The Oil Drum: Europe
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New Nuclear Reactors For The UK: Is This Really A Good Idea?

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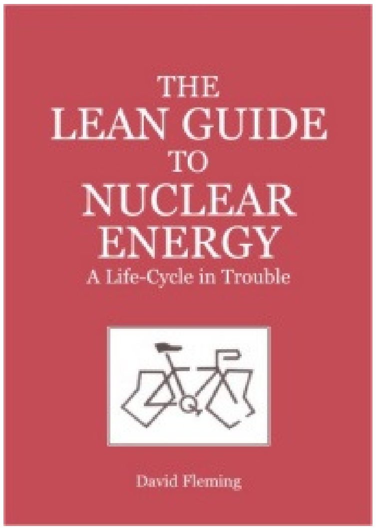
...not when you take into account the uranium-peak, the energy return on energy invested in the nuclear life-cycle, and the prospect of much of the legacy of nuclear waste being abandoned for ever.



This is a guest article by Dr. David Fleming. Fleming is the Founder Director of the Lean Economy Connection, and an independent writer in the fields of energy, environment, economics, society and culture. The article is based on Fleming's recent 56-page booklet, The Lean Guide to Nuclear Energy, which expands and references the arguments presented. The booklet is available to download here: The Lean Guide to Nuclear Energy

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Although the United Kingdom Government has not yet announced a decision to build a new generation of nuclear reactors, this is now looking likely. On Monday 26th November, 2007, the Prime Minister seemed to be preparing the ground:

> "New nuclear power stations potentially have a role to play in tackling climate change and improving energy security. Having concluded the full public consultation we will announce our final decision early in the New Year."
> Bloomberg

And he added that the planning process would be "streamlined", which means that it will not be held up by long public enquiries. This appears to be something the Government is determined will happen quickly.

There are, however, some questions to be raised about this plan. ~The first question is, where will the uranium needed to fuel the new reactors will come from? My own research, The Lean Guide to Nuclear Energy, concludes that, as early as 2013, there will be substantial shortages of uranium worldwide.

At present, annual demand for uranium is running at about 65,000 tonnes. Some 25,000 tonnes of this comes from sources other than mining, and it will be largely exhausted by 2013. 10,000 tonnes is derived from military uranium, the highly-enriched uranium used in Russia's stockpile of nuclear weapons left over from the Cold War. Russia's contract to supply the United States with fuel from this source ends in 2013, and it will not be renewed. Indeed, by that time, Russia's store of military uranium will itself be running low.

Most of the remaining 15,000 tonnes comes from "secondary supplies" – that is, from stockpiles of uranium which were built up when supplies were abundant and comparatively cheap in the 1970s. This, source, too, is getting low, and by the middle of the next decade it will be doing little or nothing to fill the gap between demand and the annual 40,000 tonnes of mined uranium supply.

The supply of mined uranium is stuck at that level, and it now looks likely to decline. Of the dozen nations which are significant sources of uranium, only Kazakhstan shows a useful rate of growth – enough for the time being to compensate for a general decline among the smaller producers. But the industry's hopes of being able to increase its uranium output depend now on two big developments: Cigar Lake in Canada and Olympic Dam in Australia.

Neither of them are looking happy at the moment. Cigar Lake has flooded. The owners are working on the problem, and in principle this could involve freezing the rock around the uranium workings. But clearly this would be an extremely energy-intensive programme and there are doubts whether it will happen. Olympic Dam is at present an underground mine, and the plan is to expand it to opencast, but there is a fundamental problem: the average ore grade is 0.029 percent, on the margin of what is even theoretically capable of yielding net energy.

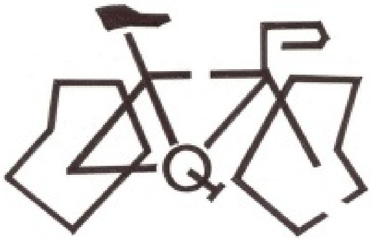
Whether this is in fact rich enough to give a net energy return is disputable, and as a contribution to the debate, *The Lean Guide to Nuclear Energy* suggests that the usual measure of energy return on energy invested (EREI) needs some refinement. On the one hand, there is the theoretical energy return on energy invested (TREI) – which means that you can get net energy from the process under ideal laboratory or prototype conditions, assuming there are no other problems. On the other hand, there is the practical return on energy invested (PREI), which takes the real world into account.

In the case of Olympic Dam, the real world is present, big time: the process of producing uranium oxide requires water – but Olympic Dam is in an area of deep drought. It will require imports of diesel with an energy content not far short of the energy ultimately derived from the uranium. There is some 350 metres of rock overburden to be removed before the ore is reached. If the project does go ahead, this will be because the ore also contains copper, gold and silver, but even this presents problems, because the copper is contaminated with uranium which has to be removed. For a practical return on energy invested (PREI), and in a mine with no secondary products such as gold, a mining company would probably require an ore-quality of 0.1 percent uranium or better. And bear in mind that if the return on energy invested in uranium mining turns negative, the carbon emissions associated with using it are higher than the emissions that would be released if the gas and diesel employed in the process were simply used to generate electricity directly.

In short, both Cigar Lake and Olympic Dam have yet to show that they have a contribution to make. Even if they did go ahead according to plan, total output by the middle of the next decade would still be some 15,000 tonnes short of demand. If it is decided not to go ahead with them, the world's uranium production will be launched on a downward trajectory in line with post-peak oil. We are already hearing the protests characteristic at this stage in the depletion process, that "rising prices will stimulate exploration and bring rich new supplies onto the market". But you can't run a nuclear reactor on rhetoric.

A cautious view would say "Let's wait and see". A useful view would make an informed estimate of the most likely outcomes, and correct it in the light of events. It is a reasonable estimate that, by 2015, the worldwide availability of uranium from all sources will be lower than it is at present. Meanwhile, reactors are being built in China and Russia, both of whom have heavyweight influence in the uranium market. All this means that if the UK Government goes ahead with the construction of, say, four nuclear reactors, ready to go online after 2015, the probability is that they will remain unused. They will be mothballed "until the temporary shortage of uranium has been resolved" – and then they will be quietly left to rot. A possible variant of this is that they will indeed be started up; however, the energy pay-back time for a new nuclear reactor is around seven years (or more, depending in part on the ore grade) so – even if they actually went on line in 2015 – they would not begin to make a net energy contribution until 2022. On current evidence, there is no reasonable prospect of the sustained flow of uranium that would be needed to make this possible.

Meanwhile, the construction projects will have diverted money and policy emphasis away from the fundamentals of energy conservation, structural reform and renewables, and we will be deep into the post-oil peak period without an energy strategy in place. The UK's energy policy, (in common with that of many other nations), will have been reduced to fiasco.



The energy-cost of waste-disposal

Nuclear energy, as everyone knows, produces a lot of waste. Some of it is extremely radioactive and has to be stored for up to 100 years in ponds, separated by boron panels to stop it going critical, and cooled by electrically-driven water pumps to stop it catching fire. It also has to be guarded to protect it from being stolen or attacked. And it has to be kept out of the path of rising sea levels. All this is known, though it is sometimes forgotten.

What is not so widely recognised is that the final disposal of waste will require a lot of energy. This begins to become clear when you think about what has to be done to keep high-level wastes safe for the thousands for years in which they must lie undisturbed. Containers have to be built from steel, lead and electrolytic copper; vast repositories have to be dug and lined with clay; much of the work needs to be done by robots; retired fuel-rods have to be kept cool and safe for a century or so before the final disposal programme begins. Then there is the energy-cost of dismantling and burying the old reactors, doing the best that can done to rehabilitate the disused uranium mines to some semblance of sustainability and safety, and dealing with the stocks of leaking depleted uranium hexafluoride gas. (It is "depleted" in the sense that it has been used as a source of the uranium-235 needed by reactors, but some uranium-235 and all the uranium-238 remains).

So far, there is no sign that we have even begun to think through the implications of the legacy of nuclear waste at present being stored around the planet, and the energy-cost of dealing with it. On the contrary, the only nuclear-waste-related programme that has so far been consistently and (on some criteria) successfully implemented is the use of DU to increase the density of the new generation of armaments. For evidence of the medical consequences and mutations arising from this, and the work of Dr Siegwart-Horst Günther in investigating it, see http://www.criticalconcern.com/depleted_uranium.htm and the Frieder Wagner film *Deadly Dust*. Action to decontaminate areas where it was used in Iraq and, to a lesser extent, in Kosovo, will never amount to more than mitigation, but it is part of the nuclear clear-up programme, and it is urgent that it should be done before the radioactive dust is blown through Central Europe and beyond. An international recognition that DU qualifies as a prohibited weapon under the Geneva and Hague Conventions, would be at least a first step towards focusing on the disturbing potential of the planet's nuclear legacy. A second step would be to take action with respect to the many thousands of tonnes of depleted uranium hexafluoride gas, now in storage all over the planet in containers originally designed to be "temporary".

To deal with the total legacy of waste left by a nuclear reactor through its whole life-cycle requires energy equivalent to about 25 percent of the gross energy supplied by the reactor to the grid. That is a working estimate, which will vary with time and place; the numbers depend critically on the standard of waste management that is adopted – it could of course be done to leaky cowboy standards for less. But that 25 percent – derived from Jan Willem Storm van Leeuwen's work at http://www.stormsmith.nl/, gives us an outline for thinking about it. And note that it is based on like-for-like energy: the unit of account is high-quality energy, the energy that nuclear reactors generate and fed to the grid. In fact, much of the work of clearing the waste would be diesel – which, for each joule it contains, yields roughly one third of a joule of work (mechanical energy and electricity). So, at current efficiency levels, for every joule of energy needed to clean up the nuclear industry's waste, diesel containing roughly three times that amount of energy is needed.

Now, the nuclear energy industry is just coming up to its sixtieth birthday (1950-2010). That means that there is about 60 years-worth of accumulated waste – the "legacy" – to get rid of. 25 percent of that equals 15 years of nuclear electricity production.

And according to some estimates – very optimistic but at least convenient – there are some sixty years of uranium left (at current rates of production). That would mean another 15 years of nuclear electricity production needed just to get rid of the waste that will be produced in the future.

Moreover, the nuclear industry needs a lot of front-end energy too – all the energy used to mine and mill the fuel, build the reactor, etc. That, too, comes to around 25 percent of the nuclear energy produced for the grid.

So, what would this mean for a nuclear industry that really did have the prospect of another sixty years supply of uranium? Subtract (15+15+15) years from the total of 60 years, and we are left with a net flow of nuclear electricity lasting for another 15 years. By 2025, on these assumptions, the nuclear industry will have reached the point at which it must use the whole of its net electricity output (i.e. net of front-end energy costs) to deal with its wastes. If (before 2025) it has not made a substantial start on the waste-disposal programme, and if (after 2025) it does not direct the whole of its net output into the task of waste disposal, it will never be able to dispose of its own wastes using its own energy (or energy equal to its own output from another source). On the assumptions set out here, therefore, the nuclear industry will, in 2025, become energy-bankrupt.

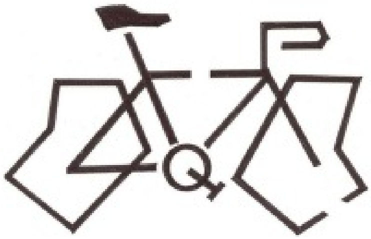
Now, what if there were substantially less – or substantially more – than 60 years supply of uranium left? Some estimates are set out in the table. Suppose, for instance, there were only 30 years supply left (i.e. 2010-2040). That gives us a turning point to energy- bankruptcy in 2010. If there were a mere 10 years supply left (2010-2020), the year of energy-bankruptcy would be 2000.

ENERGY BALANCE SHEET: YEARS OF NET NUCLEAR ENERGY REMAINING FROM 2010 at current rates of extraction. (Assumed start-date for industry 1950. Assumed present 2010. Numbers in years)				
1. Estimate: years of positive PREI ore remaining	10	30	60	200
2. Front-end: process energy (25% remaining years)	2.5	7.5	15	50
3. Energy to clear new waste (25% of remaining years)	2.5	7.5	15	50
4. Energy to clear old waste (25% of past 60 years)	15	15	15	15
5. Total needed for front end plus back end (2+3+4)	20	30	45	115
6. Years remaining (1-5)	-10	0	15	85

7. Year of energy-bankruptcy: all energy produced is needed to dispose of new and old waste: (6+2010)	2000	2010	2025	2095

Suppose the industry, starting with no waste, has 200 years before its usable ore runs out. During that time, it generates a gross amount of energy which it feeds into the grid, but at the same time it must (a) provide the energy needed for its own front-end operation, (b) pay back the energy it used to mine its ore, build its reactors, etc., and (c) clear up its own wastes. As explained in chapter 3, pp 17-18, each of these amount to about 25 percent of its gross energy output. Therefore that amount – 75 percent of its gross output, must be subtracted to find the number of years for which the industry can continue before using the whole of its output to pay back its energy debt and clear up its wastes.

There are other ways in which this could be calculated – for instance, using net output (gross output less the front-end energy cost factored in over time); or the back-end work could start sooner. These would tell slightly different stories, but they would be equally valid. The method shown in the table is a reminder that the industry actually supplies less energy (net) than the gross energy that it puts into the grid. At a time of energy scarcity, this is a key consideration. And it tells us how long the industry has left before waste-disposal becomes the reason for its existence.



Are there other usable sources of uranium?

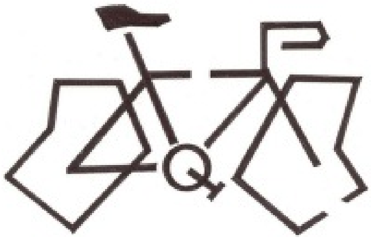
In the light of this, it would come as a relief even to those of us who see nuclear energy as being part of the energy problem, rather than part of the solution, to think that there were some other sources of uranium to sustain supplies while the nuclear industry devotes its final years to the task of cleaning itself up. Various sources have been considered.

For example, there is uranium in granite – about 4 parts per million or 0.0004 percent. The problem here is that it would require so much energy to extract it that the energy used by the nuclear cycle as a whole would amount to around 25 times the energy produced. Seawater also contains some 30 parts per billion, or 0.000003 percent. Here, the energy balance would be better, but the nuclear life-cycle would still use about twice as much energy as it was able to extract and make available to the grid. Phosphate ores are more promising, with uranium concentrations of between 0.007 and 0.23 percent, with an average of around 0.01 percent: the higher-grade ores might give a break-even energy balance in theory, but they still fall a long way short of the cut-off point for a practical return (PREI), which is around 0.1 percent.

And that leaves fast-breeders, based on plutonium-239. The problem here is, first of all, that successful breeding requires three processes: the breeding itself, reprocessing and fuel fabrication. These are fiercely-difficult technologies, awash with radioactive pollutants such as plutonium-241, americium, technetium and other transuranic actinides which have to be separated out (using solvents with a high global warming potential) and then disposed of. Each of the steps has been achieved under test conditions, but sustaining them all three concurrently, safely, on a commercial scale and at a realistic cost is another matter; indeed, there are some doubts as to whether all these criteria can be met at the same time, even in theory. (See *The Lean Guide to Nuclear Energy*, chapter 4).

Secondly, we need to be aware of the limitations of scale here. In the highly-unlikely event of being able to perfect the technology and find sufficient plutonium to start, say, 80 breeders worldwide in 25 years time (2035), then, 40 years later (2075), we would have 160 fast breeders in operation. And that would be our entire fleet of nuclear reactors, for the 440 conventional reactors now in operation – and their successors – will by then be out of fuel.

And thorium? It is an inelegant technology, lumbering through a decay sequence from thorium 232 to thorium-233 to protactinium-233 – and eventually to uranium 233 – along with a swarm of contaminants including the neutron-emitters uranium-232 and thorium-228. Added complications include the long half-life of the protactinium-233 (27 days), so that it lingers around, causing problems in the reactor, and the awkward fact that uranium-233 can be used in nuclear weapons. Then there is the question of what start-up fuel to use: the best one would be uranium-233, but you only get a supply of that at the end of the first cycle. If plutonium-239 is available, it would seem to be more sensible to use it for the fast-breeder programme than to start the even more uncertain thorium cycle. And the problem of scale is even more decisive in the case of the thorium cycle than in the case of fast-breeders. On the best estimate available at present, and pretending for a moment that the technical difficulties are eventually solved, we could look forward in 2075 to a global fleet of perhaps two thorium-based reactors.



How should the remaining years of nuclear energy be used?

Now, that takes us back to the range of depletion forecasts in the table. Opinion will vary, without real prospect of agreement, between the three more realistic turning-points 10, 30 and 60 years hence (2030, 2050 and 2070) beyond which the production of uranium from mines can no longer be sustained at the current rate – and we should bear in mind that actual shortages of uranium will occur well before those dates as the world’s inventories are used up. In my own view, it is sensible to see sustained uranium supplies at current levels lasting for another 10-30 years. This would give us a point of energy-bankruptcy at between 2000 and 2010 – which would mean that the nuclear industry has in effect already passed the point of energy-bankruptcy. On the other hand, critics could rationally argue a case for a production turning-point of 60 years from the present – and that’s fine, but note that this would give us a point of energy bankruptcy in 2025. In other words, unless one is going to take a truly incoherent view and argue that production can be sustained at the current rate for 200 years, it is evident that the end of the life of the nuclear industry as a net source of energy is at hand, and may already have passed. Nuclear energy is not going to be a solution to the coming hydrocarbon-based energy famine. We have a problem.

After the turning-point to energy-bankruptcy, there is a spectrum of choices. At one extreme, it will be agreed that the task of disposing of nuclear waste is so important that the other sources of energy – such as oil – must be directed into the mammoth task of dealing with the nuclear industry’s waste-disposal programme.

At the other extreme, the waste will be left to fend for itself for thousands of years to come. It is unlikely that the electricity supply needed to cool the high-level waste and stop it catching fire will be maintained for that time. There will be no maintenance to prevent leaks, no security to prevent theft, no action to remove high-level wastes from their temporary repositories close to sea-level, and nothing to prevent UF6 gas leaking into the atmosphere. So far, no environmental impact assessment of this situation has been made.

In the light of all this, it is clear that the way forward is to discard any pretence that any of the Big Four energy options are going to be available in the future. Nor is it realistic to hope that renewables will fill the energy gap, The only available option is a systems-approach to energy:

> **Step 1.** Develop the conservation options and technologies as far as possible and with all speed.
> **Step 2.** Move ahead with root-and-branch structural change in the whole pattern of energy use, based on the "proximity principle", and following through the implications for transport, industry, food-production, leisure, land-use and settlement patterns. This has to be a bottom-up process, calling (at long last) on the intelligence and inventiveness of the people rather than relying on government regulation.
> **Step 3.** Develop renewables systems and technologies to match the requirements of Steps 1 and 2. These will be to a large extent localised systems under local control and designed for particular local conditions and energy sources. Local self reliance, local responsibility, local monitoring and local intelligence will need to come together in local systems.

And these three steps – the Lean Energy formula – require a framework, guiding the energy descent, providing ample notice for the dramatic structural changes that will be needed, and guaranteeing all energy users a fair entitlement to supplies of energy throughout this long, ambitious, life-changing programme. Such a framework exists in Tradable Energy Quotas (TEQs), www.teqs.net (previously discussed on The Oil Drum here).

Conclusion

In this article, I have explained why nuclear energy will not provide solutions, or even a rational response, to the coming energy famine. The industry should now be required to use its remaining capability as a source of energy to deal with the legacy of waste which will otherwise be left to contaminate the planet in perpetuity. The implications of that legacy of waste being left untended indefinitely should as an overriding priority be scientifically assessed and published. And I leave you with the conclusion that, whatever details may still be missing from this under-researched subject, the nuclear energy is a life-cycle in trouble.

The United Kingdom Government might think it is worth taking some of these remarks into account before going ahead with its planned new generation of nuclear reactors.