An industry out of time

Submission to the South Australian Nuclear Fuel Cycle Royal Commission

July 2015

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Submission

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Summary

Nuclear power is not a practical option for South Australia.

Even divorced from issues like security, proliferation, safety, insurance, and public opposition, nuclear energy in Australia faces an insurmountable hurdle: solar and wind power, right now, is cheaper than nuclear power, and getting cheaper. In the time it would take to develop an Australian nuclear power industry, it will be made redundant by renewables, if it isn't already.

The case for high level waste storage or use in South Australia is much worse.

Put very simply: there are many countries with a mature nuclear industry, and most of them hold a large amount of high level nuclear waste. If there was a way to profit from that waste, those countries would be in the best position to profit from it.

Expansion of the nuclear fuel cycle in Australia carries tremendous risks for dubious rewards. The problem of what to do with high level nuclear waste is something most developed nations have struggled with, and to date no country has solved it.

By expanding the nuclear industry in Australia, we would create a high level waste problem for ourselves in the hopes that we would be able to not merely solve it, but profit from it. This goes against all the evidence.

Renewables such as solar and wind are rapidly declining in cost and improving in reliability and versatility, and are already cheaper than nuclear power in terms of unsubsidised levelised cost of energy. Why should Australia take on the risks inherent in the production, storage, or processing of nuclear waste and the uncertainties of developing a new industry when ample safe energy is already available?

Introduction

The South Australian government has launched a royal commission into the nuclear fuel cycle, and whether it is desirable to expand the industry, perhaps into power generation, fuel enrichment, and waste storage. The Commission is accepting submissions on four issues papers relating to:

1) Exploration, mining and milling nuclear material
2) Processing and manufacture of radioactive substances
3) Electricity generation from nuclear fuel
4) Nuclear and radioactive waste

Our submission relates mainly to issues papers 2, 3 and 4, in particular relating to economic issues.

Some public figures have been enthusiastic in their support for a nuclear industry in South Australia. Perhaps most prominent is South Australian Senator Sean Edwards, who outlined a plan for South Australia to be paid to take other country's nuclear waste and gain "free electricity".[1]

Unfortunately this plan is not practical for South Australia, as will be clear from our discussion around the issues papers, relating to several broad themes:

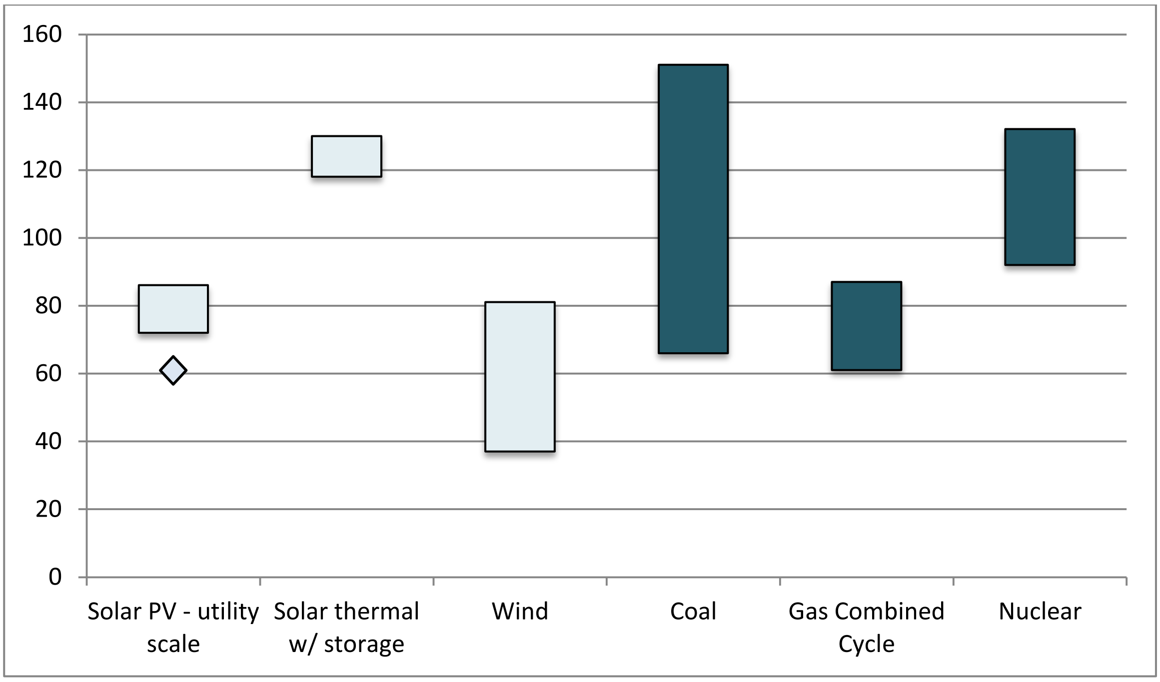
[1] http://decarbonisesa.com/2015/04/08/we-must-act-and-we-must-act-now-speech-from-senator-sean-edwards/

- Comparative costs of nuclear and renewable energy
- Proliferation of nuclear weapons
- Economics of nuclear waste storage
- Technical problems of nuclear waste storage

Comparative costs of nuclear and renewable energy[2]

Global energy markets are at a crossroads. With renewable technology advancing rapidly, and now for the first time being cheaper than older forms of generation in terms of unsubsidised levelised costs,[3] the economics of investment into new fuel-based generators, such as nuclear, is becoming more uncertain.

Figure 5 – Unsubsidised levelised cost of energy ($US/WMh)



Source: Lazard's Levelized Cost of Energy Analysis – Version 8. Note: The diamond shape for solar PV ($60) represents estimated implied levelised cost in 2017.

Whether new, current-technology nuclear power generation is financially viable is doubtful in Australia and even in countries with a more established nuclear history.

France derives almost 80% of its electricity from nuclear power, by far the highest proportion of any country.[4] Despite this, France's state-controlled nuclear power company, Areva, announced a 2014 net loss of about €4.9 billion, greater than the company's stock market value of €3.7 billion (in February 2015).[5] The Olkiluoto power plant Areva is building in Finland is expected to open nine years late and several billion euros over budget.[6]

In the UK, Hinkley Point C is progressing with a generous government guarantee to buy electricity at £92.50/MWh in 2012 prices, which will be linked to inflation for the period of construction and 35 years of operation. By comparison, in January 2015 the unhedged price

[2] Addressing question 3.7; 3.8; 3.16
[3] http://www.lazard.com/media/1777/levelized_cost_of_energy_-_version_80.pdf
[4] http://www.world-nuclear.org/info/Current-and-Future-Generation/Nuclear-Power-in-the-World-Today/
[5] http://www.nytimes.com/2015/02/24/business/international/areva-nuclear-results.html?_r=0
[6] http://www.world-nuclear.org/info/Country-Profiles/Countries-A-F/Finland/

of electricity in the UK was around £50/MWh. Liberium Capital described this arrangement as "economically insane".[7]

Despite this spectacular deal, EDF, the French company contracted to build Hinkley C, has delayed its decision on whether to proceed with the investment, and is proceeding with layoffs at the site.[8] Mycle Schnieder Consulting had this to say:

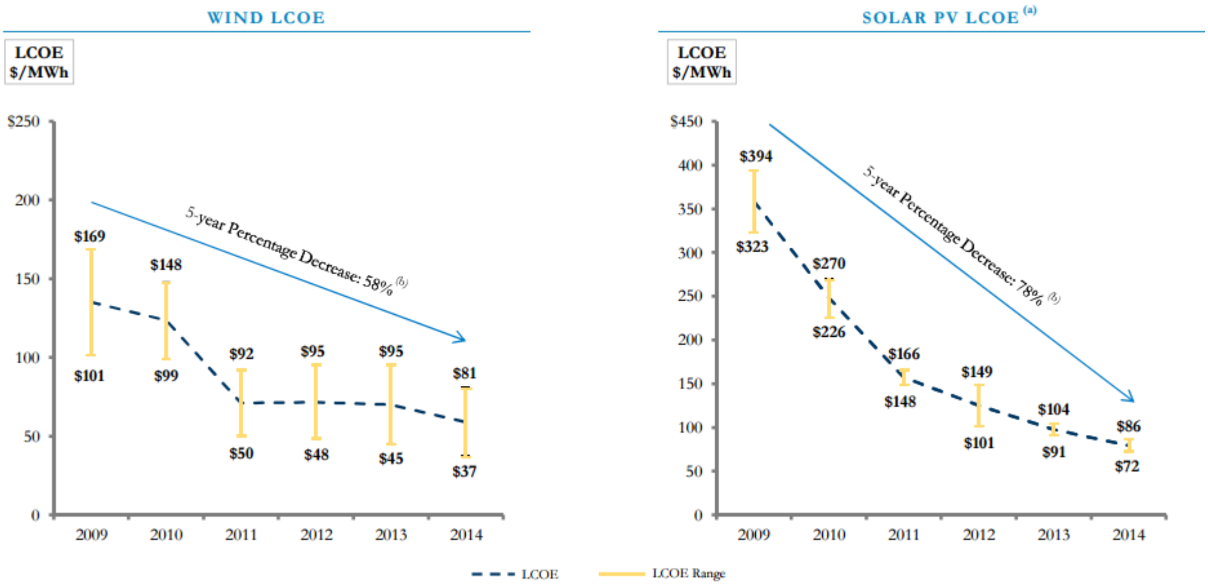
> *Hinkley Point C stands for events and trends. The project was meant to represent the first nuclear new-build decision in the UK for decades, the beginning of a new era of nuclear investment, a sign for the country, for Europe as a whole and far beyond. Today, the project is in a shambles. The selected builder … is technically bankrupt. The selected strategic investor … struggles with a €34 billion debt load and chronically negative cash flow.*[9]

In the US, the first nuclear construction project in 30 years is US$900 million over budget.[10]

These are current-generation reactors being built by experienced nuclear power operators, in countries that already have established nuclear power infrastructure. The Hinkley C project has a guaranteed market worth almost twice the current price, and it is still in trouble.

In contrast to the declining economics of nuclear energy, the main forms of renewable energy are seeing their economics improve. Solar and wind generation technologies have seen rapid declines in cost, and this trend seems set to continue.

Figure 1 – Historical levelised cost of energy – Wind/Solar PV ($US/WMh)



Source: Lazard's Levelized Cost of Energy Analysis – Version 8.0

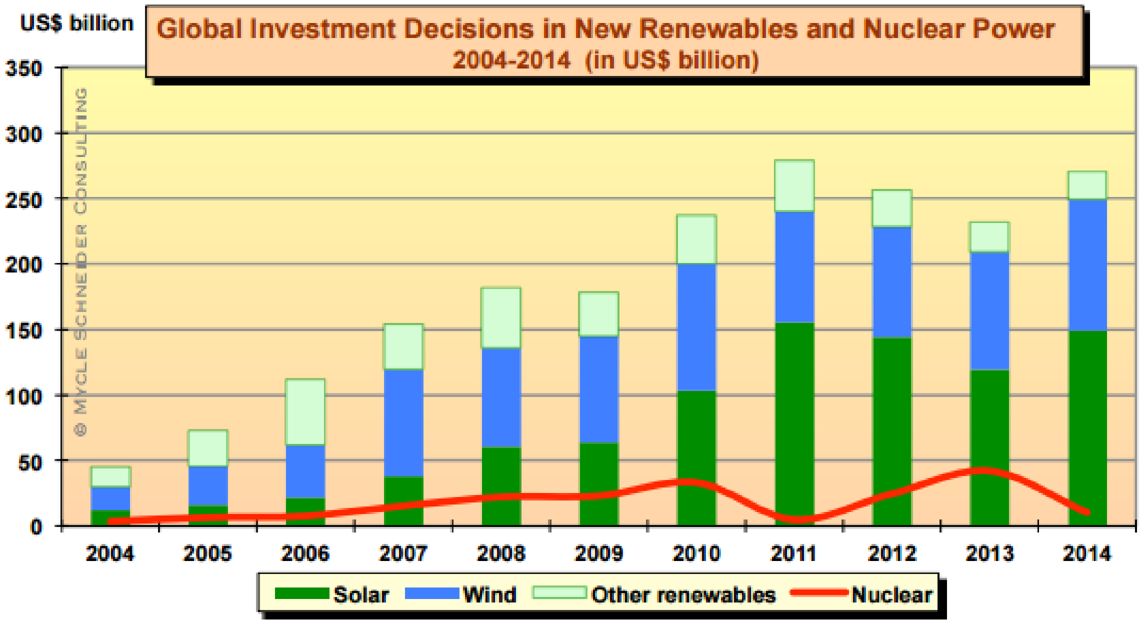
The levelised cost comparison is especially stark for nuclear power. Capital costs are extremely high,[11] and largely up-front, with future fuel costs representing a small proportion

[7] http://www.theguardian.com/environment/2013/oct/30/hinkley-point-nuclear-power-plant-uk-government-edf-underwrite
[8] http://www.nytimes.com/2015/02/24/business/international/areva-nuclear-results.html?_r=0
[9] http://www.worldnuclearreport.org/IMG/pdf/20150715wnisr2015-v1-lr.pdf
[10] http://www.post-gazette.com/businessnews/2013/10/20/Westinghouse-clashes-with-Georgia-Power-over-nuclear-plant-cost-overruns/stories/201310200290
[11] http://www.world-nuclear.org/info/Economic-Aspects/Economics-of-Nuclear-Power/

of the total cost of energy.[12] While solar and wind are becoming cheaper, nuclear power has become more expensive: the OECD Nuclear Energy Agency's calculation of the overnight cost for a nuclear power plant built in the OECD rose from about US$1,900/kWe at the end of the 1990s to US$3,850/kWe in 2009.[13]

The risk involved in building nuclear power plants, with a return on investment requiring a life span that extends far into an uncertain future, appears to have weighed on nuclear investment decisions. Despite talk about a "nuclear renaissance" since 2001,[14] new investment has largely stagnated,[15] especially in comparison to renewables, as seen in Figure 2.

Figure 2 – Global investment, renewables and nuclear, 2004-2014 ($US billions)



Source: FS-UNEP 2015 and WNISR research, from Mycle Schneider Consulting 2015: 'The World Nuclear Industry Status Report 2015'

Looking further ahead, the cost of battery storage that will allow solar and wind to provide 24 hour power is plummeting, as can be seen in figure 3.

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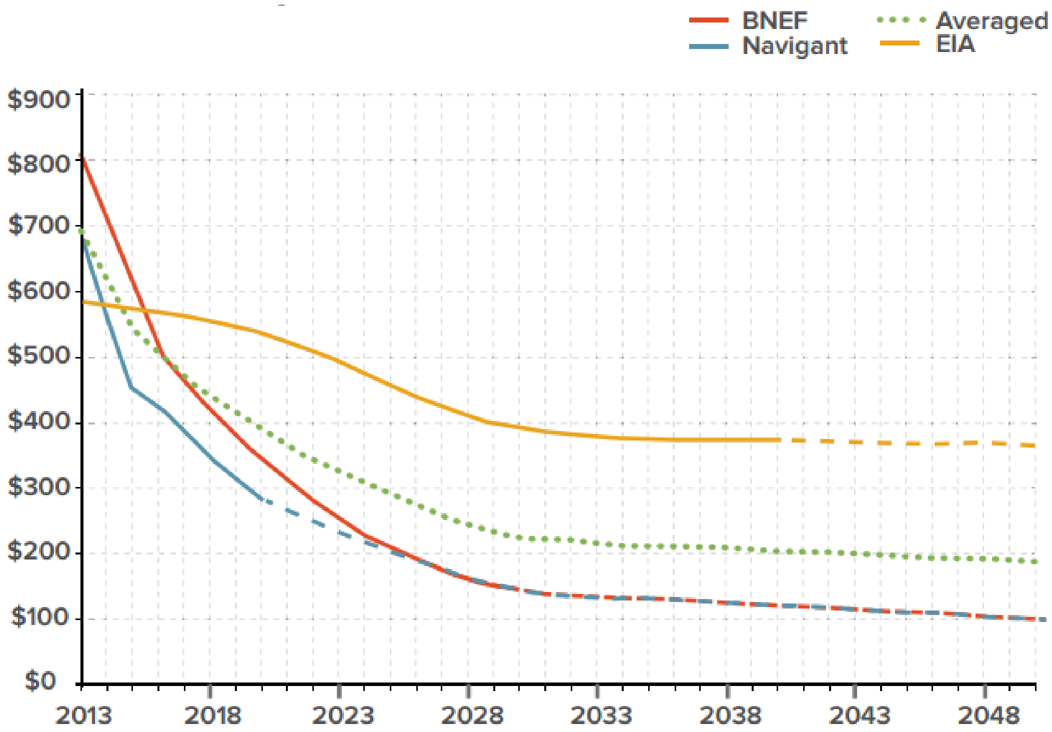
12 http://www.nei.org/Knowledge-Center/Nuclear-Statistics/Costs-Fuel,-Operation,-Waste-Disposal-Life-Cycle

13 http://www.world-nuclear.org/info/Economic-Aspects/Economics-of-Nuclear-Power/

14 http://www.world-nuclear.org/info/Current-and-Future-Generation/The-Nuclear-Renaissance/

15 http://will.illinois.edu/nfs/RenaissanceinReverse7.18.2013.pdf

Figure 3 – Battery price projections (2012 US$/kWh)



Source: Rocky Mountain Institute. 'The Economics of Grid Defection', based on EIA, Bloomberg New Energy Finance, and Navigant Research, Note: dashed line represents extrapolations

The predictions in Figure 3 appear to be conservative: the Massachusetts Institute of Technology (MIT) recently announced assembly-line production of new battery technology at half these prices.[16] Anyone making an investment in nuclear technology would need to consider the price and viability of renewables-plus-battery technology in the decades to come – and on current trends it would appear that renewables are by far the safer bet.

Even existing technology – solar thermal with storage – is competitive with nuclear power in terms of levelised costs, [17] and is capable of peaking generation.[18]

The risks inherent in running a civilian nuclear power program are such that commercially available insurance is inadequate. A range of regimes provide for compensation for damage and loss of life, with a disproportionate amount of the risk borne by governments – and hence by the citizens of nuclear power producing nations.[19] The risk is socialised.

The Fukushima disaster has resulted in the Japanese government covering up to nine trillion yen (around a hundred billion dollars) in expenses.[20] According to reinsurer Swiss Re, the insurance industry will emerge largely unscathed (my bold):

> *Coverage for nuclear facilities in Japan excludes earthquake shock, fire following earthquake and tsunami, for both physical damage and liability. Swiss Re believes that the incident at the Fukushima nuclear power plant is **unlikely to result in a significant direct loss for the Property & Casualty insurance industry**.*[21]

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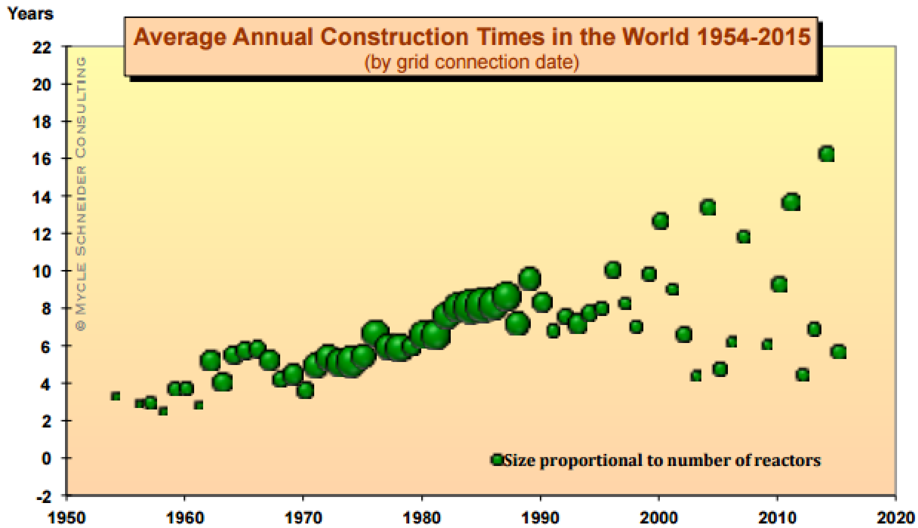
16 http://newsoffice.mit.edu/2015/manufacturing-lithium-ion-battery-half-cost-0623
17 http://www.lazard.com/media/1777/levelized_cost_of_energy_-_version_80.pdf
18 http://www.forbes.com/sites/tonyseba/2011/06/21/the-worlds-first-baseload-247-solar-power-plant/
19 http://www.oecd-nea.org/brief/brief-04-1.html
20 http://www.japantimes.co.jp/news/2015/03/23/national/%C2%A5189-billion-in-public-money-spent-on-fukushima-cleanup-so-far/#.VbWMyvmqpBd
21 http://www.swissre.com/media/news_releases/pr_20110321_japan.html

Unsubsidised levelised costs of energy already favour renewables, but the case for nuclear is even worse when the insurance cover for nuclear power stations is seen as, in effect, a significant subsidy paid by governments for nuclear power.

Australia has considered nuclear power in the past[22], and rejected it. Since then other forms of power have become cheaper and more reliable, while nuclear power has become more expensive[23] and new projects less certain – Figure 4 shows that construction times have frequently blown out in recent years.

Figure 4 – Average annual reactor construction times by grid connection rate



Source: Mycle Schnieder Consulting, based on IAEA-PRIS 2015

As Table 1 shows, countries with well-established nuclear power industries tended to have much lower mean times to build reactors, but even they could have widely varying build times. Note well that this table shows reactors that were successfully completed. The IAEA-PRIS report shows that 87 reactors were cancelled after beginning construction since 1977.

Table 1 – Construction time (in years) of reactor start-ups between 2005 and July 2015

Country	Units	Mean time	Min. time	Max. time
China	18	5.7	4.4	11.2
India	7	7.3	5.1	11.6
South Korea	5	4.9	4	6.4
Japan	3	4.6	3.9	5.1
Russia	3	28.0	25.3	31.9
Argentina	1	32.9	32.9	32.9
Iran	1	36.3	36.3	36.3
Pakistan	1	5.3	5.3	5.3
Romania	1	24.1	24.1	24.1
Total	40	9.4	3.9	36.3

[22] http://www.ansto.gov.au/__data/assets/pdf_file/0005/38975/Umpner_report_2006.pdf
[23] http://www.world-nuclear.org/info/Economic-Aspects/Economics-of-Nuclear-Power/

Source: IAEA-PRIS, MSC, 2015

If Australia begins to develop a nuclear power industry, build times are likely to be long enough that renewables and storage will be well established long before completion, invalidating any realistic business case which is, if European nuclear power profitability and current levelised cost of energy is any guide, already tenuous.

One often stated hope of the nuclear power industry is the fourth generation reactor designs, designed to be safer and to reduce the waste problem by burning spent fuel.

However, despite being based on technology piloted decades ago[24], at commercial scales these reactors are still at the concept stage, and no fourth generation power plants yet exist.[25] Even third generation plants are still getting established, representing a tiny proportion of reactors – the first were built in Japan,[26] and all of Japan's reactors have been shut down since 2011.[27]

Problems with the development of fast reactors, the basis for fourth generation technology, lead the International Atomic Energy Agency (IAEA) to note:

> *During the past 15 years there has been stagnation in the development of fast reactors in the industrialized countries that were involved, earlier, in intensive development of this area. All studies on fast reactors have been stopped in countries such as Germany, Italy, the United Kingdom and the United States of America and* ***the only work being carried out is related to the decommissioning of fast reactors****.*[28]

Fourth generation technology appears on paper to be a great improvement over previous reactor types – but until some are actually built, the risk of developing first-of-its-kind technology are uncertain. The devil may be in the detail.

Proliferation of nuclear weapons[29]

An Australian enrichment or nuclear power industry is a proliferation risk.

At present, needing to create essentially an entire industry from scratch, an Australian government set on developing nuclear weapons would face at least 10-15 years of development. With established enrichment facilities or power stations, a government could realistically develop a weapon in a single term of government.

Centrifuge enrichment

Even low-enriched fuel (~4% uranium-235) represents a significant step towards weapons grade quality.

Uranium naturally exists as two isotopes. The vast majority of natural uranium is U-238, which is not fissile and is not useful as fuel in most reactors. U-235, which is useful,

[24] http://www.ne.anl.gov/About/reactors/frt.shtml
[25] http://www.world-nuclear.org/info/Nuclear-Fuel-Cycle/Power-Reactors/Advanced-Nuclear-Power-Reactors/
[26] Ibid
[27] http://www.world-nuclear.org/info/Country-Profiles/Countries-G-N/Japan/
[28] http://www-pub.iaea.org/MTCD/publications/PDF/Pub1320_web.pdf Bold added
[29] Addressing questions 2.12; 3.14

represents only about 0.72% of the total, or around 1 atom of U-235 for every 139 atoms of U-238.[30] This concentration needs to be increased for uranium to be used as fuel for most reactors, or in weapons.

Centrifuge enrichment involves the conversion of uranium to a gas, uranium hexaflouride (UF_6, often called “hex” in relation to the nuclear fuel cycle). This gas is then cycled through centrifuges to remove non-fissile U-238 until the fissile U-235 represents the desired proportion of the total.[31]

The gross amount of U-235 is not increased. The process simply removes U-238 until the mix is right.

To use a very simple example:[32] imagine a natural mix of 10 atoms of U-235 and 1390 atoms of U-238. Enrichment to 4-5% requires that you remove 1160 atoms from the mix. The resulting mix of 10 atoms of U-235 to 230 atoms of U-238 is sufficient for most light water reactors.

Highly enriched uranium, with 20% or more U-235, used in some reactor types, requires that another 192 atoms of U-238 are removed.

Weapons grade uranium, at around 90% enrichment, requires one more step. This removes nearly all of the remaining U-238, or 38 atoms.

Table 2 – Example stages of enrichment of uranium

Enrichment	Atoms of U-235	Atoms of U-238	% removed	U-238 removed
Natural	10	1390	-	-
Low enrichment (4-5%)	10	230	~80	1160
High enrichment (>20%)	10	38	~80	192
Weapons grade (>90%)	10	1	~80	37

Source: TAI calculations

Purely in terms of mass, each step actually gets easier as the process continues – the vast majority of the mass removed is done so in the first step.[33] By enriching just to a low level, you are actually doing about 70 percent of the work required to make weapons grade material.[34]

A simple bomb design using uranium enriched to weapons grade is so reliable and so simple that the first use of a nuclear weapon in war – the Little Boy bomb dropped on Hiroshima – was done without a prior weapons test.[35] That is, it was the first ever detonation of a uranium-based bomb.

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[30] http://www.nrc.gov/materials/fuel-cycle-fac/ur-enrichment.html
[31] Ibid
[32] http://lewis.armscontrolwonk.com/archive/2620/iran-to-enrich-20-percent-leu
[33] http://www.politifact.com/punditfact/statements/2015/feb/25/michael-morell/odd-reality-irans-centrifuges-enough-bomb-not-powe/
[34] http://www.washingtonpost.com/wp-dyn/content/article/2010/02/08/AR2010020801384.html
[35] http://www.history.army.mil/html/books/011/11-10/CMH_Pub_11-10.pdf

Any Australian government with centrifuge enrichment can produce weapons-grade uranium simply by using the same methods used for fuel production.[36]

SILEX enrichment

Virtually all enrichment is presently done with centrifuges. A new method, however, was developed by an Australian company. Separation of isotopes by laser excitation (SLIEX) is a method to enrich uranium with lasers.[37]

This form of enrichment is especially worrying with respect to proliferation.

Centrifuge technology is well established, but the technical work involved in their construction is extremely specialised, and even nation states have tried and failed to reproduce this technology. There is no realistic way for non-state actors to produce centrifuge cascades and enrich uranium.

With present technology, SILEX enrichment is just as technically challenging. However, unlike the materials and engineering science needed for centrifuges, where the difficulty of manufacturing centrifuges has not significantly improved in decades, laser technology is advancing rapidly. With simpler lasers, it is likely that SILEX processing will become easier than centrifuge enrichment in the near future.[38]

It is also well suited to proliferation because of its size, and relative difficulty to detect. A 1999 US State Department assessment stated "a facility might be easier to build without detection and could be a more efficient producer of high enriched uranium for a nuclear weapons program."[39]

This threat to proliferation is recognised in a treaty between the US and Australia[40] which allows the US to regulate whether the technology can be deployed.

If developed as part of a commercial enrichment industry in Australia, with larger numbers of people necessarily involved in the project than just the research team, the opportunities for proliferation of this sensitive technology necessarily increases. Defection or espionage could quickly allow such technology to reach countries interested in rapid development of a clandestine enrichment program.

Reactors and waste

The use of uranium fuel results in the conversion of some uranium into plutonium.[41] This is not only an extremely dangerous element of nuclear waste, with a half-life of 24,000 years, it is also used in the production of nuclear weapons.[42]

Although highly enriched uranium can be used to build extremely reliable nuclear weapons – such as the Little Boy bomb used to destroy Hiroshima – miniaturised and powerful nuclear weapons more practical for deployment by missile use plutonium. This is also a far more efficient use of uranium – the amount of plutonium needed can be created by converting uranium into plutonium.[43]

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[36] http://www.washingtonpost.com/wp-dyn/content/article/2010/02/08/AR2010020801384_pf.html
[37] http://www.silex.com.au/businesses/silex
[38] http://thebulletin.org/silex-and-proliferation
[39] Ibid
[40] Agreement for cooperation between Australia and the Unite States of America concerning technology for the separation of isotopes of uranium by laser excitation, 1999
[41] http://www.nrc.gov/reading-rm/doc-collections/fact-sheets/plutonium.html
[42] http://fas.org/nuke/intro/nuke/plutonium.htm
[43] Ibid

By generating nuclear power through reactors, Australia could gain access to plutonium. High level waste also usually contains plutonium, which can be extracted.

Fourth generation fast-neutron reactors, such as integral fast reactors (IFR), including General Electric's PRISM design,[44] have been proposed to reduce the possibility of a proliferation threat. That is, wastes, including plutonium, can be recycled through the reactor and burned, leaving a final waste profile that is not useful for creating weapons (apart from "dirty bombs").

However, integral fast reactors are based on breeder reactor technology,[45] which was originally designed specifically to create plutonium for use in weapons programs. An IFR could be used as breeder reactor to generate plutonium for weapons.

Indeed, a US government report mentions General Electric (now GE Hitachi), the same company who is attempting to sell the PRISM IFR design: "GE representatives described the flexibility of converting their full-scale reactor design from burner to breeder operation in a November 1993 status report to DOE."[46]

The report goes on to say:

> *Thus, for the purpose of evaluating the potential impact of the ALMR/IFR on nuclear proliferation risks, it must be considered a breeder-capable reactor system. Even though this system might be capable of operating in a way that uses up plutonium from sources such as dismantled weapons, **if properly modified it could also be used to breed more plutonium**.*[47]

Whatever the initial intention, Australian reactors could be converted by an Australian government to produce weapons far more easily than they could if they needed to begin a nuclear industry from scratch.

Thus fast reactors carry a risk of proliferation.[48] Enrichment necessarily carries a proliferation risk.[49] Even storage of high level waste provides an opportunity to extract weapons-usable material, or to create a "dirty bomb". Reprocessing waste is not the most efficient means to develop weapons, but it is a viable proliferation risk.[50]

A future Australian government wanting to develop nuclear weapons would need to create a nuclear fuel cycle from scratch, taking a decade at least. But with access to either enrichment or power plants, this could realistically be done within a single term of government.

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44 http://gehitachiprism.com/what-is-prism/how-prism-works/
45 http://www.ne.anl.gov/About/reactors/integral-fast-reactor.shtml
46 U.S. Congress, Office of Technology Assessment, Technical Options for the Advanced Liquid Metal Reactor---Background Paper, OTA-BP-ENV-126, May 1994
47 Ibid. Bold added
48 U.S. Congress, Office of Technology Assessment, Technical Options for the Advanced Liquid Metal Reactor---Background Paper, OTA-BP-ENV-126, May 1994
49 http://thebulletin.org/converting-civilian-enrichment-plant-nuclear-weapons-material-facility
50 http://www.world-nuclear.org/info/Nuclear-Fuel-Cycle/Fuel-Recycling/Plutonium/

Economics of nuclear waste storage:[51]

In 2001 Russia made it legal to import radioactive waste for storage, with the government citing hopes to generate $20 billion from importing spent fuel.[52] Large scale movement of waste did not occur, and in 2006 Russia's state nuclear corporation Rosatom announced it would not proceed with taking any foreign-origin used fuel.[53]

Any Australian program to store waste for profit would need to answer the question: if Russia, with a mature nuclear industry, a vast territory, and experience with existing stockpiles of waste was not able to profit from taking waste, how could Australia expect to?

With the ability of governments to export waste a political issue, there is no reliable means to determine which countries could export to an Australian site, or the amount that might be available. For example:

- It is contrary to UK government policy to export nuclear waste, except for reprocessing and return.[54]
- After criticism about legislation that may allow the export of nuclear waste, a spokesman for the German government reiterated that German waste would be kept in Germany.[55]
- The Nuclear Waste Policy Act commits the US to the development of a long term storage facility in the US.[56]
- The World Nuclear Association writes: "At present there is clear and unequivocal understanding that each country is ethically and legally responsible for its own wastes, therefore the default position is that all nuclear wastes will be disposed of in each of the 50 or so countries concerned."[57]

Additionally, the same fourth generation technology that Australia might hope to build which turns spent fuel into a resource[58] would invalidate any business case for high-level waste storage. If Australia can profit from waste by generating electricity, why can't everyone else? If reprocessing can be profitable, wouldn't it be more profitable if sited next to existing stockpiles and existing reactors?

If waste can be profitably turned into electricity, as fourth generation reactors appear able to do, why would anyone pay us to take their waste?

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[51] Addressing questions 4.3; 4.11
[52] http://www.theguardian.com/world/2001/apr/19/russia.ameliagentleman
[53] http://www.world-nuclear.org/info/Nuclear-Fuel-Cycle/Nuclear-Wastes/International-Nuclear-Waste-Disposal-Concepts/
[54] www.gov.uk/government/uploads/system/uploads/attachment_data/file/335821/Final_strategy_NORM.pdf
[55] http://www.dw.com/en/possible-export-of-nuclear-waste-draws-criticism/a-16500605
[56] http://energy.gov/downloads/nuclear-waste-policy-act
[57] http://www.world-nuclear.org/info/Nuclear-Fuel-Cycle/Nuclear-Wastes/International-Nuclear-Waste-Disposal-Concepts/
[58] http://www.ne.anl.gov/About/reactors/integral-fast-reactor.shtml

In April 2015, South Australian Sean Edwards outlined a plan for South Australia to be paid to take other country's nuclear waste, and then turn that waste into electricity.[59]

This plan is self-defeating. If fourth generation reactors are made to work at commercial scales, then other countries don't need to pay us to take their waste – they can use it as fuel. And if fourth generation reactors cannot be effectively deployed, Australia will end up with the same intractable high level waste problem that other countries have failed to solve.

Technical problems of nuclear waste storage[60]

Given the need to store high-level nuclear waste for periods of ten thousand years, it is not possible for any waste storage facility to have truly succeeded yet, but multiple issues with several long-term storage facilities is cause for concern.

In storage facilities meant to last for thousands of years, failures and issues that come up in mere decades are indicative of the perhaps-insurmountable challenge involved.

- Germany's Asse II is a former salt mine which was used to store nuclear waste. Research revealed that radioactive elements were leaking for 20 years before it was reported.[61]

- Another deep geological repository in Germany at Morsleben is in trouble. The salt dome over the facility is now in a state of collapse, and urgent work is proceeding to shore it up.[62]

- Finland is building state of the art storage at Olkiluoto. However, the Royal Institute of Technology in Stockholm found that the planned storage containers corrode one hundred times faster than they were designed to.[63]

- The Waste Isolation Pilot Plant in the US leaked plutonium into the atmosphere when one of the containers exploded, after the wrong kind of cat litter was used to pack the contents.[64]

- After billions of dollars were spent, the US has begun closing the never-used Yucca Mountain repository. In 2009 Steven Chu, then US Secretary for Energy, said, "Yucca Mountain as a repository is off the table. What we're going to be doing is saying, let's step back. We realize that we know a lot more today than we did 25 or 30 years ago."[65]

The technical problems in developing a repository that can last thousands of years are extremely challenging. It remains to be seen if it is even possible.

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[59] http://decarbonisesa.com/2015/04/08/we-must-act-and-we-must-act-now-speech-from-senator-sean-edwards/

[60] This section addresses questions 4.5; 4,8; 4.9

[61] http://www.asse2.de/download/2007-11-01%20Englisch%20ASSE%20II%20Chronologie.pdf

[62] http://www.bfs.de/SharedDocs/Pressemitteilungen/BfS/DE/2009/028.html

[63] http://www.stralsakerhetsmyndigheten.se/Global/Publikationer/Rapport/Technical%20Note/2012/SSM-Rapport-2012-17.pdf

[64] http://www.npr.org/sections/thetwo-way/2014/05/23/315279895/organic-kitty-litter-chief-suspect-in-nuclear-waste-accident

[65] http://www.technologyreview.com/news/413475/q-a-steven-chu/

On such huge timescales, even signs are challenging. The Human Interference Task Force has been working on the problem of warning future humans about the danger for decades.[66] No language has lasted nearly so long, and cultural associations also change. For example, a sequence of images showing a person contacting radioactive material and dying, if read backwards, would show a sick person becoming healthy. The greater the security measures placed on sites, the more that future generations may see those measures has guarding an item of great worth.

No conclusive answer has been found.[67][68]

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66 http://www.osti.gov/scitech/servlets/purl/6799619/

67 http://99percentinvisible.org/episode/ten-thousand-years/

68 http://www.sehn.org/pdf/Kuyek-theory%20and%20Practice%20final%20(July%202011).pdf

Conclusion

Nuclear power is not a practical option for South Australia.

Even divorced from issues like security, proliferation, safety, insurance, and public opposition, nuclear energy in Australia faces an insurmountable hurdle: solar and wind power, right now, is cheaper than nuclear power, and getting cheaper.

Thermal solar with storage – capable of 24 hour electricity generation – is already comparable in cost to nuclear power, and the battery technology that will make renewables viable as a sole generation source is improving rapidly.

In the time it would take to develop an Australian nuclear power industry, it will be made redundant by renewables, if it isn't already.

The case for high level waste storage or use in Australia is much worse.

Put very simply: there are many countries with a mature nuclear industry, and most of them hold a large amount of high level nuclear waste. If there was a way to profit from that waste, those countries would be in the best position to profit from it.

Discussions about free electricity refer to the ability of fourth generation reactor technology – which is yet to be built – to use waste as fuel. Australia may hope to be paid to store other countries' waste, then use that waste to generate electricity.

This opportunity is illusory.

Even if Australia somehow piloted a successful program to deal with the world's nuclear waste problem at a profit – creating a nuclear industry almost from scratch, with all the risks and costs associated with first-of-its-kind technologies – there is nothing preventing those countries with large stockpiles of waste and a developed nuclear industry from profitably replicating our innovations.

If we develop a way for everyone to profit from waste, why would anyone pay us to take their waste? Where is our competitive advantage?

By developing a nuclear power and/or waste industry in Australia, we would create a high level waste problem for ourselves in the hopes that we, unlike all the other nations who have tried, could solve it – like a person who takes up smoking just to prove they can quit.

A far better solution for South Australia would be to avoid the problem in the first place.

A country with large stockpiles of high level nuclear waste has a strong motivation to develop a solution. There are several wealthy industrialised nations with far larger economies than Australia's who have just that problem. Surely, if it is worth the investment to develop new technologies that could provide a solution, they should make that investment. And even if we were able to prove those technologies, surely they would use those solutions themselves – eliminating the very reason for our own industry to exist.

Transferring the problem to Australia carries the maximum possible risk for the minimum possible reward.

Fourth generation integral fast reactor technology – if it can be made to work on an industrial scale – represents a great opportunity for countries with existing stockpiles of high level waste, taking waste that lasts tens of thousands of years, and turning it into waste that will last only a few hundred years.

But Australia would not be reducing ten-thousand-year waste down to five-hundred-year waste. Australia, by developing a new nuclear industry, would be going from no high level waste at all, up to five-hundred-year waste. Will it be easier to deal with than ten-thousand-year waste? Yes. But five hundred years is still a long time, and this waste is still much worse than having no high level waste at all.

A lot can happen in five hundred years. Construction of waste storage that can last so long is not a simple task.

That also relies on fourth generation reactor technology working the way it is hoped. On paper it seems excellent, but the devil may be in the detail. If it doesn't work as planned or at the scales required Australia could be saddled with waste that lasts tens of thousands of years.

Quite apart from the difficulty of securing high level waste against the worst that ten thousand years of nature might throw at it, we truly have no idea what kind of society might exist on such time scales. Just developing warning signs that will be understood by future humans has been a massive task.

So far, multiple facilities designed to store waste for thousands of years have run into problems in mere decades. Asse II was leaking for 20 years before it was reported; the Morsleben salt dome is collapsing; Olkiluoto's storage containers have been found to corrode a hundred times faster than they were designed to; and last year the WIPP in the US leaked plutonium into the local environment when one of the containers exploded, after the wrong kind of kitty litter was used to pack the contents.

In 2001 the Russian Duma passed legislation permitting the import of nuclear waste for storage, and government sources expressed the hope that they could generate $20 billion by taking spent fuel from other countries. Five years later Russia's state nuclear corporation Rosatom announced it had given up trying to take any foreign-origin used fuel.

If Russia, with vast territory, a mature nuclear power industry, and experience with their own stockpiles of waste, could not establish a waste dump for profit, what chance does Australia have of succeeding in such an enterprise?

The scale of risk involved in developing a long term solution to high level waste is immense, and whether a solution exists to be found is uncertain. There is no reason to think Australia will succeed where everyone else has failed, let alone do it so well that we can profit from the business.

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