Submission to the Senate Environment and Communications Legislation Committee

Inquiry into the *Environment and Other Legislation Amendment (Removing Nuclear Energy Prohibitions) Bill 2022*

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The Wilderness Society
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Conservation SA
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1. EXECUTIVE SUMMARY

Our groups maintain that federal and state legal prohibitions against the construction of nuclear power reactors have served Australia well. We strongly support the retention of these prudent, long-standing protections.

Proponents of the *Environment and Other Legislation Amendment (Removing Nuclear Energy Prohibitions) Bill 2022 (The Bill)* are seeking to remove these prohibitions, claiming this is needed to address climate change. However nuclear power is – at best – a distraction to effective climate action.

It is important to note that promoters of nuclear power in Australia are not suggesting we build the nuclear technology that currently exists in the commercial world. The reactors that exist today are increasingly seen as a high cost and high-risk way to make electricity. They are also directly linked to high-level radioactive waste and nuclear security, weapons and terrorism concerns.

Nuclear promoters are staking their hopes – and Australia's energy future – on technology which is uncertain and unproven. At the time of the 2021 Glasgow COP26, the UN Secretary General's Special Advisor on Climate Change Selwin Hart stated that nations seeking to base their climate response on technologies that have not yet been developed are "reckless and irresponsible."[1]

The good news about the renewed nuclear discussion is that it highlights that business as usual with fossil fuels is not an option. The bad news is the very real risk of delay, distraction and a failure to advance a just energy transition.

In response to the 2019 federal inquiry by the Standing Committee on Environment and Energy into the pre-requisites for nuclear power, over 60 Australian organisations representing millions of Australians, and including trade unions, Indigenous, environment, health, faith and peace groups, signed a joint statement opposing nuclear power:

> *"Our nation faces urgent energy challenges. Against a backdrop of increasing climate impacts and scientific evidence the need for a clean and renewable energy transition is clear and irrefutable. All levels of government need to actively facilitate and manage Australia's accelerated transition from reliance on fossil fuels to low carbon electricity generation.*
> *The transition to clean, safe, renewable energy should also re-power the national economy. The development and commercialisation of manufacturing, infrastructure and new energy thinking is already generating employment and opportunity. This should be grown to provide skilled and sustainable jobs and economic activity, particularly in regional Australia.*
> *There should be no debate about the need for this energy transition, or that it is already occurring. However, choices and decisions are needed to make sure that the transition best meets the interests of workers, affected communities and the broader Australian society.*
> *Against this context the federal government has initiated an Inquiry into whether domestic nuclear power has a role in this necessary energy transition. Our organisations, representing a diverse cross section of the Australian community, strongly maintain that nuclear power has no role to play in Australia's energy future.*
> *Nuclear power is a dangerous distraction from real movement on the pressing energy decisions and climate actions we need. We maintain this for a range of factors, including:*

[1] https://au.news.yahoo.com/broke-the-trust-telling-detail-in-morrisons-call-with-french-pm-222011707.html

Waste: *Nuclear reactors produce long-lived radioactive wastes that pose a direct human and environmental threat for many thousands of years and impose a profound inter-generational burden. Radioactive waste management is costly, complex, contested and unresolved, globally and in the current Australian context. Nuclear power cannot be considered a clean source of energy given its intractable legacy of nuclear waste.*
Water: *Nuclear power is a thirsty industry that consumes large volumes of water, from uranium mining and processing through to reactor cooling. Australia is a dry nation where water is an important resource and supply is often uncertain.*
Time: *Nuclear power is a slow response to a pressing problem. Nuclear reactors are slow to build and license. Globally, reactors routinely take ten years or more to construct and time over-runs are common. Construction and commercialisation of nuclear reactors in Australia would be further delayed by the lack of nuclear engineers, a specialised workforce, and a licensing, regulatory and insurance framework.*
Cost: *Nuclear power is highly capital intensive and a very expensive way to produce electricity. The 2016 South Australian Nuclear Fuel Cycle Royal Commission concluded nuclear power was not economically viable. The controversial Hinkley reactors being constructed in the UK will cost more than $35 billion and lock in high cost power for consumers for decades. Cost estimates of other reactors under construction in Europe and the US range from $17 billion upwards and all are many billions of dollars over-budget and many years behind schedule. Renewable energy is simply the cheapest form of new generation electricity as the CSIRO and the Australian Energy Market Operator concluded in their December 2018 report.*
Security: *Nuclear power plants have been described as pre-deployed terrorist targets and pose a major security threat. This in turn would likely see an increase in policing and security operations and costs and a commensurate impact on civil liberties and public access to information. Other nations in our region may view Australian nuclear aspirations with suspicion and concern given that many aspects of the technology and knowledge base are the same as those required for nuclear weapons. On many levels nuclear is a power source that undermines confidence.*
Inflexible or unproven: *Existing nuclear reactors are highly centralised and inflexible generators of electricity. They lack capacity to respond to changes in demand and usage, are slow to deploy and not well suited to modern energy grids or markets. Small Modular Reactors (SMRs) are not in commercial production or use and remain unproven and uncertain. This is no basis for a national energy policy.*
Safety: *All human made systems fail. When nuclear power fails it does so on a massive scale. The human, environmental and economic costs of nuclear accidents like Chernobyl and Fukushima have been massive and continue. Decommissioning and cleaning up old reactors and nuclear sites, even in the absence of any accidents, is technically challenging and very costly.*
Unlawful and unpopular: *Nuclear power and nuclear reactors are prohibited under existing federal, state and territory laws. The nuclear sector is highly contested and does not enjoy broad political, stakeholder or community support. A 2015 IPSOS poll found that support among Australians for solar power (78–87%) and wind power (72%) is far higher than support for coal (23%) and nuclear (26%).*
Disproportionate impacts: *The nuclear industry has a history of adverse impacts on Aboriginal communities, lands and waters. This began in the 1950s with British atomic testing and continues today with uranium mining and proposed nuclear waste dumps. These problems would be magnified if Australia ever advanced domestic nuclear power.*

> ***Better alternatives:*** *If Australia's energy future was solely a choice between coal and nuclear then a nuclear debate would be needed. But it is not. Our nation has extensive renewable energy options and resources and Australians have shown clear support for increased use of renewable and genuinely clean energy sources.*
> ***The path ahead:*** *Australia can do better than fuel higher carbon emissions and unnecessary radioactive risk. We need to embrace the fastest growing global energy sector and become a driver of clean energy thinking and technology and a world leader in renewable energy technology.*
> *We can grow the jobs of the future here today. This will provide a just transition for energy sector workers, their families and communities and the certainty to ensure vibrant regional economies and secure sustainable and skilled jobs into the future.*
> *Renewable energy is affordable, low risk, clean and popular. Nuclear is simply not. Our shared energy future is renewable, not radioactive."*

There is now a consensus or near-consensus that, in the words of Dr. Ziggy Switkowski at the 2019 federal nuclear inquiry, "the window is now closed for gigawatt-scale nuclear" in Australia. Dr. Switkowski further noted that "nuclear power has got more expensive, rather than less expensive", that there is "no coherent business case to finance an Australian nuclear industry", and that no-one knows how a network of small modular reactors (SMRs) might work in Australia because no such network exists "anywhere in the world at the moment".

The 2019 federal nuclear inquiry[2] included Coalition MPs who were, in principle, enthusiastic about nuclear power. However, the Committee's report argued that the government should retain legal bans prohibiting the development of conventional, large nuclear power reactors ("Generation I, Generation II and Generation III").[3] Committee chair Ted O'Brien said, "Australia should say a definite 'no' to old nuclear technologies."[4]

The Committee's report called for a partial repeal of legal bans to permit the development of "new and emerging nuclear technologies" including SMRs, a call that was ruled out by the Morrison government.[5] The current Labor federal government and the Australian Greens (among others) support the legal prohibitions.

The Labor dissenting report to the 2019 federal nuclear inquiry argued for retaining the prohibition:

> *"There is no basis for lifting the legislative prohibition on nuclear energy (Recommendation 3). There is no need for additional work or specific investigations into the science or economics of nuclear energy (Recommendation 2) as Australia already has significant expertise and engagement in this space through the Australian Nuclear Science and Technology Organisation (ANSTO), the Australian Radiation Protection and Nuclear Safety Agency (ARPANSA), the Australian Energy Market Operator (AEMO), the Commonwealth Scientific and Industrial Research Organisation (CSIRO), and through our nuclear-related international treaty-based collaborations. Devoting resources to a nuclear wish-fulfilment exercise, including what sounds like a nuclear propaganda exercise (e.g., 'manage a*

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[2] https://www.aph.gov.au/Parliamentary_Business/Committees/House/Environment_and_Energy/Nuclearenergy
[3] https://www.aph.gov.au/Parliamentary_Business/Committees/House/Environment_and_Energy/Nuclearenergy/Report
[4] https://www.aph.gov.au/About_Parliament/House_of_Representatives/About_the_House_News/Media_Releases/Nuclear_Energy_-_Not_without_your_approval
[5] https://www.adelaidenow.com.au/technology/parliamentary-committee-recommends-lifting-ban-on-modern-nuclear-power-technology/news-story/5038879775154790521 1b5a49cf3786f
https://www.smh.com.au/politics/federal/taylor-rejects-call-for-partial-lift-of-nuclear-power-ban-20191213-p53jsf.html

> *community engagement program that would educate and inform Australians') would be a costly and wasteful distraction."*

We wholeheartedly agree.

A January 2019 statement issued by the Climate Council, comprising Australia's leading climate scientists and other policy experts[6] argued that nuclear power reactors "are not appropriate for Australia and probably never will be" and further stated:

> *"Nuclear power stations are highly controversial, can't be built under existing law in any Australian state or territory, are a more expensive source of power than renewable energy, and present significant challenges in terms of the storage and transport of nuclear waste, and use of water".*

The pressing climate and energy crisis would be exacerbated by opening the door to nuclear power which would complicate and delay the much-needed transition away from fossil fuels. The opportunity cost of investing time and money in Gen IV nuclear power concepts and SMRs would be high and would distract from far more effective climate responses, especially as novel nuclear technology is unproven, not commercially available, and retains many of the same problems and risks as conventional, large-scale nuclear power.

SMRs do not have any meaningful existence. Some small reactors exist but currently there is no such SMR mass manufacturing capacity, and no company, consortium, utility or national government is seriously considering betting billions building an SMR mass manufacturing capacity. The only two operating SMRs – one each in Russia and China – could only loosely be described as SMRs (lacking serial factory construction of reactor components or 'modules'). Both were long delayed and subject to large cost increases.

Instead, we should embrace a diverse suite of renewable energy options. Australia is well placed to be a global leader in this sector and to grow and enjoy the clear environmental, energy security and economic benefits.

Further, we maintain that the prohibitions on nuclear power should be retained because:

1. Nuclear power could not possibly pass any reasonable economic test. It could not be introduced or maintained without huge taxpayer subsidies and would undoubtedly result in higher electricity prices.
2. There is no clear social license to introduce nuclear power to Australia. Opinion polls indicate that Australians are strongly opposed to a nuclear power reactor being built in their local vicinity (10–28% support, 55–73% opposition); and opinion polls find that support for renewable energy sources far exceeds support for nuclear power (for example a 2015 IPSOS poll found 72–87% support for solar and wind power but just 26% support for nuclear power).
3. The pursuit of a nuclear power industry would almost certainly worsen patterns of disempowerment and dispossession that Australia's First Nations communities have and continue to experience from uranium, nuclear and radioactive waste projects.
4. The issue of the long-term management of low, intermediate and high-level nuclear waste resulting from a nuclear power should preclude further consideration nuclear power as an energy option. This unresolved inter-generational waste issue highlights that nuclear is not a 'clean' energy source.

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[6] https://www.climatecouncil.org.au/nuclear-power-stations-are-not-appropriate-for-australia-and-probably-never-will-be/

5. The introduction of nuclear power would delay and undermine the development of effective and cost-effective energy and climate policies based on renewable energy sources and energy efficiency.
6. Introducing nuclear power to Australia would necessitate 10 years for planning and approvals, 10 years for construction, and an estimated 6.5 years[7] to repay the energy and carbon debts from construction. Thus, nuclear power could only begin to contribute to reducing greenhouse emissions around 2050 even in the unlikely event that legal prohibitions were repealed in the near future. If we assume 10 years for the repeal of current legal prohibitions, nuclear power could only begin to contribute to reducing greenhouse emissions around 2060.
7. Nuclear reactors are increasingly vulnerable to climatic changes and extreme weather conditions.
8. Significant security and safety considerations, including the potential for infrastructure weaponisation and the vulnerability of civilian nuclear reactors in conflict zones as highlighted in the Ukraine war.

It is important to note that the impact of the nuclear industry on First Nations communities in Australia and globally has been disproportionate and discriminatory. In Australia this can be seen in many cases, including long standing concerns and tensions over radioactive waste management.

Decades-long efforts to establish a repository and store for Australia's low and intermediate-level radioactive wastes continue to flounder. The federal Labor government has inherited and is currently progressing the previous government's plans for a national nuclear waste facility near Kimba in regional South Australia. This is despite the opposition of many local farmers and the unanimous opposition of the Barngarla Traditional Owners. A legal challenge initiated by Barngarla Traditional Owners is currently underway and contest around the waste plan is growing.

Our groups believe there is a pressing need for the federal government to pause the current National Radioactive Waste Management Facility process pending the findings of a dedicated inquiry that explores all available options for the management of Australia's existing holdings of radioactive waste.

The policy calcification and community division around the management of our existing national radioactive waste inventory should sound a cautionary note over any moves to take Australia further down a nuclear path.

Indeed, former Resources Minister Matt Canavan stated in June 2019 that "if we can't find a permanent home for low-level radioactive waste associated with nuclear medicines, we've got a pretty big challenge dealing with the high-level waste that would be produced by any energy facilities".

Fortunately, we are not faced with the limited energy options of coal, gas or nuclear.

A growing number of expert studies have mapped out viable, affordable scenarios for 100% renewable electricity generation in Australia[8], while numerous studies demonstrate the significant and widening cost advantage enjoyed by renewables compared to nuclear power. Moreover, CSIRO/AEMO research shows that even when transmission and storage costs are factored in, renewables are still far cheaper than nuclear power.

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[7] http://pandora.nla.gov.au/pan/66043/20061201-0000/www.dpmc.gov.au/umpner/docs/commissioned/ISA_report.pdf
[8] https://nuclear.foe.org.au/clean-energy-studies/#two

Australia cannot afford to lose more time on energy ‘culture-wars’ or on the false promise of unproven and non-commercial technology.

The former Chair of the US Nuclear Regulatory Commission, Professor Allison Macfarlane, provided a further reality check in 2021 stating, “when it comes to averting the imminent effects of climate change, even the cutting edge of nuclear technology will prove to be too little, too late.”[9]

Wishful thinking is no substitute for real world evidence and action, or for effective climate action.

Renewable energy exists in the real world and this is the crucial decade when real climate action is urgently needed to make the required transition to a low carbon future.

It is our considered view that the pursuit of nuclear power would delay and undermine efforts to reduce Australia’s greenhouse emissions and address the challenges and opportunities of climate change.

Our shared energy future is renewable, not radioactive.

Recommendation:
Our groups call on the Committee to support effective climate action by recommending against the proposed Bill and reaffirming support for the existing and prudent federal nuclear prohibitions.

[9] https://www.foreignaffairs.com/world/nuclear-energy-will-not-be-solution-climate-change

2. THE ECONOMICS OF NUCLEAR POWER

"Nuclear construction on-time and on-budget? It's essentially never happened."
– Andrew J. Wittmann, financial analyst with Robert W. Baird & Co., 2017.[10]

2.1 An Australian perspective

Nuclear power is more expensive than existing energy sources, including renewables, and therefore could not possibly contribute to efforts to reduce power prices. Nuclear power would undoubtedly result in higher electricity prices for Australian households and businesses.

Nuclear costs have increased dramatically since the Switkowski report[11] in 2006. Nuclear power suffers from a negative learning curve (it has become more rather than less expensive) as discussed below and as discussed by Dr. Ziggy Switkowski at the 29 August 2019 hearing of the federal nuclear inquiry.[12]

The 2006 Switkowski report estimated the cost of electricity from new reactors at A$40–65 per megawatt-hour (MWh).[13] That wildly inaccurate estimate is approximately one-fifth of current estimates. In its October 2021 report on levelised costs of electricity, investment firm Lazard estimates nuclear costs at A$188–293 (US$131–204) per MWh.[14]

The October 2021 Lazard report demonstrates how costly nuclear power is relative to renewables:[15]

	Levelised cost of electricity / MWh
Nuclear	US$131–204 (A$188–293)
Solar PV – utility scale	US$28–41 (A$40–59)
Wind – onshore	US$26–50 (A$37–72)

For rooftop solar PV, the October 2021 Lazard report's figure for residential solar PV (US$147–221 per MWh) is similar to nuclear (US$131–204) but of course rooftop solar does not require large downstream costs such as transmission from a power plant.[16] The Lazard report's figure for rooftop commercial and industrial solar PV (US$67–180 per MWh) is significantly lower than nuclear, again with the important proviso that rooftop solar does not require large downstream costs such as transmission from a power plant.

In 2009, Dr. Switkowski said that the construction cost of a 1,000 MW power reactor Australia would be A$4–6 billion.[17] That is approximately one-quarter of the current cost estimates for all reactors under construction in western Europe, Scandinavia and North America (see section 2.4 below). And the 2009 Switkowski estimate is approximately three times lower than the October 2021 Lazard estimate of A$11.2–18.4 billion (US$7.8–12.8 billion) for a 1,000 MW reactor.[18]

In its May 2016 Final Report, the South Australian Nuclear Fuel Cycle Royal Commission concluded:

[10] https://www.bloomberg.com/news/articles/2017-02-13/toshiba-s-nuclear-reactor-mess-winds-back-to-a-louisiana-swamp
[11] https://webarchive.nla.gov.au/tep/66043
[12] https://parlinfo.aph.gov.au/parlInfo/search/display/display.w3p;db=COMMITTEES;id=committees%2Fcommrep%2F3abfb90c-9215-4b65-a5d2-32d112e8cd46%2F0001;query=Id%3A%22committees%2Fcommrep%2F3abfb90c-9215-4b65-a5d2-32d112e8cd46%2F0000%22
[13] https://webarchive.nla.gov.au/tep/66043
[14] https://www.lazard.com/media/451881/lazards-levelized-cost-of-energy-version-150-vf.pdf
[15] https://www.lazard.com/media/451881/lazards-levelized-cost-of-energy-version-150-vf.pdf
[16] https://www.lazard.com/media/451881/lazards-levelized-cost-of-energy-version-150-vf.pdf
[17] https://www.theaustralian.com.au/opinion/a-clean-and-green-way-to-fuel-the-nation/news-story/92aabe042acb3ef3ffdbdfacc65631bf
[18] https://www.lazard.com/media/451881/lazards-levelized-cost-of-energy-version-150-vf.pdf

> *"Taking into account the South Australian energy market characteristics and the cost of building and operating a range of nuclear power plants, the Commission has found it would not be commercially viable to develop a nuclear power plant in South Australia beyond 2030 under current market rules."*[19]

2.2 Pro-nuclear inaccuracy regarding renewable energy costs in Australia

In submissions to the 2019 federal nuclear inquiry (and other similar inquiries), numerous nuclear advocates made inaccurate claims not only about nuclear costs but also about the cost of renewables.

This problem was addressed by *RenewEconomy* editor Giles Parkinson in a 2019 article.[20] A brief excerpt from Parkinson's analysis is reproduced here:

> *"It is generally accepted in the energy industry that the cost of new nuclear is several times that of wind and solar, even when the latter are backed up by storage. The GenCost 2018 report from the CSIRO and the Australian Energy Market Operator (AEMO) puts the cost of nuclear at two to three times the cost of "firmed renewables".*
> *"The nuclear lobby, however, has been insisting to the parliamentary inquiry that wind and solar are four to seven times the cost of nuclear, and to try and prove the point the lobby has been making such extraordinary and outrageous claims that it makes you wonder if anything else they say about nuclear – its costs and safety – can be taken seriously.*
> *"RenewEconomy has been going through the 290-something submissions and reading the public hearing transcripts, and has been struck by one consistent theme from the pro-nuclear organisations and ginger groups: When it comes to wind, solar and batteries, they just make stuff up.*
> *"A typical example is the company SMR Nuclear Technology – backed by the coal baron Trevor St Baker – which borrows some highly questionable analysis to justify its claim that going 100 per cent renewables would cost "four times" that of replacing coal with nuclear.*
> *"It bases this on modelling by a consultancy called EPC, based on the south coast of NSW, apparently a husband and wife team, Robert and Linda Barr, who are also co-authors of "The essential veterinarian's phone book", a guide to vets on how to set up telephone systems.*
> *"The EPC report admits to deliberately ignoring the anticipated cost reductions of wind and solar from AEMO's 2018 integrated system plan. Even worse, the report dials in a completely absurd current cost of wind at A$157/MWh (before transmission costs), which is about three times the current cost in Australia, and A$117/MWh for solar, which is more than double.*
> *The costs of wind and solar are not hard to verify. They are included in the GenCost report, in numerous pieces of analysis, and even in public announcements from companies involved, both buyers and sellers."*

[19] South Australian Nuclear Fuel Cycle Royal Commission Final Report, May 2016, https://nuclear.foe.org.au/wp-content/uploads/NFCRC_Final_Report_Web_5MB.pdf
[20] Giles Parkinson, RenewEconomy, 23 Oct 2019, 'Why the nuclear lobby makes stuff up about the cost of wind and solar, https://reneweconomy.com.au/why-the-nuclear-lobby-makes-stuff-up-about-cost-of-wind-and-solar-46538/
See also: Giles Parkinson, 28 Oct 2022, 'Dutton and Coalition still ignorant and deluded on battery storage and nuclear', https://reneweconomy.com.au/dutton-and-coalition-still-ignorant-and-deluded-on-battery-storage-and-nuclear/

2.3 Australia's energy future is renewable, not radioactive

A further indication of the dim prospects for nuclear power in Australia is that several conservative governments and parties contributed submissions to a 2019 federal nuclear inquiry opposing nuclear power – the SA Liberal government[21], the Tasmanian Liberal government[22], and the Queensland Liberal-National Party[23] – while none contributed submissions supporting nuclear power (see section 7 for more detail). The NSW Coalition government has no interest in pursuing nuclear power. NSW Treasurer Matt Kean said in October 2021 that nuclear power is like "chasing a unicorn" and that nuclear is several times more expensive than renewables backed up with energy storage.[24] A Victorian parliamentary inquiry concluded in its 2020 report that "without subsidisation a nuclear power industry will remain economically unviable in Australia" and that those promoting nuclear power "have not presented any argument, data or proof in support of their position that cannot be nullified by those arguing against."[25]

State and Territory governments (including conservative governments) are focused on the renewables transition. Tasmania leads the pack thanks to its hydro resources. South Australia is another pacesetter: wind and solar supply around two-thirds of local power generation and SA is on track to comfortably meet its target of 100% net renewables by 2030.

The federal Department of Industry, Science, Energy and Resources expects 69% renewable supply to the National Electricity Market by 2030[26] and the Albanese government's target is 82% renewable supply to the National Electricity Market by 2030.[27]

Table 5: Renewable share of generation, %

Percentage of renewables	2005	2019	2025	2030
National Electricity Market		23	51	69
Queensland		*12*	*37*	*43*[6]
New South Wales/ACT		*16*	*46*	*84*
Victoria		*22*	*50*	*61*
South Australia		*53*	*97*	*96*
Tasmania		*96*	*100*	*100*[7]
Western Australia Wholesale Electricity Market		15	37	45
Other grids, including off-grid		1	8	13
Whole sector	**9**[8]	**21**	**45**	**61**

Source: Australia's emissions projections 2021, Department of Industry, Science, Energy and Resources.

[21] https://www.aph.gov.au/DocumentStore.ashx?id=1519c7ea-3f47-47a0-a65d-97d691827bf0&subId=671226
[22] https://www.aph.gov.au/DocumentStore.ashx?id=69cdc369-9b09-477f-ba35-2b9ec182774a&subId=670563
[23] https://www.aph.gov.au/DocumentStore.ashx?id=5c2cf4df-5ef7-420c-86f3-eee32033fa3f&subId=669992
[24] https://www.abc.net.au/news/2021-10-24/nationals-provide-in-principle-support-for-net-zero-2050-target/100564192
https://iview.abc.net.au/video/NC2109V038S00
[25] https://www.parliament.vic.gov.au/epc-lc/article/4350
[26] https://reneweconomy.com.au/renewables-to-supply-69-pct-of-australias-main-grid-by-2030-government-projections-show/
[27] https://keystone-alp.s3-ap-southeast-2.amazonaws.com/prod/61a9693a3f3c53001f975017-PoweringAustralia.pdf

2.4 Nuclear power's economics crisis

Supporters of nuclear power have issued any number of warnings[28] in recent years about nuclear power's "rapidly accelerating crisis"[29] and a "crisis that threatens the death of nuclear energy in the West"[30], while pondering what if anything might be salvaged from the "ashes of today's dying industry".[31]

The crisis has been particularly acute in the US and western Europe:

- The V.C. Summer project in South Carolina (two AP1000 reactors) was abandoned in 2017 after the expenditure of around US$9 billion (A$12.9 billion).
- The only remaining reactor construction project in the US is the Vogtle project in Georgia (two AP1000 reactors). The current cost estimate of US$34 billion (A$48.9 billion) is more than double the estimate when construction began (US$14–15.5 billion).
- In 2006, Westinghouse said it could build an AP1000 reactor for as little as US$1.4 billion (A$2.0 billion) – 12 times lower than the current estimate for Vogtle.
- In the late 2000s, the estimated construction cost for one EPR reactor in the UK was £2 billion (A$3.5 billion). The current cost estimate for two EPR reactors under construction at Hinkley Point – the only reactor construction project in the UK – is £25–26 billion (A$43.8–45.5 billion). The current cost estimate is over six times greater than the initial estimate of £2 billion per reactor.
- The only current reactor construction project in France is one EPR reactor under construction at Flamanville. The current cost estimate of €19.1 billion (A$29.7 billion) is 5.8 times greater than the original estimate of €3.3 billion (A$5.1 billion).
- In Finland, one EPR reactor (Olkiluoto-3) was finally completed in March 2022. The cost of about €11 billion (A$17.1 billion) was 3.7 times greater than the original estimate of €3 billion (A$4.7 billion). Olkiluoto-3 was 13 years behind schedule and commissioning problems have further delayed commercial operation.

The following statements, many from industry insiders, address nuclear power's economic crisis and its dim prospects:

- "I don't think we're building any more nuclear plants in the United States. I don't think it's ever going to happen. They are too expensive to construct." – *William Von Hoene, Senior Vice-President of Exelon, 2018.*[32]
- Nuclear power "just isn't economic, and it's not economic within a foreseeable time frame." – *John Rowe, recently-retired CEO of Exelon, 2012.*[33]
- "It's just hard to justify nuclear, really hard." – *Jeffrey Immelt, General Electric's CEO, 2012.*[34]
- "We see renewables plus battery storage without incentives being cheaper than natural gas, and cheaper than existing coal and existing nuclear." – *Jim Robo, NextEra CEO, 2019.*[35]
- France's nuclear industry is in its "worst situation ever"[36], a former EDF director said in November 2016 – and the situation has worsened since then.[37]

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[28] https://www.wiseinternational.org/nuclear-monitor/839/nuclear-power-crisis-or-it-merely-end
[29] http://www.environmentalprogress.org/big-news/2017/2/13/why-its-big-bet-on-westinghouse-nuclear-bankrupted-toshiba
[30] http://www.environmentalprogress.org/big-news/2017/2/16/nuclear-must-change-or-die
[31] https://thebreakthrough.org/index.php/voices/ted-nordhaus/the-end-of-the-nuclear-industry-as-we-know-it
[32] https://www.spglobal.com/platts/en/market-insights/latest-news/electric-power/041218-no-new-nuclear-units-will-be-built-in-us-due-to-high-cost-exelon-official
[33] https://www.forbes.com/sites/jeffmcmahon/2012/03/29/exelons-nuclear-guy-no-new-nukes/
[34] https://www.ft.com/content/60189878-d982-11e1-8529-00144feab49a
[35] https://reneweconomy.com.au/us-energy-giant-says-renewables-and-batteries-beat-coal-gas-and-nukes-78962/
[36] http://www.theguardian.com/environment/2016/nov/29/french-nuclear-power-worst-situation-ever-former-edf-director
[37] https://climatenewsnetwork.net/frances-nuclear-industry-struggles-on/

- Nuclear power is "ridiculously expensive" and "uncompetitive" with solar. – *Nobuo Tanaka, former executive director of the International Energy Agency, and former executive board member of the Japan Atomic Industrial Forum, 2018.*[38]
- "In developed markets, we see little economic rationale for new nuclear build. Renewables are significantly cheaper and offer quicker payback on scalable investments at a time when power demand is stagnating. New nuclear construction requires massive upfront investments in complex projects with long lead times and risk of major cost overruns." – *S&P Global Ratings, 2019.*[39]
- Compounding problems facing nuclear developers "add up to something of a crisis for the UK's nuclear new-build programme." – *Tim Yeo, former Conservative parliamentarian and now a nuclear industry lobbyist, 2017.*[40]
- "It sometimes seems like U.S. and European nuclear companies are in competition to see which can heap greater embarrassment on their industry." – *Financial Times, 2017, 'Red faces become the norm at nuclear power groups'.*[41]
- "I don't think a CEO of a utility could in good conscience propose a nuclear-power reactor to his or her board of directors." – *Alan Schriesheim, director emeritus of Argonne National Laboratory, 2014.*[42]
- "New-build nuclear in the West is dead" due to "enormous costs, political and popular opposition, and regulatory uncertainty" – *Morningstar market analysts Mark Barnett and Travis Miller, 2013.*[43]
- "Nuclear construction on-time and on-budget? It's essentially never happened." – *Andrew J. Wittmann, financial analyst with Robert W. Baird & Co., 2017.*[44]
- "Nuclear power and solar photovoltaics both had their first recorded prices in 1956. Since then, the cost of nuclear power has gone up by a factor of three, and the cost of PV has dropped by a factor of 2,500." – *J. Doyne Farmer, Oxford University economics professor, 2016.*[45]

Even the International Atomic Energy Agency (IAEA) – which is tasked with promoting nuclear power – said in a September 2018 report that global nuclear power capacity "risks shrinking in the coming decades as ageing reactors are retired and the industry struggles with reduced competitiveness".[46] The IAEA's estimates for global nuclear power capacity in 2030 are 36% lower than the same estimates in 2010, the year before the Fukushima disaster.[47]

2.5 Nuclear stagnation and decline compared to the growth of renewables

Nuclear power's contribution to global electricity generation has fallen 40% from a peak of 17.5% in 1996 to 9.8% now.[48] Nuclear power has fallen below 10% for the first time in four decades and the slide is set to continue. Renewables currently account for 28% of global electricity generation and the sector continues to grow.[49]

As of 1 July 2022, 411 reactors were operating in 33 countries, four less than in July 2021 and 27 below the 2002-peak of 438.[50] Those figures, from the World Nuclear Industry Status Report, exclude reactors

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[38] http://www.asahi.com/ajw/articles/AJ201807240045.html
[39] https://www.euractiv.com/wp-content/uploads/sites/2/2019/11/Energy-Transition_Nuclear-Dead-And-Alive_11-Nov.-2019.pdf
[40] www.telegraph.co.uk/business/2017/04/01/can-britains-nuclear-ambitions-avoid-meltdown/
[41] https://www.ft.com/content/db592ce6-7b4e-11e7-9108-edda0bcbc928
[42] http://www.forbes.com/sites/jeffmcmahon/2014/12/09/another-giant-declares-nuclear-dead-in-fracking-america/
[43] https://www.forbes.com/sites/jeffmcmahon/2013/11/10/new-build-nuclear-is-dead-morningstar/
[44] https://www.bloomberg.com/news/articles/2017-02-13/toshiba-s-nuclear-reactor-mess-winds-back-to-a-louisiana-swamp
[45] https://www.popularmechanics.com/science/energy/a18818/can-us-nuclear-power-get-un-stuck/
[46] https://www.iaea.org/newscenter/pressreleases/new-iaea-energy-projections-see-possible-shrinking-role-for-nuclear-power
[47] https://www.wiseinternational.org/nuclear-monitor/866/new-iaea-report-sees-possible-shrinking-role-nuclear-power
[48] https://www.worldnuclearreport.org/The-World-Nuclear-Industry-Status-Report-2022-HTML.html
[49] See p.51 of bp Statistical Review of World Energy,
[50] https://www.worldnuclearreport.org/The-World-Nuclear-Industry-Status-Report-2022-HTML.html

in long-term outage (i.e. they have not operated for many years, e.g. 23 reactors in Japan that have not generated power since 2010–2013). The International Atomic Energy Agency describes reactors in long-term outage as 'in operation', a classification described by former World Nuclear Association executive Steve Kidd as "misleading" and "clearly ridiculous".[51]

As of 1 July 2022, 53 power reactors were under construction worldwide, 16 fewer than in 2013.[52]

Nuclear electricity generating capacity declined in 2021 over the previous year by 0.4 gigawatts (GW).[53] Renewable capacity grew by 314 GW – another record year.[54] The International Energy Agency expects 305 GW of annual renewable capacity additions between 2021 and 2026 in its 'main case' forecast, accounting for 95% of capacity additions.[55]

Outside of China, there were 48 power reactor start-ups (grid connections) in the 20 years from 2002–2021 and 105 permanent reactor closures: a net loss of 57 reactors (and a net loss of 25 GW of capacity).[56] Over the same period, there were 50 reactor start-ups in China (and no closures). Nonetheless, even China's nuclear program is modest: from 2011 to 2021, China averaged just 2.5 reactor construction starts per year.[57] Wind and solar (combined) generate more than twice as much electricity as nuclear power in China, and hydro generates more than three times as much as nuclear power (see section 2.5).

Globally, nuclear power has been stagnant for 30 years – a marginal decline in the number of operating reactors, a marginal increase in nuclear capacity and generation.[58]

There is one big difference between the current situation and the situation 30 years ago: the reactor fleet was young then, now it is old. The ageing of the reactor fleet is a huge problem for the industry (as is the ageing of the nuclear workforce – the silver tsunami[59]). The average age of the world's reactor fleet continues to rise, and by mid-2022 reached 31 years.[60] The mean age of the 29 reactors shut down between 2017 and 2021 was 42.2 years[61] (claims that reactors will operate for 60–80+ years lack credibility and would greatly increase the sector's risk profile).

With the ageing of the global reactor fleet, the International Atomic Energy Agency anticipates the annual closure of around 10 reactors (10 GW of capacity) over the next three decades – 139 GW from 2018–2030 and up to 186 GW of further shutdowns from 2030–2050.[62]

The recent reactor build rate will need to double just to maintain that pattern of stagnation. Reactor construction starts (and reactor start-ups or grid connections) need to match closures just for the industry to maintain its 30-year pattern of stagnation, yet annual construction starts have averaged just 5.1 since 2014:[63]

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[51] http://www.neimagazine.com/opinion/opinionnuclear-power-in-the-world-pessimism-or-optimism-5031270/
[52] https://www.worldnuclearreport.org/The-World-Nuclear-Industry-Status-Report-2022-HTML.html
[53] https://www.worldnuclearreport.org/The-World-Nuclear-Industry-Status-Report-2022-HTML.html
[54] https://www.worldnuclearreport.org/The-World-Nuclear-Industry-Status-Report-2022-HTML.html
[55] https://www.iea.org/reports/renewables-2021/renewable-electricity?mode=market&region=World&publication=2021&product=Total
See also: https://www.iea.org/reports/renewables-2021/executive-summary
[56] https://www.worldnuclearreport.org/The-World-Nuclear-Industry-Status-Report-2022-HTML.html
[57] Calculated from IAEA database: https://pris.iaea.org/PRIS/
[58] https://pris.iaea.org/PRIS/
[59] https://smithharroff.com/the-nuclear-workforce-gap-dealing-with-the-impending-silver-tsunami/
[60] https://www.worldnuclearreport.org/The-World-Nuclear-Industry-Status-Report-2022-HTML.html
[61] https://www.worldnuclearreport.org/The-World-Nuclear-Industry-Status-Report-2022-HTML.html
[62] https://www-pub.iaea.org/MTCD/Publications/PDF/RDS-1-38_web.pdf
[63] IAEA, PRIS database, https://pris.iaea.org/pris/ See also: IAEA, 2019, 'Nuclear Power Reactors in the World', https://www-pub.iaea.org/MTCD/Publications/PDF/RDS-2-39_web.pdf

	2002–07	*2008–13*	*2014–21*
Global power reactor construction starts	24 in 6 years	59 in 6 years	41 in 8 years
Annual average	4.0	9.8	5.1

The November 2022 edition of the World Nuclear Industry Status report includes similar calculations and reaches the same conclusion: a doubling of the reactor build rate is required just for the industry to maintain its 30-year pattern of stagnation.[64]

Slow decline is the most likely scenario over the next 20 years (beyond which it is unwise to speculate). At best, the industry could hope to maintain the pattern of stagnation that has prevailed over the past 30 years. Significant growth is highly unlikely. The pro-nuclear International Atomic Energy Agency has assessed its past performance of predicting the future of nuclear power and found that even its low-growth projections tend to be too high, by 13% on average.[65] The IAEA's current low-growth projection is for stagnation through to the end of this decade.[66] Further, the IAEA's low-case projections suggest that nuclear power's share of total global electricity generation could decline to about 6% by 2050 compared to 9.8% currently.

The IAEA stated in a 2021 report: "Currently, about two thirds of nuclear power reactors have been in operation for over 30 years, highlighting the need for significant new nuclear capacity to offset retirements in the long term. Uncertainty remains regarding the replacement of the large number of reactors scheduled to be retired around 2030 and beyond, particularly in Northern America and Europe."[67]

After a growth spurt followed by 30 years of stagnation, nuclear power is now entering a third and possibly final period, the Era of Nuclear Decommissioning, which will be characterised by a decline in the number of operating reactors; an increasingly unreliable and accident-prone reactor fleet as ageing sets in; countless battles over lifespan extensions for ageing reactors; an internationalisation of anti-nuclear opposition as neighbouring countries object to the continued operation of ageing reactors; and escalating battles over – and problems with – decommissioning and waste disposal.[68]

The striking contrast between nuclear power and renewables is detailed in the 2022 World Nuclear Industry Status Report (WNISR):[69]

- Levelised Cost of Energy (LCOE) analysis by US bank Lazard shows that between 2009 and 2021, utility-scale solar costs came down 90% and wind 72%, while new nuclear costs increased by 36%. The gap continues to widen.
- The WNISR report states: "The growth of renewable energy is now not only outcompeting nuclear power but is rapidly overtaking fossil fuels and has become the source of economic choice for new generation."
- In 2021, total investment in non-hydro renewable electricity capacity reached a record US$366 billion, 15 times greater than global investment decisions for the construction of nuclear power plants.

[64] https://www.worldnuclearreport.org/The-World-Nuclear-Industry-Status-Report-2022-HTML.html
[65] Tables 33 and 34, p.56, https://www-pub.iaea.org/mtcd/publications/pdf/pub1304_web.pdf
https://www.wiseinternational.org/nuclear-monitor/811/fanciful-growth-projections-world-nuclear-association-and-iaea
[66] Page 3, https://www-pub.iaea.org/MTCD/Publications/PDF/RDS-1-41_web.pdf
[67] https://www-pub.iaea.org/MTCD/Publications/PDF/RDS-1-41_web.pdf
[68] https://reneweconomy.com.au/era-nuclear-decommissioning-13370/
[69] https://www.worldnuclearreport.org/The-World-Nuclear-Industry-Status-Report-2022-HTML.html

- Nuclear power's contribution to global electricity generation has fallen to 9.8%, slightly lower than non-hydro renewables (10.2%) and nearly three times lower than all renewables (including hydro) (28%).
- Nuclear electricity generating capacity declined in 2021 over the previous year by 0.4 GW. Renewable capacity grew by nearly 314 GW – another record year – including 257 GW of non-hydro renewables. (The International Energy Agency expects 305 GW of annual renewable capacity additions between 2021 and 2026 in its 'main case' forecast, accounting for 95% of capacity additions.[70])
- In China in 2021, wind (656 terrawatt-hours – TWh) and solar (327 TWh) combined generated 2.6 times more electricity than nuclear power (383 TWh net) while hydro (1300 TWh) generated more than three times as much electricity as nuclear power. Wind, solar and hydro combined (2,283 TWh) generated 6.0 times more electricity than nuclear power.
- In European Union countries, renewable electricity generation reached a new record of 1,068 TWh in 2021 and accounted for 37% of EU electricity production (compared to 26% for nuclear power).
- In India, combined wind and solar generated 3.4 times more power than nuclear plants in 2021.

2.6 Recent reactor construction experience in the US and western Europe: catastrophic cost overruns

North America

The V.C. Summer project in South Carolina (two AP1000 reactors) was abandoned after the expenditure of around US$9 billion (A$12.9 billion).[71] Construction began in 2013 and the project was abandoned in 2017. The project was initially estimated to cost US$11.5 billion; when it was abandoned, the estimate was US$25 billion.[72] Largely because of the V.C. Summer disaster, Westinghouse filed for bankruptcy and its parent company Toshiba only avoided bankruptcy by selling its most profitable assets. Both companies decided that they would no longer take on the huge risks associated with reactor construction projects. In 2018, Toshiba announced its withdrawal from the planned Moorside nuclear power project in the UK; just two years earlier, the company said its goal was to win overseas orders for at least 45 AP1000 reactors by 2030.[73] Criminal investigations and prosecutions related to the V.C. Summer project are ongoing.[74]

With the abandonment of the V.C. Summer project in South Carolina, the only remaining reactor construction project in the US is the Vogtle project in Georgia (two AP1000 reactors). The current cost estimate of US$34 billion (A$48.9 billion) is more than double the estimate when construction began (US$14–15.5 billion).[75] Costs continue to increase, and the project only survives because of multi-billion-dollar taxpayer bailouts.[76]

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[70] https://www.iea.org/reports/renewables-2021/renewable-electricity?mode=market&region=World&publication=2021&product=Total
See also: https://www.iea.org/reports/renewables-2021/executive-summary
[71] https://www.worldnuclearreport.org/Toshiba-Westinghouse-The-End-of-New-build-for-the-Largest-Historic-Nuclear.html
[72] https://www.nytimes.com/2017/07/31/climate/nuclear-power-project-canceled-in-south-carolina.html
[73] https://www.japantimes.co.jp/news/2017/02/15/national/toshibas-woes-weigh-heavily-governments-ambition-sell-japans-nuclear-technology/
[74] https://thebulletin.org/2021/08/us-attorney-details-illegal-acts-at-construction-projects-sealing-the-fate-of-the-nuclear-renaissance/
https://www.postandcourier.com/business/3-years-later-how-the-fallout-from-scs-9-billion-nuclear-fiasco-continues/article_5d2a2684-d264-11ea-946f-935bbd3ffa98.html
https://www.lexingtonchronicle.com/search/node/nuclear%20fraud
https://en.wikipedia.org/wiki/Nukegate_scandal
[75] https://www.worldnuclearreport.org/The-World-Nuclear-Industry-Status-Report-2022-HTML.html#_idTextAnchor086
https://www.wiseinternational.org/nuclear-monitor/867/vogtles-reprieve-snatching-defeat-jaws-defeat
[76] https://www.wiseinternational.org/nuclear-monitor/867/vogtles-reprieve-snatching-defeat-jaws-defeat

In 2006, Westinghouse said it could build an AP1000 reactor for as little as US$1.4 billion (A$2.0 billion)[77] – 12 times lower than the current estimate for Vogtle (US$17 billion per reactor). In 2005, the Senior Vice President of the US Nuclear Energy Institute claimed that Westinghouse's estimate of US$1,365 / kW "has a solid analytical basis, has been peer-reviewed, and reflects a rigorous design, engineering and constructability assessment."[78] That claim was proven to be wrong by a factor of 12.

Construction of the two Vogtle reactors began in 2013 and the expected completion dates of 2016 and 2017 have been pushed back by 6–7 years to April 2023 and late 2023, with further delays likely.[79] In 2014, Westinghouse claimed a three-year construction schedule for AP1000 reactors.[80] If the current schedule is met, Vogtle will be a 9–10 year construction project. (The four AP1000 reactors built in China were 8–9 year construction projects.[81])

The Watts Bar 2 reactor in Tennessee began operation in 2016, 43 years after construction began.[82] When construction resumed in 2008 after a long hiatus (and with the reactor 60% complete[83]), the cost estimate to complete the reactor was US$2.5 billion but the final completion cost was US$4.7 billion.[84] In 2008, completion was scheduled in 2013 but that timeline was missed by three years.[85]

Watts Bar 2 was the only reactor start-up in the US over the past 25 years. The previous reactor start-up in the US was Watts Bar 1, completed 20 years earlier (1996) after a 23-year construction period.[86]

Watts Bar 1 and 2 – both massively delayed and massively-over-budget – are the only reactor start-ups in the US over the past 30 years.

In 2021, TVA abandoned the unfinished Bellefonte nuclear plant in Alabama, 47 years after construction began and following the expenditure of an estimated US$5.8 billion (A$8.3 billion).[87]

There have been no other power reactor construction projects in the US over the past 25 years other than those listed above. Numerous other reactor projects were abandoned before construction began, some following the expenditure of hundreds of millions of dollars.

During the ill-fated nuclear 'renaissance', the US Nuclear Regulatory Commission received applications to build 31 reactors[88], but all that remains is the Vogtle project in Georgia. Twelve reactors have been permanently shut down over the past decade with many more closures in the pipeline.[89] Twenty unprofitable, ageing reactors have been saved by nuclear bailout funding, but their future is

[77] https://www.nytimes.com/2006/07/16/magazine/16nuclear.html
[78] https://www.govinfo.gov/content/pkg/CHRG-109shrg20004/pdf/CHRG-109shrg20004.pdf
[79] https://www.world-nuclear-news.org/Articles/In-service-dates-and-cost-forecast-revised-for-Vog
[80] www.iaea.org/inis/collection/NCLCollectionStore/_Public/46/136/46136339.pdf
[81] https://pris.iaea.org/PRIS/CountryStatistics/ReactorDetails.aspx?current=908
https://pris.iaea.org/PRIS/CountryStatistics/ReactorDetails.aspx?current=909
https://pris.iaea.org/PRIS/CountryStatistics/ReactorDetails.aspx?current=879
https://pris.iaea.org/PRIS/CountryStatistics/ReactorDetails.aspx?current=880
[82] https://www.counterpunch.org/2021/09/24/the-record-breaking-failures-of-nuclear-power/
[83] https://www.powermag.com/commitment-teamwork-and-perseverance-pay-off-as-nuclear-unit-wins-plant-of-the-year/
[84] https://neutronbytes.co/2021/03/26/centrus-aims-for-haleu-production-by-2022/
[85] https://www.powermag.com/watts-bar-unit-2-a-deferred-nuclear-plant-gets-back-into-the-game/
[86] https://www.counterpunch.org/2021/09/24/the-record-breaking-failures-of-nuclear-power/
[87] Ibid.
[88] Mark Holt, "Nuclear Energy Policy" (Washington, D. C.: Congressional Research Service, October 15, 2014).
[89] https://www.world-nuclear.org/information-library/country-profiles/countries-t-z/usa-nuclear-power.aspx. Three Mile Island 1, Pilgrim, San Onofre 2 and 3, Crystal River 3, Vermont Yankee, Oyster Creek, Duane Arnold, Fort Calhoun, Kewaunee, and Indian Point 2 and 3.

precarious.[90] Indeed the fate of the entire reactor fleet of 92 reactors is precarious given its age (a mean age of 41.6 years[91]) and multiple economic challenges.

In addition to the V.C Summer corruption scandal, nuclear bailout programs are mired in corruption as discussed by the Nuclear Information & Resource Service:[92]

> *"In fact, both Exelon and Energy Harbor (a spinoff of FirstEnergy), are the subjects of federal corruption cases over billion-dollar nuclear bailouts for which they lobbied in Illinois and Ohio, respectively. In both cases, prosecutors have indicted former company lobbyists and staff to the Speakers of the House of Representatives in each state. Also in both cases, Exelon and FirstEnergy have signed deferred prosecution agreements with federal prosecutors to pay fines and restitution and to cooperate with the prosecutions. As the investigations proceed, more corporate executives, legislators, and lobbyists could be indicted.*
>
> *"In the case of FirstEnergy and Energy Harbor, there are also multiple state-level investigations of these nuclear bailout scandals. At the heart of that case, FirstEnergy made $61 million in bribes and payments to former House Speaker Larry Householder's political action committee. Through the scheme, FirstEnergy helped win Householder the speakership after the 2018 election, by also buying the support of Republican legislators and Ohio Gov. Mike DeWine. As a result, FirstEnergy was able to get Ohio to enact a $1 billion nuclear bailout, which was key in winning the support of the corporation's creditors in a major bankruptcy proceeding. The bankruptcy settlement resulted in FirstEnergy spinning off its power plants into Energy Harbor, a new, unaffiliated corporation that only owns the unprofitable nuclear and coal power plants. As a result of the federal corruption case, Ohio legislators repealed the nuclear bailout earlier this year, leaving Energy Harbor without the subsidies its creditors were assured it would have when they agreed to the bankruptcy settlement.*
>
> *"In addition to the federal corruption case, states where FirstEnergy operates want to know where the $61 million in bribes came from. In April, under pressure in the federal case, FirstEnergy filed a report with the Federal Energy Regulatory Commission indicating that "all 14 of its power-providing companies" in five states misappropriated ratepayer monies for a decade. State utility commissions in three of those states – Maryland, New Jersey, and Ohio – are investigating how much money the corporation misappropriated from state residents' power bills to fund the nuclear bailout corruption scheme.*
>
> *"The corruption investigation in Illinois stems from two bills that have cost electricity consumers billions of dollars: a 2011 "smart grid" law, and a 2016 energy law. The latter awarded Exelon a 10-year, $2.35 billion subsidy for three uneconomical reactors that Exelon threatened to close without the bailout. Consumers have already paid out $1 billion over the last four years. Exelon awarded jobs to associates and relatives of former House Speaker Michael Madigan and other legislators, in exchange for lucrative legislative outcomes. Despite the ongoing investigation, Exelon is now pursuing subsidies in Illinois for its other eight reactors in Illinois, which it claims are also under economic pressure.*

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[90] https://www.world-nuclear.org/information-library/country-profiles/countries-t-z/usa-nuclear-power.aspx. Three Mile Island 1, Pilgrim, San Onofre 2 and 3, Crystal River 3, Vermont Yankee, Oyster Creek, Duane Arnold, Fort Calhoun, Kewaunee, and Indian Point 2 and 3.

[91] https://www.worldnuclearreport.org/The-World-Nuclear-Industry-Status-Report-2022-HTML.html

[92] https://www.nirs.org/nuclear-power-runs-on-dirty-money-the-corporate-scandal-of-the-proposed-national-nuclear-subsidy/

> *"In the same year as the Illinois bailout, Exelon won a massive 12-year, $7.6 billion subsidy for four reactors in New York, and won final approval of a deal that has made it the largest utility company in the country. In those cases, there were eyebrow-raising reports of backroom lobbying, employment favors, and political contributions. And in 2018, Exelon and PSEG (the other big winner from a federal bailout) got New Jersey to enact a $300 million/year subsidy for three reactors in that state. Exelon pulls in about $85 million/year through its ownership stake in two of the New Jersey reactors.*
>
> *"In total, Exelon is receiving nearly $11 billion in nuclear subsidies at the state level. $24.5 billion in federal subsidies may assist Exelon in winning investors' support for its plan to spin off its nuclear business, as FirstEnergy did. But how is any of this going to help the country solve the climate crisis?"*

The 2022 edition of the World Nuclear Industry Status Report notes that since 2017, the US Justice Department has opened three investigations against utility corporations over criminal activities related to nuclear power, resulting in indictments of executives, lobbyists, and state officials, and that the cases have been accompanied by additional lawsuits and state-level investigatory proceedings.[93] The Status Report notes that significant recent developments include the indictment of former Illinois House Speaker Michael Madigan in a corruption investigation focusing on Exelon, and the initiation of trial proceedings for former Westinghouse executive Jeff Benjamin in the V.C. Summer fraud investigation.[94]

Ninety-two reactors account for 18.9% of power generation in the US, down from the peak of 22.5% in 1995.[95] With an average age of 41.6 years (as of mid-2022), the US reactor fleet is amongst the oldest in the world.[96]

In Canada, no reactors are under construction and none have come online since Darlington-4 in 1993 (five years behind schedule and billions of dollars over-budget). Reactor lifespan extension projects have been subject to delays and cost blowouts.[97]

The UK

Over the past decade, three of six proposed new nuclear power plants have been abandoned (Moorside, Wylfa, Oldbury), two remain in limbo (Sizewell C and Bradwell) and Hinkley Point C is at the early stages of construction.

In the late 2000s, the estimated construction cost for one EPR reactor in the UK was £2 billion (A$3.5 billion).[98] The current cost estimate for two EPR reactors at Hinkley Point is £25–26 billion (A$43.8–45.5 billion).[99] Thus the current cost estimate is over six times greater than the initial estimate of £2 billion per reactor and there will undoubtedly be further cost increases.

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93 https://www.worldnuclearreport.org/The-World-Nuclear-Industry-Status-Report-2022-HTML.html#_idTextAnchor086
94 https://www.worldnuclearreport.org/The-World-Nuclear-Industry-Status-Report-2022-HTML.html#_idTextAnchor086
See also https://www.wqad.com/article/news/crime/madigan-mcclain-enter-not-guilty-pleas-comed-commonwealth-edison-att-illinois/526-dfaeffe5-6757-4cd0-baa5-4e94468187c2
95 https://www.worldnuclearreport.org/The-World-Nuclear-Industry-Status-Report-2022-HTML.html#_idTextAnchor086
96 https://www.worldnuclearreport.org/The-World-Nuclear-Industry-Status-Report-2022-HTML.html#_idTextAnchor086
97 https://theconversation.com/why-ontario-must-rethink-its-nuclear-refurbishment-plans-127667
98 https://energypost.eu/saga-hinkley-point-c-europes-key-nuclear-decision/
99 https://www.worldnuclearreport.org/The-World-Nuclear-Industry-Status-Report-2022-HTML.html#_idTextAnchor083

The UK National Audit Office estimates that taxpayer subsidies for Hinkley Point – primarily in the form of a guaranteed payment of £92.50 (A$162) / MWh (2012 prices), indexed for inflation, for 35 years – could amount to £30 billion (A$52.5 billion)[100] while other credible estimates put the figure as high as £48.3 billion (A$84.5 billion).[101]

The delays associated with Hinkley Point have been as shocking as the cost overruns. In 2007, EDF boasted that Britons would be using electricity from an EPR reactor at Hinkley Point to cook their Christmas turkeys in 2017 – but construction of the two reactors didn't even begin until December 2018 and December 2019, respectively.[102] Further delays (and cost increases) have been announced since construction began and the current hope is that the first of the two reactors will be generating electricity in 2027.[103] One wouldn't hold one's breath.

Nuclear industry lobbyist Tim Yeo said in 2017 that the UK's nuclear power program faces "something of a crisis".[104] The following year, Toshiba abandoned the planned Moorside nuclear power project near Sellafield despite generous offers of government support[105] – a "crushing blow" according to Yeo.[106] Then in 2019, Hitachi abandoned the planned Wylfa reactor project in Wales after the estimated cost of the twin-reactor project had risen from A$22.3 billion to A33.5 billion (¥2 trillion to ¥3 trillion).[107] Hitachi abandoned the project despite an offer from the UK government to take a one-third equity stake in the project; to consider providing all of the required debt financing; and to consider providing a guarantee of a generous minimum payment per unit of electricity.[108]

The UK Nuclear Free Local Authorities noted that Hitachi joined a growing list of companies and utilities backing out of the UK nuclear new-build program:[109]

> *"Let's not forget that Hitachi are not the first energy utility to come to the conclusion that new nuclear build in the UK is not a particularly viable prospect. The German utilities RWE Npower and E-on previously tried to develop the site before they sold it on Hitachi in order to protect their own vulnerable energy market share in the UK and Germany. British Gas owner Centrica pulled out of supporting Hinkley Point C, as did GDF Suez and Iberdrola at Moorside, before Toshiba almost collapsed after unwise new nuclear investments in the United States forced it to pull out of the Sellafield Moorside development just a couple of months ago."*

The UK government hopes to progress the Sizewell project and is once again offering very generous support including taking an equity stake in the project and using a 'regulated asset base' model[110] which foists financial risks onto taxpayers and could result in taxpayers paying billions for failed projects – as it has in the US.[111] If recent experience is any guide, the government will struggle to find corporations or utilities willing to invest in Sizewell regardless of generous government support. The same could be said for plans for SMRs (or mid-sized reactors envisaged by Rolls-Royce) – it is doubtful whether private finance can be secured despite generous taxpayer subsidies.

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[100] https://www.theguardian.com/uk-news/2016/jul/13/hinkley-point-c-cost-30bn-top-up-payments-nao-report
[101] http://www.no2nuclearpower.org.uk/wp/wp-content/uploads/2017/09/Time-to-Cancel-HinkleyFinal.pdf
[102] https://pris.iaea.org/PRIS/CountryStatistics/CountryDetails.aspx?current=GB
[103] https://www.worldnuclearreport.org/The-World-Nuclear-Industry-Status-Report-2022-HTML.html#_idTextAnchor083
[104] https://www.telegraph.co.uk/business/2017/04/01/can-britains-nuclear-ambitions-avoid-meltdown/
[105] https://www.wiseinternational.org/nuclear-monitor/869/toshiba-gives-moorside-nuclear-power-project-uk
[106] https://www.ft.com/content/3f655db2-e30a-11e8-a6e5-792428919cee
[107] https://mainichi.jp/english/articles/20181225/p2a/00m/0na/011000c
[108] https://www.gov.uk/government/speeches/statement-on-suspension-of-work-on-thewylfa-newyddnuclear-project
https://wiseinternational.org/nuclear-monitor/871/uk-nuclear-new-build-program-collapsing
[109] http://www.nuclearpolicy.info/news/nfla-argues-priority-anglesey-safe-decommissioning-wylfa-new-jobs-renewable-decentralised-energy/
[110] https://stopsizewellc.org/rab/
[111] https://theintercept.com/2019/02/06/south-caroline-green-new-deal-south-carolina-nuclear-energy/
https://thecurrentga.org/2021/10/15/latest-vogtle-deal-may-mean-extra-3-78-month-on-georgia-power-bill-bills/

The last power reactor start-up in the UK was Sizewell B in 1995. Nine operating reactors account for 14.8% of UK power production[112], down from the peak of 26.9% in 1997.[113] Nuclear power generation decreased from 64 TWh in 2017 to 42 TWh in 2021.[114] Renewables have risen from 2.5% of power generation in 2001 to 39.6% in 2021.[115]

France

The last reactor start-up in France was in 1999. The only current reactor construction project is one EPR reactor under construction at Flamanville. The current cost estimate of €19.1 billion (A$29.7 billion) is 5.8 times greater than the original estimate of €3.3 billion (A$5.1 billion).[116] (Lower costs cited for the Flamanville reactor usually exclude finance costs.)

The Flamanville reactor is 12 years behind schedule: construction began in 2007, the planned start-up date was 2012, and EDF now hopes for initial fuel loading in 2024.[117] At best it will be a 17-year construction project, and further delays are likely.

Half or more of France's reactors were offline in the first half of 2022 (and many remain offline as of Jan. 2023) due to cracks and suspected cracks in emergency core cooling systems, maintenance, repair, backfitting, and summer heat resulting in river water (tapped for reactor cooling) being too warm to allow full output under environmental regulations designed to protect fish life.[118]

The 2022 edition of the World Nuclear Industry Status Report commented:[119]

> *"All of these new problems for an already strained industry did not prevent the French President making a landmark speech on 10 February 2022 hailing a "French nuclear renaissance". While current legislation stipulates the closure of a dozen reactors until 2035 and the reduction of the nuclear share in the power mix to 50 percent, the President wishes that "six EPR2 be built and that we launch the studies for the construction of eight additional EPR2". For now, the EPR2 does not even exist on the drawing board, no detailed design is available yet. The government administration estimated in October 2021 in an internal note that 19 million engineering hours still had to be deployed to get from "basic design" to the "detailed design" stage and that, if everything goes well, the first EPR2 could start up by 2039–2040. In case unexpected industrial difficulties occur – as they have in the past and do currently – it could take until 2043 to commission the first EPR2, the project review states."*

Majority state-owned utilities Areva and EDF long dominated France's nuclear industry. Areva went bankrupt in 2015, leading to a complex restructuring and a €5 billion (A$7.9 billion) government bailout.[120] The *Financial Times* noted in October 2021 that EDF is "saddled with €41bn [A$63.8 billion]

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[112] https://pris.iaea.org/PRIS/CountryStatistics/CountryDetails.aspx?current=GB
[113] https://www.worldnuclearreport.org/The-World-Nuclear-Industry-Status-Report-2022-HTML.html#_idTextAnchor077
[114] https://www.worldnuclearreport.org/The-World-Nuclear-Industry-Status-Report-2022-HTML.html#_idTextAnchor077
[115] https://www.worldnuclearreport.org/The-World-Nuclear-Industry-Status-Report-2022-HTML.html#_idTextAnchor077
[116] https://en.wikipedia.org/wiki/Flamanville_Nuclear_Power_Plant
https://www.worldnuclearreport.org/The-World-Nuclear-Industry-Status-Report-2020-HTML.html#_idTextAnchor236
https://www.worldnuclearreport.org/The-World-Nuclear-Industry-Status-Report-2021-HTML.html#_idTextAnchor025
EDF estimates the 'overnight cost' (excluding finance) at €12.7 billion. See https://www.worldnuclearreport.org/The-World-Nuclear-Industry-Status-Report-2022-HTML.html#_idTextAnchor030
[117] https://www.montelnews.com/news/1292315/edf-delays-flamanville-start-up-to-end-2023-on-weld-issue
https://www.world-nuclear-news.org/Articles/Further-delay-to-Flamanville-EPR-start-up
[118] https://www.theenergymix.com/2022/06/29/corrosion-problem-shutters-half-of-frances-nuclear-reactors/
https://www.worldnuclearreport.org/The-World-Nuclear-Industry-Status-Report-2022-HTML.html#_idTextAnchor030l
[119] https://www.worldnuclearreport.org/The-World-Nuclear-Industry-Status-Report-2022-HTML.html#_idTextAnchor030
[120] https://energyandcarbon.com/where-did-it-all-go-wrong-for-french-nuclear-giant-areva/

of debt and a colossal maintenance and investment programme to fund."[121] The government has announced the nationalisation of EDF due to its crippling debts.

EDF's debt stood at €43 billion (A$67 billion) according to the 2022 edition of the World Nuclear Industry Status Report. The debt may be far higher by the end of 2022 as the Status Report noted:[122]

> *"[S]ome estimates put EDF's expected net debt as high as €65 billion (US$67.9 billion) at the end of 2022. Trade union officials let it be known that the company "might not make it through the year". In early July 2022, the government announced it would fully re-nationalize EDF (it currently holds 84 percent). Following the avalanche of disastrous news over the past few years, EDF's shares had plunged below €8 (US$8), less than one tenth of the peak in 2007, picked up a bit due to the nationalization announcement and remained just below the advertised takeover offer of €12 (US$12) per share. However, analysts and commentators were quick in arguing that the nationalization would not solve EDF's problems."*

In 2021, 56 operating reactors produced 360.7 TWh, down from the 2005 peak of 431.2 TWh.[123] EDF expects nuclear generation in 2022 fell to 280–300 TWh.[124]

Finland

One EPR reactor (Olkiluoto-3) was finally completed in March 2022 (before which the last reactor start-up was in 1980). Commissioning has been problematic: following the discovery of cracks in feedwater pumps in October 2022, "test electricity production" was set to resume in December 2022 with regular operation from March 2023.[125]

The cost of about €11 billion (A$17.1 billion) for the Olkiluoto-3 reactor was 3.7 times greater than the original estimate of €3 billion (A$4.7 billion).[126] Olkiluoto-3 was 13 years behind schedule: construction began in 2005, start-up was expected in 2009 but was not realised until 2022.[127]

Commissioning of Olkiluoto-3 (OL3) has proven to be problematic as discussed in the November 2022 edition of the World Nuclear Industry Status Report:[128]

> *"Following the pattern of countless technical problems and delays during the construction phase, the commissioning stage of OL3 continues to be hampered by "unexpected" events like the untimely triggering of the boron pumps in April 2022 and "foreign material issues observed in the turbine's steam reheater" in May 2022. Therefore, according to TVO "regular electricity production is to start in December 2022, instead of the previously announced start in September 2022". In mid-2020, the schedule was still for commercial operation to begin by 31 May 2021, but progressively delayed to July, then September, then December 2022. Even after first grid connection, technical issues keep impacting the startup schedule."*

[121] https://www.ft.com/content/a1c95212-c122-4a29-8952-14a346381b91
[122] https://www.worldnuclearreport.org/The-World-Nuclear-Industry-Status-Report-2022-HTML.html#_idTextAnchor030
[123] https://www.worldnuclearreport.org/The-World-Nuclear-Industry-Status-Report-2022-HTML.html#_idTextAnchor034
[124] https://www.worldnuclearreport.org/The-World-Nuclear-Industry-Status-Report-2022-HTML.html#_idTextAnchor030
[125] https://www.world-nuclear-news.org/Articles/Finnish-EPR-set-to-resume-test-operation
[126] https://www.worldnuclearreport.org/World-Nuclear-Industry-Status-Report-2018-HTML.html#lien21
[127] https://www.reuters.com/business/energy/finlands-olkiluoto-3-nuclear-reactor-faces-another-delay-2021-08-23/
https://www.tvo.fi/en/index/news/pressreleasesstockexchangereleases/2021/theregularelectricityproductionofol3eprwillbepostponedduetoextensionofturbineoverhaul.html
https://www.worldnuclearreport.org/The-World-Nuclear-Industry-Status-Report-2021-HTML.html#_idTextAnchor022
[128] https://www.worldnuclearreport.org/The-World-Nuclear-Industry-Status-Report-2022-HTML.html#_idTextAnchor030

Plans for a Russian-designed reactor on the Hanhikivi peninsula were abandoned following Russia's invasion of Ukraine in 2022. In addition to Olkiluoto-3, Finland has four reactors with an average age of 43.3 years.

2.7 Other countries

Over 80% of the world's countries have never operated nuclear power plants (158/195 countries or 81%).

The number of countries planning to phase-out nuclear power now includes Germany, Belgium, Taiwan, Spain and Switzerland. Italy (1990), Lithuania (2009) and Kazakhstan (1999) have already phased out nuclear power.

An 'organic' nuclear phase out is underway in many other countries: existing reactors are ageing and the prospects for new reactors are slim or nil.[129]

Over the 31-year period from 1991–2021, only five countries started up their first power reactors – China (1991), Romania (1996), Iran (2011), UAE (2020) and Belarus (2020).[130]

Several countries began construction of a power reactor but never operated one – Austria, Cuba, Libya, Poland and North Korea[131] (although North Korea has used an 'experimental power reactor', based on the British Magnox design, to produce plutonium for weapons).

China

China's nuclear power program has stalled twice over the past decade – after the 2011 Fukushima disaster and again in late 2016.[132] From 2011 to 2021, China averaged just 2.5 reactor construction starts per year.[133] The most likely outcome over the next decade is that a small number of new reactor projects will be approved each year in China, well short of previous projections and not nearly enough to match the decline in the rest of the world. Currently, 55 reactors account for 5% of power generation, with 18 under construction.[134]

This table captures the birth and death of the short-lived nuclear 'renaissance' in China:[135]

	2000–07	*2008–10*	*2011–21*
Average annual power reactor construction starts	0.9 (7 in 8 years)	8.3 (25 in 3 years)	2.5 (27 in 11 years)

Former World Nuclear Association executive Steve Kidd noted in August 2018 that the growth of renewables in China "dwarf the nuclear expansion" and that "many of the negative factors which have affected nuclear programmes elsewhere in the world are now also equally applicable in China."[136]

In China in 2021, wind (656 terrawatt-hours – TWh) and solar (327 TWh) combined generated 2.6 times more electricity than nuclear power (383 TWh net) while hydro (1,300 TWh) generated more than

[129] https://www.worldnuclearreport.org/WNISR2019-Assesses-Climate-Change-and-the-Nuclear-Power-Option.html
[130] https://www.worldnuclearreport.org/The-World-Nuclear-Industry-Status-Report-2022-HTML.html
[131] https://en.wikipedia.org/wiki/Nuclear_power_phase-out
[132] https://wiseinternational.org/nuclear-monitor/871/china-rescue
[133] Calculated from IAEA database: https://pris.iaea.org/PRIS/
[134] https://pris.iaea.org/PRIS/CountryStatistics/CountryDetails.aspx?current=CN
[135] https://pris.iaea.org/PRIS/
[136] http://www.neimagazine.com/opinion/opinionnuclear-in-china-where-is-it-heading-now-6275899/

three times as much electricity as nuclear power. Wind, solar and hydro combined (2,283 TWh) generated 6.0 times more electricity than nuclear power.

The 2020 comparison was striking: 2 GW of nuclear power capacity were added in China compared to 135 GW of renewable capacity.[137]

Little independent information is available on nuclear costs in China – although the strong preference for renewables gives a strong indication as to relative costs. The following factors reduce nuclear costs but increase risks:

- Numerous insiders have warned about inadequate nuclear safety standards.[138] China's reluctance to shut down a Taishan EPR reactor in mid-2021 following a fuel cladding failure – and the unwillingness to provide accurate, timely information about the problem – provides further evidence of inadequate safety standards.[139]
- China's nuclear regulatory agency is not independent[140] and it is understaffed.[141]
- China's nuclear program lacks transparency[142] and there are repressive controls on the media and social media / the internet.[143]
- Whistleblowers who raise concerns about inadequate nuclear safety standards have been persecuted.[144]
- China has some of the world's worst nuclear insurance and liability arrangements.[145]
- Security risks[146] particularly those associated with China's fast reactor program[147] include inadequate laws and regulations for the physical security of materials and for mitigating insider threats.
- Risks arising from political instability, governance challenges, and "colossal corruption [at] every scale of state and society".[148]

China's plans to establish a nuclear export industry are near-dormant[149] and its hopes to build reactors in the UK have been dropped for various reasons including cybersecurity concerns.

Japan

Japan's nuclear industry has been decimated in the aftermath of the continuing Fukushima disaster.

Reactor construction has come to a standstill: five reactors have begun operation since the turn of the century (none since Fukushima) compared to 33 reactors in the 21 years before that.[150] Of Japan's pre-Fukushima fleet of 54 reactors, just 10 have restarted, more than twice that number have been

[137] https://www.worldnuclearreport.org/The-World-Nuclear-Industry-Status-Report-2021-HTML.html#_idTextAnchor021
[138] https://www.chinadialogue.net/article/show/single/en/5808-Chinese-nuclear-di
[139] https://edition.cnn.com/2021/06/14/politics/china-nuclear-reactor-leak-us-monitoring/index.html
https://beyondnuclearinternational.org/2021/06/20/the-taishan-death-blow/
https://www.spectator.co.uk/article/how-taishan-almost-became-china-s-chernobyl
https://edition.cnn.com/2021/07/22/china/edf-taishan-nuclear-plant-china-intl-hnk/index.html
https://www.world-nuclear-news.org/Articles/Operator-to-decide-on-Taishan-1-outage-says-EDF
[140] http://www.eurekalert.org/pub_releases/2011-06/acs-cni062211.php
[141] https://www.world-nuclear.org/info/Country-Profiles/Countries-A-F/China--Nuclear-Power/
[142] http://www.bloomberg.com/news/2014-06-18/french-nuclear-regulator-says-china-cooperation-lacking.html
[143] http://en.rsf.org/china-china-12-03-2012,42077.html
[144] https://www.hrichina.org/sites/default/files/PDFs/CRF.1.2006/CRF-2006-1_Sun.pdf
[145] http://www.globaltimes.cn/content/856971.shtml
[146] http://ntiindex.org/countries/china/
[147] https://www.belfercenter.org/publication/security-risks-chinas-nuclear-reprocessing-facilities
[148] http://blog.transparency.org/2014/12/03/asia-pacific-growing-economies-growing-corruption/
[149] https://www.worldnuclearreport.org/The-World-Nuclear-Industry-Status-Report-2021-HTML.html#_idTextAnchor021
[150] https://pris.iaea.org/PRIS/CountryStatistics/CountryDetails.aspx?current=JP

permanently shut down (27 in total, of which 21 closures occurred after the Fukushima disaster[151]), and the fate of the remaining reactors remains undecided.[152]

In a 2019 report, the Japan Center for Economic Research estimated that the total cost of the Fukushima accident, including compensation, decontamination and decommissioning, could reach ¥81 trillion (A$904 billion).[153] The intention for direct disposal of Fukushima liquid waste to the Pacific is causing significant regional concern. Indirect costs – such as replacement power for shuttered reactors, and lost tourism revenue – also amount to hundreds of billions of dollars.[154] Direct and indirect costs combined far exceed A$1 trillion (note: Chernobyl was also a trillion-dollar disaster[155]).

India

India's leaders have for decades promised a massive nuclear power expansion, but it never happens. Currently, 22 reactors account for 3.2% of national electricity generation, with another eight reactors under construction.[156] In the decade from 2012 to 2021, there were just four power reactor construction starts.[157]

Combined, wind and solar generated 3.4 times more power than nuclear plants in 2021.[158]

Russia

In Russia, 37 power reactors supply 20% of total electricity generation, with four reactors under construction and just four power reactor construction starts in the decade from 2012 to 2021.[159]

South Korea

The previous government under President Moon Jae-in pursued a long-term phase-out policy and took concrete actions in support of that policy including the shut-down of the Kori-1 and Wolsong-1 reactors in 2017 and 2019 respectively, and suspension or cancellation of plans for six further reactors.[160] However, following the 2022 presidential election, the new government under President Yoon Suk-yeol supports nuclear power and has ditched the phase-out policy. Currently, 25 reactors account for 28% of power generation, with three power reactors under construction.

South Korea's nuclear industry has been rocked by industry-wide corruption scandals.[161] Other than the 2009 contract to supply four reactors to the UAE (also mired in scandal[162]), South Korea's efforts to establish a nuclear export business have been unsuccessful. South Korean utilities opted out of the Wylfa and Moorside projects in the UK (as did Japanese companies Hitachi[163] and Toshiba[164]) despite offers of billions of dollars of British taxpayer subsidies.

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[151] https://www.worldnuclearreport.org/The-World-Nuclear-Industry-Status-Report-2022-HTML.html#_idTextAnchor053
[152] https://www.worldnuclearreport.org/The-World-Nuclear-Industry-Status-Report-2022-HTML.html#_idTextAnchor053
https://www.bloomberg.com/news/articles/2021-06-23/japan-restarts-first-nuclear-reactor-since-2018-amid-hurdles
[153] https://www.jcer.or.jp/english/accident-cleanup-costs-rising-to-35-80-trillion-yen-in-40-years
[154] https://www.wiseinternational.org/nuclear-monitor/836/economic-impacts-fukushima-disaster
[155] https://globalhealth.usc.edu/wp-content/uploads/2016/01/2016_chernobyl_costs_report.pdf
[156] https://pris.iaea.org/PRIS/CountryStatistics/CountryDetails.aspx?current=IN
[157] https://pris.iaea.org/PRIS/
[158] https://www.worldnuclearreport.org/The-World-Nuclear-Industry-Status-Report-2022-HTML.html#_idTextAnchor049
[159] https://pris.iaea.org/PRIS/, https://pris.iaea.org/PRIS/CountryStatistics/CountryDetails.aspx?current=RU
[160] https://www.wiseinternational.org/nuclear-monitor/844/south-koreas-nuclear-industry-model-others-follow
[161] https://wiseinternational.org/nuclear-monitor/887/nuclear-monitor-887-17-june-2020
https://www.wiseinternational.org/nuclear-monitor/844/south-koreas-nuclear-mafia
[162] https://wiseinternational.org/nuclear-monitor/887/nuclear-monitor-887-17-june-2020
[163] https://www.theguardian.com/business/2019/jan/17/hitachi-set-to-scrap-16bn-nuclear-project-anglesey-wales

The South Korean nuclear industry's business model is to trade off safety to improve economics. The CEO of French nuclear utility Areva likened Korea's AP1400 reactor design to "a car without airbags and safety belts."[165] Ironically, French utilities are likely to skimp on safety features with the envisaged EPR2 design following the catastrophic cost blowouts with EPR reactors under construction in France and Finland (and despite safety problems with an EPR reactor in China).

2.8 'Generation IV' and small modular reactor economics

With respect to 'advanced' or 'Generation IV' nuclear power concepts, the findings of the 2015/16 South Australian Nuclear Fuel Cycle Royal Commission still hold. Numerous lobbyists and enthusiasts made the case for the introduction of 'advanced' nuclear reactors to South Australia, but the Royal Commission concluded:

> *"[A]dvanced fast reactors or reactors with other innovative designs are unlikely to be feasible or viable in South Australia in the foreseeable future. No licensed and commercially proven design is currently operating. Development to that point would require substantial capital investment. Moreover, the electricity generated has not been demonstrated to be cost-competitive with current light water reactor designs."*

Claims that Generation IV concepts and small modular reactors (SMRs) are leading to 'cleaner, safer and more efficient energy production' have no evidentiary basis. The words of Admiral Hyman Rickover, a pioneer of the US nuclear program, are as relevant now as when they were penned in 1953:

> *"An academic reactor or reactor plant almost always has the following basic characteristics: (1) It is simple. (2) It is small. (3) It is cheap (4) It is light. (5) It can be built very quickly. (6) It is very flexible in purpose ('omnibus reactor'). (7) Very little development is required. It will use mostly off-the-shelf components. (8) The reactor is in the study phase. It is not being built now.*
>
> *"On the other hand, a practical reactor plant can be distinguished by the following characteristics: (1) It is being built now. (2) It is behind schedule. (3) It is requiring an immense amount of development on apparently trivial items. Corrosion, in particular, is a problem. (4) It is very expensive. (5) It takes a long time to build because of the engineering development problems. (6) It is large. (7) It is heavy. (8) It is complicated. …*
>
> *"For a large part those involved with the academic reactors have more inclination and time to present their ideas in reports and orally to those who will listen. Since they are innocently unaware of the real but hidden difficulties of their plans, they speak with great facility and confidence. Those involved with practical reactors, humbled by their experience, speak less and worry more."*

Numerous Generation IV and SMR projects have been abandoned over the past decade. The 'advanced' nuclear sector is generating attention, but not electricity. It is a high-risk sector, hence the deep reluctance of the private sector and national governments to invest the funds that would be required to advance any possibility of progress.

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[164] https://www.theguardian.com/environment/2018/nov/08/toshiba-uk-nuclear-power-plant-project-nu-gen-cumbria
[165] Nucleonics Week, 22 April 2010, 'No core catcher, double containment for UAE reactors, South Koreans say'.

Most small modular reactors under construction are significantly over-budget as was the case with the two completed SMRs. The economics of small modular reactors are summarised in section 3 of this submission and discussed in detail in a submission to the 2019 federal nuclear inquiry.[166]

Historical experience is not promising with 'advanced' reactors. For example, fast neutron reactors are neither new nor cheap. For example, the French Superphenix fast neutron reactor was promoted as the first commercial-scale fast breeder reactor in the world but the electricity it produced is estimated to have cost an astonishing US$1,330 / MWh.[167] Japan will have wasted over A$20 billion on its failed Monju fast neutron reactor once decommissioning is complete.[168]

2.9 Nuclear power's negative learning curve

It is a standard characteristic of technological development that unit costs decrease over time, as the industry gains experience. Yet nuclear power is subject to a 'negative learning curve' − it has become increasingly expensive over time.[169] Citigroup states:

> *"The capital cost of nuclear build has actually risen in recent decades in some developed markets, partly due to increased safety expenditure, and due to smaller construction programmes (i.e. lower economies of scale). Moreover the 'fixed cost' nature of nuclear generation in combination with its relatively high price (when back end liabilities are taken into account) also places the technology at a significant disadvantage; utilities are reluctant to enter into a very long term (20+ years of operation, and decades of aftercare provisioning) investment with almost no control over costs post commissioning, with the uncertainty and rates of change currently occurring in the energy mix."*[170]

Even the large-scale, standardised French nuclear power program has been subject to a negative learning curve.[171] The problem of escalating costs is worsening with the massive cost blowouts associated with the EPR projects in France and Finland.

In 2009, an updated version of a 2003 MIT Interdisciplinary Study on the Future of Nuclear Power was published, stating:[172]

> *"The estimated cost of constructing a nuclear power plant has increased at a rate of 15% per year heading into the current economic downturn. This is based both on the cost of actual builds in Japan and Korea and on the projected cost of new plants planned for in the United States."*

Note that these significant cost escalations were very much in evidence before the March 2011 Fukushima disaster.

The high capital costs of nuclear power make it vulnerable to interest rate rises, credit squeezes and construction delays. As the World Nuclear Association notes, "long construction periods will push up financing costs, and in the past they have done so spectacularly."[173]

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[166] https://www.aph.gov.au/DocumentStore.ashx?id=7a9318c0-aad6-405e-832f-66212a87d158&subId=669038
[167] Salahodeen Abdul-Kafi, 30 March 2011, 'The Superphénix Fast-Breeder Reactor', http://large.stanford.edu/courses/2011/ph241/abdul-kafi1/
[168] See Appendix 2 in the joint NGO submission to the federal nuclear inquiry, https://www.aph.gov.au/DocumentStore.ashx?id=9eee9d5f-4362-4b30-b0b8-3b65ff98215f&subId=670271
[169] Joe Romm, 6 April 2011, 'Does nuclear power have a negative learning curve?', http://thinkprogress.org/romm/2011/04/06/207833/does-nuclear-power-have-a-negative-learning-curve/
[170] www.businessinsider.com.au/5-charts-that-show-nuclear-is-declining-2013-10
[171] Arnulf Grubler, September 2010, 'The costs of the French nuclear scale-up: A case of negative learning by doing', *Energy Policy*, Vol.38, Issue 9, pp.5174–5188, www.sciencedirect.com/science/article/pii/S0301421510003526
[172] http://web.mit.edu/nuclearpower/

Citigroup commented on three 'Corporate Killers' in a 2009 report:[174]

> *"Three of the risks faced by developers − Construction, Power Price, and Operational − are so large and variable that individually they could each bring even the largest utility company to its knees financially. This makes new nuclear a unique investment proposition for utility companies."*

Thus, Citigroup foreshadowed the bankruptcy filing of Westinghouse (and the near-bankruptcy of its parent company Toshiba), which resulted primarily from massive cost overruns at the V.C. Summer reactor project in South Carolina and the abandonment of that project after the expenditure of at least A$12.9 billion (US$9 billion), as well as dramatic cost overruns with the Vogtle reactor project in the US state of Georgia.

[173] World Nuclear Association, 'The Economics of Nuclear Power', http://web.archive.org/web/20140212215105/www.world-nuclear.org/info/Economic-Aspects/Economics-of-Nuclear-Power/
[174] Citigroup, 9 Nov 2009, 'New Nuclear - the Economics Say No: UK Green Lights New Nuclear – Or Does It?', http://nonuclear.se/files/SEU27102.pdf

3. SMALL MODULAR REACTORS

3.1 Introduction

'Small modular reactors' (SMRs) would have a capacity of under 300 megawatts (MW), whereas large reactors typically have a capacity of about 1,000 MW. Construction at reactor sites would be replaced with standardised factory production of reactor components (or 'modules') then installation at the reactor site. The term 'modular' also refers to the option of building clusters of small reactors at the same site.

SMRs don't have any meaningful existence. Some small reactors exist, and there are hopes and dreams of mass factory production of SMRs. But currently there is no such SMR mass manufacturing capacity, and no company, consortium, utility or national government is seriously considering betting billions building an SMR mass manufacturing capacity.

With near-zero prospects for new large nuclear power reactors in Western countries, SMRs are being promoted to rescue an industry that even nuclear lobbyists acknowledge is in crisis.[175] In essence, the nuclear industry's solution to its expensive and uncompetitive large reactors is to offer up even more expensive power from SMRs.

Previous attempts to build SMRs have failed and there is no reason to expect success now. M.V. Ramana concludes an analysis of the history of SMRs:[176]

> *"Once again, we see history repeating itself in today's claims for small reactors – that the demand will be large, that they will be cheap and quick to construct. But nothing in the history of small nuclear reactors suggests that they would be more economical than full-size ones. In fact, the record is pretty clear: Without exception, small reactors cost too much for the little electricity they produced, the result of both their low output and their poor performance."*

No private sector SMR projects have reached the construction stage. A small number of SMRs are under construction, by state nuclear agencies in Russia, China and Argentina. Most or all of them are over-budget and behind schedule. None are factory built (the essence of the concept of modular reactors).

Alarmingly, about half of the SMRs under construction are intended to facilitate the exploitation of fossil fuel reserves in the Arctic, the South China Sea and elsewhere. The primary purpose of the Russian floating plant is to power fossil fuel mining operations in the Arctic.[177] Russia's pursuit of nuclear-powered icebreaker ships (nine such ships are planned by 2035) is closely connected to its agenda of establishing military and economic control of the Northern Sea Route – a route that owes its existence to climate change.[178] China General Nuclear Power Group plans to use floating nuclear power plants for oilfield exploitation in the Bohai Sea and deep-water oil and gas development in the South China Sea.[179]

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[175] https://www.wiseinternational.org/nuclear-monitor/839/nuclear-power-crisis-or-it-merely-end
[176] https://spectrum.ieee.org/the-forgotten-history-of-small-nuclear-reactors
[177] https://www.wiseinternational.org/nuclear-monitor/861/worlds-first-purpose-built-floating-nuclear-plant-akademik-lomonosov-reaches
[178] https://www.popularmechanics.com/military/navy-ships/a27615565/ural-russia-icebreaker/
[179] http://en.cgnpc.com.cn/encgn/c100050/business_tt.shtml

There are disturbing, multifaceted connections between SMR projects and nuclear weapons proliferation and militarism more generally:[180]

- Argentina's experience and expertise with small reactors derives from its historic weapons program, and its interest in SMRs is interconnected with its interest in small reactors for naval propulsion.
- China's interest in SMRs extends beyond fossil fuel mining and includes powering the construction and operation of artificial islands in its attempt to secure claim to a vast area of the South China Sea.
- Saudi Arabia's interest in SMRs is likely connected to its interest in developing nuclear weapons or a latent weapons capability.
- A subsidiary of Holtec International has actively sought a military role, inviting the US National Nuclear Security Administration to consider the feasibility of using a proposed SMR to produce tritium, used to boost the explosive yield of nuclear weapons.
- Proposals are under consideration in the US to build SMRs at military bases and perhaps even to use them to power forward operating bases.
- In the UK, Rolls-Royce is promoting SMRs on the grounds that "a civil nuclear UK SMR programme would relieve the Ministry of Defence of the burden of developing and retaining skills and capability".

3.2 Widespread scepticism about SMRs

The prevailing skepticism about SMRs is evident in a 2017 Lloyd's Register report based on the insights of almost 600 professionals and experts from utilities, distributors, operators and equipment manufacturers.[181] They predict that SMRs have a "low likelihood of eventual take-up and will have a minimal impact when they do arrive".[182]

Likewise, American Nuclear Society consultant Will Davis said in 2014 that the SMR "universe is rife with press releases, but devoid of new concrete."[183]

A 2014 report produced by *Nuclear Energy Insider*, drawing on interviews with more than 50 "leading specialists and decision makers", noted a "pervasive sense of pessimism" resulting from abandoned and scaled-back SMR programs.[184]

Dr. Ziggy Switkowski – who headed the Howard Government's nuclear review in 2006 – noted in 2019 that "nobody's putting their money up'' to build SMRs and "it is largely a debate for intellects and advocates because neither generators nor investors are interested because of the risk."[185] Moreover "the window for gigawatt-scale nuclear has closed", Dr. Switkowski said[186], and nuclear power is no longer cheaper than renewables with costs rapidly shifting in favour of renewables.[187]

[180] https://wiseinternational.org/nuclear-monitor/872-873/small-modular-reactors-and-nuclear-weapons-proliferation
https://wiseinternational.org/nuclear-monitor/872-873/military-bromance-smrs-support-and-cross-subsidize-uk-nuclear-weapons
https://wiseinternational.org/nuclear-monitor/872-873/smrs-power-military-installations-and-forward-bases-united-states
[181] http://info.lr.org/techradarlowcarbon
[182] http://www.world-nuclear-news.org/EE-Nuclear-more-competitive-than-fossil-fuels-report-09021702.html
[183] http://ansnuclearcafe.org/2014/02/13/carem-25-carries-torch-for-smr-construction/
[184] http://1.nuclearenergyinsider.com/LP=362
[185] https://www.afr.com/politics/federal/no-investment-appetite-for-nuclear-switkowski-20190805-p52dwv
[186] https://www.theage.com.au/business/the-economy/australia-has-missed-the-boat-on-nuclear-power-20180111-p4yyeg.html
[187] http://www.smh.com.au/business/the-economy/safety-risks-stall-nuclear-role-in-australia-s-energy-mix-20180125-p4yyvj.html

World Finance reported in October 2018 that "while SMRs are purported to be the key to transforming the nuclear sector, history has painted a troubling picture: SMR designs have been in the works for decades, but none have reached commercial success."[188]

Former World Nuclear Association executive Steve Kidd wrote about SMR "myths" in 2015:[189]

> *"The jury is still out on SMRs, but unless the regulatory system in potential markets can be adapted to make their construction and operation much cheaper than for large LWRs [light-water reactors], they are unlikely to become more than a niche product. Even if the costs of construction can be cut with series production, the potential O&M [operating and maintenance] costs are a concern. A substantial part of these are fixed, irrespective of the size of reactor."*

The South Australian Nuclear Fuel Cycle Royal Commission's final report in 2016 identified numerous hurdles and uncertainties facing SMRs, including:[190]

- SMRs have a relatively small electrical output, yet some costs including staffing may not decrease in proportion to the decreased output.
- SMRs have lower thermal efficiency than large reactors, which generally translates to higher fuel consumption and spent fuel volumes over the life of a reactor.
- SMR-specific safety analyses need to be undertaken to demonstrate their robustness, for example during seismic events.
- It is claimed that much of the SMR plant can be fabricated in a factory environment and transported to site for construction. However, it would be expensive to set up this facility and it would require multiple customers to commit to purchasing SMR plants to justify the investment.
- Reduced safety exclusion zones for small reactors have yet to be confirmed by regulators.
- Timescales and costs associated with the licensing process are still to be established.
- SMR designers need to raise the necessary funds to complete the development before a commercial trial of the developing designs can take place.
- Customers who are willing to take on first-of-a-kind technology risks must be secured.

In 2019, Kevin Anderson, North American Project Director for Nuclear Energy Insider, said that there "is unprecedented growth in companies proposing design alternatives for the future of nuclear, but precious little progress in terms of market-ready solutions."[191]

The business plan for SMRs also face a fuel supply issue. The fuel needed for some proposed SMRs is high-assay low enriched uranium (HALEU) which is limited in availability (due to limited demand). SMR developers in the US need security of fuel supply and potential fuel manufacturers need security of demand to invest in the technology.[192]

3.3 Operating and under-construction SMRs

The November 2022 edition of the World Nuclear Industry Status Report provides the following summary of operating SMRs, under-construction SMRs, and a few of the most important SMR projects in the design or planning stage:

> *"**Argentina.** The CAREM-25 project has been under construction since 2014. Following numerous delays, the latest estimated date for startup is 2027. The lower end of cost*

[188] https://www.worldfinance.com/markets/nuclear-power-continues-its-decline-as-renewable-alternatives-steam-ahead
[189] https://www.neimagazine.com/opinion/opinionnuclear-myths-is-the-industry-also-guilty-4598343/
[190] https://nuclear.foe.org.au/wp-content/uploads/NFCRC_Final_Report_Web_5MB.pdf
[191] https://www.nuclearenergyinsider.com/international-smr-advanced-reactor
[192] https://www.reuters.com/business/energy/americas-new-nuclear-power-industry-has-russian-problem-2022-10-20/

estimates per installed kilowatt correspond to roughly twice the cost estimates for the most expensive Generation-III reactors.

Canada. *There is continuous strong federal and provincial government support for the promotion of SMRs. While several grants to the value of tens of millions of dollars have been awarded to different design developers, the amounts remain small when compared to what would be required to advance one of these designs to the point of being licensed for construction. No design has yet been transmitted to the safety authority for review, leave alone for certification.*

China. *Construction on two high-temperature reactor modules started in 2012. The first module was connected to the grid for a few days in December 2021, almost five years behind schedule. Reportedly, neither unit has generated power since. The reasons are unknown. Construction started on a second design, the ACP100 or Linglong One, in July 2021, six years later than planned. It is scheduled to be completed by early 2026.*

France. *In February 2022, President Macron announced a US$1.1 billion contribution until 2030 to the financing of the development of the Nuward SMR design. However, EDF made it clear that the project is not high amongst its priorities.*

India. *An Advanced Heavy Water Reactor (AHWR) design has been under development since the 1990s, but its construction has been continuously delayed. Earlier in 2022, the government announced that a "Pre-Licensing Design Safety appraisal of the reactor has been completed".*

Russia. *Russia operates two SMRs on a barge called the Akademik Lomonosov. Both reactors were connected to the grid in December 2019, nine years later than planned. Since then, their performance has been mediocre. A second SMR project, a lead-cooled fast reactor design, was launched in June 2021.*

South Korea. *The System-Integrated Modular Advanced Reactor (SMART) has been under development since 1997. In 2012, the design received approval by the safety authority, but there have been no orders. Reportedly, several other designs are in very early stages of development.*

United Kingdom. *Since 2014, Rolls Royce has been developing the "UK SMR", a 470 MW reactor (exceeding the size-limit of 300 MW for the usual SMR definition). In November 2021, Rolls Royce announced it had received US$281 million in government funding and US$261 million from private sources (including company funding), far short of its earlier calls for US$2.8 billion in support. In March 2022, the regulator accepted the design for a Generic Design Assessment (GDA).*

(We note recent statements from Rolls Royce around options for the siting of a facility planned to manufacture SMR components. Any advance on this is contingent on agreement with the UK government on future SMR deployment and remains highly uncertain).

United States. *The Department of Energy (DOE) has already spent more than US$1.2 billion on SMRs and has announced further awards over the next decade that could amount to an additional US$5.5 billion. However, there is still not a single reactor under construction. Only one design, NuScale, has received a final safety evaluation report. However, since then, the design capacity has been increased from 50 MW to 77 MW per module, and many issues remain unsolved. In October 2021, eight municipalities withdrew from the only investment project in Utah, leaving the 6-module 462 MW project with subscriptions amounting to just 101 MW. Cost estimates (including financing) have ballooned to US$5.3 billion."*

Operating SMRs

Just two SMRs are said to be operating – neither meeting the ‘modular’ definition of serial factory production of reactor components. The two operational SMRs – one each in Russia and China – exhibit familiar problems of massive cost blowouts and multi-year delays. SMR reality doesn’t come close to matching SMR rhetoric.

Russia's has a floating nuclear power plant with two 35 MW reactors. The construction cost increased six-fold from 6 billion rubles to 37 billion rubles (A$785 million)[193], equivalent to A$10.1 billion / gigawatt (GW).

According to the OECD's Nuclear Energy Agency, electricity produced by the Russian floating plant costs an estimated US$200 (A$288) / megawatt-hour (MWh), with the high cost due to large staffing requirements, high fuel costs, and resources required to maintain the barge and coastal infrastructure.[194] To put that in perspective, the Minerals Council of Australia states that SMRs won't find a market in Australia unless they can produce power at a cost of A$60–80 / MWh[195] – about one-quarter of the cost of electricity produced by the Russian plant.

Rapid construction timelines are said to be a feature of SMRs, but the Russian floating plant took 12 years to build.[196] Shortly before construction began in 2007, Rosatom announced that the plant would begin operating in October 2010, but it was not completed until 2019.[197] A three-year construction project became a 12-year project. Russia's plan to have seven floating nuclear power plants by 2015 was not realised.[198]

The performance of Russia’s floating nuclear power plant appears to be mediocre: the lifetime load factors for the two reactors stand at 38.8% and 17.2%.[199]

The other operating SMR (loosely defined) is China's demonstration 210 MW (2 x 105 MW) high-temperature gas-cooled reactor (HTGR). A 2016 report said that the estimated construction cost was about US$5 billion (A$7.2 billion) / GW – about twice the initial cost estimates – and that cost increases arose from higher material and component costs, increases in labour costs, and project delays.[200] The World Nuclear Association states that the cost of the demonstration HTGR is US$6 billion (A$8.6 billion) / GW[201], roughly twice the cost of larger Chinese ‘Hualong’ reactors (US$2.6–3.5 billion / GW).[202] Those figures (US$5–6 billion / GW) are 2–3 times higher than the US$2 billion (A$2.88 billion) / GW estimate in a 2009 paper by Tsinghua University researchers.[203]

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[193] https://www.worldnuclearreport.org/The-World-Nuclear-Industry-Status-Report-2021-HTML.html#_idTextAnchor013
http://bellona.org/news/nuclear-issues/2015-05-new-documents-show-cost-russian-nuclear-power-plant-skyrockets
[194] https://www.oecd-nea.org/jcms/pl_14924
[195] https://www.parliament.vic.gov.au/images/stories/committees/SCEP/Inquiry_into_Nuclear_Prohibition_Inquiry_/Transcripts/25_June_2020/5._FINAL_-_Minerals_Council_Aust.pdf
[196] https://www.worldnuclearreport.org/The-World-Nuclear-Industry-Status-Report-2021-HTML.html#_idTextAnchor013
[197] https://www.worldnuclearreport.org/The-World-Nuclear-Industry-Status-Report-2022-HTML.html
[198] https://en.wikipedia.org/wiki/Russian_floating_nuclear_power_station
[199] https://pris.iaea.org/PRIS/CountryStatistics/ReactorDetails.aspx?current=895,
https://pris.iaea.org/PRIS/CountryStatistics/ReactorDetails.aspx?current=896
[200] http://www.nextbigfuture.com/2016/12/chinas-plans-to-begin-converting-coal.html
See also https://www.nextbigfuture.com/2017/08/china-small-modular-pebble-beds-will-be-400-million-for-200-mw-and-1-2-billion-for-600-mw.html
[201] https://www.world-nuclear.org/information-library/country-profiles/countries-a-f/china-nuclear-power.aspx
[202] https://www.worldnuclearreport.org/The-World-Nuclear-Industry-Status-Report-2022-HTML.html#_idTextAnchor147
[203] https://www.researchgate.net/publication/245194953_Current_status_and_technical_description_of_Chinese_2_250_MW_th_HTR-PM_demonstration_plant

Wang Yingsu, secretary general of the nuclear power branch of the China Electric Power Promotion Council, said in 2021 that HTGRs would never be as cheap as conventional light-water reactors.[204]

In 2004, the CEO of Chinergy said construction of the first HTGR would begin in 2007 and it would be completed by the end of the decade.[205] However, construction of the demonstration HTGR did not begin until 2012 (with an estimated construction time of 50 months[206]) and it was completed in 2021 after repeated delays. This nine-year construction project – more than double the construction time estimate in 2012 – undermines claims that SMRs could be built in as little as 2–3 years.

China's HTGR is said to be operational but the November 2022 edition of the World Nuclear Industry Status Report indicates that problems have arisen:[207]
"The first of two High Temperature Gas Cooled Reactor (HTGR) units at Shidao Bay (Shidao Bay 1-1 and 1-2) – IAEA-PRIS considers these as one plant – was connected to the grid on 20 December 2021. As of the time of this writing, there is no public announcement that the second unit has been connected. Further, between January and June 2022, there was no power fed to the grid from this site, according to China Nuclear Energy Industry Association (CNEIA). No information has been published about the reasons for the additional delays in commissioning the second unit and for the shutdown of the first unit in the first half-year of 2022."

However a December 2022 World Nuclear Association article was more upbeat, citing Chinese project partners stating that the HTGR reached "initial full power" on 9 December 2022, thus "laying the foundation for the project to be put into operation".[208]

Neutron Bytes reported in June 2020: "It has been reported by several sources that the high cost of manufacturing the HTGR reactor components and building it are caused, in part, by the need for specialty materials to deal with the high heat it generates, and by the usual first-of-a-kind costs of a new design which have contributed to the schedule delay. In any case, China's ambitious plans to make Shandong Province a showcase for advanced nuclear reactors have been put on hold."[209]

NucNet reported in 2020 that China's State Nuclear Power Technology Corp. dropped plans to manufacture 20 HTGRs after levelised cost of electricity estimates rose to levels higher than a conventional pressurised water reactor such as China's Hualong One.[210] Likewise, the World Nuclear Association states that plans for 18 additional HTGRs at the same site as the demonstration HTGR have been "dropped".[211]

Multiple nations have tried to develop high-temperature gas-cooled reactors but then abandoned those efforts.[212]

SMRs under construction and NuScale's SMR plans

Three SMRs are under construction – again with the qualification that they don't involve serial factory production of reactor components so don't meet the 'modular' part of the definition of SMRs.

[204] https://www.scmp.com/news/china/science/article/3159945/china-revives-abandoned-htgr-nuclear-technology-safe-power-drive
[205] https://www.worldnuclearreport.org/The-World-Nuclear-Industry-Status-Report-2022-HTML.html#_idTextAnchor147
[206] https://www.worldnuclearreport.org/The-World-Nuclear-Industry-Status-Report-2022-HTML.html#_idTextAnchor147
[207] https://www.worldnuclearreport.org/The-World-Nuclear-Industry-Status-Report-2022-HTML.html#_idTextAnchor030
[208] https://www.world-nuclear-news.org/Articles/China-s-demonstration-HTR-PM-reaches-full-power
[209] https://neutronbytes.com/2020/06/14/china-nuclear-energy-news-for-06-14-20/
[210] https://www.nucnet.org/news/progress-and-status-in-the-race-for-commercialisation-2-4-2020
[211] https://www.world-nuclear-news.org/NN-First-vessel-installed-in-Chinas-HTR-PM-unit-2103164.html
[212] https://ucsusa.org/sites/default/files/2021-03/advanced-isnt-always-better-full.pdf
https://wiseinternational.org/nuclear-monitor/872-873/high-temperature-gas-cooled-zombie-smrs

Cost estimates for the CAREM SMR under construction in Argentina have ballooned. In 2004, when the CAREM reactor was in the planning stage, Argentina's Bariloche Atomic Center estimated an overnight cost of US$1 billion / GW for an integrated 300 MW plant (while acknowledging that to achieve such a cost would be a "very difficult task").[213] In 2005, Argentina's National Atomic Energy Commission CNEA estimated a cost about US$105 million (US$4.2 billion / GW).[214] When construction began in 2014, the estimated cost was US$17.8 billion / GW (US$446 million for a 25-MW reactor).[215] In 2021, the cost estimate increased to US$23.4 billion / GW (US$750 million (A$1.1 billion) with the capacity uprated from 25 MW to 32 MW).[216] That's over one billion Australian dollars for a plant with the capacity of a handful of large wind turbines.

The CAREM project is years behind schedule and costs will likely increase further. The project was launched by CNEA in 1984.[217] When construction began in 2014, 30 years later – completion was expected in 2017.[218] But progress has been slow, work was suspended on several occasions[219] and completion was pushed back to 2024. Further delays pushed the estimated completion date back to late 2027.[220] A three-year construction project has become, at best, a 13-year construction project. Thirty-eight years after the project was launched, the first prototype remains incomplete.

In July 2021, China National Nuclear Corporation (CNNC) New Energy Corporation began construction of the 125 MW pressurised water reactor ACP100 at Hainan[221] with an estimated construction time of just under five years (58 months).[222] CNNC says it will be the world's first land-based commercial SMR.[223] The ACP100 has been under development since 2010.[224] Construction was supposed to begin as early as 2013 (and, later, 2015 … and 2016 … and 2017) but did not begin until 2021.[225] According to CNNC, construction costs per kilowatt will be twice the cost of large reactors, and the levelised cost of electricity will be 50% higher than large reactors.[226]

In June 2021, construction of the 300 MW demonstration lead-cooled BREST fast neutron reactor began in Russia. Plans for a lead-cooled fast reactor in Russia date from the 1990s but construction has been repeatedly delayed.[227] In 2016, construction of BREST was expected to begin in 2017 and completion was expected in 2020[228] – but construction hadn't even begun in 2020. Completion is now expected in 2026. In 2012, the estimated cost for the reactor and associated facilities was 42 billion rubles (A$891 million)[229]; now, the estimate has more than doubled to 100 billion rubles (A$2.1 billion).[230]

[213] https://www.researchgate.net/publication/267579277_CAREM_concept_A_competitive_SMR
[214] IAEA, Aug 2021, 'Technology Roadmap for Small Modular Reactor Deployment', https://www-pub.iaea.org/MTCD/Publications/PDF/PUB1944_web.pdf
[215] http://www.world-nuclear-news.org/NN-Construction-of-CAREM-underway-1002144.html
[216] https://www.gihub.org/resources/showcase-projects/carem-25-prototype/, https://www.gihub.org/quality-infrastructure-database/case-studies/carem-25-prototype/
[217] https://www-pub.iaea.org/MTCD/Publications/PDF/PUB1944_web.pdf
[218] https://www.world-nuclear-news.org/NN-Construction-of-CAREM-underway-1002144.html
[219] https://www.world-nuclear-news.org/Articles/Construction-of-Argentinas-small-CAREM-25-unit-to
[220] https://world-nuclear.org/information-library/country-profiles/countries-a-f/argentina.aspx
[221] https://world-nuclear-news.org/Articles/Installation-of-containment-starts-at-Chinese-SMR
[222] https://www.worldnuclearreport.org/The-World-Nuclear-Industry-Status-Report-2022-HTML.html#_idTextAnchor147
[223] https://world-nuclear-news.org/Articles/Installation-of-containment-starts-at-Chinese-SMR
[224] https://world-nuclear-news.org/Articles/Installation-of-containment-starts-at-Chinese-SMR, https://www.worldnuclearreport.org/The-World-Nuclear-Industry-Status-Report-2022-HTML.html#_idTextAnchor147
[225] https://www.worldnuclearreport.org/The-World-Nuclear-Industry-Status-Report-2022-HTML.html#_idTextAnchor147
[226] https://nucleus.iaea.org/sites/INPRO/df17/IV.1.-DanrongSong-ACP100.pdf
[227] https://www.neimagazine.com/features/featurebrest-is-best/
https://www.powermag.com/nuclear-first-work-starts-on-russian-fast-neutron-reactor/
[228] https://www.nsenergybusiness.com/news/newsconstruction-of-russias-brest-reactor-to-start-next-year-4974446/
https://www.nsenergybusiness.com/news/newsbreakthrough-project-continues-as-brest-reactor-is-postponed-5718901/
https://bellona.org/news/nuclear-issues/2015-05-perpetual-search-perpetuum-mobile
[229] https://bellona.org/news/nuclear-issues/2015-05-perpetual-search-perpetuum-mobile
[230] https://tass.com/economy/1300401

NuScale Power

The SMR plans of US company NuScale Power are heavily promoted.[231] Development of NuScale SMR technology dates from 2003 – 20 years ago – yet the company has not even begun construction of a single reactor.[232] A study by WSP / Parsons Brinckerhoff, commissioned by the South Australian Nuclear Fuel Cycle Royal Commission, estimated costs of A$225 / MWh for power from SMRs based on the NuScale design.[233] As noted above, the Minerals Council of Australia states that SMRs won't find a market unless they can produce power at a cost of A$60–80 / MWh[234] – about one-third of the WSP / Parsons Brinckerhoff estimate for NuScale technology.

In January 2023, NuScale announced a massive increase in its cost estimates for its proposed SMR plant in the US state of Idaho. According to NuScale, the new estimate was “influenced by external factors such as inflationary pressures and increases in the price of steel, electrical equipment and other construction commodities not seen for more than 40 years.”[235] The latest US$89 / MWh estimate is 53% higher than the previous estimate of US$58 / MWh – an “eye-popping” increase according to the Institute for Energy Economics and Financial Analysis.[236] The 53% increase in costs-per-MWH reflects a 75% increase in the estimated construction cost, from US$5.3 billion to US$9.3 billion (A$13.3 billion) for a 462 MW plant with six reactors.[237] That equates to US$20.1 billion (A$28.8 billion) per GW – far more expensive than the wildly over-budget Vogtle project (US$34 billion / 2.2 GW = $15.5 billion per GW). It should also be considered that pre-construction cost estimates for other SMR projects have dramatically underestimated true costs – e.g. the doubling of cost estimates for China’s HTGR, and a six-fold cost increase for Russia’s floating plant – and the same should be expected with NuScale.

Over the coming months, 27 UAMPS municipalities will need to ratify the new budget or withdraw from the plan to finance the first NuScale SMR in Idaho.[238] UAMPS is a Utah-based group of 50 municipal utilities in six states. Even if all 27 municipalities agree to proceed, NuScale Power will require considerable additional support to proceed. Indeed the 27 UAMPS municipalities have agreed to purchase just one-quarter of the plant’s expected power generation (in capacity terms, 116 MW of a total of 462 MW).[239] “We’re going to have to see measured improvement off the current subscription to keep moving forward with the project,” UAMPS Chief Executive Mason Baker said in November 2022.[240] Another UAMPS spokesperson said the entire 462 MW of capacity must be fully subscribed for the project to go forward.[241]

The Institute for Energy Economics and Financial Analysis notes that NuScale’s cost estimates would be “much higher” if not for government subsidies.[242] The *Portland Business Journal* noted in January 2023: “The U.S. Department of Energy has approved $1.4 billion to support the project, and the recently

[231] For further information on NuScale see:
Institute for Energy Economics and Financial Analysis, Feb. 2022, ‘NuScale’s Small Modular Reactor: Risks of Rising Costs, Likely Delays, and Increasing Competition Cast Doubt on Long-Running Development Effort‘. Too late, too expensive, too risky and too uncertain. http://ieefa.org/wp-content/uploads/2022/02/NuScales-Small-Modular-Reactor_February-2022.pdf
M.V. Ramana, 2020, ‘Eyes Wide Shut: Problems with the Utah Associated Municipal Power Systems Proposal to Construct NuScale Small Modular Nuclear Reactors‘. https://d3n8a8pro7vhmx.cloudfront.net/oregonpsrorg/pages/21/attachments/original/1600287829/EyesWideShutReport_Final-30August2020.pdf
[232] https://d3n8a8pro7vhmx.cloudfront.net/oregonpsrorg/pages/21/attachments/original/1600287829/EyesWideShutReport_Final-30August2020.pdf
[233] http://nuclearrc.sa.gov.au/app/uploads/2016/05/WSP-Parsons-Brinckerhoff-Report.pdf
[234] https://www.parliament.vic.gov.au/images/stories/committees/SCEP/Inquiry_into_Nuclear_Prohibition_Inquiry_/Transcripts/25_June_2020/5._FINAL_-_Minerals_Council_Aust.pdf
[235] https://www.nuscalepower.com/en/news/press-releases/2023/nuscale-reaches-key-milestone-in-the-development-of-the-carbon-free-power-project
[236] https://ieefa.org/resources/eye-popping-new-cost-estimates-released-nuscale-small-modular-reactor
[237] https://ieefa.org/resources/eye-popping-new-cost-estimates-released-nuscale-small-modular-reactor
[238] https://www.bizjournals.com/portland/news/2023/01/09/nuscale-uamps-costs-surge.html
[239] https://www.eenews.net/articles/rising-costs-imperil-nations-leading-small-reactor-project/
[240] https://www.eenews.net/articles/rising-costs-imperil-nations-leading-small-reactor-project/
[241] https://www.eenews.net/articles/rising-costs-imperil-nations-leading-small-reactor-project/
[242] https://ieefa.org/resources/eye-popping-new-cost-estimates-released-nuscale-small-modular-reactor

adopted Inflation Reduction Act allows for a production tax credit of $25 per megawatt-hour for 10 years or an investment tax credit of 30%."[243] Total committed subsidies are estimated at US$4 billion in a January 2023 *Seeking Alpha* article.[244]

The Committee may receive evidence claiming that NuScale has received all necessary licensing approvals in the US (in particular, a Final Safety Evaluation Report in September 2020). In fact, licensing decisions referred to NuScale's planned 50 MW reactor modules and further approvals are required due to the company's decision to increase the module size to 77 MW.[245]

NuScale has submitted an application for Standard Design Approval of the updated design, based on a 6 x 77 MW (462 MW) plant configuration. In preliminary correspondence, NRC staff raised concerns about the new design, saying it raised "several challenging and/or significant issues."[246] Physicist Dr. Edwin Lyman from the Union of Concerned Scientists said: "The NRC's assessment clearly shows that NuScale's standard design approval draft application for the 77 MWe module is not ready for prime time. Of most concern, there is no evidence that NuScale has done the hard work yet to fully evaluate the major safety impacts" of its uprated design.[247]

The 2015/16 South Australian Nuclear Fuel Cycle Royal Commission commissioned research[248] on the economic potential of two SMR designs: Generation mPower (which was abandoned in 2017[249]) and NuScale (which may be abandoned and is far from building let alone operating its first reactor).

3.4 Failed SMR projects

Numerous SMR projects have been cancelled over the past decade including the following:

- The French government abandoned the planned 100–200 MW ASTRID demonstration fast reactor in 2019.[250]
- Babcock & Wilcox abandoned its Generation mPower SMR project in the US despite receiving government funding of US$111 million (A$160 million).[251]
- Transatomic Power gave up on its molten salt reactor R&D in 2018.[252]
- MidAmerican Energy gave up on its plans for SMRs in Iowa in 2013 after failing to secure legislation that would require ratepayers to partially fund construction costs.[253]
- TerraPower abandoned its plan for a prototype fast neutron reactor in China due to restrictions placed on nuclear trade with China by the Trump administration.[254]
- The US government abandoned consideration of 'integral fast reactors' for plutonium disposition in 2015[255]
- The UK government abandoned consideration of 'integral fast reactors' for plutonium disposition in 2019.[256]

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[243] https://www.bizjournals.com/portland/news/2023/01/09/nuscale-uamps-costs-surge.html
[244] https://seekingalpha.com/article/4569771-nuscale-smr-technology-costs-problematic
[245] https://www.world-nuclear-news.org/Articles/Further-cost-refinements-announced-for-first-US-SM
[246] https://www.eenews.net/articles/rising-costs-imperil-nations-leading-small-reactor-project/
https://www.utilitydive.com/news/nrc-nuscale-smr-small-modular-application-utah-uamps/637456/
[247] https://www.utilitydive.com/news/nrc-nuscale-smr-small-modular-application-utah-uamps/637456/
[248] http://nuclearrc.sa.gov.au/app/uploads/2016/05/WSP-Parsons-Brinckerhoff-Report.pdf
[249] https://wiseinternational.org/nuclear-monitor/872-873/mpower-obituary
[250] https://www.reuters.com/article/us-france-nuclearpower-astrid/france-drops-plans-to-build-sodium-cooled-nuclear-reactor-idUSKCN1VK0MC
[251] https://wiseinternational.org/nuclear-monitor/872-873/mpower-obituary
[252] https://wiseinternational.org/nuclear-monitor/867/nuclear-news-nuclear-monitor-867-15-october-2018
[253] https://pauldeaton.com/2013/06/04/iowa-pulls-the-plug-on-nuclear-power/
[254] https://www.reuters.com/article/us-terrapower-china/bill-gates-nuclear-venture-hits-snag-amid-us-restrictions-on-china-deals-wsj-idUSKCN1OV1S5
[255] https://nuclear.foe.org.au/wp-content/uploads/2019-Federal-Nuclear-Inquiry-Joint-ENGO-Submission-Final.pdf
[256] Appendix 3, https://nuclear.foe.org.au/wp-content/uploads/2019-Federal-Nuclear-Inquiry-Joint-ENGO-Submission-Final.pdf

3.5 SMR inefficiencies

SMRs would be more inefficient than large reactors in every respect, and hence more costly.

A 2016 European Commission report notes that decommissioning and waste management costs of SMRs "will probably be higher than those of a large reactor (some analyses state that between two and three times higher)."[257]

The 2016 South Australian Nuclear Fuel Cycle Royal Commission report stated: "SMRs have lower thermal efficiency than large reactors, which generally translates to higher fuel consumption and spent fuel volumes over the life of a reactor."[258]

A *Nuclear Technology* journal article notes that integral pressurised water SMRs (iPWRs) "are likely to have higher requirements for uranium ore and enrichment services compared to gigawatt-scale reactors. This is because of the lower burnup of fuel in iPWRs, which is difficult to avoid because of smaller core size and all-in-all-out core management."[259]

Prof. M.V. Ramana notes that "a smaller reactor, at least the water-cooled reactors that are most likely to be built earliest, will produce more, not less, nuclear waste per unit of electricity they generate because of lower efficiencies."[260]

A study published in the *Proceedings of the National Academy of Sciences* in 2022 concludes that SMRs will produce more voluminous and chemically/physically reactive waste than conventional large reactors due to the use of neutron reflectors and/or of chemically reactive fuels and coolants in SMR designs.[261] The study finds that water, molten salt, and sodium cooled SMR designs will significantly increase the volume of nuclear waste.

3.6 Diseconomies of scale

Power produced by SMRs will be more expensive than large reactors.[262] SMRs will inevitably suffer diseconomies of scale: a 250 MW SMR will generate 25% as much power as a 1,000 MW reactor, but it will require more than 25% of the material inputs and staffing, and other costs including waste management and decommissioning will be proportionally higher. It is highly unlikely that potential savings arising from standardised factory production will make up for those diseconomies of scale.

Cost *reductions* arising from mass production of SMRs are entirely speculative. Cost *increases* arising from diseconomies of scale are certain – they are built into the very concept of SMRs.

3.7 Independent economic assessments

Every independent economic assessment finds that electricity from SMRs will be more expensive than that from large reactors.[263]

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[257] https://eur-lex.europa.eu/legal-content/EN/ALL/?uri=CELEX%3A52017SC0158&print=true
[258] https://nuclear.foe.org.au/wp-content/uploads/NFCRC_Final_Report_Web_5MB.pdf
[259] https://www.tandfonline.com/doi/abs/10.13182/NT13-A19873
[260] http://thehill.com/opinion/energy-environment/393717-the-future-of-nuclear-power-in-the-us-is-bleak
[261] https://www.pnas.org/doi/10.1073/pnas.2111833119
[262] https://wiseinternational.org/nuclear-monitor/872-873/smr-economics-overview
[263] https://wiseinternational.org/nuclear-monitor/872-873/smr-economics-overview

As noted previously, A study by WSP / Parsons Brinckerhoff, commissioned by the South Australian Nuclear Fuel Cycle Royal Commission, estimated costs of A$180–184 / MWh for large pressurised water reactors and boiling water reactors, and A$225 / MWh for SMRs based on the NuScale design (and a slightly lower figure for the mPower design that was abandoned in 2017).[264]

The South Australian Nuclear Fuel Cycle Royal Commission stated in its 2016 report:[265]

> *"Advanced fast reactors and other innovative reactor designs are unlikely to be feasible or viable in the foreseeable future. The development of such a first-of-a-kind project in South Australia would have high commercial and technical risk. Although prototype and demonstration reactors are operating, there is no licensed, commercially proven design. Development to that point would require substantial capital investment."*

A 2015 report by the International Energy Agency and the OECD Nuclear Energy Agency predicts that electricity costs from SMRs will typically be 50−100% higher than for current large reactors.[266]

A report by the consultancy firm Atkins for the UK Department for Business, Energy and Industrial Strategy found that electricity from the first SMR in the UK (assuming one is ever built) would be 30% more expensive than power from large reactors, because of diseconomies of scale and the costs of deploying first-of-a-kind technology.[267]

An article by four current and former researchers from Carnegie Mellon University's Department of Engineering and Public Policy, published in 2018 in the *Proceedings of the National Academy of Science*, considered options for the development of an SMR market in the US. They concluded that it would not be viable unless the industry received "several hundred billion dollars of direct and indirect subsidies" over the next several decades "since present competitive energy markets will not induce their development and adoption."[268]

A 2014 study published in *Energy and Power Engineering* concluded that fuel costs for integral pressurized water SMRs are estimated to be 15% to 70% higher than for large light water reactors, and points to research indicating similar comparisons for construction costs.[269]

The Institute for Energy Economics and Financial Analysis states:[270]

> *"For all the hype in certain quarters, commercial deployment of small modular reactors (SMRs) have to-date been as successful as hypothesized cold fusion – that is, not at all. Even assuming massive ongoing taxpayer subsidies, SMR proponents do not expect to make a commercial deployment at scale any time soon, if at all, and more likely in a decade from now if historic delays to proposed timetables are acknowledged."*

A 2018 US Department of Energy report states that to make a "meaningful" impact, about US$10 billion of government subsidies would be needed to deploy 6 GW of SMR capacity by 2035. But there's no indication or likelihood that the US government will subsidise the industry to that extent.[271]

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[264] http://nuclearrc.sa.gov.au/app/uploads/2016/05/WSP-Parsons-Brinckerhoff-Report.pdf
[265] https://nuclear.foe.org.au/wp-content/uploads/NFCRC_Final_Report_Web_5MB.pdf
[266] https://www.oecd-nea.org/jcms/pl_14756
[267] https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/665197/TEA_Project_1_Vol_1_-_Comprehensive_Analysis_and_Assessment_SMRs.pdf
[268] https://www.pnas.org/content/115/28/7184
[269] https://www.scirp.org/journal/PaperInformation.aspx?PaperID=45669
[270] https://www.aph.gov.au/DocumentStore.ashx?id=8297e6ba-e3d4-478e-ac62-a97d75660248&subId=669740
[271] https://www.energy.gov/ne/downloads/report-examination-federal-financial-assistance-renewable-energy-market

William Von Hoene, senior vice-president at US energy and nuclear giant Exelon, has expressed skepticism about SMRs, saying they are "prohibitively expensive".[272]

A 2018 article in the Proceedings of the National Academy of Science summarised private-sector investment in SMRs and other 'advanced' nuclear concepts:[273]

> *"Often, proponents of nuclear power note that private enterprise is faring better than the government at advancing non-light water reactor concepts. Indeed, more than $1.3 billion has been secured by close to four dozen such companies. However, a dozen of these are working not on advanced fission reactors but on fusion reactors or nuclear fuels. Another dozen reactors either belong to bankrupt companies (e.g., Westinghouse) or are proceeding at a very low level of activity (e.g., the DOE's Next Generation Nuclear Plant and various university ventures that are very much in the conceptual design phase). Moreover, while $1.3 billion sounds impressive, that sum is dominated by one firm, TerraPower, which has found it remarkably challenging to build or secure access to the range of equipment, materials, and technology required to successfully commercialize its innovative design."*

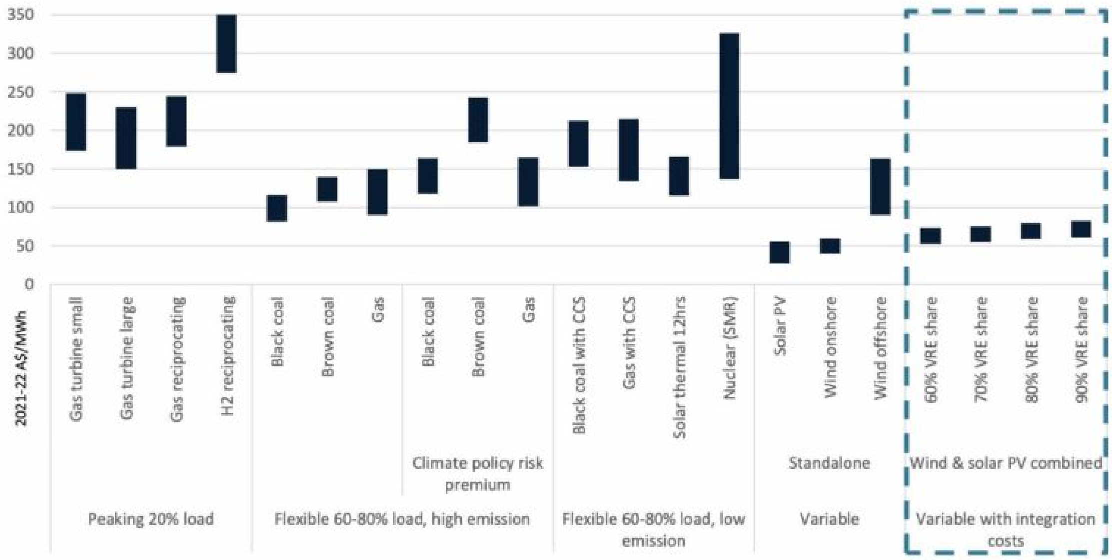
3.8 CSIRO / Australian Energy Market Operator studies

In its July 2022 *GenCost* report, CSIRO provides these 2030 cost estimates for Australia:[274]
* Nuclear (small modular): A$136-326 / MWh
* 90% wind and solar PV with integration costs (transmission, storage and synchronous condensers) necessary to allow these variable renewables to provide 90% of electricity in the National Electricity Market: A$61-82 / MWh.

Nuclear power from SMRs is estimated to cost at least twice as much – and up to five times as much – as “firmed” wind and solar PV including storage and transmission costs.[275]

[272] https://www.spglobal.com/platts/en/market-insights/latest-news/electric-power/041218-no-new-nuclear-units-will-be-built-in-us-due-to-high-cost-exelon-official

[273] https://www.pnas.org/content/115/28/7184
[274] https://www.csiro.au/-/media/News-releases/2022/GenCost-2022/GenCost2021-22Final_20220708.pdf
[275] For discussion see: https://reneweconomy.com.au/slow-expensive-and-no-good-for-1-5-target-csiro-crushes-coalition-nuclear-fantasy/



ES Figure 0-1 Calculated LCOE by technology and category for 2030

Source: GenCost 2022.

Some nuclear advocates have questioned the 2030 SMR cost estimate of A$136-326 / MWh. The upper figure is based on widely-available figures on the cost of power from large reactors, adjusted upwards to reflect the acknowledgement from the International Energy Agency and the OECD's Nuclear Energy Agency that SMR power costs could be up to 100% more expensive than power from large reactors.[276] Only two operational SMRs exist and cost-per-MWh data is only available for one of these: the OECD Nuclear Energy Agency's estimate of US$200 (A$288) / MWh for the Russian SMR.[277]

The low SMR estimate of A$136 / MWh is based on heroic and implausible assumptions about SMR learning rates and cost reductions, yet it is still far more expensive than firmed renewables.[278] Lower SMR cost estimates are based on an even greater degree of wishful thinking. For example, a Minerals Council of Australia report asserts that "robust estimates" using "conservative assumptions" suggest that SMRs will produce power at a cost of A$64-77 / MWh by 2030.[279] In fact, the estimate is not based on "robust estimates" using "conservative assumptions", but is based more on wishful thinking from those seeking taxpayer subsidies to develop SMRs.[280] The A$64-77 / MWh figure is three times lower than the Lazard estimate for power from conventional, large reactors (A$193–300 / MWh) despite the inevitable diseconomies of scale for SMRs. The A$64-77 / MWh figure is far lower than the only real-world figure available for SMRs (A$288 / MWh for the Russian SMR). In short, the Minerals Council's estimate is deeply implausible and the Council's claim that it is based on "robust estimates" using "conservative assumptions" is demonstrably false.

[276] See pp.14-15 in the GenCost report.
[277] https://www.oecd-nea.org/jcms/pl_14924
[278] For discussion see: https://reneweconomy.com.au/small-modular-reactor-rhetoric-hits-a-hurdle-62196/
[279] https://www.minerals.org.au/sites/default/files/Small%20Modular%20Reactors%20in%20the%20Australian%20Context%202021.pdf
[280] For discussion see: https://reneweconomy.com.au/small-nuclear-reactors-huge-costs/ and https://reneweconomy.com.au/small-modular-reactor-rhetoric-hits-a-hurdle-62196/

The Minerals Council of Australia said in 2020 that SMRs won't find a market unless they can produce power at a cost of A$60–80 / MWh.[281] The likelihood of SMRs producing power in that cost range in the foreseeable future is negligible.

3.9 State-run SMR programs

Funding for state-run SMR programs – such as those in Argentina, China, Russia, and South Korea – has been minuscule compared to investments in other energy programs.

South Korea, for example, won't build any of its domestically designed SMART SMRs in South Korea ("this is not practical or economic" according to the World Nuclear Association[282]). South Korea's plan to export SMART technology to Saudi Arabia is problematic[283] and may in any case be in trouble.[284]

China and Argentina hope to develop a large export market for their high-temperature gas-cooled reactors and small pressurised water reactors, but so far all they can point to are demonstration reactors (the completed HTGR in China and the incomplete SMR in Argentina) that have been subject to major cost overruns and delays.

Russia planned to have seven floating nuclear power plants by 2015, but only recently began operation of its first plant.

3.10 Creative accounting

As noted above (section 3.7), the Minerals Council of Australia's estimate that SMRs will produce power at a cost of A$64-77 / MWh by 2030 is implausible as is the Council's claim that the estimate is based on "robust estimates" using "conservative assumptions".

The Energy Information Reform Project (EIRP) purports to have conducted a 'standardized cost analysis of advanced nuclear technologies in commercial development'.[285] But the EIRP doesn't have any credible cost data or estimates for the 'advanced nuclear technologies' it considers (none of which are in commercial development). Indeed, the EIRP just uses estimates provided by companies involved in R&D, despite their obvious interest in providing low estimates. The EIRP researchers heavily qualified their findings: "There is inherent and significant uncertainty in projecting NOAK [nth-of-a-kind] costs from a group of companies that have not yet built a single commercial-scale demonstration reactor, let alone a first commercial plant."

In support of its claim that "it is likely that SMRs will be Australia's lowest-cost generation source", SMR Nuclear Technology Pty Ltd cites[286] the EIRP report. SMR Nuclear Technology's claim is no more credible than the company estimates used in the EIRP paper. Based on that faulty premise, SMR Nuclear Technology further claims that failing to repeal federal legislative bans against nuclear power would come at "great cost to the economy". However, the introduction of nuclear power to Australia would most likely have resulted in the major cost overruns and delays that have crippled every reactor construction project in the US and western Europe over the past decade.

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281 https://www.parliament.vic.gov.au/images/stories/committees/SCEP/Inquiry_into_Nuclear_Prohibition_Inquiry_/Transcripts/25_June_2020/5._FINAL_-_Minerals_Council_Aust.pdf
282 https://www.world-nuclear.org/information-library/country-profiles/countries-o-s/south-korea.aspx
283 https://www.wiseinternational.org/nuclear-monitor/800/small-modular-reactors-chicken-and-egg-situation
284 http://www.businesskorea.co.kr/news/articleView.html?idxno=26628
285 https://www.innovationreform.org/wp-content/uploads/2018/01/Advanced-Nuclear-Reactors-Cost-Study.pdf
286 www.parliament.nsw.gov.au/lcdocs/submissions/63873/0004%20SMR%20Nuclear%20Technology%20Pty%20Ltd.pdf

The Minerals Council of Australia claimed in its submission to the federal nuclear inquiry that SMRs could generate electricity for as little as $60 / MWh.[287] That claim was based on a report by the Economic and Finance Working Group (EFWG) of the Canadian government-industry 'SMR Roadmap' initiative.[288] Yet the EFWG paper takes a made-up, ridiculously-high learning rate and subjects SMR cost estimates to eight 'cumulative doublings' based on the learning rate. That is creative accounting and one can only wonder why the Minerals Council would present it as a credible estimate.

Here are the first-of-a-kind SMR cost estimates from the EFWG paper, all of them far higher than the figure cited by the Minerals Council:

300-megawatt (MW) on-grid SMR:	C$162.67 / MWh (A$175 / MWh)
125-MW off-grid heavy industry:	C$178.01 / MWh
20-MW off-grid remote mining:	C$344.62 / MWh
3-MW off-grid remote community:	C$894.05 / MWh (A$960/MWh)

The EFWG paper used a range of estimates from the literature and vendors. It notes problems with its inputs, such as the fact that many of the vendor estimates have not been independently vetted, and "the wide variation in costs provided by expert analysts". Thus, the EFWG qualifies its findings by noting that "actual costs could be higher or lower depending on a number of eventualities".

The 'Bright New World' nuclear lobby group (disbanded in 2021) promoted a 2016 study in support of its claims about nuclear construction costs, but the study was widely criticised for cherry-picking[289] including by a former World Nuclear Association executive.[290]

3.11 More information on SMRs

Steve Thomas, Paul Dorfman, Sean Morris & M.V. Ramana, July 2019, 'Prospects for Small Modular Reactors in the UK & Worldwide', https://www.nuclearconsult.com/wp/wp-content/uploads/2019/07/Prospects-for-SMRs-report-2.pdf

M.V. Ramana, 27 April 2015, 'The Forgotten History of Small Nuclear Reactors', IEEE Spectrum, https://spectrum.ieee.org/the-forgotten-history-of-small-nuclear-reactors

WISE Nuclear Monitor 2019 report, https://wiseinternational.org/nuclear-monitor/872-873/nuclear-monitor-872-873-7-march-2019

Wrong reaction: Why 'next-generation' nuclear is not a credible energy solution, Australian Conservation Foundation, October 2022

Institute for Energy Economics and Financial Analysis, Feb. 2022, 'NuScale's Small Modular Reactor: Risks of Rising Costs, Likely Delays, and Increasing Competition Cast Doubt on Long-Running Development Effort'. Too late, too expensive, too risky and too uncertain. http://ieefa.org/wp-content/uploads/2022/02/NuScales-Small-Modular-Reactor_February-2022.pdf

M.V. Ramana, 2020, 'Eyes Wide Shut: Problems with the Utah Associated Municipal Power Systems Proposal to Construct NuScale Small Modular Nuclear Reactors'.

[287] https://www.afr.com/companies/energy/mining-industry-predicts-nuclear-will-be-cheapest-power-20190913-p52r29
[288] https://smrroadmap.ca/wp-content/uploads/2018/12/Economics-Finance-WG.pdf
[289] https://www.wiseinternational.org/nuclear-monitor/840/nuclear-economics-critical-responses-breakthrough-institute-propaganda
[290] https://www.neimagazine.com/opinion/opinionachieving-better-nuclear-economics-new-designs-and-industry-structure-4848005/

https://d3n8a8pro7vhmx.cloudfront.net/oregonpsrorg/pages/21/attachments/original/1600287829/EyesWideShutReport_Final-30August2020.pdf

'The 'advanced' nuclear power sector is fuelling climate change, and WMD proliferation', 11 Sept 2019, https://reneweconomy.com.au/the-advanced-nuclear-power-sector-is-fuelling-climate-change-and-wmds-40205/

'Nuclear power exits Australia's energy debate, enters culture wars', 13 June 2019, https://reneweconomy.com.au/nuclear-power-exits-australias-energy-debate-enters-culture-wars-47702/

4. 'ADVANCED' OR 'GENERATION IV' REACTOR CONCEPTS

Please also see relevant appendices in the joint NGO submission to the 2019 federal nuclear inquiry:[291]
Appendix 2: Fast neutron reactors (a.k.a. fast spectrum or fast breeder reactors)
Appendix 3: Integral fast reactors (IFRs)
Appendix 4: Fusion scientist debunks fusion power
Appendix 5: Thorium
Appendix 6: High-temperature gas-cooled zombie reactors

4.1 Overview

Conventional (or 'light water') reactors are fueled by uranium and cooled by ordinary ('light') water, which also slows (or 'moderates') the neutrons that maintain the nuclear chain reaction. 'Advanced' nuclear power generally refers to reactors – large or small – with different fuels, moderators and coolants.

'Advanced' or 'Generation IV' nuclear power concepts are generally not new and not promising, and most might best be described as failed Generation I concepts.

So-called Generation IV reactor concepts are diverse. Some are far from new – indeed most have been investigated for decades and have a troubled history. David Elliott – who previously worked with the UK Atomic Energy Authority – has written a book about this troubled history.[292] In an article[293] discussing some themes taken up in his book, Elliot writes:

> *"While some nuclear enthusiasts hope that these Generation III reactors, like the EPR or its rivals, will be successful, there is also pressure to move on to new technology and so-called Generation IV options, including liquid sodium-cooled fast neutron breeder reactors, helium-cooled high temperature reactors and thorium-fuelled molten salt reactors, at various scales. As I describe in my new book Nuclear Power: Past, Present and Future, many of them are in fact old ideas that were looked at in the early days and mostly abandoned. There were certainly problems with some of these early experimental reactors, some of them quite dramatic.*
>
> *"Examples include the fire at the Simi Valley Sodium Reactor in 1959, and the explosion at the 3MW experimental SL-1 reactor at the US National Reactor Testing Site in Idaho in 1961, which killed three operators. Better known perhaps was and the core melt down of the Fermi Breeder reactor near Detroit in 1966. Sodium fires have been a major problem with many of the subsequent fast neutron reactor projects around the world, for example in France, Japan and Russia.*
>
> *"For good or ill, ideas like this are back on the agenda, albeit in revised forms. … Fast neutron breeder reactors can produce new plutonium fuel from otherwise unused uranium-238 and may also be able to burn up some wastes, as in the Integral Fast Reactor concept and also the Traveling Wave Reactor variant. Molten Salt Reactors using thorium may be able to do*

[291] https://www.aph.gov.au/DocumentStore.ashx?id=9eee9d5f-4362-4b30-b0b8-3b65ff98215f&subId=670271
[292] David Elliott, May 2017, 'Nuclear Power: Past, Present and Future', Morgan & Claypool Publishers, http://bit.ly/2pIIX9Q
[293] David Elliott, 25 May 2017, 'Back to the future: old nukes for new', Nuclear Monitor #844, https://www.wiseinternational.org/nuclear-monitor/844/back-future-old-nukes-new

> *this without producing plutonium or using liquid metals for cooling. Both approaches are being promoted, but both have problems, as was found in the early days. Certainly fast breeder reactors were subsequently mostly sidelined as expensive and unreliable. And as heightening nuclear weapons proliferation risks. The US gave up on them in the 1970s, France and the UK in the 1990s. Japan soldiered on but has now abandoned its troubled Monju plant. For the moment it's mainly Russia that has continued, including with a molten lead cooled reactor, although India also has a fast reactor programme, linked to its thorium reactors plans.*
>
> *"Thorium was used as a fuel for some reactors in some early experiments and is now being promoted again – there is more of it available globally than uranium. But there are problems. It isn't fissile, but neutrons, fast or slow, provided by uranium 235 or plutonium fission, can convert Thorium 232 into fissile U233. However, on the way to that, a very radioactive isotope, U232, is produced, which makes working with the fuel hard. Another isotope, U234 is also produced by neutron absorption. Ideally, to maximise U233 production, that should be avoided, but experts are apparently divided on whether this can be done effectively.*
>
> *"The use of molten salts may help with some of these problems, perhaps making it easier to play with the nuclear chemistry and tap off unwanted by-products, but it is far from proven technically or economically. The economics is certainly challenging."*

In the US, even if all the private-sector Generation IV R&D funding (an estimated US$1.3 billion[294]) was pooled, it is unlikely that it would suffice to build a single prototype reactor. An article by pro-nuclear researchers from Carnegie Mellon University's Department of Engineering and Public Policy, published in the *Proceedings of the National Academy of Science* in 2018, argues that no US advanced reactor design will be commercialised before mid-century and that purported benefits remain "speculative".[295]

The US government has spent US$2 billion on Generation IV reactor R&D since the late 1990s "with very little to show for it" according to the Carnegie Mellon University researchers.[296]

4.2 SA Nuclear Fuel Cycle Royal Commission

The SA Nuclear Fuel Cycle Royal Commission investigated claims made about Generation IV concepts and concluded in its May 2016 Final Report:[297]

> *"[A]dvanced fast reactors and other innovative reactor designs are unlikely to be feasible or viable in the foreseeable future. The development of such a first-of-a-kind project in South Australia would have high commercial and technical risk. Although prototype and demonstration reactors are operating, there is no licensed, commercially proven design. Development to that point would require substantial capital investment. Moreover, electricity generated from such reactors has not been demonstrated to be cost competitive with current light water reactor designs."*

Little has changed since then – except the collapse of numerous Generation IV and SMR R&D projects.

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[294] M. Granger Morgan, Ahmed Abdulla, Michael J. Ford, and Michael Rath, July 2018 'US nuclear power: The vanishing low-carbon wedge', Proceedings of the National Academy of Science, http://www.pnas.org/content/early/2018/06/26/1804655115
[295] ibid.
[296] M. Granger Morgan, Ahmed Abdulla, Michael J. Ford, and Michael Rath, July 2018 'US nuclear power: The vanishing low-carbon wedge', Proceedings of the National Academy of Science, http://www.pnas.org/content/early/2018/06/26/1804655115
Media release, 2 July 2018, 'The vanishing nuclear industry', www.eurekalert.org/pub_releases/2018-07/coec-tvn062918.php
[297] https://nuclear.foe.org.au/wp-content/uploads/NFCRC_Final_Report_Web_5MB.pdf

4.3 Always decades away

Notwithstanding the history of (mostly failed) R&D projects, much work would need to be done to bring Generation IV concepts to commercial deployment. The World Nuclear Association noted in 2009 that "progress is seen as slow, and several potential designs have been undergoing evaluation on paper for many years."[298] The same could be said in 2022.

The Generation IV International Forum states: "It will take at least two or three decades before the deployment of commercial Gen IV systems. In the meantime, a number of prototypes will need to be built and operated. The Gen IV concepts currently under investigation are not all on the same timeline and some might not even reach the stage of commercial exploitation."[299] It could be argued that most or all of them are unlikely to reach commercial-scale deployment.

It should not be understood from the above statement that Generation IV systems will be commercialised in 2–3 decades. The point is that they are *always* 2–3 decades away. In general, R&D has not been promising and has been abandoned (either in the early stages or following the failure of prototype reactors). R&D budgets are far too small to commercialise the concepts and the pursuit of alternative energy sources has rightly been prioritised.

A 2015 report[300] by the French government's Institute for Radiological Protection and Nuclear Safety (IRSN) is of particular significance as it comes from a government which has invested heavily in nuclear technology. IRSN is a government authority with approximately 1,790 staff under the joint authority of the Ministries of Defense, the Environment, Industry, Research, and Health. The IRSN report states: *"There is still much R&D to be done to develop the Generation IV nuclear reactors, as well as for the fuel cycle and the associated waste management which depends on the system chosen."[301] The report says that for lead-cooled fast reactors and gas-cooled fast reactors systems, small prototypes might be built by mid-century. For molten salt reactors (MSR) and SuperCritical Water Reactors (SCWR) systems, there "is no likelihood of even an experimental or prototype MSR or SCWR being built during the first half of this century" and "it seems hard to imagine any reactor being built before the end of the century".*

4.4 Purported benefits

It is doubtful whether the purported benefits of Generation IV reactors will be realised.

Physicist Dr. Edwin Lyman has written an important report for the Union of Concerned Scientists debunking claims that 'advanced' nuclear power concepts offer significant advantages over conventional nuclear power. The report considers sodium-cooled fast reactors, high-temperature gas–cooled reactors, and molten salt reactors.

Dr. Lyman writes:[302]

> *"Based on the available evidence, we found that the designs we analyzed are not likely to be significantly safer than today's nuclear plants. In fact, certain alternative reactor designs pose even more safety, proliferation, and environmental risks than the current fleet.*

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[298] World Nuclear Association, 15 Dec 2009, 'Fast moves? Not exactly...', www.world-nuclear-news.org/NN_France_puts_into_future_nuclear_1512091.html
[299] www.gen-4.org/gif/jcms/c_41890/faq-2
[300] Institute for Radiological Protection and Nuclear Safety, 2015, 'Review of Generation IV Nuclear Energy Systems', www.irsn.fr/EN/newsroom/News/Pages/20150427_Generation-IV-nuclear-energy-systems-safety-potential-overview.aspx
Direct download: www.irsn.fr/EN/newsroom/News/Documents/IRSN_Report-GenIV_04-2015.pdf
[301] ibid.
[302] https://ucsusa.org/resources/advanced-isnt-always-better

> *Developing new designs that are clearly superior to LWRs [light water reactors] overall is a formidable challenge, as improvements in one respect can create or exacerbate problems in others. For example, increasing the physical size of a reactor core while keeping its power generation rate constant could make the reactor easier to cool in an accident, but it could also increase cost."*

The French government's Institute for Radiological Protection and Nuclear Safety (IRSN) reviewed the six concepts prioritised by the Generation IV International Forum and concluded:[303]

> *"At the present stage of development, IRSN does not notice evidence that leads to conclude that the systems under review are likely to offer a significantly improved level of safety compared with Generation III reactors, except perhaps for the VHTR [Very High Temperature Reactor] ..."*

The IRSN further states that the VHTR system could bring about significant safety improvements "but only by significantly limiting unit power".[304] The IRSN notes that it is difficult to thoroughly evaluate safety and radiation protection standards of Generation IV systems as some concepts have been partially tried and tested while others are still in the early stages of development.

The IRSN is unenthusiastic about research into transmutation of minor actinides (long-lived waste products in spent fuel), saying that "this option offers only a very slight advantage in terms of inventory reduction and geological waste repository volume when set against the induced safety and radiation protection constraints for fuel cycle facilities, reactors and transport." The IRSN notes that ASN, the French nuclear safety authority, has announced that minor actinide transmutation would not be a deciding factor in the choice of a future reactor system. Those factors partly explain the French government's recent decision to abandon the 100–200 MW ASTRID demonstration fast neutron reactor project.

Some Generation IV concepts promise major advantages such as the potential to use long-lived nuclear waste and weapons-usable material (esp. plutonium) as reactor fuel. However, fast neutron reactor technology might more accurately be described as failed Generation I technology. The history of fast reactors has largely been one of extremely expensive, underperforming, and accident-prone reactors which have contributed more to WMD proliferation problems than to their resolution. The troubled history of fast reactors is detailed in a report by the International Panel on Fissile Materials[305] and in two appendices to the joint NGO submission to the 2019 federal nuclear inquiry (Appendix 2. Fast Neutron Reactors; Appendix 3. Integral Fast Reactors).[306] Most of the countries that invested in fast reactor R&D have abandoned those efforts.

Most importantly, whether Generation IV concepts deliver on their potential depends on a myriad of factors − not just the resolution of technical challenges. India's fast reactor / thorium program illustrates how badly things can go wrong, and it illustrates problems that cannot be solved with technical innovation. John Carlson, former Director-General of the Australian Safeguards and Non-proliferation Office, writes:[307]

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[303] ibid.
[304] ibid.
[305] International Panel on Fissile Materials, Feb 2010, 'Fast Breeder Reactor Programs: History and Status', www.ipfmlibrary.org/rr08.pdf
On the use of fast reactors in support of weapons production, see also Mycle Schneider, 2009, 'Fast Breeder Reactors in France', *Science and Global Security*, 17:36–53, www.princeton.edu/sgs/publications/sgs/archive/17-1-Schneider-FBR-France.pdf
[306] https://www.aph.gov.au/DocumentStore.ashx?id=9eee9d5f-4362-4b30-b0b8-3b65ff98215f&subId=670271
[307] John Carlson, 2014, first submission to Joint Standing Committee on Treaties, inquiry into Australia–India Nuclear Cooperation Agreement, Parliament of Australia, https://www.aph.gov.au/DocumentStore.ashx?id=79a1a29e-5691-4299-8923-06e633780d4b&subId=301365

"India has a plan to produce [weapons-grade] plutonium in fast breeder reactors for use as driver fuel in thorium reactors. This is problematic on non-proliferation and nuclear security grounds. Pakistan believes the real purpose of the fast breeder program is to produce plutonium for weapons (so this plan raises tensions between the two countries); and transport and use of weapons-grade plutonium in civil reactors presents a serious terrorism risk (weapons-grade material would be a priority target for seizure by terrorists)."

There is nothing 'advanced' about India's 'advanced' breeder / thorium reactor program. On the contrary, it is dangerous and irresponsible, even more so since India refuses to allow IAEA safeguards inspections of its fast reactor / thorium program.

4.5 US Government Accountability Office Report

In 2015, the US Government Accountability Office (GAO) released a report on the status of small modular reactors (SMRs) and other new reactor concepts in the US that concluded:[308]

"While light water SMRs and advanced reactors may provide some benefits, their development and deployment face a number of challenges. Both SMRs and advanced reactors require additional technical and engineering work to demonstrate reactor safety and economics, although light water SMRs generally face fewer technical challenges than advanced reactors because of their similarities to the existing large LWR [light water] reactors. Depending on how they are resolved, these technical challenges may result in higher-cost reactors than anticipated, making them less competitive with large LWRs or power plants using other fuels. ...

"Both light water SMRs and advanced reactors face additional challenges related to the time, cost, and uncertainty associated with developing, certifying or licensing, and deploying new reactor technology, with advanced reactor designs generally facing greater challenges than light water SMR designs. It is a multi-decade process, with costs up to $1 billion to $2 billion, to design and certify or license the reactor design, and there is an additional construction cost of several billion dollars more per power plant.

"Furthermore, the licensing process can have uncertainties associated with it, particularly for advanced reactor designs. A reactor designer would need to obtain investors or otherwise commit to this development cost years in advance of when the reactor design would be certified or available for licensing and construction, making demand (and customers) for the reactor uncertain. For example, the price of competing power production facilities may make a nuclear plant unattractive without favorable rates set by a public authority or long term prior purchase agreements, and accidents such as Fukushima as well as the ongoing need for a long-term solution for spent nuclear fuel may affect the public perception of reactor safety. These challenges will need to be addressed if the capabilities and diversification of energy sources that light water SMRs and advanced reactors can provide are to be realized."

Many of the same reasons explain the failure of the Next Generation Nuclear Plant (NGNP) Project. Under the Energy Policy Act of 2005, the US Department of Energy (DOE) was to deploy a prototype

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See also: John Carlson, 2015, supplementary submission to Joint Standing Committee on Treaties, 'Suggested revisions to the text of 5 September 2014, as requested by JSCOT at the hearing of 9 February 2015', https://www.aph.gov.au/DocumentStore.ashx?id=242f5715-24fd-4b3e-8a4f-4c30651d1dc4&subId=301365

[308] US Government Accountability Office, July 2015, 'Nuclear Reactors: Status and challenges in development and deployment of new commercial concepts', GAO-15-652, www.gao.gov/assets/680/671686.pdf

'next generation' reactor using advanced technology to generate electricity and/or hydrogen by the end of fiscal year 2021. The project was initiated in 2005 but the DOE decided not to proceed with it in 2011, citing an impasse between the DOE and the NGNP Industry Alliance regarding cost-sharing arrangements.[309]

According to the GAO report, SMRs and new reactor concepts "face some common challenges such as long time frames and high costs associated with the shift from development to deployment − that is, in the construction of the first commercial reactors of a particular type."

Advanced reactor designers told the GAO that they have been challenged to find investors due to the lengthy timeframe, high costs, and uncertainty. Advanced reactor concepts face greater technical challenges than light water SMRs because of fundamental design differences.

4.6 False arguments advanced by ANSTO in support of participation in the Generation IV International Forum

Comments made in ANSTO's 'National Interest Analysis' (NIA)[310] justifying Australian participation in the Generation IV International Forum (GIF) include false and tenuous arguments, some of which are briefly discussed here.

The NIA asserts that participation in the (GIF) will further Australia's non-proliferation and nuclear safety objectives. No evidence is supplied to justify that tenuous assertion. There is much else that Australia could do – but is not doing – that would demonstrably further non-proliferation objectives, e.g.

- A ban on reprocessing of Australian Obligated Nuclear Materials (AONM).
- A reversal of the decision to permit uranium sales to countries that have not signed or ratified the NPT or who are not compliant with their NPT disarmament obligations.
- Refusing uranium sales to countries that refuse to sign or ratify the Comprehensive Test Ban Treaty.
- Constructively addressing the flaws and underfunding of the IAEA safeguards system.

Nuclear non-proliferation objectives would also be far better realised by Australian ratification of the UN Treaty on the Prohibition of Nuclear Weapons, rather than participation in GIF.

Other actions that Australia could do – but is not doing – that would demonstrably further safety objectives, include:

- Insisting that uranium customer countries establish a strong, independent regulatory regime (as opposed to the inadequate regulation in customer countries including, China[311], India[312], Russia[313], the US[314], Japan[315], South Korea[316] and others).

[309] Nuclear Regulatory Commission, accessed 20 May 2019, 'Next Generation Nuclear Plant (NGNP)', https://www.nrc.gov/reactors/new-reactors/advanced/ngnp.html

[310] http://www.aph.gov.au/~/media/02%20Parliamentary%20Business/24%20Committees/244%20Joint%20Committees/JSCT/2017/Nuclear%20Energy/ATNIA%2013.pdf?la=en

[311] Emma Graham-Harrison, 25 May 2015, 'China warned over 'insane' plans for new nuclear power plants', https://www.theguardian.com/world/2015/may/25/china-nuclear-power-plants-expansion-he-zuoxiu

[312] A. Gopalakrishnan, 13 Nov 2017, 'India Should Halt Further Expansion of its Nuclear Power Program', The Citizen, https://www.thecitizen.in/index.php/en/NewsDetail/index/2/12239/India-Should-Halt-Further-Expansion-of-its-Nuclear-Power-Program

[313] Vladimir Slivyak, 2014, 'Russian Nuclear Industry Overview', https://ecdru.files.wordpress.com/2017/04/russian-nuc-ind-overviewrgb.pdf

[314] Edwin Lyman, 29 Aug 2019, 'Aging nuclear plants, industry cost-cutting, and reduced safety oversight: a dangerous mix', https://thebulletin.org/2019/08/aging-nuclear-plants-industry-cost-cutting-and-reduced-safety-oversight-a-dangerous-mix/
Gregory Jaczko, 17 May 2019, 'I Oversaw the US Nuclear Power Industry. Now I Think It Should Be Banned', https://www.commondreams.org/views/2019/05/17/i-oversaw-us-nuclear-power-industry-now-i-think-it-should-be-banned

- Revisiting the decision to sell uranium to Ukraine given the ongoing conflict and serious safety and regulatory inadequacies.[317]
- Giving effect to the recommendations of the September 2011 United Nations system-wide study on the implications of the accident at the Fukushima Daiichi nuclear power plant.[318]

The NIA states that ongoing participation in GIF will help Australia maintain its permanent position on the IAEA's 35-member Board of Governors. ANSTO routinely makes such arguments – in support of the construction of the OPAL reactor, in support of the development of nuclear power in Australia, and now in support of Australian participation in GIF. Australia has held a permanent position on the IAEA's Board of Governors for decades and there is scant reason to believe that participation or non-participation in GIF will change that situation. Further, the practical importance of that permanent position is often overstated.

The NIA states that ongoing participation in GIF "will improve the Australian Government's awareness and understanding of nuclear energy developments throughout the region and around the world, and contribute to the ability of the Australian Nuclear Science and Technology Organisation (ANSTO) to continue to provide timely and comprehensive advice on nuclear issues."

These arguments are tenuous: little or no information will be obtained through GIF participation that would not otherwise be available.

The NIA states that "Generation IV designs will use fuel more efficiently, reduce waste production, be economically competitive, and meet stringent standards of safety and proliferation resistance." These incorrect promotional claims are refuted in this submission (see esp. sections 3.5 and 4.4, and see appendices 2–6 in the joint NGO submission to the federal nuclear inquiry[319]).

4.7 Generation IV concepts and nuclear waste

These issues are discussed in section 5.5 of this submission.

4.8 Generation IV concepts and nuclear weapons proliferation

Advocates of every conceivable type of reactor claim that their preferred reactor type is proliferation-proof or proliferation-resistant.

A thorium enthusiast claims that thorium is "thoroughly useless for making nuclear weapons."[320] But the proliferation risks associated with thorium fuel cycles can be as bad as the risks associated with conventional uranium reactor technology.[321]

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315 Nuclear Monitor #800, 19 March 2015, 'Japan's 'nuclear village' reasserting control', www.wiseinternational.org/nuclear-monitor/800/japans-nuclear-village-reasserting-control
316 Nuclear Monitor #844, 25 May 2017, 'South Korea's 'nuclear mafia'', www.wiseinternational.org/nuclear-monitor/844/south-koreas-nuclear-mafia
317 L. Todd Wood, 30 March 2017, 'Ukrainian corruption casts nuclear pall over Europe', http://www.washingtontimes.com/news/2017/mar/30/ukrainian-corruption-casts-nuclear-pall-over-all-e/
Nuclear Monitor #832, 19 Oct 2016, 'Ukraine's nuclear power program going from bad to worse', https://www.wiseinternational.org/nuclear-monitor/832/ukraines-nuclear-power-program-going-bad-worse
318 https://www.un.org/ga/search/view_doc.asp?symbol=SG/HLM/2011/1
319 https://www.aph.gov.au/DocumentStore.ashx?id=9eee9d5f-4362-4b30-b0b8-3b65ff98215f&subId=670271
320 Tim Dean, 16 March 2011, 'The greener nuclear alternative', https://www.abc.net.au/news/2011-03-16/thoriumdean/45178
321 'Thor-bores and uro-sceptics: thorium's friendly fire', Nuclear Monitor #801, 9 April 2015, https://www.wiseinternational.org/nuclear-monitor/801/thor-bores-and-uro-sceptics-thoriums-friendly-fire

An enthusiast of integral fast reactors (IFR) claims they "cannot be used to generate weapons-grade material."[322] But IFRs *can* be used to produce plutonium for weapons – or at least they could be used to produce plutonium for weapons if they existed. Dr. George Stanford, who worked on an IFR R&D program in the US, notes that proliferators "could do [with IFRs] what they could do with any other reactor − operate it on a special cycle to produce good quality weapons material."[323]

Fusion has yet to generate a single Watt of useful electricity, but it has already contributed to proliferation problems. According to Khidhir Hamza, a senior nuclear scientist involved in Iraq's weapons program in the 1980s: "Iraq took full advantage of the IAEA's recommendation in the mid-1980s to start a plasma physics program for "peaceful" fusion research. We thought that buying a plasma focus device ... would provide an excellent cover for buying and learning about fast electronics technology, which could be used to trigger atomic bombs."[324]

Fusion scientist Dr. Daniel Jassby discusses the proliferation risks associated with fusion concepts in a 2017 article in the *Bulletin of the Atomic Scientists*.[325]

All existing and proposed reactor types and nuclear fuel cycles pose proliferation risks. The UK Royal Society notes: "There is no proliferation proof nuclear fuel cycle. The dual use risk of nuclear materials and technology and in civil and military applications cannot be eliminated."[326] Likewise, John Carlson, former Director-General of the Australian Safeguards and Non-Proliferation Office, notes that "no presently known nuclear fuel cycle is completely proliferation proof".[327]

4.9 Thorium

There is a great deal of rhetoric regarding thorium. This, for example:[328]

> *"Thorium is a superior nuclear fuel to uranium in almost every conceivable way ... If there is such a thing as green nuclear power, thorium is it. ... For one, a thorium-powered nuclear reactor can never undergo a meltdown. It just can't. ... Thorium is also thoroughly useless for making nuclear weapons. ... But wait, there's more. Thorium doesn't only produce less waste, it can be used to consume existing waste."*

Those claims do not stand up to scrutiny.

Readiness

The World Nuclear Association (WNA) notes that the commercialisation of thorium fuels faces some "significant hurdles in terms of building an economic case to undertake the necessary development work." The WNA states:[329]

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[322] Barry Brook, 9 June 2009, 'An inconvenient solution', The Australian, http://bravenewclimate.com/2009/06/11/an-inconvenient-solution/
[323] George Stanford, 18 Sep 2010, 'IFR FaD 7 – Q&A on Integral Fast Reactors', http://bravenewclimate.com/2010/09/18/ifr-fad-7/
[324] Khidhir Hamza, Sep/Oct 1998, 'Inside Saddam's Secret Nuclear Program', Bulletin of the Atomic Scientists, Vol. 54, No. 5, https://books.google.com.au/books?id=rwsAAAAAMBAJ
[325] Daniel Jassby, 19 April 2017, 'Fusion reactors: Not what they're cracked up to be', Bulletin of the Atomic Scientists, https://thebulletin.org/2017/04/fusion-reactors-not-what-theyre-cracked-up-to-be/
[326] UK Royal Society, 13 Oct 2011, 'Fuel cycle stewardship in a nuclear renaissance', http://royalsociety.org/policy/projects/nuclear-non-proliferation/report
[327] John Carlson, 2009, 'Introduction to the Concept of Proliferation Resistance', www.foe.org.au/sites/default/files/Carlson%20ASNO%20ICNND%20Prolif%20Resistance.doc or http://archive.foe.org.au/sites/default/files/Carlson%20ASNO%20ICNND%20Prolif%20Resistance.doc
[328] Tim Dean, 16 March 2011, 'The greener nuclear alternative', https://www.abc.net.au/news/2011-03-16/thoriumdean/45178
[329] www.world-nuclear.org/info/Current-and-Future-Generation/Thorium/

> *"A great deal of testing, analysis and licensing and qualification work is required before any thorium fuel can enter into service. This is expensive and will not eventuate without a clear business case and government support. Also, uranium is abundant and cheap and forms only a small part of the cost of nuclear electricity generation, so there are no real incentives for investment in a new fuel type that may save uranium resources.*
>
> *"Other impediments to the development of thorium fuel cycle are the higher cost of fuel fabrication and the cost of reprocessing to provide the fissile plutonium driver material. The high cost of fuel fabrication (for solid fuel) is due partly to the high level of radioactivity that builds up in U-233 chemically separated from the irradiated thorium fuel. Separated U-233 is always contaminated with traces of U-232 which decays (with a 69-year half-life) to daughter nuclides such as thallium-208 that are high-energy gamma emitters. Although this confers proliferation resistance to the fuel cycle by making U-233 hard to handle and easy to detect, it results in increased costs. There are similar problems in recycling thorium itself due to highly radioactive Th-228 (an alpha emitter with two-year half life) present."*

A 2012 report by the UK National Nuclear Laboratory states:[330]

> *"NNL has assessed the Technology Readiness Levels (TRLs) of the thorium fuel cycle. For all of the system options more work is needed at the fundamental level to establish the basic knowledge and understanding. Thorium reprocessing and waste management are poorly understood. The thorium fuel cycle cannot be considered to be mature in any area."*

Fiona Rayment from the UK National Nuclear Laboratory stated:[331]

> *"It is conceivable that thorium could be introduced in current generation reactors within about 15 years, if there was a clear economic benefit to utilities. This would be a once-through fuel cycle that would partly realise the strategic benefits of thorium.*
>
> *"To obtain the full strategic benefit of the thorium fuel cycle would require recycle, for which the technological development timescale is longer, probably 25 to 30 years.*
>
> *"To develop radical new reactor designs, specifically designed around thorium, would take at least 30 years. It will therefore be some time before the thorium fuel cycle can realistically be expected to make a significant contribution to emissions reductions targets."*

Kirk Sorensen, founder of a US firm which aims to build a demonstration 'liquid fluoride thorium reactor' (a type of molten salt reactor − MSR), notes that "several technical hurdles" confront thorium-fueled MSRs, including materials corrosion, reactor control and in-line processing of the fuel.[332]

Nuclear physicist Prof. George Dracoulis writes:[333]

> *"MSRs are not currently available at an industrial scale, but test reactors with different configurations have operated for extended periods in the past. But there are a number of technical challenges that have been encountered along the way. One such challenge is that the hot beryllium and lithium "salts" – in which the fuel and heavy wastes are dissolved – are highly reactive and corrosive. Building a large-scale system that can operate reliably for*

[330] UK National Nuclear Laboratory Ltd., 5 March 2012, 'Comparison of thorium and uranium fuel cycles', www.decc.gov.uk/assets/decc/11/meeting-energy-demand/nuclear/6300-comparison-fuel-cycles.pdf
[331] Stephen Harris, 9 Jan 2014, 'Your questions answered: thorium-powered nuclear', www.theengineer.co.uk/energy-and-environment/in-depth/your-questions-answered-thorium-powered-nuclear/1017776.article
[332] Stephen Harris, 9 Jan 2014, 'Your questions answered: thorium-powered nuclear', www.theengineer.co.uk/energy-and-environment/in-depth/your-questions-answered-thorium-powered-nuclear/1017776.article
[333] George Dracoulis, 19 Dec 2011, 'Thoughts from a thorium 'symposium'', http://theconversation.com/thoughts-from-a-thorium-symposium-4545

> *decades is non-trivial. That said, many of the components have been the subject of extensive research programs."*

The 2015 report[334] by the French government's Institute for Radiological Protection and Nuclear Safety states that for molten salt reactors (MSR) and SuperCritical Water Reactors (SCWR) systems, there "is no likelihood of even an experimental or prototype MSR or SCWR being built during the first half of this century" and "it seems hard to imagine any reactor being built before the end of the century".

Thorium is no 'silver bullet'

Do thorium reactors potentially offer significant advantages compared to conventional uranium reactors?

Prof. George Dracoulis states: "Some of the rhetoric associated with thorium gives the impression that thorium is, somehow, magical. In reality it isn't."[335]

The UK National Nuclear Laboratory report argues that thorium has "theoretical advantages regarding sustainability, reducing radiotoxicity and reducing proliferation risk" but that "while there is some justification for these benefits, they are often overstated."[336] The report further states that the purported benefits "have yet to be demonstrated or substantiated, particularly in a commercial or regulatory environment." The report further states: "Thorium fuelled reactors have already been advocated as being inherently safer than LWRs [light water reactors], but the basis of these claims is not sufficiently substantiated and will not be for many years, if at all."

Thorium and proliferation

Claims that thorium reactors would be proliferation-resistant or proliferation-proof do not stand up to scrutiny.[337] Irradiation of thorium-232 produces uranium-233, which can be and has been used in nuclear weapons.

The World Nuclear Association states:[338]

> *"The USA produced about 2 tonnes of U-233 from thorium during the 'Cold War', at various levels of chemical and isotopic purity, in plutonium production reactors. It is possible to use U-233 in a nuclear weapon, and in 1955 the USA detonated a device with a plutonium-U-233 composite pit, in Operation Teapot. The explosive yield was less than anticipated, at 22 kilotons. In 1998 India detonated a very small device based on U-233 called Shakti V."*

According to Assoc. Prof. Nigel Marks, both the US and the USSR tested uranium-233 bombs in 1955.[339]

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[334] Institute for Radiological Protection and Nuclear Safety, 2015, 'Review of Generation IV Nuclear Energy Systems', www.irsn.fr/EN/newsroom/News/Pages/20150427_Generation-IV-nuclear-energy-systems-safety-potential-overview.aspx
Direct download: www.irsn.fr/EN/newsroom/News/Documents/IRSN_Report-GenIV_04-2015.pdf

[335] George Dracoulis, 5 Aug 2011, 'Thorium is no silver bullet when it comes to nuclear energy, but it could play a role', http://theconversation.com/thorium-is-no-silver-bullet-when-it-comes-to-nuclear-energy-but-it-could-play-a-role-1842

[336] UK National Nuclear Laboratory Ltd., 5 March 2012, 'Comparison of thorium and uranium fuel cycles', www.decc.gov.uk/assets/decc/11/meeting-energy-demand/nuclear/6300-comparison-fuel-cycles.pdf

[337] 'Thor-bores and uro-sceptics: thorium's friendly fire', Nuclear Monitor #801, 9 April 2015, https://www.wiseinternational.org/nuclear-monitor/801/thor-bores-and-uro-sceptics-thoriums-friendly-fire

[338] www.world-nuclear.org/info/Current-and-Future-Generation/Thorium/

[339] Nigel Marks, 2 March 2015, 'Should Australia consider thorium nuclear power?', http://theconversation.com/should-australia-consider-thorium-nuclear-power-37850

Uranium-233 is contaminated with uranium-232 but there are ways around that problem. Kang and von Hippel note:[340]

> *"[J]ust as it is possible to produce weapon-grade plutonium in low-burnup fuel, it is also practical to use heavy-water reactors to produce U-233 containing only a few ppm of U-232 if the thorium is segregated in "target" channels and discharged a few times more frequently than the natural-uranium "driver" fuel."*

John Carlson, former Director-General of the Australian Safeguards and Non-proliferation Office, discusses the proliferation risks associated with thorium:[341]

> *"The thorium fuel cycle has similarities to the fast neutron fuel cycle – it depends on breeding fissile material (U-233) in the reactor, and reprocessing to recover this fissile material for recycle. ...*
>
> *"Proponents argue that the thorium fuel cycle is proliferation resistant because it does not produce plutonium. Proponents claim that it is not practicable to use U-233 for nuclear weapons.*
>
> *"There is no doubt that use of U-233 for nuclear weapons would present significant technical difficulties, due to the high gamma radiation and heat output arising from decay of U-232 which is unavoidably produced with U-233. Heat levels would become excessive within a few weeks, degrading the high explosive and electronic components of a weapon and making use of U-233 impracticable for stockpiled weapons. However, it would be possible to develop strategies to deal with these drawbacks, e.g. designing weapons where the fissile "pit" (the core of the nuclear weapon) is not inserted until required, and where ongoing production and treatment of U-233 allows for pits to be continually replaced. This might not be practical for a large arsenal, but could certainly be done on a small scale.*
>
> *"In addition, there are other considerations. A thorium reactor requires initial core fuel – LEU or plutonium – until it reaches the point where it is producing sufficient U-233 for self-sustainability, so the cycle is not entirely free of issues applying to the uranium fuel cycle (i.e. requirement for enrichment or reprocessing). Further, while the thorium cycle can be self-sustaining on produced U-233, it is much more efficient if the U-233 is supplemented by additional "driver" fuel, such as LEU or plutonium. For example, India, which has spent some decades developing a comprehensive thorium fuel cycle concept, is proposing production of weapons grade plutonium in fast breeder reactors specifically for use as driver fuel for thorium reactors. This approach has obvious problems in terms of proliferation and terrorism risks.*
>
> *"A concept for a liquid fuel thorium reactor is under consideration (in which the thorium/uranium fuel would be dissolved in molten fluoride salts), which would avoid the need for reprocessing to separate U-233. If it proceeds, this concept would have non-proliferation advantages.*

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[340] Jungmin Kang and Frank N. von Hippel, 2001, "U-232 and the Proliferation-Resistance of U-233 in Spent Fuel", *Science & Global Security*, Volume 9, pp.1-32, www.princeton.edu/sgs/publications/sgs/pdf/9_1kang.pdf

[341] John Carlson, 2009, 'Introduction to the Concept of Proliferation Resistance', www.foe.org.au/sites/default/files/Carlson%20ASNO%20ICNND%20Prolif%20Resistance.doc or http://archive.foe.org.au/sites/default/files/Carlson%20ASNO%20ICNND%20Prolif%20Resistance.doc

"Finally, it cannot be excluded that a thorium reactor – as in the case of other reactors – could be used for plutonium production through irradiation of uranium targets.
"Arguments that the thorium fuel cycle is inherently proliferation resistant are overstated. In some circumstances the thorium cycle could involve significant proliferation risks."

False distinctions between thorium and uranium

Some thorium advocates posit a sharp distinction between thorium and uranium. But there is little to distinguish the two. A much more important distinction is between conventional reactor technology and some 'Generation IV' concepts − in particular, those based on repeated (or continuous) fuel recycling and the 'breeding' of fissile isotopes from fertile isotopes (Thorium-232>Uranium-233 or Uranium-238>Plutonium-239).

A report by the Idaho National Laboratory states:[342]

"For fuel type, either uranium-based or thorium-based, it is only in the case of continuous recycle where these two fuel types exhibit different characteristics, and it is important to emphasize that this difference only exists for a fissile breeder strategy. The comparison between the thorium/U-233 and uranium/Pu-239 option shows that the thorium option would have lower, but probably not significantly lower, TRU [transuranic waste] inventory and disposal requirements, both having essentially equivalent proliferation risks.

"For these reasons, the choice between uranium-based fuel and thorium-based fuels is seen basically as one of preference, with no fundamental difference in addressing the nuclear power issues.

"Since no infrastructure currently exists in the U.S. for thorium-based fuels, and processing of thorium-based fuels is at a lower level of technical maturity when compared to processing of uranium-based fuels, costs and RD&D requirements for using thorium are anticipated to be higher."

Prof. George Dracoulis takes issue with the "particularly silly claim" by a science journalist (and others) that almost all the thorium is usable as fuel compared to just 0.7% of uranium (i.e. uranium-235), and that thorium can therefore power civilization for millennia. Prof. Dracoulis states:[343]

"In fact, in that sense, none of the thorium is usable since it is not fissile. The comparison should be with the analogous fertile isotope uranium-238, which makes up nearly 100% of natural uranium. If you wanted to go that way (breeding that is), there is already enough uranium-238 to 'power civilization for millennia'."

Some Generation IV concepts promise major advantages, such as the potential to use long-lived nuclear waste and weapons-usable material (esp. plutonium) as reactor fuel using breeding and continuous recycling. But those concepts are generally those that face the greatest technical challenges. Moreover, uranium/plutonium fast reactor technology might more accurately be described as failed Generation I technology: the history of fast reactors has largely been one of extremely expensive, underperforming and accident-prone reactors which have contributed more to WMD proliferation problems than to the resolution of those problems.[344]

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[342] Idaho National Laboratory, Sept 2009, 'AFCI Options Study', INL/EXT-10-17639, https://www.researchgate.net/publication/255214351_AFCI_Options_Study or https://inldigitallibrary.inl.gov/sites/sti/sti/4480296.pdf
[343] George Dracoulis, 5 Aug 2011, 'Thorium is no silver bullet when it comes to nuclear energy, but it could play a role', http://theconversation.com/thorium-is-no-silver-bullet-when-it-comes-to-nuclear-energy-but-it-could-play-a-role-1842
[344] 'The slow death of fast reactors', 2 Nov 2016, https://energypost.eu/slow-death-fast-reactors/

Most importantly, whether Generation IV concepts deliver on their potential depends on a myriad of factors − not just the resolution of technical challenges. India's fast reactor / thorium program illustrates how badly things can go wrong, and it illustrates problems that can't be solved with technical innovation. John Carlson writes:

> *"India has a plan to produce [weapons-grade] plutonium in fast breeder reactors for use as driver fuel in thorium reactors. This is problematic on non-proliferation and nuclear security grounds. Pakistan believes the real purpose of the fast breeder program is to produce plutonium for weapons (so this plan raises tensions between the two countries); and transport and use of weapons-grade plutonium in civil reactors presents a serious terrorism risk (weapons-grade material would be a priority target for seizure by terrorists)."*[345]

Generation IV thorium concepts such as molten salt reactors (MSR) have a lengthy, uncertain R&D road ahead of them − notwithstanding the fact that there is some previous R&D to build upon.[346] Kirk Sorensen, founder of a US firm which aims to build a demonstration 'liquid fluoride thorium reactor' (a type of MSR), notes that "several technical hurdles" confront thorium-fuelled MSRs, including materials corrosion, reactor control and in-line processing of the fuel.[347]

Prof. George Dracoulis writes:[348]

> *"MSRs are not currently available at an industrial scale, but test reactors with different configurations have operated for extended periods in the past. But there are a number of technical challenges that have been encountered along the way. One such challenge is that the hot beryllium and lithium "salts" – in which the fuel and heavy wastes are dissolved – are highly reactive and corrosive. Building a large-scale system that can operate reliably for decades is non-trivial. That said, many of the components have been the subject of extensive research programs."*

Further information on thorium

The following report provides useful information:
Dr. Rainer Moormann, 2018, 'Thorium – a better fuel for nuclear technology?', Nuclear Monitor #858, https://www.wiseinternational.org/nuclear-monitor/858/thorium-%E2%80%92-better-fuel-nuclear-technology

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[345] John Carlson, 2014, submission to Joint Standing Committee on Treaties, Parliament of Australia, www.aph.gov.au/DocumentStore.ashx?id=79a1a29e-5691-4299-8923-06e633780d4b&subId=301365
[346] Stephen Harris, 9 Jan 2014, 'Your questions answered: thorium-powered nuclear', www.theengineer.co.uk/energy-and-environment/in-depth/your-questions-answered-thorium-powered-nuclear/1017776.article
See also: Oliver Tickell, August/September 2012, 'Thorium: Not 'green', not 'viable', and not likely', www.no2nuclearpower.org.uk/nuclearnews/NuClearNewsNo43.pdf
[347] Stephen Harris, 9 Jan 2014, 'Your questions answered: thorium-powered nuclear', The Engineer (UK). Article available from jim.green@foe.org.au
[348] George Dracoulis, 19 Dec 2011, 'Thoughts from a thorium 'symposium'', http://theconversation.com/thoughts-from-a-thorium-symposium-4545

5. NUCLEAR WASTE

5.1 Introduction

"The disposal of radioactive waste in Australia is ill-considered and irresponsible. Whether it is short-lived waste from Commonwealth facilities, long-lived plutonium waste from an atomic bomb test site on Aboriginal land, or reactor waste from Lucas Heights. The government applies double standards to suit its own agenda; there is no consistency, and little evidence of logic." – nuclear engineer Alan Parkinson.[349]

The 2006 Switkowski (UMPNER) report noted: "Establishing a nuclear power industry would substantially increase the volume of radioactive waste to be managed in Australia and require management of significant quantities of HLW [high-level nuclear waste]."[350]

In the mid- to late-2000s, Dr. Ziggy Switkowski, former Chair of the Board of the Australian Nuclear Science and Technology Organisation and head of the UMPNER Review, was promoting the construction of as many as 50 nuclear power reactors in Australia.[351]

Over a 50-year lifespan, a 50-reactor (50-gigawatt) nuclear power program would:[352]

- be responsible for 1.8 billion tonnes of low-level radioactive tailings waste (assuming the uranium came from Olympic Dam).
- be responsible for 430,000 tonnes of depleted uranium waste.
- produce 75,000 tonnes of high-level nuclear waste (approx. 25,000 cubic metres).
- produce 750,000 cubic metres of low-level waste and intermediate-level waste.
- produce 750 tonnes of plutonium, enough for 75,000 nuclear weapons.

A demonstrated ability to manage Australia's current radioactive waste challenges would be necessary to establish confidence that Australia could manage the streams of radioactive and nuclear wastes arising from a nuclear power program.

However, Australia's current radioactive waste challenges are either being mismanaged or not managed at all:

- Previous governments failed in their attempts to impose a national radioactive waste repository and store on unwilling communities in SA (1998–2004) and the NT (2005–2014).
- The current push to establish a national radioactive waste repository and store in SA is strongly contested and currently subject to legal challenge by Traditional Owners of the targeted site near Kimba on the Eyre Peninsula.
- The management of radioactive tailings waste at past and current uranium mines has been deficient in many respects.[353] Cases in point here include continuing contamination concerns at both Mary Kathleen (Queensland) and Rum Jungle (NT).

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[349] Alan Parkinson, 2002, 'Double standards with radioactive waste', *Australasian Science*, https://nuclear.foe.org.au/flawed-clean-up-of-maralinga/

[350] Switkowski Review, 2006, Uranium Mining, Processing and Nuclear Energy Review, http://pandora.nla.gov.au/tep/66043

[351] Ziggy Switkowski, 3 Dec 2009, 'Australia must add a dash of nuclear ambition to its energy agenda', www.smh.com.au/opinion/politics/australia-must-add-a-dash-of-nuclear-ambition-to-its-energy-agenda-20091201-k3pq.html

[352] Based primarily on figures in the UMPNER report. For information on the calculations for uranium tailings waste, see: 'There's No Nuclear Power Without Waste', 3 Dec 2010, http://web.archive.org/web/20130117002550/http://newmatilda.com/2010/12/03/theres-no-nuclear-power-without-waste

[353] See section 1.11 (p.74) in the joint submission to the SA Nuclear Fuel Cycle Royal Commission, https://nuclear.foe.org.au/wp-content/uploads/NFCRC-submission-FoEA-ACF-CCSA-FINAL-AUGUST-2015.pdf

- At the former uranium mine at Radium Hill in SA, a radioactive waste repository "is not engineered to a standard consistent with current internationally accepted practice" according to a 2003 SA government audit.[354]
- The Port Pirie uranium treatment plant in SA is still contaminated over 50 years after its closure.[355] It took a six-year community campaign just to get the site fenced off and to carry out a partial rehabilitation. As of July 2015, the SA government's website stated that "a long-term management strategy for the former site" is being developed.
- SA regulators failed to detect Marathon Resource's illegal dumping of low-level radioactive waste in the Arkaroola Wilderness Sanctuary.[356] If not for the detective work of the managers of the Sanctuary, the illegal activities would never have been detected. The incident represents a serious failure of SA government regulation.
- The 'clean-up' of nuclear waste at the Maralinga nuclear test site in the late 1990s was mismanaged and breached Australian and international standards regarding the disposal of long-lived radioactive waste.[357] Four scientists with first-hand information were highly critical of the 'clean up'.[358] The area remains the focus of continuing publicly funded remediation work.
- CSIRO faced a A$30 million clean-up bill after barrels of radioactive waste at Woomera were found to be "deteriorating rapidly" and possibly leaking. An inspection found "significant rusting" of many of the 9,725 drums. An ARPANSA report found that the mixture of water and concentrated radioactive material inside some of the drums has the potential to produce explosive hydrogen gas.[359]

Former Liberal Party Senator Nick Minchin has commented on the difficulty of managing wastes from a nuclear power program:[360]

> *''My experience with dealing with just low-level radioactive waste from our research reactor tells me it would be impossible to get any sort of consensus in this country around the management of the high level waste a nuclear reactor would produce."*

Likewise, former federal Resources Minister Senator Matt Canavan noted in June 2019:[361]

> *"We have been trying for 40 years to find a long-term repository for radioactive waste that is produced at Lucas Heights and some legacy waste we have from other activities. If we can't find a permanent home for low-level radioactive waste associated with nuclear medicines, we've got a pretty big challenge dealing with the high-level waste that would be produced by any energy facilities."*

5.2 Global challenges with nuclear waste

There are no operating repositories for high-level nuclear waste anywhere in the world. The one and only deep underground repository for long-lived intermediate-level waste − the Waste Isolation Pilot Plant in the US – was shut for three years following a chemical explosion in an underground waste barrel.

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[354] See section 3.2 (p.11) in the joint submission to the SA Nuclear Fuel Cycle Royal Commission, https://nuclear.foe.org.au/wp-content/uploads/NFCRC-submission-FoEA-ACF-CCSA-FINAL-AUGUST-2015.pdf
[355] Ibid.
[356] Ibid.
[357] Numerous articles on the flawed 'clean up' are posted at https://nuclear.foe.org.au/flawed-clean-up-of-maralinga/
[358] https://nuclear.foe.org.au/flawed-clean-up-of-maralinga/
[359] See the information posted at https://nuclear.foe.org.au/woomera/
[360] Brad Crouch, 21 May 2006, 'No nuke plant in 100 years', *The Advertiser*.
[361] Matthew Killoran, 21 June 2019, 'What a waste: Minister's question for nuclear inquiry', The Courier-Mail, https://www.couriermail.com.au/news/queensland/queensland-government/what-a-waste-ministers-question-for-nuclear-inquiry/news-story/b5dcfdcd0e81653c22137934d28a799b

Finland and Sweden are the countries most advanced with deep geological repository projects. Despite this the planned high-level nuclear waste repository in Finland is years behind schedule. The planned high-level nuclear waste repository in Sweden has hit a snag with the Swedish Land and Environmental Court ruling that SKB's application can only be approved if *"SKB can provide documentation that shows the final storage facility complies in the long-term with requirements of the Environmental Code despite the uncertainties remaining on how the canisters protective capability is effected by a) corrosion due to reaction in oxygen-free water"* and four other issues regarding copper corrosion, including the influence of radiation on three additional variables. Amongst other things, SKB has not carried out corrosion tests with a canister containing spent fuel.[362]

Other countries operating nuclear power plants – including the US, the UK, Japan, South Korea, Germany, etc. – have not even established a site for a high-level nuclear waste repository, let alone commenced construction or operation. One example of a protracted, expensive and failed attempt to establish a high-level nuclear waste repository can be seen in the plan for a repository at Yucca Mountain in Nevada. This was abandoned in 2009 and current attempts to revive the project are being strongly contested. Over 20 years of work was put into the repository plan and well over A$10 billion wasted on the failed project. The repository plan was controversial and subject to scandals including one involving the falsification of safety data in relation to groundwater modeling. Studies found that Yucca Mountain could not meet the existing radiation protection standards in the long term and subsequent moves by the US Environmental Protection Agency to weaken radiation protection standards generated further controversy.[363]

A January 2019 report details the difficulties with high-level nuclear waste management in seven countries (Belgium, France, Japan, Sweden, Finland, the UK and the US) and serves as a useful overview of the serious problems that Australia has avoided by eschewing nuclear power.[364]

5.3 Long-term costs of high-level nuclear waste management

Estimated construction costs for high-level nuclear waste repositories are in the tens of billions of dollars and cost estimates have increased dramatically.[365] For example, the construction cost estimate in France was €25 billion (A$38.9 billion) as of 2016, well above the 2005 estimate of €13.5–16.5 billion (A$21.0–25.7 billion).[366]

The UK provides another example of dramatic escalations of cost estimates. Estimates of the clean-up costs for a range of civil and military UK nuclear sites including Sellafield have jumped from a 2005 estimate of £56 billion (A$98 billion) to over £100 billion (A$175 billion).[367]

Operation of waste repositories adds many billions more to the costs. The US government estimates that to build a high-level nuclear waste repository and operate it for 150 years would cost US$96.2 billion (in 2007 dollars) (A$138 billion), a 67% increase on the 2001 estimate.[368]

[362] Miles Goldstick, 29 Jan 2018, 'Swedish nuclear industry loses battle over repository but battle rages on', https://www.wiseinternational.org/nuclear-monitor/856/swedish-nuclear-industry-loses-battle-over-repository-battle-rages
[363] Nuclear Information & Resource Service, http://archives.nirs.us/radwaste/yucca/yuccahome.htm
[364] Robert Alvarez, Hideyuki Ban, Charles Laponche, Miles Goldstick, Pete Roche and Bertrand Thuillier, Jan 2019, 'Report - The Global Crisis of Nuclear Waste', https://www.greenpeace.fr/report-the-global-crisis-of-nuclear-waste/
[365] Ibid.
[366] World Nuclear Association, http://www.world-nuclear-news.org/WR-Minister-sets-benchmark-cost-for-French-repository-1801165.html
[367] Jonathan Leake, 9 Dec 2012, 'Nuclear cleanup to take 120 years and cost £100bn', https://www.thetimes.co.uk/article/nuclear-cleanup-to-take-120-years-and-cost-pound100bn-qmmczbh5rft
[368] World Nuclear Association, 6 Aug 2008, 'Yucca Mountain cost estimate rises to $96 billion', http://www.world-nuclear-news.org/WR-Yucca_Mountain_cost_estimate_rises_to_96_billion_dollars-0608085.html

The South Australian Nuclear Fuel Royal Commission estimated a similar figure: A$145 billion over 120 years for construction, operation and decommissioning of a high-level nuclear waste repository.[369]

5.4 Fire and chemical explosion in the world's only deep underground nuclear waste repository

No operating deep underground repositories for high-level nuclear waste exist, however there is one deep underground repository for long lived intermediate-level nuclear waste − the Waste Isolation Pilot Plant (WIPP) in the US state of New Mexico.

On 5 February 2014, a truck hauling salt caught fire at WIPP. Six workers were treated at the Carlsbad hospital for smoke inhalation, another seven were treated at the site, and 86 workers were evacuated. A March 2014 report by the US Department of Energy identified the root cause of the fire as the "failure to adequately recognize and mitigate the hazard regarding a fire in the underground." In 2011, the Defense Nuclear Facilities Safety Board, an independent advisory board, reported that WIPP "does not adequately address the fire hazards and risks associated with underground operations."[370]

In a separate incident, on 14 February 2014, an explosion (resulting from a heat-generating chemical reaction) ruptured one of the barrels stored underground at WIPP. This was followed by a failure of the filtration system meant to ensure that radiation did not reach the outside environment. Twenty-two workers were exposed to low-level radiation. WIPP was closed for three years. Direct and indirect costs associated with the accident are estimated at over US$2 billion (A$2.9 billion).[371]

A US government report blamed the barrel rupture and radiation release on the operator and regulator of WIPP, noting their "failure to fully understand, characterize, and control the radiological hazard ... compounded by degradation of key safety management programs and safety culture."[372]

A safety analysis conducted before WIPP opened predicted that one radiation release accident might occur every 200,000 years.[373] On the basis of real-world experience, i.e. empirical evidence, that estimate needs to be revised upwards to 10,000 radiation-release accidents over a 200,000-year period.

A troubling aspect of the WIPP problems is that complacency and cost-cutting set in just 10−15 years after the repository opened. Earl Potter, a lawyer who represented Westinghouse, WIPP's first operating contractor, said: "At the beginning, there was an almost fanatical attention to safety. I'm afraid the emphasis shifted to looking at how quickly and how inexpensively they could dispose of this waste."[374] Likewise, Rick Fuentes, president of the Carlsbad chapter of the United Steelworkers union, said: "In the early days, we had to prove to the stakeholders that we could operate this place safely for both people and the environment. After time, complacency set in. Money didn't get invested into the equipment and the things it should have."[375]

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[369] Nuclear Fuel Cycle Royal Commission Report, May 2016, https://nuclear.foe.org.au/wp-content/uploads/NFCRC_Final_Report_Web_5MB.pdf
[370] 6 June 2014, 'Fire and leaks at the world's only deep geological waste repository', Nuclear Monitor #787, www.wiseinternational.org/node/4245
[371] https://www.latimes.com/nation/la-na-new-mexico-nuclear-dump-20160819-snap-story.html
[372] US Dept of Energy, Office of Environmental Management, April 2014, 'Accident Investigation Report: Phase 1: Radiological Release Event at the Waste Isolation Pilot Plant on February 14, 2014', http://energy.gov/em/downloads/radiological-release-accident-investigation-report
[373] Matthew Wald, 29 Oct 2014, 'In U.S. Cleanup Efforts, Accident at Nuclear Site Points to Cost of Lapses', www.nytimes.com/2014/10/30/us/in-us-cleanup-efforts-accident-at-nuclear-site-points-to-cost-of-lapses.html
[374] Patrick Malone, 14 Feb 2015, 'Repository's future uncertain, but New Mexico town still believes', www.santafenewmexican.com/special_reports/from_lanl_to_leak/repository-s-future-uncertain-but-new-mexico-town-still-believes/article_38b0e57b-2d4e-5476-b3f5-0cfe81ce94cc.html
[375] ibid.

For more information on the WIPP accidents, see:

- Nuclear Monitor #801, 9 April 2015, 'One deep underground dump, one dud', https://www.wiseinternational.org/nuclear-monitor/801/one-deep-underground-dump-one-dud
- The Ecologist, 27 Nov 2014, 'New Mexico nuclear waste accident a 'horrific comedy of errors' that exposes deeper problems', https://theecologist.org/2014/nov/27/new-mexico-nuclear-waste-accident-horrific-comedy-errors-exposes-deeper-problems

5.5 Nuclear waste generated by small modular reactors and Generation IV reactors

Small modular reactors

Claims that small modular reactors (SMRs) based on conventional light-water reactor technology are advantageous with respect to nuclear waste have no logical or evidentiary basis.

The South Australian Nuclear Fuel Cycle Royal Commission said in its Final Report that "SMRs have lower thermal efficiency than large reactors, which generally translates to higher fuel consumption and spent fuel volumes over the life of a reactor."[376]

Likewise, a 2017 article by Princeton University researchers concludes: "Of the different major SMR designs under development, it seems none meets simultaneously the key challenges of costs, safety, waste, and proliferation facing nuclear power today and constraining its future growth. In most, if not all designs, it is likely that addressing one or more of these four problems will involve choices that make one or more of the other problems worse."[377]

One of the authors of the above-mentioned article, M.V. Ramana, notes in a different article that "a smaller reactor, at least the water-cooled reactors that are most likely to be built earliest, will produce more, not less, nuclear waste per unit of electricity they generate because of lower efficiencies."[378]

A 2016 European Commission document states:[379]
"At the current stage of development it cannot be assessed whether the decommissioning and waste management costs of SMRs will significantly differ from those of larger reactors. Due to the loss of economies of scale, the decommissioning and waste management unit costs of SMR will probably be higher than those of a large reactor (some analyses state that between two and three times higher)."

Generation IV concepts and nuclear waste

Lindsay Krall and Allison Macfarlane have written an important article in the *Bulletin of the Atomic Scientists* debunking claims that certain Generation IV reactor concepts promise major advantages with respect to nuclear waste management.[380] Krall is a post-doctoral fellow at the George Washington University. Macfarlane is a professor at the same university, a former chair of the US Nuclear

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[376] https://nuclear.foe.org.au/wp-content/uploads/NFCRC_Final_Report_Web_5MB.pdf
[377] M.V. Ramana and Zia Mian, Jan 2017, 'Small Modular Reactors and the Challenges of Nuclear Power', https://www.aps.org/units/fps/newsletters/201701/reactors.cfm
[378] M.V. Ramana, 23 June 2018, 'The future of nuclear power in the US is bleak', http://thehill.com/opinion/energy-environment/393717-the-future-of-nuclear-power-in-the-us-is-bleak
[379] European Commission, 4 April 2016, 'Commission Staff Working Document, Accompanying the document: Communication from the Commission, Nuclear Illustrative Programme presented under Article 40 of the Euratom Treaty for, the opinion of the European Economic and Social Committee', https://ec.europa.eu/energy/sites/ener/files/documents/1_EN_autre_document_travail_service_part1_v10.pdf
[380] Lindsay Krall and Allison Macfarlane, 2018, 'Burning waste or playing with fire? Waste management considerations for non-traditional reactors', Bulletin of the Atomic Scientists, 74:5, pp.326-334, https://tandfonline.com/doi/10.1080/00963402.2018.1507791

Regulatory Commission from July 2012 to December 2014, and a member of the Blue Ribbon Commission on America's Nuclear Future from 2010 to 2012.

Krall and Macfarlane focus on molten salt reactors and sodium-cooled fast reactors and draw on the experiences of the US Experimental Breeder Reactor II and the US Molten Salt Reactor Experiment.

The article abstract notes that Generation IV developers and advocates "are receiving substantial funding on the pretense that extraordinary waste management benefits can be reaped through adoption of these technologies" yet "molten salt reactors and sodium-cooled fast reactors – due to the unusual chemical compositions of their fuels – will actually exacerbate spent fuel storage and disposal issues."

Krall and Macfarlane further state:

> *"The core propositions of non-traditional reactor proponents – improved economics, proliferation resistance, safety margins, and waste management – should be re-evaluated. The metrics used to support the waste management claims – i.e. reduced actinide mass and total radiotoxicity beyond 300 years – are insufficient to critically assess the short- and long-term safety, economics, and proliferation resistance of the proposed fuel cycles.*
>
> *"Furthermore, the promised (albeit irrelevant) actinide reductions are only attainable given exceptional technological requirements, including commercial-scale spent fuel treatment, reprocessing, and conditioning facilities. These will create low- and intermediate-level waste streams destined for geologic disposal, in addition to the intrinsic high-level fission product waste that will also require conditioning and disposal.*
>
> *"Before construction of non-traditional reactors begins, the economic implications of the back end of these non-traditional fuel cycles must be analyzed in detail; disposal costs may be unpalatable. The reprocessing/treatment and conditioning of the spent fuel will entail costs, as will storage and transportation of the chemically reactive fuels. These are in addition to the cost of managing high-activity operational wastes, e.g. those originating from molten salt reactor filter systems. Finally, decommissioning the reactors and processing their chemically reactive coolants represents a substantial undertaking and another source of non-traditional waste. ...*
>
> *"Finally, treatment of spent fuels from non-traditional reactors, which by Energy Department precedent is only feasible through their respective (re)processing technologies, raises concerns over proliferation and fissile material diversion. Pyroprocessing and fluoride volatility-reductive extraction systems optimized for spent fuel treatment can – through minor changes to the chemical conditions – also extract plutonium (or uranium 233 bred from thorium). Separation from lethal fission products would eliminate the radiological barriers protecting the fuel from intruders seeking to obtain and purify fissile material. Accordingly, cost and risk assessments of predisposal spent fuel treatments must also account for proliferation safeguards.*
>
> *"Radioactive waste cannot be "burned"; fission of actinides, the source of nuclear heat, inevitably generates fission products. Since some of these will be radiotoxic for thousands of years, these high-level wastes should be disposed of in stable waste forms and geologic repositories. But the waste estimates propagated by nuclear advocates account only for the bare mass of fission products, rather than that of the conditioned waste form and associated repository requirements.*
>
> *"These estimates further assume that the efficiency of actinide fission will surge, but this actually relies on several rounds of recycling using immature reprocessing technologies. The low- and intermediate-level wastes that will be generated by these activities will also be*

destined for geologic disposal but have been neglected in the waste estimates. More important, reprocessing remains a security liability of dubious economic benefit, so the apparent need to adopt these technologies simply to prepare non-traditional spent fuels for storage and disposal is a major disadvantage relative to light water reactors. Theoretical burnups for fast and molten salt reactors are too low to justify the inflated back-end costs and risks, the latter of which may include a commercial path to proliferation.
"Reductions in spent fuel volume, longevity, and total radiotoxicity may be realized by breeding and burning fissile material in non-traditional reactors. But those relatively small reductions are of little value in repository planning, so utilization of these metrics is misleading to policy-makers and the general public. We urge policy-makers to critically assess non-traditional fuel cycles, including the feasibility of managing their unusual waste streams, any loopholes that could commit the American public to financing quasi-reprocessing operations, and the motivation to rapidly deploy these technologies."

Pyroprocessing: the integral fast reactor waste fiasco

In theory, integral fast reactors (IFRs) would consume nuclear waste and convert it into low-carbon electricity. In practice, the EBR-II (IFR) R&D program in Idaho has left a legacy of troublesome waste. This saga is detailed in a 2017 article[381] and a longer report[382] by the Union of Concerned Scientists' senior scientist Dr. Edwin Lyman, drawing on documents obtained under Freedom of Information legislation.

Lyman writes:[383]

"[P]yroprocessing has taken one potentially difficult form of nuclear waste and converted it into multiple challenging forms of nuclear waste. DOE has spent hundreds of millions of dollars only to magnify, rather than simplify, the waste problem. …
"The FOIA documents we obtained have revealed yet another DOE tale of vast sums of public money being wasted on an unproven technology that has fallen far short of the unrealistic projections that DOE used to sell the project …

"Everyone with an interest in pyroprocessing should reassess their views given the real-world problems experienced in implementing the technology over the last 20 years at INL. They should also note that the variant of the process being used to treat the EBR-II spent fuel is less complex than the process that would be needed to extract plutonium and other actinides to produce fresh fuel for fast reactors. In other words, the technology is a long way from being demonstrated as a practical approach for electricity production."

5.6 Importing nuclear waste as a money-making venture and/or to fuel Generation IV reactors

The abandoned proposal for nuclear waste importation in SA

The 2015/16 SA Nuclear Fuel Cycle Royal Commission had a significant level of pro-nuclear bias[384] but nevertheless rejected most of the options it was asked to consider – uranium conversion and

[381] Ed Lyman / Union of Concerned Scientists, 12 Aug 2017, 'The Pyroprocessing Files', http://allthingsnuclear.org/elyman/the-pyroprocessing-files
[382] Edwin Lyman, 2017, 'External Assessment of the U.S. Sodium-Bonded Spent Fuel Treatment Program', https://s3.amazonaws.com/ucs-documents/nuclear-power/Pyroprocessing/IAEA-CN-245-492%2Blyman%2Bfinal.pdf
[383] Ed Lyman / Union of Concerned Scientists, 12 Aug 2017, 'The Pyroprocessing Files', http://allthingsnuclear.org/elyman/the-pyroprocessing-files

enrichment, nuclear fuel fabrication, conventional and Generation IV nuclear power reactors, and spent fuel reprocessing.

The Royal Commission did however recommend further consideration of a proposal to import large volumes of nuclear waste (138,000 tonnes of high-level nuclear waste (spent nuclear fuel) and 390,000 cubic metres of intermediate-level waste) as a money-making venture. Following the Royal Commission, the government initiated a Citizens' Jury which voted strongly against the proposal.[385] The SA Liberal Opposition announced its intention to campaign against the proposal. The Nick Xenophon Team also announced its opposition while the SA Greens had opposed the proposal from the start. Premier Jay Weatherill later said that the plan is "dead", there is "no foreseeable opportunity for this", and it is "not something that will be progressed by the Labor Party in Government".[386]

The proposal has little or no political support in SA, and it never enjoyed public support. The statewide consultation process led by the government randomly surveyed over 6,000 South Australians and found 53% opposition to the proposal compared to 31% support.[387] A November 2016 poll commissioned by the *Sunday Mail* found 35% support for the nuclear dump plan among 1,298 respondents.

Opposition from Traditional Owners was overwhelming[388] and was a significant factor in the Citizen Jury's rejection of the proposal. The Jury's report said: "There is a lack of Aboriginal consent. We believe that the government should accept that the Elders have said NO and stop ignoring their opinions."[389]

While in office, Premier Weatherill said Traditional Owners should have a right of veto over any proposal to build nuclear waste storage or disposal facilities on their land – and he later wrote to then Prime Minister Turnbull suggesting that the same right of veto should apply to plans for a national radioactive waste facility in SA. The federal plan for a facility near Kimba that was inherited and is currently being continued by the federal Labor government is being contested in the courts by Barngarla Traditional Owners and is facing growing opposition from Eyre Peninsula grain producers, the SA Labor government and broader community and civil society groups.

In October 2017, a cross-party SA Parliament Joint Committee on the Findings of the Nuclear Fuel Cycle Royal Commission released its report with just one recommendation: "That the South Australian Government should not commit any further public funds to pursuing the proposal to establish a repository for the storage of nuclear waste in South Australia."[390]

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[384] 'A Critique of the South Australian Nuclear Fuel Cycle Royal Commission', Dec 2015, https://nuclear.foe.org.au/critique-of-the-sa-nuclear-fuel-cycle-royal-commission/
'Bias of SA Nuclear Royal Commission finally exposed', 4 Nov 2016, http://reneweconomy.com.au/bias-sa-nuclear-royal-commission-finally-exposed-57819/
'SA Nuclear Royal Commission Is A Snow Job', 29 April 2016, http://reneweconomy.com.au/sa-nuclear-royal-commission-is-a-snow-job-18368/
[385] Citizens' Jury report: http://web.archive.org/web/20220306105550/http://assets.yoursay.sa.gov.au/production/2016/11/06/07/20/56/26b5d85c-5e33-48a9-8eea-4c860386024f/final%20jury%20report.pdf
[386] http://indaily.com.au/news/politics/2017/06/07/theres-no-foreseeable-opportunity-jay-declares-nuke-dump-dead/
[387] http://web.archive.org/web/20220306105615/http://assets.yoursay.sa.gov.au/production/2016/11/11/09/37/34/0c1d5954-9f04-4e50-9d95-ca3bfb7d1227/NFCRC%20CARA%20Community%20Views%20Report.pdf
[388] https://www.anfa.org.au/wp-content/uploads/2016/10/Traditional-Owner-statements-SA-dump-Oct2016.pdf
[389] http://web.archive.org/web/20220306105550/http://assets.yoursay.sa.gov.au/production/2016/11/06/07/20/56/26b5d85c-5e33-48a9-8eea-4c860386024f/final%20jury%20report.pdf
[390] http://www.parliament.sa.gov.au/Committees/Pages/Committees.aspx?CTId=2&CId=333

Importing high-level nuclear waste for use in fast reactors

The Committee will likely receive submissions arguing that Australia should import high-level nuclear waste which could be converted into fuel for 'integral fast reactors' (IFRs – discussed in Appendix 3 to the joint NGO submission to the federal nuclear inquiry[391]).

The SA Nuclear Fuel Cycle Royal Commission investigated such propositions and concluded:[392]

> *"[A]dvanced fast reactors and other innovative reactor designs are unlikely to be feasible or viable in the foreseeable future. The development of such a first-of-a-kind project in South Australia would have high commercial and technical risk. Although prototype and demonstration reactors are operating, there is no licensed, commercially proven design. Development to that point would require substantial capital investment. Moreover, electricity generated from such reactors has not been demonstrated to be cost competitive with current light water reactor designs."*

Little has changed since the Royal Commission reported – except the collapse of a number of Generation IV R&D projects including Generation mPower, Transatomic Power, MidAmerican Energy's SMR plans, and TerraPower's plan for a demonstration fast reactor in China. Further, The UK government abandoned consideration of 'integral fast reactors' for plutonium disposition in March 2019 – and the US government did the same in 2015.

Creative accounting

The engineering of a positive economic case to proceed with the nuclear waste import plan was discussed by ABC journalist Stephen Long: "Would you believe me if I told you the report that the commission has solely relied on was co-authored by the president and vice president of an advocacy group for the development of international nuclear waste facilities?"[393]

Worse still, there was no peer review of the report that was co-authored by the president and vice president of an advocacy group for the development of international nuclear waste facilities.

Prof. Barbara Pocock, then an economist at the University of South Australia, said: "All the economists who have replied to the analysis in that report have been critical of the fact that it is a 'one quote' situation. We haven't got a critical analysis, we haven't got a peer review of the analysis".[394]

The Royal Commission's economic claims were eventually subject to a peer review. The SA Parliament's Joint Committee commissioned a report by the Nuclear Economics Consulting Group which noted that the Royal Commission's economic analysis failed to consider important issues which "have significant serious potential to adversely impact the project and its commercial outcomes"; that assumptions about price were "overly optimistic" in which case "project profitability is seriously at risk"; that the 25% cost contingency for delays and blowouts was likely to be a significant underestimate; and that the assumption the project would capture 50% of the available market had "little support or justification".[395]

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[391] https://www.aph.gov.au/DocumentStore.ashx?id=9eee9d5f-4362-4b30-b0b8-3b65ff98215f&subId=670271
[392] https://nuclear.foe.org.au/wp-content/uploads/NFCRC_Final_Report_Web_5MB.pdf
[393] http://www.abc.net.au/news/2016-11-08/should-south-australia-be-storing-nuclear-waste-above-ground/8003156
[394] http://www.abc.net.au/news/2016-11-03/radioactive-waste-dump-would-boost-sa-economy-commission-hears/7991170
[395] http://nuclear-economics.com/wp-content/uploads/2016/11/2016-11-11-NECG-Review-of-Jacobs-MCM-Report-for-SA-Parliament.pdf

South Australian economist Prof. Richard Blandy from Adelaide University said: "The forecast profitability of the proposed nuclear dump rests on highly optimistic assumptions. Such a dump could easily lose money instead of being a bonanza."[396]

Likewise, a detailed report by the Australia Institute concluded that the business case for a nuclear waste storage facility in South Australia was exaggerated, that the project would be risky, and that an economic loss was well within the range of possible outcomes.[397]

Further information on the abandoned proposal for nuclear waste importation to SA

Submission to the SA Parliament's Joint Select Committee by Friends of the Earth, Conservation SA and Australian Conservation Foundation, July 2016, https://nuclear.foe.org.au/wp-content/uploads/SA-Joint-Select-Cttee-FoE-ACF-CCSA-final.pdf

5.7 Transportation of nuclear waste

Transport incidents and accidents are commonplace

A UK government database − Radioactive Material Transport Event Database (RAMTED) − contains information on 1018 events from 1958 to 2011 (an average of 19 incidents each year) involving all forms of radioactive and nuclear materials, including waste.[398] Of the 38 incidents in the UK in 2011 alone, 11 involved irradiated nuclear fuel flasks (up from eight in 2010). One of those 11 events involved a low-impact collision.[399]

In a report on 806 recorded radioactive transport incidents in the UK from 1958−2004, Hughes et al. found that 111 involved 'residues inc. discharged INF flasks', 101 involved irradiated fuel, and 63 involved (other) radioactive wastes:[400]

MATERIAL TYPE *Source: Hughes et al, 2006*	**NUMBER OF EVENTS (806) FROM 1958−2004**	**PERCENTAGE**
Medical & industrial isotopes	376	46.7
Residues inc. discharged INF flasks	111	13.8
Irradiated fuel	101	12.5
Radiography sources	78	9.7
Radioactive wastes	63	7.8
Uranium ore concentrate	33	4

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396 http://www.abc.net.au/news/2016-11-03/radioactive-waste-dump-would-boost-sa-economy-commission-hears/7991170
See also Prof. Blandy's submission to the Royal Commission: http://nuclearrc.sa.gov.au/app/uploads/2016/04/Blandy-Richard.pdf
See also https://indaily.com.au/news/business/analysis/2016/06/07/how-a-high-level-nuclear-waste-dump-could-lose-money/
397 https://www.tai.org.au/content/digging-answers or direct download:
https://www.tai.org.au/sites/default/files/P222A%20Digging%20for%20answers%20-%20SA%20Nuclear%20Royal%20Commission%20Submission%20FINAL.pdf
398 Some recent annual reviews of transport incidents in the UK are posted at
http://webarchive.nationalarchives.gov.uk/20140722091854/www.hpa.org.uk/Publications/Radiation/CRCEScientificAndTechnicalReportSeries/
Some earlier annual reviews are posted at:
http://webarchive.nationalarchives.gov.uk/20140722091854/www.hpa.org.uk/Publications/Radiation/HPARPDSeriesReports/
See also M.P. Harvey and A.L Jones, Aug 2012, 'HPA-CRCE-037 - Radiological Consequences Resulting from Accidents and Incidents Involving the Transport of Radioactive Materials in the UK – 2011 Review', www.hpa.org.uk/Publications/Radiation/CRCEScientificAndTechnicalReportSeries/HPACRCE037/
399 M.P Harvey and A.L Jones (UK Health Protection Agency), August 2012, 'Radiological Consequences Resulting from Accidents and Incidents Involving the Transport of Radioactive Materials in the UK − 2011 Review', commissioned by UK Office for Nuclear Regulation, www.hpa.org.uk/Publications/Radiation/CRCEScientificAndTechnicalReportSeries/HPACRCE037/
400 J.S. Hughes, D. Roberts, and S.J. Watson, July 2006, 'Review of Events Involving the Transport of Radioactive Materials in the UK, from 1958−2004, and their Radiological Consequences',
http://webarchive.nationalarchives.gov.uk/20140714084352/www.hpa.org.uk/webc/HPAwebFile/HPAweb_C/1194947346295

Other	44	5.5

There were 187 incidents during the shipment of irradiated nuclear fuel flasks from 1958−2004[401] – 23% of the total number of 806 recorded incidents. There is no evidence of safety improvements in the UK:

- In 2008, 18% of recorded incidents (7/39) involved irradiated nuclear fuel flasks.[402]
- In 2009, 24% of recorded incidents (8/33) involved irradiated nuclear fuel flasks.[403]
- In 2010, 27% of recorded incidents (8/30) involved irradiated nuclear fuel flasks.[404]
- In 2011, 29% of recorded incidents (11/38) involved irradiated nuclear fuel flasks.[405]

Transport incidents are also commonplace in France and presumably a comparable percentage involve nuclear wastes. In 2008, the French nuclear safety agency IRSN produced a report summarising radioactive transport accidents and incidents from 1999−2007.[406] The IRSN manages a database listing reported deviations, anomalies, incidents and accidents (known generically as "events") relating to transport. The database lists 901 events from 1999−2007 − on average 100 events annually or about two each week.

In the US, in the eight years from 2005 to 2012, 72 incidents involving trucks carrying radioactive material on highways caused US$2.4 million in damage and one death, according to the Transportation Department's Pipeline and Hazardous Materials Safety Administration.[407]

Costs of accidents

Nuclear transport accidents involving spent nuclear fuel / high-level nuclear waste have the potential to be extraordinarily expensive. Dr. Marvin Resnikoff and Matt Lamb from Radioactive Waste Management Associates in New York City calculated 355−431 latent cancer fatalities attributable to a "maximum" hypothetical rail cask accident, compared to the US Department of Energy's estimate of 31 fatalities. Using the Department of Energy's model, they calculated that a severe truck cask accident could result in US$20 billion to US$36 billion in cleanup costs for an accident in an urban area, and a severe rail accident in an urban area could result in costs from US$145 billion to US$270 billion.[408]

An example of a million-dollar accident occurred in Roane County, Tennessee in 2004. A Bechtel-Jacobs truck spilled strontium-90 across nearly two miles of Highway 95. More than five hours after the spill occurred, authorities finally closed the road. Highway 95 remained closed for two days, after sections

[401] J.S. Hughes, D. Roberts, and S.J. Watson, July 2006, 'Review of Events Involving the Transport of Radioactive Materials in the UK, from 1958−2004, and their Radiological Consequences', http://webarchive.nationalarchives.gov.uk/20140714084352/www.hpa.org.uk/webc/HPAwebFile/HPAweb_C/1194947346295

[402] M. P. Harvey, Aug 2010, 'HPA-CRCE-003 - Radiological Consequences Resulting from Accidents and Incidents Involving the Transport of Radioactive Materials in the UK – 2009 Review', www.hpa.org.uk/Publications/Radiation/CRCEScientificAndTechnicalReportSeries/HPACRCE003/

[403] ibid.

[404] M. P. Harvey and A. L. Jones, 2011, 'HPA-CRCE-024: Radiological Consequences Resulting from Accidents and Incidents Involving the Transport of Radioactive Materials in the UK – 2010 Review', www.hpa.org.uk/Publications/Radiation/CRCEScientificAndTechnicalReportSeries/HPACRCE024/

[405] M.P. Harvey and A.L Jones, Aug 2012, 'HPA-CRCE-037 - Radiological Consequences Resulting from Accidents and Incidents Involving the Transport of Radioactive Materials in the UK – 2011 Review', www.hpa.org.uk/Publications/Radiation/CRCEScientificAndTechnicalReportSeries/HPACRCE037/

[406] IRSN (France), 21 Oct 2008, 'Information report: Incidents in transport of radioactive materials for civil use: IRSN draws lessons from events reported between 1999 and 2007',
www.irsn.fr/EN/publications/technical-publications/Documents/IRSN_ni_transports_analysis_20081021.pdf
www.irsn.fr/EN/Library/Documents/IRSN_ni_transports_analysis_20081021.pdf
www.irsn.fr/EN/Pages/home.aspx

[407] Anna M. Tinsley, 15 April 2012, 'Radioactive waste may soon travel on DFW highways', http://web.archive.org/web/20130504150446/www.star-telegram.com/2012/04/15/3884220/radioactive-waste-may-soon-travel.html

[408] 7 July 2000, www.state.nv.us/nucwaste/news2000/nn10719.htm

of the road were cleaned and re-paved. The Department of Energy said the clean-up bill would exceed US$1 million.[409]

Direct and indirect costs associated with the Feb. 2014 chemical explosion underground at the Waste Isolation Plant in New Mexico are estimated at over US$2 billion (A$2.9 billion).[410]

European nuclear waste transport scandal

In the late 1990s, a whistleblower supplied WISE-Paris, an environmental and energy NGO, with information which sparked a major controversy over frequent excessive radioactive contamination of waste containers, rail cars, and trucks.[411] Nuclear waste shipments from German nuclear reactor sites to reprocessing plants in the UK and France were banned, and transport within France was suspended, in the aftermath of the controversy.

WISE-Paris summarised the controversy in mid-1998:[412]

> *"There are two scandals, both unprecedented. The first lies in the fact that for 15 years the nuclear industry – power plants, transport companies, plutonium factories and nuclear safety institutes in France, Germany, Switzerland and the UK at least – have managed to hide the fact that the international transport regulations for spent fuel shipments have been constantly violated, up to levels exceeding several thousand times the limit. This is all the more stunning as the original recommendation stems from the industry friendly, heavily pro-nuclear International Atomic Energy Agency (IAEA) in Vienna.*
> *"The second scandal derives from the fact that the French nuclear safety authority DSIN has been aware of the problem since autumn 1997, agreed with the French nuclear industry representatives over the wording of a mere "cleanliness problem", and kept silent until a journalistic investigation brought the story to light. The safety authority neither informed its ministers nor its foreign counterparts and, of course, nor did it inform the public. Worse, when the story broke, the authority played the role of the tough transparent State control agency finally cleaning up ... without actually taking any kind of regulatory or disciplinary consequences, while downplaying health consequences and the persistent outrageous violation of regulations.*
>
> *"The risk seems rather high that people have been exposed to significant levels of radiation over the period the contaminated transports have crossed countries. Worse, hot particles have been spread into the environment along rail tracks and roads. People might actually continue to get contaminated presently and for a long time to come."*

French Environment Minister Dominique Voynet said:[413]

> *"Beyond the level of contamination, I'm shocked by the fact that as soon as one asks some simple questions to the operators, one realises that this has been going on for years, that the three companies questioned (EDF, Transnucléaire, COGEMA) were perfectly aware of it and that they have not said anything."*

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409 www.nuclearfiles.org/menu/timeline/timeline_page.php?year=2004
410 https://www.latimes.com/nation/la-na-new-mexico-nuclear-dump-20160819-snap-story.html
411 WISE-Paris, Plutonium Investigation, No.6, May-June 1998,
www.wise-paris.org/index.html?/english/ournewsletter/6_7/contents.html
and
www.wise-paris.org/english/ournewsletter/6_7/no6_7.pdf
412 www.wise-paris.org/index.html?/english/ournewsletter/6_7/editorial.html&/english/frame/menu.html
and
http://www.wise-paris.org/index.html?/english/ournewsletter/6_7/page4.html&/english/frame/menu.html&/english/frame/band.html
413 http://www.wise-paris.org/english/ournewsletter/6_7/no6_7.pdf

Some examples of accidents and incidents

Some examples of accidents and incidents involving the transport of radioactive waste are noted here:

In early 1998, it was revealed that "airtight" spent fuel storage canisters at ANSTO's Lucas Heights site had been infiltrated by water − 90 litres in one case − and corrosion had resulted. When canisters were retrieved for closer inspection, three accidents took place (2/3/98, 13/8/98, 1/2/99), all of them involving the dropping of canisters containing spent fuel while trying to transport them from the 'dry storage' site to another part of the Lucas Heights site. The public may never have learnt about those accidents if not for the fact that an ANSTO whistleblower told the local press. One of those accidents (1/2/99) subjected four ANSTO staff members to small radiation doses (up to 0.5 mSv).[414]

ANSTO has acknowledged that there are 1−2 accidents or 'incidents' every year involving the transportation of radioactive materials to and from the Lucas Heights reactor plant.[415] ANSTO provides no further detail but presumably some of the accidents and incidents involve waste materials.

In October 2014, a ship carrying radioactive waste which was set adrift in the North Sea after it caught fire led to the evacuation of the nearby Beatrice oil platform, part-owned by Ithaca Energy. The MV Parida was transporting six 500-litre drums of cemented radioactive waste from Scrabster in northern Scotland to Antwerp, Belgium, when the fire broke out in one of its funnels. The blaze was put out by the ship's crew. Meanwhile 52 workers were airlifted off the oil platform as a precaution in case the drifting MV Parida struck it. The ship was subsequently towed to a secure pier at the Port of Cromarty Firth by a commercial operator, despite the Aberdeen coastguard sending two emergency tugs to assist. The cargo was reportedly undamaged. The waste was from the Dounreay experimental nuclear power plant.[416] Angus Campbell, the leader of the Western Isles Council, said the Parida incident highlighted the need for a second coastguard tug in the Minch. "A ship in similar circumstances on the west coast would be reliant on the Northern Isles-based ETV [emergency towing vessel] which would take a considerable amount of time to get to an incident in these waters."[417]

On 5 February 2014, a truck hauling salt caught fire at the Waste Isolation Pilot Plant (WIPP) in New Mexico. Six workers were treated at the Carlsbad hospital for smoke inhalation, another seven were treated at the site, and 86 workers were evacuated. A March 2014 report by the US Department of Energy identified the root cause of the fire as the "failure to adequately recognize and mitigate the hazard regarding a fire in the underground." In 2011, the Defense Nuclear Facilities Safety Board, an independent advisory board, reported that WIPP "does not adequately address the fire hazards and risks associated with underground operations."[418]

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[414] Sutherland Shire Environment Centre:
https://nuclearhistory.wordpress.com/2011/03/17/safety-problems-at-antso/
www.ssec.org.au/our_environment/issues_campaigns/nuclear/info_sheets/2002_sep_1.htm

[415] ANSTO, 2003, Submission to NSW Parliament's 'Joint Select Committee into the Transportation and Storage of Nuclear Waste'

[416] Andrew Snelling, 9 Oct 2014, 'Oil rig evacuated after radioactive fire',
www.energynewspremium.net/StoryView.asp?storyID=826936500&section=General+News&sectionsource=s63&aspdsc=yes
NFLA / KIMO, 8 Oct 2014, 'NFLA and KIMO call for urgent inquiry into Parida nuclear waste transport fire off the Moray Firth',
www.nuclearpolicy.info/docs/news/NFLA_KIMO_Parida_incident.pdf
West Highland Free Press 26 July 2014, www.whfp.com/2014/07/25/concern-over-nuclear-waste-shipments/
16 Oct 2014, 'Call for safety review following ship fire', www.fia.uk.com/en/information/details/index.cfm/call-for-safety-review-following-ship-fire
World Nuclear News, 8 Oct 2014, www.world-nuclear-news.org/WR-Dounreay-ready-to-assist-fire-investigation-08101401.html

[417] Herald, 30 July 2014 www.heraldscotland.com/news/home-news/plans-for-radioactive-waste-by-sea-are-criticised.24898732

[418] 6 June 2014, 'Fire and leaks at the world's only deep geological waste repository', Nuclear Monitor #787, www.wiseinternational.org/node/4245

16 January 2014: A driver abandoned his stricken car at a level crossing moments before it was dragged 300 metres down a railway track by an empty nuclear waste train in the UK. The train is used to take spent nuclear fuel to Sellafield but, as it was returning to Cheshire, was empty.[419]

23 December 2013: A rail freight wagon carrying nuclear waste was derailed at a depot in Drancy, 3 km northeast of Paris. The wagon carried spent fuel from the Nogent nuclear power plant destined for AREVA's reprocessing plant at La Hague in Normandy. Although no leakage of radiation was measured at the accident location, the Nuclear Safety Authority (ASN) reported that subsequent testing by AREVA revealed a hotspot on the rail car that delivered a dose of 56 microsieverts.[420]

September 2002: A truck carrying nuclear waste from Idaho to the Waste Isolation Pilot Plant in New Mexico, USA, ran off Interstate 80 in Wyoming. The driver said he felt ill and attempted to pull over, but he blacked out before he made it to the roadside. The truck crossed the median, headed across the westbound lane and left the road. The accident was the second in less than two weeks. On Aug. 25, a truck bound for the WIPP plant near Carlsbad was hit by an alleged drunk driver. Nobody was injured and no contaminants were released in either accident, WIPP officials said.[421]

A serious incident occurred in the UK in 2002.[422] AEA Technology was fined £250,000 for the incident during a 130-mile truck journey. A highly radioactive beam was emitted from a protective flask as it was driven across northern England and it was "pure good fortune" that no-one was dangerously contaminated, Leeds Crown Court was told. The problem arose when a plug was left off a specially-built 2.5-tonne container carrying radioactive material on a lorry. Staff used the wrong packaging equipment and failed to carry out essential safety checks before the radioactive cobalt-60 (decommissioned cancer treatment equipment) was transported from West Yorkshire to Cumbria. The court heard the 8mm-wide beam of radiation escaped through the bottom of the flask, pointing directly into the ground, throughout the three-hour road journey. Had the beam travelled horizontally, anyone within 280 metres would have been at risk of contamination from a beam of gamma rays up to 1000 times more powerful than a "very high dose rate". Radiation experts from the Health and Safety Executive said that anyone exposed to the beam could have exceeded the legal dose within seconds and suffered burns within minutes. One scientist estimated that someone standing a metre from the source and in the direct path of the rays would have been dead in two hours. The judge, Norman Jones, QC, said staff at the firm had acted in a "cavalier and somewhat indifferent" manner with a "degree of arrogance" towards their duties. He said the risk from the leak had been "considerable". In addition to the fine, he ordered the company to pay more than £150,000 in costs to the UK Health and Safety Executive.

3 February 1997 − High-level nuclear waste transport derails. A train carrying three casks with about 180 tons of high-level radioactive waste derailed near Apach (France). The waste was on its way from the nuclear power plant in Lingen (Germany) to Sellafield, UK, where it was to be reprocessed. The train was going at about 30 kilometers per hour, and the casks did not turn over. The incident was not a unique event. On 15 January 1997 a nuclear fuel cask derailed in front of the German nuclear power

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[419] CORE Briefing, 15 Jan 2014, www.corecumbria.co.uk/newsapp/pressreleases/pressmain.asp?StrNewsID=331
www.lancasterguardian.co.uk/news/nuclear-waste-train-in-50mph-smash-1-6376671
Morning Star, 16 Jan 2014, www.morningstaronline.co.uk/a-e91c-Level-crossing-crash-exposes-dangers-of-nuclear-trains
Lancaster Guardian, 16 Jan 2014, www.lancasterguardian.co.uk/news/nuclear-waste-train-in-50mph-smash-1-6376671
[420] International Panel on Fissile Materials, 21 Jan 2014, http://fissilematerials.org/blog/2014/01/nuclear_train_accident_in.html
[421] AP, 9 Sept 2002, 'WIPP truck runs off highway in Wyoming', http://lubbockonline.com/stories/090902/upd_075-3941.shtml
[422] UK Health and Safety Executive, 2006, 'Transport case prompts HSE reminder on the importance of radiation protection controls', www.hse.gov.uk/press/2006/e06017.htm
See also: 'Firm fined £250,000 over radioactive leak', The Scotsman, 21 February 2006, http://news.scotsman.com/topics.cfm?tid=112&id=267752006
See also: 'Toxic truck leak a radiation near-miss', 22 February 2006, www.theaustralian.news.com.au/common/story_page/0,5744,18231965%5E2703,00.html

plant at Krümmel during a track change, and on 3 February 1997 the engine driver of a nuclear waste transport from Krümmel suffered from a faint.[423]

1976, Kentucky, USA: Six drums containing radioactive waste burst open after they rolled off tractor-trailer trucks in Ashfield, Kentucky, USA. Two drivers were slightly injured. When the highway was cleaned, checks indicated radioactivity.[424]

More information on transport incidents and accidents

Section 8.5 in this submission: 'Nuclear transport security issues'.

Section 3.8 in the August 2015 joint submission to the SA Nuclear Fuel Cycle Royal Commission by Friends of the Earth Australia, the Australian Conservation Foundation, and Conservation SA.[425]

'Responsibility overboard: the shocking record of the company shipping nuclear waste to Australia', Natalie Wasley, 14 Aug 2018, Online Opinion, http://www.onlineopinion.com.au/view.asp?article=19892&page=0

[423] WISE News Communique #467, February 28, 1997
Die Tageszeitung (FRG) February 5, 1997
Greenpeace press release February 4, 1997
[424] Legislative Research Service Paper, Parliamentary Library, Canberra
[425] https://nuclear.foe.org.au/wp-content/uploads/NFCRC-submission-FoEA-ACF-CCSA-FINAL-AUGUST-2015.pdf

6. NUCLEAR ACCIDENTS AND IONISING RADIATION EXPOSURE RISKS

Please see the relevant sections in the joint submission to the SA Nuclear Fuel Cycle Royal Commission by Friends of the Earth Australia, the Australian Conservation Foundation, and Conservation SA:[426]

Section 1.8:

Public and worker health hazards
Radiation and health
Radon
Leukemia
Uranium, radiation and health
Olympic Dam whistleblower
Polonium exposure at Olympic Dam
Uranium companies promote radiation junk science
Case study: the Chernobyl death toll

Section 1.11: Past uranium industry practices, including the exposure of children to radiation at disused uranium mines and processing plants in Australia.
Section 3.9 Lessons from accidents such as Fukushima
Section 3.10 Regulation
Section 3.13:

Health and safety
History of accidents
Safety challenges
Safety of nuclear vs renewables
Probabilistic risk assessments
Attacks on nuclear plants
Childhood leukemias near nuclear power stations
Australia's track record
Counterfeit, fraudulent and suspect items

Since the joint submission to the Royal Commission was written, further evidence has emerged about the systemic corruption in South Korea's nuclear industry. This is important because South Korea would be one of the few potential suppliers of reactor technology to Australia (and it would be the preferred supplier in the view of the Australian Nuclear Association). For more information, see Appendix 1 in the joint NGO submission to the federal nuclear inquiry.[427]

The Committee will likely receive submissions stating or implying that there is a threshold below which exposure to ionising radiation is harmless. Such views are at odds with expert scientific opinion, including:

- The United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR) states in a 2010 report that "the current balance of available evidence tends to favour a non-threshold response for the mutational component of radiation-associated cancer induction at low doses and low dose rates."[428]
- The 2006 report of the US National Academy of Sciences' Committee on the Biological Effects of Ionising Radiation (BEIR) states that "the risk of cancer proceeds in a linear fashion at lower doses

[426] https://nuclear.foe.org.au/wp-content/uploads/NFCRC-submission-FoEA-ACF-CCSA-FINAL-AUGUST-2015.pdf
[427] https://www.aph.gov.au/DocumentStore.ashx?id=9eee9d5f-4362-4b30-b0b8-3b65ff98215f&subId=670271
[428] UNSCEAR, 2010, Report of the United Nations Scientific Committee on the Effects of Atomic Radiation on the Effects of Atomic Radiation 2010', www.unscear.org/docs/reports/2010/UNSCEAR_2010_Report_M.pdf

without a threshold and … the smallest dose has the potential to cause a small increase in risk to humans."[429]

- The US Nuclear Regulatory Commission (NRC) noted in a 2021 report that "[c]onvincing evidence has not yet demonstrated the existence of a threshold below which there would be no stochastic effects from exposure to low radiation doses."[430] The NRC report further notes that "authoritative scientific advisory bodies" such as the National Academy of Sciences, National Council on Radiation Protection and Measurements, International Commission on Radiological Protection and the International Atomic Energy Agency "support the continued use of the LNT [linear no-threshold] model." The NRC report further noted that three federal agencies – the National Cancer Institute, the National Institute for Occupational Safety and Health, and the EPA's Radiation Protection Division – supported the continued use of the LNT model as the basis for the NRC's radiation protection program.

Whether the relationship between radiation dose and health effects is linear at low doses is more contentious, but there is significant scientific support for a linear no-threshold (LNT) model, e.g. a report in the *Proceedings of the National Academy of Sciences* states: "Given that it is supported by experimentally grounded, quantifiable, biophysical arguments, a linear extrapolation of cancer risks from intermediate to very low doses currently appears to be the most appropriate methodology."[431]

While there is (and always will be) uncertainty with LNT at low doses and dose rates, it is important to note that the true risks may be *either higher or lower* than LNT − a point that needs emphasis and constant repetition because nuclear lobbyists routinely conflate uncertainty with zero risk. The BEIR report[432] states that "combined analyses are compatible with a range of possibilities, from a reduction of risk at low doses to risks twice those upon which current radiation protection recommendations are based." The BEIR report also states: "The committee recognizes that its risk estimates become more uncertain when applied to very low doses. Departures from a linear model at low doses, however, could either increase or decrease the risk per unit dose."

The US Nuclear Regulatory Commission (NRC) noted in a 2021 report:[433]
"Convincing evidence has not yet demonstrated the existence of a threshold below which there would be no stochastic effects from exposure to low radiation doses. As such, the NRC's view is that the LNT model continues to provide a sound basis for a conservative radiation protection regulatory framework that protects both the public and occupational workers."

The 2021 NRC report further notes that "authoritative scientific advisory bodies" such as the National Academy of Sciences, National Council on Radiation Protection and Measurements, International Commission on Radiological Protection and the International Atomic Energy Agency "support the continued use of the LNT model."

The 2021 NRC report further states that in addition to the findings of the national and international authoritative scientific advisory bodies, three Federal agencies supported the continued use of the LNT model as the basis for the NRC's radiation protection program:

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[429] US Committee on the Biological Effects of Ionising Radiation, US National Academy of Sciences, 2006, 'Health Risks from Exposure to Low Levels of Ionizing Radiation: BEIR VII Phase 2',
www.nap.edu/books/030909156X/html
[430] https://www.regulations.gov/document/NRC-2015-0057-0671
[431] David Brenner et al., 2003, 'Cancer risks attributable to low doses of ionizing radiation: Assessing what we really know', Proceedings of the National Academy of Sciences, November 25, 2003, vol.100, no.24, pp.13761–13766, www.ncbi.nlm.nih.gov/pubmed/14610281
[432] US Committee on the Biological Effects of Ionising Radiation, US National Academy of Sciences, 2006, 'Health Risks from Exposure to Low Levels of Ionizing Radiation: BEIR VII Phase 2',
www.nap.edu/books/030909156X/html
[433] https://www.regulations.gov/document/NRC-2015-0057-0671

1. National Cancer Institute (NCI), National Institutes of Health, Department of Health and Human Services;
2. National Institute for Occupational Safety and Health, Centers for Disease Control and Prevention, Department of Health and Human Services; and
3. Radiation Protection Division, Office of Air and Radiation, Environmental Protection Agency.

The 2021 NRC report further states that the NRC's Advisory Committee on the Medical Uses of Isotopes recommended that the NRC continue to rely upon the LNT model.

6.1 Death toll from the Chernobyl and Fukushima disasters

Claims that the Chernobyl death toll was <100 have no basis in scientific evidence. UN reports in 2005/06 estimated up to 4,000 eventual deaths among the higher-exposed Chernobyl populations (emergency workers from 1986−1987, evacuees and residents of the most contaminated areas) and an additional 5,000 deaths among populations exposed to lower doses in Belarus, the Russian Federation and Ukraine.[434] The estimated death toll rises further when populations beyond those three countries are included. For example, a study by Cardis et al. published in the *International Journal of Cancer* estimates 16,000 deaths.[435]

Likewise, claims that exposure to ionising radiation from the Fukushima disaster will not result in cancer deaths have no basis in scientific evidence. The World Health Organization states that for people in the most contaminated areas in Fukushima Prefecture, the estimated increased risk for all solid cancers will be around 4% in females exposed as infants; a 6% increased risk of breast cancer for females exposed as infants; a 7% increased risk of leukemia for males exposed as infants; and for thyroid cancer among females exposed as infants, an increased risk of up to 70% (from a 0.75% lifetime risk up to 1.25%).[436]

6.2 Inadequate regulation

The Fukushima disaster resulted from grossly inadequate safety and regulatory standards in Japan's nuclear industry. Standards improved somewhat in the aftermath of the disaster, but the collusive practices of Japan's 'nuclear village' are returning.[437] In other words, if lessons were learnt from the disaster, they are already being forgotten. This repeats the situation that followed the Chernobyl disaster − stronger safety and regulatory standards for a time, followed by complacency, cost-cutting, and governments ceding to industry calls to lower safety standards.

Inadequate regulation is evident in numerous countries with which Australia has uranium supply and nuclear cooperation agreements, e.g. China[438], India[439], Russia[440], the US[441], Japan[442], South Korea[443] and Ukraine.[444]

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[434] Chernobyl Forum, 2005, 'Chernobyl's Legacy: Health, Environmental and Socio-Economic Impacts', www.iaea.org/Publications/Booklets/Chernobyl/chernobyl.pdf
World Health Organization, 2006, www.who.int/mediacentre/news/releases/2006/pr20/en/index.html
www.who.int/ionizing_radiation/chernobyl/backgrounder/en/

[435] Cardis E, Krewski D, Boniol et al, 'Estimates of the Cancer Burden in Europe from Radioactive Fallout from the Chernobyl', International Journal of Cancer, Volume 119, Issue 6, pp.1224-1235, Published Online: 20 April 2006,
www.ncbi.nlm.nih.gov/pubmed/16628547
http://onlinelibrary.wiley.com/doi/10.1002/ijc.22037/pdf

[436] WHO, 28 Feb 2013, 'Global report on Fukushima nuclear accident details health risks', www.who.int/mediacentre/news/releases/2013/fukushima_report_20130228/en/

[437] Nuclear Monitor #800, 19 March 2015, 'Japan's 'nuclear village' reasserting control', www.wiseinternational.org/nuclear-monitor/800/japans-nuclear-village-reasserting-control

[438] Emma Graham-Harrison, 25 May 2015, 'China warned over 'insane' plans for new nuclear power plants', https://www.theguardian.com/world/2015/may/25/china-nuclear-power-plants-expansion-he-zuoxiu

7. PUBLIC OPINION

The introduction of nuclear power would require bipartisan support at the federal level – and bipartisan support in the relevant state/territory – over a period of five or more election cycles.

This essential pre-condition does not exist and there is no reasonable expectation that this political landscape will change. Along with the long-standing federal legal prohibitions a number of states also have legislation or explicit policies banning nuclear power.

The last time one of the major parties promoted nuclear power was in the mid-2000s when Prime Minister John Howard and some other members of the Coalition government promoted nuclear power. During the 2007 election campaign, at least 22 Coalition candidates publicly distanced themselves from the government's pro-nuclear power policy. The policy was seen to be a liability and it was abandoned by the Coalition immediately after its election defeat in 2007.

The current promotion of nuclear power by a small number of Coalition MPs has once again generated division within the Coalition:

- The Queensland state Liberal National Party made a submission[445] to the 2019 federal nuclear inquiry arguing for the retention of federal legislation banning nuclear power and that "Australia's rich renewable energy sources are more affordable and bring less risk than the elevated cost and risk associated with nuclear energy". The submission further states: "We would encourage the Committee to ensure an increased emphasis is placed on measures designed to encourage investment in renewable energy that creates green jobs and lowers electricity bills, both for consumers and industry, which does not include nuclear energy."
- Likewise, the South Australian Liberal government's submission to the 2019 federal nuclear inquiry said that "nuclear power remains unviable now and into the foreseeable future".[446]
- The Tasmanian Liberal government's submission to the 2019 federal nuclear inquiry said that "Tasmania will not pursue nuclear energy … and considers that Australia's energy needs are best met by pursuing renewable energy options, such as pumped hydro, with additional firming capacity supported through greater grid interconnection."[447]
- The NSW government also remains sceptical about nuclear power. Treasurer Matt Kean said that nuclear power was like "chasing a unicorn" and "doesn't stack up at the moment on practical grounds or on economic grounds".[448] Kean said that nuclear is several times more expensive than renewables backed up with energy storage — a claim supported by CSIRO/AEMO research.[449]

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[439] A. Gopalakrishnan, 13 Nov 2017, 'India Should Halt Further Expansion of its Nuclear Power Program', The Citizen, https://www.thecitizen.in/index.php/en/NewsDetail/index/2/12239/India-Should-Halt-Further-Expansion-of-its-Nuclear-Power-Program

[440] Vladimir Slivyak, 2014, 'Russian Nuclear Industry Overview', https://ecdru.files.wordpress.com/2017/04/russian-nuc-ind-overviewrgb.pdf

[441] Edwin Lyman, 29 Aug 2019, 'Aging nuclear plants, industry cost-cutting, and reduced safety oversight: a dangerous mix', https://thebulletin.org/2019/08/aging-nuclear-plants-industry-cost-cutting-and-reduced-safety-oversight-a-dangerous-mix/
Gregory Jaczko, 17 May 2019, 'I Oversaw the US Nuclear Power Industry. Now I Think It Should Be Banned', https://www.commondreams.org/views/2019/05/17/i-oversaw-us-nuclear-power-industry-now-i-think-it-should-be-banned

[442] Nuclear Monitor #800, 19 March 2015, 'Japan's 'nuclear village' reasserting control', www.wiseinternational.org/nuclear-monitor/800/japans-nuclear-village-reasserting-control

[443] Nuclear Monitor #844, 25 May 2017, 'South Korea's 'nuclear mafia'', www.wiseinternational.org/nuclear-monitor/844/south-koreas-nuclear-mafia

[444] L. Todd Wood, 30 March 2017, 'Ukrainian corruption casts nuclear pall over Europe', http://www.washingtontimes.com/news/2017/mar/30/ukrainian-corruption-casts-nuclear-pall-over-all-e/
Nuclear Monitor #832, 19 Oct 2016, 'Ukraine's nuclear power program going from bad to worse', https://www.wiseinternational.org/nuclear-monitor/832/ukraines-nuclear-power-program-going-bad-worse

[445] https://www.aph.gov.au/DocumentStore.ashx?id=5c2cf4df-5ef7-420c-86f3-eee32033fa3f&subId=669992

[446] https://www.aph.gov.au/DocumentStore.ashx?id=1519c7ea-3f47-47a0-a65d-97d691827bf0&subId=671226

[447] https://www.aph.gov.au/DocumentStore.ashx?id=69cdc369-9b09-477f-ba35-2b9ec182774a&subId=670563

[448] https://iview.abc.net.au/video/NC2109V038S00

[449] https://doi.org/10.25919/5eb5ac371d372

Public support for nuclear power in Australia has varied significantly over the past decade according to opinion polls. Part of the variation could be explained by polling questions, sample sizes etc. Some poll results are as follows:

- 2019: 44% support for nuclear power, 40% opposition.[450] (51% believe nuclear power would help lower power prices, 26% disagree.)
- 2019: 45% support, 40% opposition[451] (rising to 51% support if the question was preceded by this rather loaded statement: 'If the worries about carbon dioxide are a real problem, many suggest that the cleanest energy source Australia can use is nuclear power.')
- 2015: 26.6% support for nuclear power in South Australia (level of opposition not surveyed).[452]
- 2013: 30% support for nuclear power, 53% opposition.[453]
- 2011 (after the Fukushima disaster): 34% support for nuclear power, 61% opposition (Roy Morgan poll).

As noted above, support rose 6% in a 2019 poll when the question was preceded by the dubious assertion that 'many suggest that the cleanest energy source Australia can use is nuclear power'. Unsurprisingly, opposition rises when questions about nuclear power mention radioactive waste or the risk of serious accidents. A 2012 poll found that 63% of respondents agreed that nuclear power isn't worth it because of the need to manage radioactive waste, and 62% agreed that nuclear power is too risky because of the potential for serious accidents.[454]

Opposition to a locally-built nuclear power plant is clear:

- 2019: 28% "would be comfortable living close to a nuclear power plant", 60% would not.
- 2019: 19% would agree to a nuclear power plant being built in their area, 58% would be opposed and a further 23% would be "anxious" (so 81% would be opposed or anxious).[455]
- 2011: 12% of Australians would support a nuclear plant being built in their local area, 73% would oppose it. (Morgan poll)
- 2006: 10% Australians would strongly support a nuclear plant being built in their local area, 55% would strongly oppose it. (Newspoll)

Opinion polls clearly show that renewables are far more popular than nuclear power:

- A 2019 survey of 1,960 Australians aged 18 years and older found that only 22% included nuclear power in their top three preferences, behind solar 76%, wind 58%, hydro 39% and power storage 29%.[456] Further, 59% of respondents put nuclear power in their bottom three preferences.[457]
- 2015: An IPSOS poll found support among Australians for solar power (78–87%) and wind power (72%) is far higher than support for coal (23%) and nuclear (26%).[458]
- 2015: When given the option of eight energy sources, 84% included solar in their top three, 69% included wind, 21% included gas and only 13% included nuclear.[459]

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[450] https://www.theguardian.com/australia-news/2019/jun/18/australians-support-for-nuclear-plants-rising-but-most-dont-want-to-live-near-one
[451] http://www.roymorgan.com/findings/8144-nuclear-power-in-australia-september-2019-201910070349
[452] Paul Starick, 13 March 2015, 'Voters reject Premier Jay Weatherill's agenda to transform the state', www.adelaidenow.com.au/news/south-australia/voters-reject-premier-jay-weatherills-agenda-to-transform-the-state/story-fni6uo1m-1227262025901
[453] John McAneney et al., 14 Oct 2013, 'Why don't Australians see nuclear as a climate change solution?', http://theconversation.com/why-dont-australians-see-nuclear-as-a-climate-change-solution-19099
[454] NSW Parliamentary Research Service, Sept 2019, 'Uranium Mining and Nuclear Energy in New South Wales', https://www.parliament.nsw.gov.au/researchpapers/Pages/Uranium-Mining-and-Nuclear-Energy-in-New-South-Wales.aspx
[455] http://www.roymorgan.com/findings/8144-nuclear-power-in-australia-september-2019-201910070349
[456] Australia Institute, Sept 2019, 'Climate of the Nation 2019 Tracking Australia's attitudes towards climate change and energy', https://www.tai.org.au/sites/default/files/Climate%20of%20the%20Nation%202019%20%5BWEB%5D.pdf
[457] Katharine Murphy, 10 Sept 2019, 'Australians increasingly fear climate change-related drought and extinctions' https://www.theguardian.com/environment/2019/sep/10/australians-increasingly-fear-climate-change-related-drought-and-extinctions
[458] http://www.ipsos.com.au/Ipsos_docs/Solar-Report_2015/Ipsos-ARENA_SolarReport.pdf
[459] http://www.solarquotes.com.au/blog/climate-institute-poll-finds-australians-support-renewables/

- 2013: Expanding the use of renewable energy sources (71%) was the most popular option to tackle climate change, followed by energy-efficient technologies (58%) and behavioural change (54%), with nuclear power (17.4%) a distant fourth.[460]

Regarding community engagement, nuclear lobbyists would need to convince Australians to accept the "non-negligible" risk of a catastrophic accident, to use the words of Dr. Ziggy Switkowski at the 29 August 2019 hearing of the federal nuclear inquiry.[461] Australians would need to be persuaded that a solution exists for nuclear waste management even though no country in the world has an operating repository for high-level nuclear waste, and the deep underground repository for intermediate-level waste in the US (the Waste Isolation Pilot Plant) was shut for three years after safety and regulatory lapses resulted in a chemical explosion in an underground waste barrel.

Australians would also need to be persuaded that nuclear power makes economic sense in this country even though it clearly does not. Peter Farley, a fellow of the Australian Institution of Engineers, offered this comparison in January 2019:[462]

> *"As for nuclear the 2,200 MW Plant Vogtle is costing US$25 billion plus financing costs, insurance and long term waste storage. ... For the full cost of US$30 billion, we could build 7,000 MW of wind, 7,000 MW of tracking solar, 10,000 MW of rooftop solar, 5,000MW of pumped hydro and 5,000 MW of batteries. ... That is why nuclear is irrelevant in Australia. It has nothing to do with greenies, it's just about cost and reliability."*

[460] John McAneney et al., 14 Oct 2013, 'Why don't Australians see nuclear as a climate change solution?', http://theconversation.com/why-dont-australians-see-nuclear-as-a-climate-change-solution-19099
[461] www.aph.gov.au/Parliamentary_Business/Committees/House/Environment_and_Energy/Nuclearenergy/Public_Hearings
[462] https://reneweconomy.com.au/how-did-wind-and-solar-perform-in-the-recent-heat-wave-40479/

8. SECURITY IMPLICATIONS

Security risks associated with civil nuclear programs include:
- military strikes by nation-states on nuclear sites (primarily to prevent their use in weapons programs)
- attacks on or theft from nuclear facilities (or transport vehicles) by individuals or sub-national groups
- nuclear theft and smuggling
- sabotage / insider threats (e.g. the sabotage incident at Sellafield in 2000[463]).

8.1 Military strikes on nuclear plants in Ukraine and elsewhere

The November 2022 edition of the World Nuclear Industry Status Report states:[464]

> *"Russia's invasion of Ukraine has led to several unprecedented events including the operation of commercial nuclear power plants during a full-scale war, shelling of commercial reactor sites, the occupation by enemy forces of nuclear facilities, and the operation of reactors under physical threat. No nuclear power plant in the world has been designed to operate under those conditions."*
>
> *"A nuclear power plant depends on continuously functioning cooling systems to evacuate decay heat from reactor cores and spent fuel pools, even when the reactor is shut down. … Failure to evacuate residual decay heat will lead to core meltdown or spent fuel fire with potentially large releases of radioactivity. Effective cooling chains – usually three cooling circuits linked together via heat exchangers and a final heat sink like a river, a lake, or the ocean – must be available at all times to evacuate residual heat from the reactor core and from the spent fuel pool."*

Loss of off-site power, and thus reliance on diesel generators, significantly increases the risk of a nuclear disaster. All four of Ukraine's nuclear power plants (comprising a total of 15 reactors) have had to deal with the complete loss of off-site power at various stages in 2022, in some cases repeatedly.[465] Risks remain high.

Historical examples of (conventional) military strikes on nuclear plants include the following:
- Israel's destruction of a research reactor in Iraq in 1981.
- the United States' destruction of two smaller research reactors in Iraq in 1991.
- attempted military strikes by Iraq and Iran on each other's nuclear facilities during the 1980-88 war.
- Iraq's attempted missile strikes on Israel's nuclear facilities in 1991.
- Israel's bombing of a suspected nuclear plant in Syria in 2007.

Most of the above examples have been motivated by attempts to prevent weapons proliferation. Nuclear plants might also be targeted with the aim of widely dispersing radioactive material or, in the case of power reactors, disrupting electricity supply.

If and when nuclear-powered nations go to war, they will have to choose between i) shutting down their power reactors or ii) taking the risk of attacks potentially leading to widespread, large-scale dispersal of radioactive materials. Shutting down reactors would reduce risks, but vulnerabilities would

[463] 27 March 2000, 'Sabotage inquiry at Sellafield under way', www.irishtimes.com/news/sabotage-inquiry-at-sellafield-under-way-1.260139
[464] https://www.worldnuclearreport.org/The-World-Nuclear-Industry-Status-Report-2022-HTML.html#_idTextAnchor155
[465] https://www.newscientist.com/article/2348196-ukraines-nuclear-plants-face-uncertain-future-after-russian-attacks/

remain including reactor cores, waste stores and reprocessing plants (in those countries with reprocessing programs). Both scenarios have played out in Ukraine: continued operation of nuclear reactors despite direct (and adjacent) military fighting, and the closure of reactors (which could prove particularly difficult against the backdrop of a Ukrainian winter).

Nuclear physicist Richard Garwin poses these questions:[466]

> *"What happens with a failed state with a nuclear power system? Can the reactors be maintained safely? Will the world (under the IAEA and U.N. Security Council) move to guard nuclear installations against theft of weapon-usable material or sabotage, in the midst of chaos? Not likely."*

National and international safety, security and proliferation safeguards inspections have been severely compromised in Ukraine since Russia's invasion in early 2022.

8.2 Nuclear theft and smuggling

The IAEA summarises problems associated with nuclear theft, smuggling and other such illicit activities:[467]

> *"From January 1993 to December 2013, a total of 2477 incidents were reported to the ITDB by participating States and some non-participating States. Of the 2477 confirmed incidents, 424 involved unauthorized possession and related criminal activities. Incidents included in this category involved illegal possession, movement or attempts to illegally trade in or use nuclear material or radioactive sources. Sixteen incidents in this category involved high enriched uranium (HEU) or plutonium. There were 664 incidents reported that involved the theft or loss of nuclear or other radioactive material and a total of 1337 cases involving other unauthorized activities, including the unauthorized disposal of radioactive materials or discovery of uncontrolled sources."*

8.3 Insider threats

Matthew Bunn and Scott Sagan discuss the problem of insider threats in a paper − 'A Worst Practices Guide to Insider Threats: Lessons from Past Mistakes' − which forms part of a larger project on insider threats under the Global Nuclear Future project of the American Academy of Arts and Sciences.[468] One example they cite was the apparent insider sabotage of a diesel generator at the San Onofre nuclear plant in the United States in 2012. Another example was a 1982 incident in which an insider placed explosives directly on the steel pressure vessel head of a nuclear reactor in South Africa and detonated them − thankfully the plant had not yet begun operating. All known thefts of plutonium or highly enriched uranium appear to have been perpetrated by insiders or with the help of insiders. Similarly, most of the sabotage incidents that have occurred at nuclear facilities were perpetrated by insiders.

Bunn and Sagan look at past incidents caused by insiders and draw from them 10 lessons about what not to do:
#1 Don't assume that serious insider problems are NIMO (Not In My Organization)
#2 Don't assume that background checks will solve the insider problem
#3 Don't assume that red flags will be read properly

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[466] Richard L. Garwin, 2001, 'Can the World Do Without Nuclear Power?', www.solarpeace.ch/solarpeace/Download/20010409_Garwin_NuclearPowerArticle.pdf
[467] www-ns.iaea.org/security/itdb.asp
[468] Matthew Bunn and Scott Sagan, April 2014, 'A Worst Practices Guide to Insider Threats: Lessons from Past Mistakes', Occasional Paper, American Academy of Arts & Sciences, https://www.amacad.org/publication/worst-practices-guide-insider-threats-lessons-past-mistakes

#4 Don't assume that insider conspiracies are impossible
#5 Don't rely on single protection measures
#6 Don't assume that organizational culture and employee disgruntlement don't matter
#7 Don't forget that insiders may know about security measures and how to work around them
#8 Don't assume that security rules are followed
#9 Don't assume that only consciously malicious insider actions matter
#10 Don't focus only on prevention and miss opportunities for mitigation

8.4 Nuclear weapons proliferation

The weapons proliferation risks associated with civil nuclear programs are well understood and there is a long history of nation-states using civil nuclear programs as cover for weapons programs – five of the ten countries that have produced nuclear weapons did so under cover of a civil program, and power reactors have been used to produce plutonium for weapons in most or all of the other five nation-states (the 'declared' nuclear weapons states).[469]

The (civil) nuclear industry and its lobbyists have a long history of denying the connections between civil programs (including nuclear power programs) and weapons proliferation. However there has been a dramatic shift in recent years with a growing number of industry bodies and lobbyists acknowledging and even celebrating nuclear power–weapons connections.[470] They argue that weapons programs will be adversely affected unless further subsidies are made available to troubled nuclear power programs that make important contributions to weapons programs (personnel, materials, etc.).

To give one example of this dramatic transformation, Michael Shellenberger from 'Environmental Progress', a pro-nuclear lobby group in the US, used to deny nuclear power–weapons connections, even claiming that "nuclear energy prevents the spread of nuclear weapons".[471] However in 2018 Shellenberger stated that "national security, having a weapons option, is often the most important factor in a state pursuing peaceful nuclear energy".

An analysis by Environmental Progress found that of the 26 nations that are building or are committed to build nuclear power plants, 23 have nuclear weapons, had weapons, or have shown interest in acquiring weapons.[472] "While those 23 nations clearly have motives other than national security for pursuing nuclear energy," Shellenberger wrote, "gaining weapons latency appears to be the difference-maker."[473]

Shellenberger also pointed to research[474] which found that 31 nations had the capacity to enrich uranium or reprocess plutonium, and that 71% of them created that capacity to give themselves weapons latency.

[469] Nuclear Monitor #804, 28 May 2015, 'The myth of the peaceful atom', https://www.wiseinternational.org/nuclear-monitor/804/myth-peaceful-atom
[470] Andy Stirling and Phil Johnstone, 23 Oct 2018, ', A global picture of industrial interdependencies between civil and military nuclear infrastructures', Nuclear Monitor #868, https://www.wiseinternational.org/nuclear-monitor/868/global-picture-industrial-interdependencies-between-civil-and-military-nuclear
[471] Nuclear Monitor #865, 6 Sept 2018, 'Nuclear lobbyist Michael Shellenberger learns to love the bomb, goes down a rabbit hole', https://www.wiseinternational.org/nuclear-monitor/865/nuclear-lobbyist-michael-shellenberger-learns-love-bomb-goes-down-rabbit-hole
[472] Environmental Progress, 2018, Nations Building Nuclear – Proliferation Analysis, https://docs.google.com/spreadsheets/d/1YA4gLOekXNXiwpggCEx3uUpeu_STBlN_gHD60B5QG1E/edit#gid=0
[473] Michael Shellenberger, 29 Aug 2018, 'For Nations Seeking Nuclear Energy, The Option To Build A Weapon Remains A Feature Not A Bug', https://www.forbes.com/sites/michaelshellenberger/2018/08/29/for-nations-seeking-nuclear-energy-the-option-to-build-a-weapon-remains-a-feature-not-a-bug/
[474] Matthew Fuhrmann and Benjamin Tkach, 8 Jan 2015, 'Almost nuclear: Introducing the Nuclear Latency dataset', Conflict Management and Peace Science,
https://doi.org/10.1177/0738894214559672
http://journals.sagepub.com/doi/abs/10.1177/0738894214559672

Shellenberger noted that "at least 20 nations sought nuclear power at least in part to give themselves the option of creating a nuclear weapon" – Argentina, Australia, Brazil, Egypt, France, Italy, India, Iran, Iraq, Israel, Japan, Libya, Norway, Romania, South Africa, Sweden, Switzerland, Taiwan, West Germany, Yugoslavia.[475]

Proliferation concerns would be lessened if the international safeguards system was rigorous and properly funded. Sadly, it is neither as was discussed in section 11.1 of this submission.

8.5 Nuclear transport security issues

Hirsch et al. summarise some of the security risks associated with the transport of nuclear materials:[476]

> *"During transport, radioactive substances are a potential target for terrorists. Of the numerous materials being shipped, the following are the most important:*
> *1. Spent fuel elements from nuclear power plants and highly active wastes from reprocessing (high specific inventory of radioactive substances)*
> *2. Plutonium from reprocessing (high radiotoxicity, particularly if released as aerosol)*
> *3. Uranium hexafluoride – uranium has to be converted into this chemical form in order to undergo enrichment (high chemical toxicity of released substances, resulting in immediate health effects in case of release).*
>
> *"Since the amounts transported with one shipment are about several tonnes at most, the releases to be expected will be smaller by orders of magnitudes than those that result from attack of a storage facility – even if the transport containers are severely damaged. On the other hand, the place where the release occurs cannot be foreseen, as attacks can occur, in principle, everywhere along the transport routes. Those routes often go through urban areas; for example at ports or during rail transport. Thus, releases can take place in densely populated regions, leading to severe damage to many people, even if the area affected is comparatively small."*

Nuclear transport security issues are discussed in greater detail in section 4.10 (pp.243–250) of the joint submission to the SA Nuclear Fuel Cycle Royal Commission by Friends of the Earth Australia, the Australian Conservation Foundation, and Conservation SA.[477]

8.6 Australian nuclear security issues

Security incidents at ANSTO's Lucas Heights site in southern Sydney include the following[478]:

- 1983: nine sticks of gelignite, 25 kg of ammonium nitrate (usable in explosives), three detonators and an igniter were found in an electrical substation inside the boundary fence. A detonator was set off but did not detonate the main explosives. Two people were charged.
- 1984: a threat was made to fly an aircraft packed with explosives into the HIFAR reactor − one person was found guilty of public mischief.

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[475] Michael Shellenberger, 29 Aug 2018, 'For Nations Seeking Nuclear Energy, The Option To Build A Weapon Remains A Feature Not A Bug', https://www.forbes.com/sites/michaelshellenberger/2018/08/29/for-nations-seeking-nuclear-energy-the-option-to-build-a-weapon-remains-a-feature-not-a-bug/

[476] Helmut Hirsch, Oda Becker, Mycle Schneider and Antony Froggatt, April 2005, 'Nuclear Reactor Hazards: Ongoing Dangers of Operating Nuclear Technology in the 21st Century', report prepared for Greenpeace International, https://www.researchgate.net/publication/262630918

[477] https://nuclear.foe.org.au/wp-content/uploads/NFCRC-submission-FoEA-ACF-CCSA-FINAL-AUGUST-2015.pdf

[478] Tilman Ruff, 2006, 'Nuclear Terrorism', EnergyScience Coalition Briefing Paper #10, www.energyscience.org.au/FS10%20Nuclear%20Terrorism.pdf

- 1985: after vandalism of a pipe, radioactive liquid drained into Woronora river, and this incident was not reported for 10 days. In 1986 an act of vandalism resulted in damage to the sampling pit on the effluent pipeline.
- 2000: in the lead-up to the Sydney Olympics, New Zealand detectives foiled a plot to attack the Lucas Heights reactor by Afghan sympathisers of Osama bin Laden.
- 9 October 2001: NSW and Federal police conducted a search following a bomb threat directed at ANSTO.
- December 2001: Greenpeace activists easily breach security at the front gate and the back fence of Lucas Heights, some activists scale the reactor while another breaches the 'secure air space' in a paraglider.
- October 2003: French terror suspect Willy Brigitte deported from Australia and held on suspicion of terrorism in France. He was alleged to have been planning to attack the reactor and to have passed on bomb-making skills to two Australians.
- November 2005: multiple coordinated arrests of terrorist suspects in Sydney and Melbourne. Court documents reveal the Lucas Heights reactor was a potential target. Three of the eight alleged members of the Sydney terror cell had previously been caught near the reactor facility by police in December 2004, each alleged to have given different versions of what they had been doing.
- November 2005: a reporter and photographer were able to park a one-tonne van for more than half an hour outside the Lucas Heights back gate, protected by a simple padlock able to be cut with bolt-cutters, 800 m from the reactor. *The Australian* reported: "The back door to one of the nation's prime terrorist targets is protected by a cheap padlock and a stern warning against trespassing or blocking the driveway."[479]
- A man facing terrorism charges in 2007 had purchased five rocket launchers allegedly stolen from the army. According to a witness statement, the accused purchaser said, "I am going to blow up the nuclear place", an apparent reference to Lucas Heights.[480]

Nuclear engineers Alan Parkinson and John Large have warned that Australia's proposed national radioactive waste facility would be attractive to terrorists wanting to make a 'dirty bomb', a radioactive weapon delivered by conventional means. The same risk applies to any comparable store of nuclear materials. When the Howard government was planning a repository in SA, the government envisaged that there would be no on-site security presence whatsoever. When later governments planned a repository and waste store in the NT, it was envisaged that would be a small on-site security presence (two guards at any one time). The more dangerous waste forms (long-lived intermediate-level waste, stored above ground) would be more easily accessible than less dangerous forms (low-level waste buried in a repository).

Problems with Australia's approach to nuclear security issues are discussed in the following article: 'Nuclear security and Australia's uranium exports', 8 April 2014, Online Opinion, http://onlineopinion.com.au/view.asp?article=16197

[479] Jonathan Porter, 19 Nov 2005, 'Nuclear site left exposed at the back door', *The Australian*.
[480] Sally Neighbour, 2 July 2007, 'Nations linked by blood and Islam', *The Australian*.
Charles Ferguson, 9 Jan 2007, 'Nuclear risk could be an inside job', www.smh.com.au/news/opinion/nuclear-risk-could-be-an-inside-job/2007/01/08/1168104921045.html