaseous centrifuge (Fthenakis & Kim 2007, 2552). Even plant *operation* emits CO_2 due to materials replacement, chemicals, and auxiliary fossil fuel use (pg. 2555). The chain[5] is represented by Figure 4.

[4] Some knowledge of LCA is assumed here, as an explanation would be beyond the scope of this essay.
[5] Diesendorf illustrates the potential for nuclear weapons from the 'peaceful' nuclear chain, either from weapons-grade ^{235}U enrichment, or the reprocessing of spent fuel to extract fissile plutonium. Weapons are not discussed in this essay.

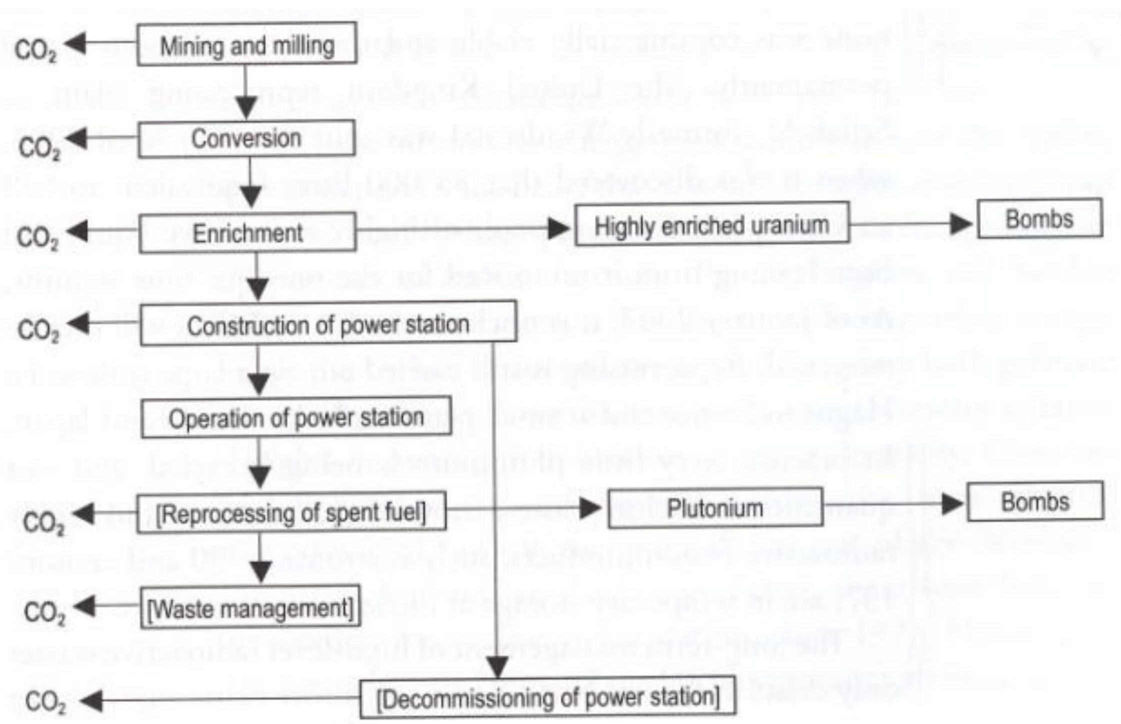

Figure 4 - The nuclear fuel chain and CO_2 emissions (Diesendorf 2007, 249)

LCA of the nuclear fuel chain is rather contested. The most famous study is that of Storm van Leeuwen and Smith from 2005. The authors have been criticised for a range of methodological flaws, questionable assumptions, and the use of poor or old data (Dones 2007); their results are then regarded as statistical 'outliers'. Further, the use of co-production in mining and especially the enrichment facilities' upstream electricity generation energy mix (fossil fuel, etc.) can have large impacts on overall emission results (Fthenakis & Kim 2007, 2553). Nonetheless, the principal message holds true: $C0_2$ emissions from the nuclear chain are significant.

Using aggregated LCA data from a recent Australian review (ISA 2006) as well as from Fthenakis & Kim, Dones, and Storm van Leeuwen and Smith (2005), I have created the following figures comparing life cycle GHG emissions from fossil fuels, various renewables[6], and a range of nuclear scenarios. Figure 5 shows forecast emission ranges from all sources; Figure 6 shows the same data for nuclear only.

[6] Photovoltaics are also highlighted to illustrate that results do not only vary for nuclear

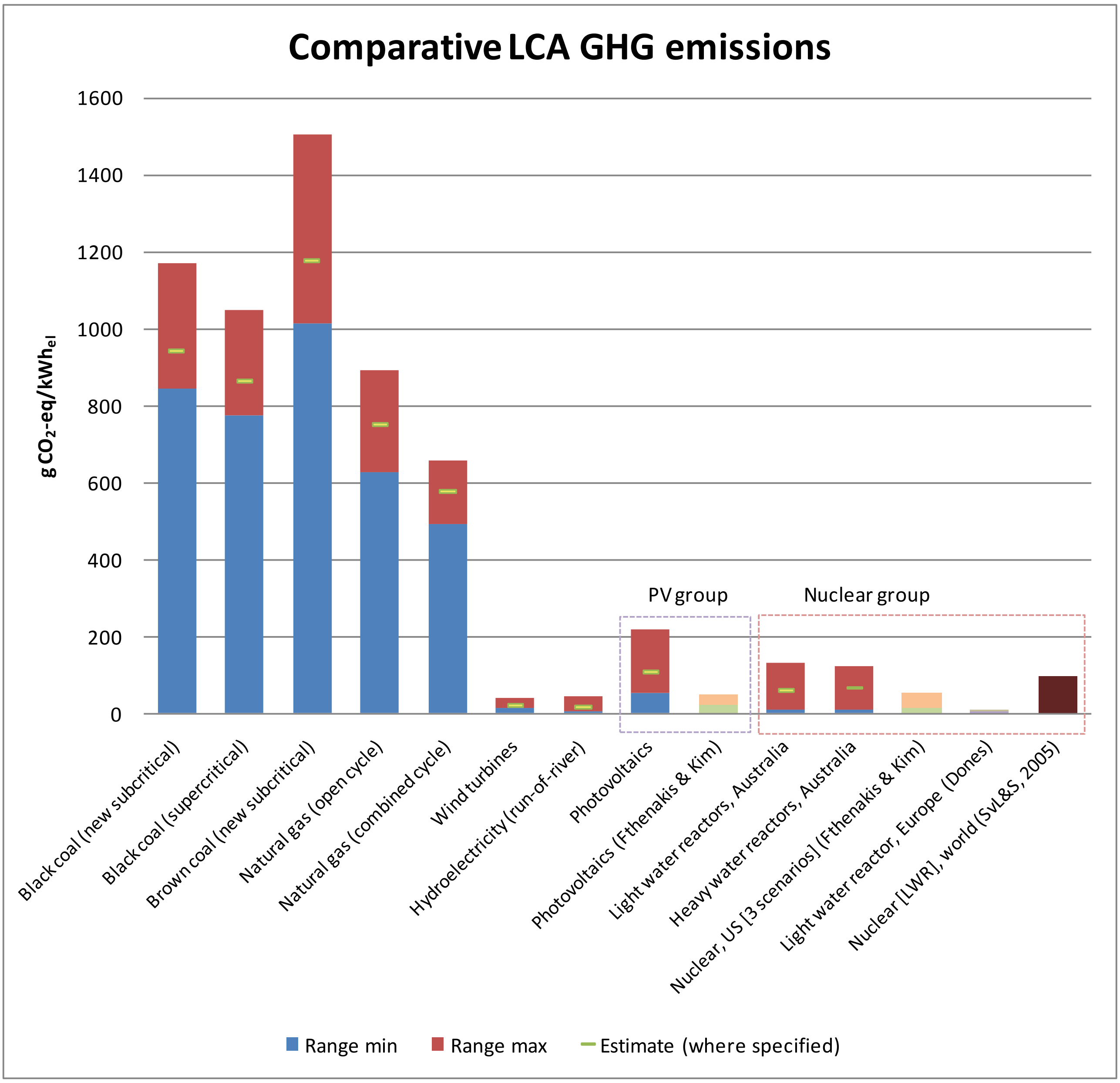

Figure 5 - Comparative GHG emissions

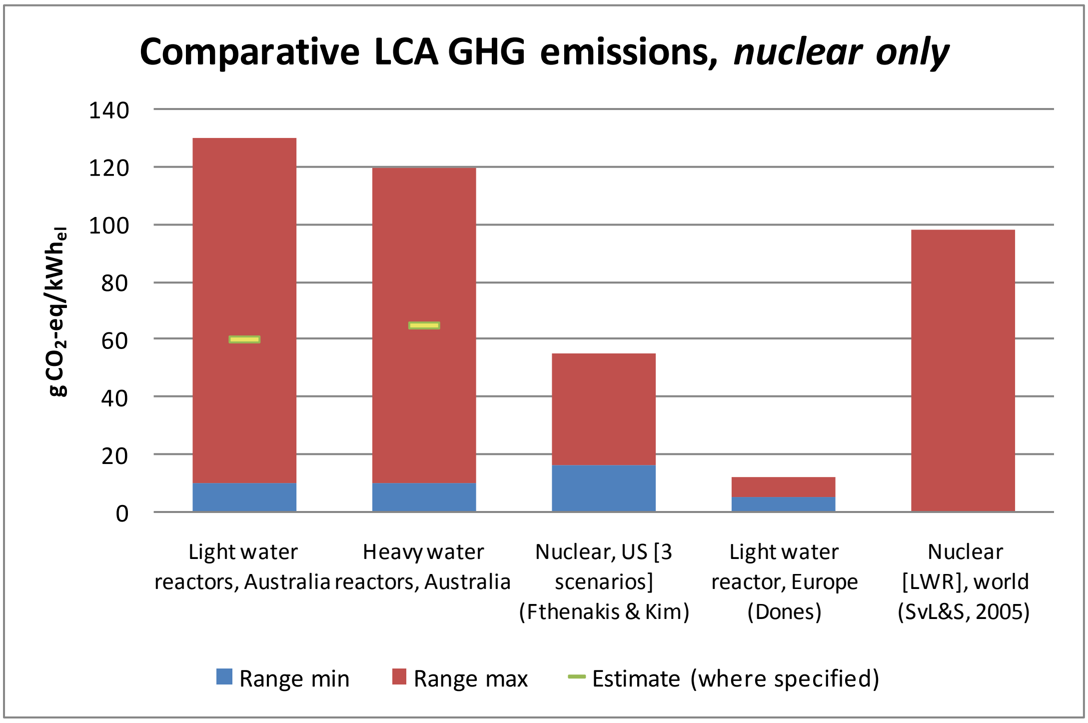

Figure 6 - Comparative GHG emissions for nuclear only

The negative energy balance

One of the most important aspects of Storm van Leeuwen and Smith's work was to call attention to the increasing energy inputs required to extract decreasing uranium ore grades (Dones 2007, 2). They assert that uranium ore grade is the most important parameter in determining the energy balance of the nuclear fuel chain (2007, website); this claim is supported by other work that shows energy for mining and milling 'increases considerably with low-grade ores' (Fthenakis & Kim 2007, 2554).

At a sufficiently low ore grade, energy losses during extraction are such that they 'set a lower limit on the accessible ore quality' (EWG 2006, 30). That is, the energy balance turns negative: more energy is expended in extraction that can be obtained from the fuel. Storm van Leeuwen and Smith found that, if including necessary energy inputs for the full fuel chain, this limit is 0.02–0.01% ore grade (EWG 2006, 31). And for ore grades below 0.01%, total CO_2 emissions are *comparable to that of an equivalent natural gas combined cycle plant* (emphasis added, Diesendorf 2007, 253).

It must be recognised that Storm van Leeuwen and Smith's critics dispute the ore grade point that produces negative energy balance. But Disendorf makes clear that there can be no doubt that extraction energy inputs must increase by at least a factor of 10 for ore grade decline by a factor of 10 (2007, 254). And because this energy is from fossil fuels, there *must* be an ore grade at which **CO_2 emissions are no longer acceptable** for the final electricity NPP can generate (emphasis added, pg. 254).

Missing the point

In many ways, nuclear energy proponents would have us swap one ecologically unsustainable, intergenerational problem for another: rapidly depleting fossil fuels and their pollutants for limited uranium supplies and permanent[7] radioactive wastes. Such thinking misses the point. It perpetuates our civilisation's entrapment in a structural paradigm that Richard Heinberg characterises as the 'Universal Ecological Dilemma', the interlinking of 'population pressure, resource depletion, and habitat destruction - and on a scale unprecedented in history' (2007).

We do not need to follow such a path. As just one example of a viable alternative, Saddler, Diesendorf, and Denniss have shown how Australia — the world's worst per capita GHG emitter and a heavy user of coal — could achieve a 'clean' stationary energy infrastructure by 2040 using only *currently existing* technologies such as biomass, wind, and natural gas (2007). Doing so would reduce Australian stationary energy GHG emissions by 50% on 2001 levels.

Conclusion

The generation of electricity from uranium fission offers no viable avenue for long-term, sustainable GHG reductions. The complex nuclear fuel chain is *by no means* free from CO_2 emissions, and when uranium ore grades decline, its emissions rise dramatically. Moreover, with only a decade or so remaining for effective action on GHG mitigation, nuclear power simply takes too long to bring online. Nuclear power is struggling to retain its *current* capacity; claims that it can play a pivotal role in GHG mitigation, given the pressing timescale of that problem, lack credibility.

Yet perhaps the biggest flaw in the nuclear power fallacy is the ultimate lack of a fuel source — world uranium supplies are unlikely to last more than 70 years, and may become exhausted in as little as 30. The net energy balance from extracting declining ore grades may well become negative long before these limitations are even reached.

Combating anthropogenic climate change and realising GHG mitigation requires different thinking, requires energy policies based on truly sustainable renewable sources and energy efficiency. Were it able to serve as a 'clean' substitute for fossil fuels, nuclear power should rightfully be pursued in the face of the unprecedented threat to our planet's climate. But it cannot do so, and any energy policy that advocates a nuclear future is formed in grave error.

[7] On any meaningful human timescale, hundreds of thousands of years is *permanent*.

REFERENCES

A Climate of Hope. 2007. Electronically-distributed video. Perth: Anti-Nuclear Alliance, WA. NOTE: this reference provided overview information and initial ideas-input, but was not the source of any specific citations in the text above.

Diesendorf, Mark. 2007. Chapter 12 – Is nuclear energy a possible solution? In *Greenhouse Solutions with Sustainable Energy*, 247-270. Sydney: UNSW Press.

Dones, Roberto. 2007. Critical note on the estimation by Storm van Leeuwen J.W. and Smith P. of the energy uses and corresponding CO2 emissions from the complete nuclear chain. *Paul Scherrer Institut*. http://gabe.web.psi.ch/pdfs/Critical%20note%20GHG%20PSI.pdf (accessed 23 October, 2007).

Energy Watch Group. 2006. Uranium Resources and Nuclear Energy. *EWG-Series No 1/2006* (background paper). http://www.energywatchgroup.org/fileadmin/global/pdf/EWG_Uraniumreport_12-2006.pdf (accessed 23 October, 2007).

Fthenakis, Vasilis M and Hyung Chul Kim. 2007. Greenhouse-gas emissions from solar electric- and nuclear power: A life-cycle study. *Energy Policy 35*: 2549-2557.

Hansen, James et. al. 2007. Climate change and trace gases. *Philosophical Transactions of the Royal Society, A* 365: 1925-1954.

Heinberg, Richard. 2007. Peak Everything. *MuseLetter #185* (periodical subscription electronic mailing list): 3 September, 2007.

International Energy Agency (IEA), 2007. *Key World Energy Statistics*. http://www.iea.org/textbase/nppdf/free/2007/key_stats_2007.pdf (accessed Sept 13, 2007).

McCarthy, Michael and David Usborne. 2006. Massive surge in disappearance of Arctic sea ice sparks global warning. *The Independent* (UK), 15 September. http://environment.independent.co.uk/article1603667.ece (accessed 17 September, 2006).

Saddler, Hugh, Mark Diesendorf, and Richard Denniss. 2007. Clean energy scenarios for Australia. *Energy Policy* 35: 1245-1256. ScienceDirect http://www.sciencedirect.com/ (accessed 23 October, 2007).

Storm van Leeuwen, Jan Willem and Philip Smith. 2007. Nuclear power – the energy balance energy insecurity and greenhouse gases (2007 update). http://www.stormsmith.nl/, including individual 'parts' as electronic documents (accessed 23 October 2007).

University of Sydney (ISA). 2006. Life-Cycle Energy Balance and Greenhouse Gas Emissions of Nuclear Energy in Australia - A study undertaken for the Department of Prime Minister and Cabinet of the Australian Government. Electronic document obtained from http://www.dpmc.gov.au/publications/umpner/docs/commissioned/ISA_report.pdf (accessed 23 October, 2007).