NUCLEAR POWER'S ECONOMIC CRISIS AND ITS IMPLICATIONS FOR AUSTRALIA

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1. INTRODUCTION & SUMMARY

Despite the abundance of evidence that nuclear power is economically uncompetitive compared to renewables, the nuclear industry and some of its supporters continue to claim otherwise.[1] Such claims are typically based on implausible cost projections for non-existent reactor concepts. For example the Minerals Council of Australia conflates self-serving, implausible company estimates for small modular reactors (SMRs) with "robust estimates" based on "conservative assumptions".[2] And the Australian Nuclear Association bases its claim that nuclear power is Australia's "least cost low carbon energy option" on the non-existent BWRX-300 SMR.[3]

Claims about 'cheap' nuclear power certainly don't consider real-world nuclear construction projects. Those following real-world developments have come to the opposite conclusion. Indeed supporters of nuclear power have issued any number of warnings[4] in recent years about nuclear power's "rapidly accelerating crisis"[5] and a "crisis that threatens the death of nuclear energy in the West"[6] while pondering what if anything might be salvaged from the "ashes of today's dying industry".[7]

Consider the following statements, many of them from industry insiders:

- "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.*[8]
- Nuclear power "just isn't economic, and it's not economic within a foreseeable time frame." – *John Rowe, recently-retired CEO of Exelon, 2012.*[9]
- "It's just hard to justify nuclear, really hard." – *Jeffrey Immelt, General Electric's CEO, 2012.*[10]
- "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.*[11]
- France's nuclear industry is in its "worst situation ever"[12], a former EDF director said in November 2016 – and the situation has worsened since then.[13]
- 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.*[14]
- "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

[1] https://reneweconomy.com.au/nuclear-power-exits-australias-energy-debate-enters-culture-wars-47702/
[2] https://reneweconomy.com.au/small-nuclear-reactors-huge-costs/
[3] https://nuclearforclimate.com.au/2021/07/20/nuclear-energy-australias-least-cost-low-carbon-energy-solution/
[4] https://www.wiseinternational.org/nuclear-monitor/839/nuclear-power-crisis-or-it-merely-end
[5] http://www.environmentalprogress.org/big-news/2017/2/13/why-its-big-bet-on-westinghouse-nuclear-bankrupted-toshiba
[6] http://www.environmentalprogress.org/big-news/2017/2/16/nuclear-must-change-or-die
[7] https://thebreakthrough.org/index.php/voices/ted-nordhaus/the-end-of-the-nuclear-industry-as-we-know-it
[8] 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
[9] https://www.forbes.com/sites/jeffmcmahon/2012/03/29/exelons-nuclear-guy-no-new-nukes/
[10] https://www.ft.com/content/60189878-d982-11e1-8529-00144feab49a
[11] https://reneweconomy.com.au/us-energy-giant-says-renewables-and-batteries-beat-coal-gas-and-nukes-78962/
[12] http://www.theguardian.com/environment/2016/nov/29/french-nuclear-power-worst-situation-ever-former-edf-director
[13] https://climatenewsnetwork.net/frances-nuclear-industry-struggles-on/
[14] http://www.asahi.com/ajw/articles/AJ201807240045.html

complex projects with long lead times and risk of major cost overruns." – *S&P Global Ratings, 2019.*[15]

- 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.*[16]
- "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'.*[17]
- "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.*[18]
- "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.*[19]
- "Nuclear construction on-time and on-budget? It's essentially never happened." – *Andrew J. Wittmann, financial analyst with Robert W. Baird & Co., 2017.*[20]
- "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.*[21]

Several reasons can be posited for the crisis which led Bob Carr – a former nuclear supporter, NSW Premier and Australian Foreign Minister – to describe nuclear power as lumbering, cripplingly expensive and moribund:[22]

- The Fukushima disaster in Japan in 2011.
- A suite of economic challenges: catastrophic cost overruns with reactor projects; nuclear power's negative learning curve (it has become more expensive over time); and nuclear power's inability to compete economically with renewables.
- Nuclear corruption scandals in many – perhaps most – of the countries operating nuclear power plants.[23]

Other reasons could be added to that list, such as the failure to find solutions to manage long-lived nuclear waste, and the explosion in the world's only deep underground nuclear waste repository in 2014.[24]

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[15] https://www.euractiv.com/wp-content/uploads/sites/2/2019/11/Energy-Transition_Nuclear-Dead-And-Alive_11-Nov.-2019.pdf

[16] www.telegraph.co.uk/business/2017/04/01/can-britains-nuclear-ambitions-avoid-meltdown/

[17] https://www.ft.com/content/db592ce6-7b4e-11e7-9108-edda0bcbc928

[18] http://www.forbes.com/sites/jeffmcmahon/2014/12/09/another-giant-declares-nuclear-dead-in-fracking-america/

[19] https://www.forbes.com/sites/jeffmcmahon/2013/11/10/new-build-nuclear-is-dead-morningstar/

[20] https://www.bloomberg.com/news/articles/2017-02-13/toshiba-s-nuclear-reactor-mess-winds-back-to-a-louisiana-swamp

[21] https://www.popularmechanics.com/science/energy/a18818/can-us-nuclear-power-get-un-stuck/

[22] https://www.theaustralian.com.au/commentary/nobodys-really-interested-in-the-nuclear-option/news-story/b401d6f4a8bdd7126b5e82db54cdf088

[23] https://www.worldnuclearreport.org/The-World-Nuclear-Industry-Status-Report-2021-HTML.html#_idTextAnchor112
https://wiseinternational.org/nuclear-monitor/887/nuclear-monitor-887-17-june-2020
https://www.nirs.org/nuclear-power-runs-on-dirty-money-the-corporate-scandal-of-the-proposed-national-nuclear-subsidy/

[24] Section 5, https://nuclear.foe.org.au/wp-content/uploads/2019-Federal-Nuclear-Inquiry-Joint-ENGO-Submission-Final.pdf

This paper focuses on nuclear power's economic problems – catastrophic cost overruns with reactor projects, and nuclear power's large and worsening economic disadvantage relative to renewables.

Summary

Every power reactor construction project in Western Europe and the US over the past decade has been a disaster:

- The only reactor construction project in France is 10 years behind schedule and the current cost estimate of A$30.6 billion is 5.8 times greater than the original estimate.
- The reactor under construction in Finland is 13 years behind schedule and the current cost estimate is 3.7 times greater than the original estimate.
- The Hinkley Point nuclear plant in the UK was meant to cost £2 billion per reactor and be complete by 2017; but construction hadn't even begun in 2017 and costs have increased more than five-fold.
- The V.C. Summer project in South Carolina was abandoned after the expenditure of around US$9 billion.
- The Vogtle project in Georgia is six years behind schedule and costs have doubled.

Western Europe and the US provide the most striking examples of nuclear power's crisis and the most striking examples of a more generalised problem: alone among energy sources, nuclear power has become more expensive over time, or in other words it has a negative learning curve.[25]

Section 5 discusses nuclear power globally and in important countries other than those in Western Europe and North America. Suffice it to note here that nuclear power is struggling almost everywhere. China is said to be the industry's shining light but nuclear growth is modest (an average of 2.1 reactor construction starts per year over the past decade) and paltry compared to renewables (2 gigawatts (GW) of nuclear power capacity added in 2020 compared to 135 GW of renewables).

Outside of China, the writing is on the wall: 48 power reactor start-ups and 98 permanent shut-downs from 2001–2020[26] as well as a looming wave of shut-downs because of the ageing of the world's reactor fleet and, in some countries, nuclear phase-out policies. Globally, renewable power capacity grew by a record 256 GW in 2020 (four times greater than Australia's total capacity) compared to 0.4 GW for nuclear power.

Small reactors have a history of failure. Recent and current SMR construction projects are few and far between and exhibit familiar patterns of lengthy delays and large cost overruns:

- The SMR under construction in Argentina is seven years behind schedule; the cost exceeds A$1 billion for a plant with the capacity of two large wind turbines; and the current cost estimate is 23 times higher than preliminary estimates.
- Russia's floating nuclear plant – said to be the only operating SMR in the world – was nine years behind schedule, more than six times over budget, and the electricity it produces is estimated to cost an exorbitant A$284 / megawatt-hour (MWh).
- The high-temperature gas-cooled SMR in China is eight years behind schedule, plans for

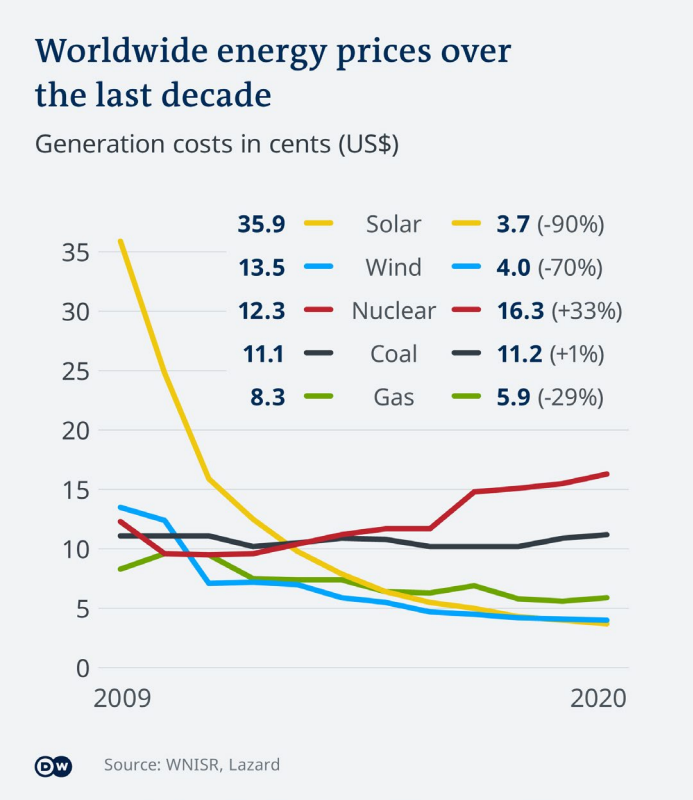
[25] https://www.sciencedirect.com/science/article/abs/pii/S0301421510003526
http://energypost.eu/exclusive-eu-paints-challenging-picture-europes-nuclear-future/
https://archive.thinkprogress.org/the-nuclear-industry-prices-itself-out-of-market-for-new-power-plants-1421750327c3/
[26] https://www.worldnuclearreport.org/The-World-Nuclear-Industry-Status-Report-2021-HTML.html

additional reactors at the same site have been dropped, the cost is 2–3 times higher than initial estimates, and hopes that the reactor could produce cheaper electricity than large nuclear reactors have been dashed.

- China recently began construction of an SMR based on conventional light-water reactor technology. According to China National Nuclear Corporation, construction costs per kilowatt (kW) will be twice the cost of large reactors, and the levelised cost of electricity will be 50% higher than large reactors.
- Russia recently began construction of an SMR based on fast reactor technology. Construction was expected to be complete in 2020, but didn't even begin until 2021. The construction cost estimate has increased by a factor of 2.4.

Sections of the nuclear industry – and some outside the industry – claim that SMRs have a bright future. Those claims have no factual or logical basis. Everything that is promising about SMRs belongs in the never-never; everything in the real-world is expensive and over-budget, slow and behind schedule. Moreover, there are disturbing, multifaceted connections between SMR projects and nuclear weapons proliferation[27], and between SMRs and fossil fuel mining.[28]

Nuclear power – large or small – has become far more expensive than renewables and the gap widens every year.



Source: World Nuclear Industry Status Report, 2021.

Research by the CSIRO and the Australian Energy Market Operator demonstrates that nuclear power is far more expensive than renewables plus backup power in the Australian context. Research by the same organisations demonstrates that nuclear power is far more expensive than renewables plus integration costs (transmission, storage and synchronous condensers).

[27] https://wiseinternational.org/nuclear-monitor/872-873/small-modular-reactors-and-nuclear-weapons-proliferation
[28] https://reneweconomy.com.au/the-advanced-nuclear-power-sector-is-fuelling-climate-change-and-wmds-40205/

Support for nuclear power in Australia has no logical or rational basis. The persistence of that support can be attributed to several factors:

- Ignorance.[29]
- Commercial interests (direct nuclear interests as well as indirect interests – Australian economist Prof. John Quiggin notes that "in practice, support for nuclear power in Australia is support for coal[30]).
- Ideological 'culture wars'.[31] Former prime minister Malcolm Turnbull describes nuclear power as the "loopy current fad … which is the current weapon of mass distraction for the backbench."[32]

All three reasons may partially explain the Minerals Council of Australia's ongoing disinformation campaign regarding nuclear power, discussed in section 4.

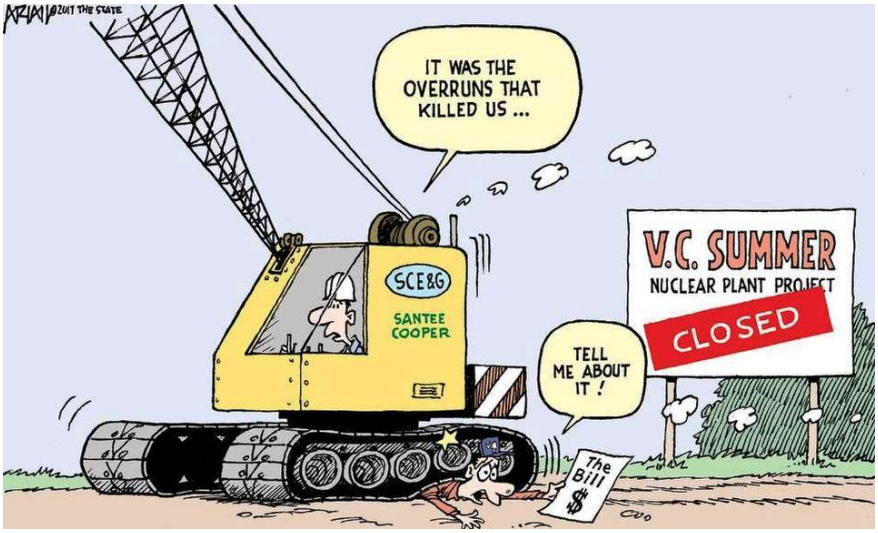
The same reasons could explain support for nuclear power within the Morrison federal government. Nonetheless, the federal Department of Industry, Science, Energy and Resources expects 69% renewable supply to the National Electricity Market by 2030.[33] There is zero or near-zero support for nuclear power among state and territory governments, including conservative governments – they are focused on the renewables transition (albeit unevenly). Tasmania leads the pack thanks to its hydro resources. South Australia is another pace-setter: wind and solar supplied 62% of local power generation over the past 12 months, wholesale electricity prices were the lowest on the mainland at an average of A$48 / MWh, and grid emissions have fallen to a record low.[34] South Australia is on track to comfortably meet its target of 100% net renewables by 2030.

[29] https://nuclear.foe.org.au/propaganda/
[30] https://johnquiggin.com/2018/08/13/coal-and-the-nuclear-lobby/
[31] https://reneweconomy.com.au/nuclear-power-exits-australias-energy-debate-enters-culture-wars-47702/ https://reneweconomy.com.au/small-modular-reactors-and-the-nuclear-culture-wars-73761/
[32] https://twitter.com/TurnbullMalcolm/status/1169566153288507392
[33] https://reneweconomy.com.au/renewables-to-supply-69-pct-of-australias-main-grid-by-2030-government-projections-show/
[34] https://reneweconomy.com.au/cheaper-cleaner-more-reliable-the-stunning-success-of-south-australias-renewable-transition/

2. THE U.S. AND WESTERN EUROPE: EVERY RECENT REACTOR CONSTRUCTION PROJECT HAS BEEN A DISASTER

2.1 The V.C. Summer project in South Carolina

The V.C. Summer project in South Carolina (two AP1000 reactors) was abandoned after the expenditure of around US$9 billion (A$12.8 billion).[35] 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.[36] Largely as a result 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.[37] Criminal investigations and prosecutions related to the V.C. Summer project are ongoing.[38]



2.2 The Vogtle project in Georgia

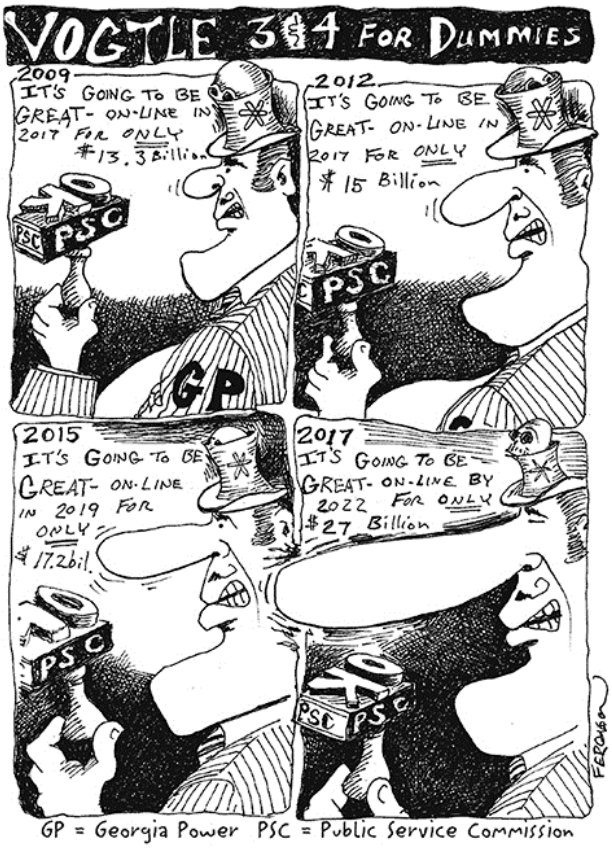
With the abandonment of the V.C. Summer project in South Carolina, the only remaining reactor construction project in the US is the Vogtle project in Georgia (two AP1000 reactors). The current cost estimate of US$27–30+ billion (A$38.3–42.6 billion) is twice the estimate when construction

[35] https://www.worldnuclearreport.org/Toshiba-Westinghouse-The-End-of-New-build-for-the-Largest-Historic-Nuclear.html
[36] https://www.nytimes.com/2017/07/31/climate/nuclear-power-project-canceled-in-south-carolina.html
[37] https://www.japantimes.co.jp/news/2017/02/15/national/toshibas-woes-weigh-heavily-governments-ambition-sell-japans-nuclear-technology/
[38] 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

began (US$14–15.5 billion).[39] Costs continue to increase[40] and the project only survives because of multi-billion-dollar taxpayer bailouts.[41]

In 2006, Westinghouse said it could build an AP1000 reactor for as little as US$1.4 billion (A$2.0 billion)[42] – 10 times lower than the current estimate for Vogtle. 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."[43] In fact, Westinghouse's claims were self-serving lies designed to win taxpayer subsidies and were proven to be wrong by an order of magnitude.

Construction of the two Vogtle reactors began in 2013 and the expected completion dates of 2016 and 2017 have been pushed back by six years to 2022 and 2023, with further delays likely.[44] In 2014, Westinghouse claimed a three-year construction schedule for AP1000 reactors.[45] 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.[46])



[39] https://www.wiseinternational.org/nuclear-monitor/867/vogtles-reprieve-snatching-defeat-jaws-defeat
[40] https://www.reuters.com/business/energy/southern-delays-georgia-vogtle-reactors-startup-boosts-costs-2021-07-29/
[41] https://www.wiseinternational.org/nuclear-monitor/867/vogtles-reprieve-snatching-defeat-jaws-defeat
[42] https://www.nytimes.com/2006/07/16/magazine/16nuclear.html
[43] https://www.govinfo.gov/content/pkg/CHRG-109shrg20004/pdf/CHRG-109shrg20004.pdf
[44] https://www.world-nuclear-news.org/Articles/In-service-dates-and-cost-forecast-revised-for-Vog
[45] www.iaea.org/inis/collection/NCLCollectionStore/_Public/46/136/46136339.pdf
[46] 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

2.3 Other reactor construction projects in the US

The Watts Bar 2 reactor in Tennessee began operation in 2016, 43 years after construction began.[47] When construction resumed in 2008 after a long hiatus (and with the reactor 60% complete[48]), the cost estimate to complete the reactor was US$2.5 billion but the final completion cost was US$4.7 billion.[49] In 2008, completion was scheduled in 2013 but that timeline was missed by three years.[50]

The previous reactor start-up in the US was Watts Bar 1, completed 20 years earlier (1996) after a 23-year construction period.[51] Thus Watts Bar 1 and 2 are the only reactor start-ups in the US over the past quarter-century.

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$8.2 billion).[52]

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[53], 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.[54] Twenty unprofitable, ageing reactors have been saved by nuclear bailout funding but their future is precarious.[55] Indeed the fate of the entire reactor fleet of 93 reactors is precarious given its age 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:[56]
"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.

[47] https://www.counterpunch.org/2021/09/24/the-record-breaking-failures-of-nuclear-power/
[48] https://www.powermag.com/commitment-teamwork-and-perseverance-pay-off-as-nuclear-unit-wins-plant-of-the-year/
[49] https://neutronbytes.co/2021/03/26/centrus-aims-for-haleu-production-by-2022/
[50] https://www.powermag.com/watts-bar-unit-2-a-deferred-nuclear-plant-gets-back-into-the-game/
[51] https://www.counterpunch.org/2021/09/24/the-record-breaking-failures-of-nuclear-power/
[52] Ibid.
[53] Mark Holt, "Nuclear Energy Policy" (Washington, D. C.: Congressional Research Service, October 15, 2014).
[54] 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.
[55] 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.
[56] https://www.nirs.org/nuclear-power-runs-on-dirty-money-the-corporate-scandal-of-the-proposed-national-nuclear-subsidy/

"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.
"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?"

In Canada, no reactors are under construction and none have come online since Darlington-4 in 1993 (five years behind schedule and billions over-budget). Reactor lifespan extension projects have been subject to delays and cost blowouts.[57]

2.4 The UK

The last power reactor start-up in the UK was Sizewell B in 1995.

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

[57] https://theconversation.com/why-ontario-must-rethink-its-nuclear-refurbishment-plans-127667

In the late 2000s, the estimated construction cost for one EPR reactor in the UK was £2 billion (A$3.8 billion).[58] In 2016, the estimated cost was £18 billion for two EPR reactors, upped to £21.5–22.5 billion in 2019 and the current cost estimate is £22–23 billion (A$41.4–43.3 billion).[59] Thus the current cost estimate is over five times greater than the initial estimate of £2 billion per reactor … and there will undoubtedly be further cost increases.

The UK National Audit Office estimates that taxpayer subsidies for Hinkley Point – primarily in the form of a guaranteed payment of £92.50 (A$174) / MWh (2012 prices), indexed for inflation, for 35 years – could amount to £30 billion (A$56.5 billion)[60] while other credible estimates put the figure as high as £48.3 billion (A$90.9 billion).[61]

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.[62] 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 2026.[63] One wouldn't hold one's breath.

[58] https://energypost.eu/saga-hinkley-point-c-europes-key-nuclear-decision/
[59] https://www.bbc.com/news/uk-england-somerset-55823575
[60] https://www.theguardian.com/uk-news/2016/jul/13/hinkley-point-c-cost-30bn-top-up-payments-nao-report
[61] http://www.no2nuclearpower.org.uk/wp/wp-content/uploads/2017/09/Time-to-Cancel-HinkleyFinal.pdf
[62] https://pris.iaea.org/PRIS/CountryStatistics/CountryDetails.aspx?current=GB
[63] https://www.powermag.com/costs-rise-as-virus-delays-hinkley-nuclear-build/

Nuclear industry lobbyist Tim yeo said in 2017 that the UK's nuclear power program faces "something of a crisis".[64] The following year, Toshiba abandoned the planned Moorside nuclear power project near Sellafield despite generous offers of government support[65] – a "crushing blow" according to Yeo.[66] 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$25.0 billion to A37.6 billion (¥2 trillion to ¥3 trillion).[67] 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.[68]

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:[69]
"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."

As of December 2021, 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[70] which foists financial risks onto taxpayers and could result in taxpayers paying billions for failed projects – as it has in the US.[71] 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.

Three ageing reactors have permanently shut down this year in the UK – Hunterston B-3 and Dungeness B1 and B2. There will be more power reactor closures than start-ups over the next 10–20 years.

2.5 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$30.6 billion) is 5.8 times greater than the original estimate of €3.3 billion (A$5.3 billion).[72]

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[64] https://www.telegraph.co.uk/business/2017/04/01/can-britains-nuclear-ambitions-avoid-meltdown/
[65] https://www.wiseinternational.org/nuclear-monitor/869/toshiba-gives-moorside-nuclear-power-project-uk
[66] https://www.ft.com/content/3f655db2-e30a-11e8-a6e5-792428919cee
[67] https://mainichi.jp/english/articles/20181225/p2a/00m/0na/011000c
[68] 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
[69] http://www.nuclearpolicy.info/news/nfla-argues-priority-anglesey-safe-decommissioning-wylfa-new-jobs-renewable-decentralised-energy/
[70] https://stopsizewellc.org/rab/
[71] 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/
[72] https://en.wikipedia.org/wiki/Flamanville_Nuclear_Power_Plant
https://www.worldnuclearreport.org/The-World-Nuclear-Industry-Status-Report-2020-HTML.html#_idTextAnchor236

The Flamanville reactor is 10 years behind schedule: construction began in 2007, the planned start-up date was 2012, and EDF now says that commercial operation cannot be expected before the end of 2022.[73] At best it will be a 15-year construction project, and further delays are likely: *Nuclear Engineering International*, citing a government decree, suggests start-up in 2024.[74]

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$8.0 billion) government bailout.[75] The *Financial Times* noted in October 2021 that EDF is "saddled with €41bn [A$65.6 billion] of debt and a colossal maintenance and investment programme to fund."[76]

2.6 Finland

The last reactor start-up in Finland was in 1980. One EPR reactor (Olkiluoto-3) is under construction. The current cost estimate of about €11 billion (A$17.6 billion) is 3.7 times greater than the original estimate of €3 billion (A$4.8 billion).[77] Olkiluoto-3 is 13 years behind schedule: construction began in 2005, start-up was expected in 2009 but has been pushed back to 2022.[78]

https://www.worldnuclearreport.org/The-World-Nuclear-Industry-Status-Report-2021-HTML.html#_idTextAnchor025

[73] https://www.worldnuclearreport.org/The-World-Nuclear-Industry-Status-Report-2021-HTML.html#_idTextAnchor030

[74] https://www.neimagazine.com/news/newsflamanville-3-startup-pushed-back-to-2024-7853088

[75] https://energyandcarbon.com/where-did-it-all-go-wrong-for-french-nuclear-giant-areva/

[76] https://www.ft.com/content/a1c95212-c122-4a29-8952-14a346381b91

[77] https://www.worldnuclearreport.org/World-Nuclear-Industry-Status-Report-2018-HTML.html#lien21

[78] 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

3. SMALL MODULAR REACTORS

Small modular reactors (SMRs) are heavily promoted but construction projects are few and far between and have exhibited disastrous cost overruns and multi-year delays.[79]

It should be noted that none of the projects discussed below meet the 'modular' definition of serial factory production of reactor components, which could potentially drive down costs. Using that definition, no SMRs have ever been built and no country, company or utility is building the infrastructure for SMR construction.

Numerous small power reactors have been built.[80] For example, most of India's operating power reactors are small but no more small reactors are being built. Numerous small Magnox reactors were built in the UK but all have been shut down and no more will be built. Academic M.V. Ramana has documented this failed history of small-reactor development:[81]
"*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.*"

The focus of this discussion is on recent and current SMR (or more accurately, small reactor) construction projects.

3.1 Argentina

The CAREM (Central Argentina de Elementos Modulares) SMR under construction in Argentina illustrates the gap between SMR rhetoric and reality. Cost estimates 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").[82]
- When construction began in 2014, the estimated cost was US$17.8 billion / GW (US$446 million for a 25 MW reactor).[83]
- Now, the cost estimate is US$23.4 billion (A$33.2 billion) / GW (US$750 million (A$1.06 billion) with the capacity increased from 25 MW to 32 MW).[84] One billion dollars for a reactor with the capacity of two large wind turbines.[85]

The CAREM project is years behind schedule and costs will likely increase further. When construction began in 2014, completion was expected in 2017.[86] But progress has been slow, work was

[79] https://wiseinternational.org/nuclear-monitor/872-873/nuclear-monitor-872-873-7-march-2019
[80] https://www.world-nuclear.org/information-library/nuclear-fuel-cycle/nuclear-power-reactors/small-nuclear-power-reactors.aspx
[81] https://spectrum.ieee.org/tech-history/heroic-failures/the-forgotten-history-of-small-nuclear-reactors
[82] https://www.researchgate.net/publication/267579277_CAREM_concept_A_competitive_SMR
[83] https://www.world-nuclear-news.org/NN-Construction-of-CAREM-underway-1002144.html
[84] https://www.gihub.org/resources/showcase-projects/carem-25-prototype/
[85] https://www.energylivenews.com/2021/08/24/goal-worlds-largest-wind-turbine-covers-six-football-pitches/ https://www.ge.com/renewableenergy/wind-energy/offshore-wind/haliade-x-offshore-turbine
[86] https://www.world-nuclear-news.org/NN-Construction-of-CAREM-underway-1002144.html

suspended on several occasions[87] and completion is now anticipated in 2024. A three-year construction project has become a 10-year project. CAREM is a scaled-down pressurised water reactor – no great innovation is involved.

The CAREM reactor under construction in Argentina.

3.2 Russia

Russia's floating nuclear power plant (with two 35 MW reactors) is said to be the only operating SMR anywhere in the world (although it doesn't fit the 'modular' definition of serial factory production). The construction cost increased six-fold from 6 billion rubles to 37 billion rubles (A$705 million)[88], equivalent to A$10.1 billion / GW.

According to the OECD's Nuclear Energy Agency, electricity produced by the Russian floating plant costs an estimated US$200 (A$284) / MWh, with the high cost due to large staffing requirements, high fuel costs, and resources required to maintain the barge and coastal infrastructure.[89] To put that in perspective, 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[90] – about one-quarter of the cost of electricity produced by the Russian plant.

The cost of electricity produced by the Russian plant also exceeds costs from large reactors – US$131–204 (A$186–289) / MWh according to the latest Lazards' report[91] – even though SMRs are being promoted as the solution to the excessive costs of large nuclear plants.

[87] https://www.world-nuclear-news.org/Articles/Construction-of-Argentinas-small-CAREM-25-unit-to

[88] 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

[89] https://www.oecd-nea.org/ndd/pubs/2016/7213-smrs.pdf

[90] 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

[91] https://www.lazard.com/media/451881/lazards-levelized-cost-of-energy-version-150-vf.pdf

SMRs are being promoted as important potential contributors to climate change abatement but the primary purpose of the Russian plant is to power fossil fuel mining operations in the Arctic.[92]

When construction began in 2007, completion of the Russian plant was anticipated in 2010 but it was not completed until 2019, nine years behind schedule.[93] Russia's plan to have seven floating nuclear power plants by 2015 was not realised.[94]

Russia's floating nuclear power plant.

3.3 China

Little independent information is available on the cost of China's demonstration 210 MW (2 x 105 MW) high-temperature gas-cooled reactor (HTGR). A 2016 report said that the estimated construction cost of China's demonstration HTGR is about US$5 billion (A$7.1 billion) / GW – about twice the initial cost estimates – and that cost increases have arisen from higher material and component costs, increases in labour costs, and project delays.[95] The World Nuclear Association states that the cost of the demonstration HTGR is US$6 billion (A$8.5 billion) / GW.[96] Those figures are 2–3 times higher than the US$2 billion (A$2.84 billion) / GW estimate in a 2009 paper by Tsinghua University researchers.[97]

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

[92] https://www.wiseinternational.org/nuclear-monitor/861/worlds-first-purpose-built-floating-nuclear-plant-akademik-lomonosov-reaches
[93] https://www.worldnuclearreport.org/The-World-Nuclear-Industry-Status-Report-2021-HTML.html#_idTextAnchor013
[94] https://en.wikipedia.org/wiki/Russian_floating_nuclear_power_station
[95] 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
[96] https://www.world-nuclear.org/information-library/country-profiles/countries-a-f/china-nuclear-power.aspx
[97] https://www.researchgate.net/publication/245194953_Current_status_and_technical_description_of_Chinese_2_250_MW_th_HTR-PM_demonstration_plant

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."[98]

In 2009, completion of the plant was anticipated in "about 2013"[99], so it is about eight years behind schedule. Construction did not begin until 2012 and the completion date has been pushed back several times since then. The twin reactors achieved first criticality in 2021[100] and the plant could begin operation in late 2021 or in 2022.

China reportedly plans to upscale the design to 655 MW (three modules feeding one turbine, total 655 MW) and to build these reactors in pairs with a total capacity of about 1,200 MW. China's Institute of Nuclear and New Energy Technology at Tsinghua University expects the cost of a 655 MWe HTGR will be 15–20% higher than the cost of a conventional 600 MW pressurised water reactor.[101]

NucNet reported in 2020 that China's State Nuclear Power Technology Corp. dropped plans to manufacture 20 of the HTGR units after levelised cost of electricity estimates rose to levels higher than a conventional pressurised water reactor such as China's Hualong One.[102] Likewise, the World Nuclear Association states that plans for 18 additional HTGRs at the same site as the demonstration plant have been "dropped".[103]

One after another country has tried to develop high-temperature gas-cooled reactors but abandoned those efforts.[104]

3.4 Other SMR construction projects

In addition to the CAREM reactor in Argentina and the HTGR in China, the World Nuclear Association lists just two other SMR (or more accurately, small reactor) construction projects.[105]

In July 2021, China National Nuclear Corporation (CNNC) New Energy Corporation began construction of the 125 MW pressurised water reactor ACP100 on China's island province of Hainan.[106] CNNC says it will be the world's first land-based commercial SMR.[107] The ACP100 has been under development since 2010.[108] According to CNNC, construction costs per kW will be twice the cost of large reactors, and the levelised cost of electricity will be 50% higher than large reactors.[109]

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[98] https://neutronbytes.com/2020/06/14/china-nuclear-energy-news-for-06-14-20/

[99] https://www.researchgate.net/publication/245194953_Current_status_and_technical_description_of_Chinese_2_250_MW_th_HTR-PM_demonstration_plant

[100] https://www.world-nuclear-news.org/Articles/Dual-criticality-for-Chinese-demonstration-HTR-PM

[101] https://www.world-nuclear.org/information-library/country-profiles/countries-a-f/china-nuclear-power.aspx

[102] https://www.nucnet.org/news/progress-and-status-in-the-race-for-commercialisation-2-4-2020

[103] https://www.world-nuclear-news.org/NN-First-vessel-installed-in-Chinas-HTR-PM-unit-2103164.html

[104] 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

[105] https://www.world-nuclear.org/information-library/nuclear-fuel-cycle/nuclear-power-reactors/small-nuclear-power-reactors.aspx

[106] https://world-nuclear-news.org/Articles/Installation-of-containment-starts-at-Chinese-SMR

[107] Ibid.

[108] Ibid.

[109] https://nucleus.iaea.org/sites/INPRO/df17/IV.1.-DanrongSong-ACP100.pdf

Fast reactors (a.k.a. fast breeder, fast neutron or fast spectrum reactors) have a troubled, expensive, accident-prone history.[110] After 70 years of development, just five are operating, all of them classed as 'demonstration' or 'experimental' reactors by the World Nuclear Association.[111] Nonetheless, in June 2021, construction of the 300 MW demonstration lead-cooled BREST fast reactor began in Russia. Plans for a lead-cooled fast reactor in Russia date from the 1990s but construction has been repeatedly delayed.[112] In 2016, construction of BREST was expected to begin in 2017 and completion was expected in 2020[113] – 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$801 million)[114]; now, the estimate is 100 billion rubles (A$1.91 billion).[115]

3.5 Planned and discontinued SMR projects

Much more could be said about the proliferation of SMRs in the 'planning' stage, and the accompanying hype.[116] For example a recent review asserts that more than 30 commercial scale demonstrations of different 'advanced' reactor designs are in progress across the globe.[117] In fact, few have progressed beyond the planning stage, and few will. Private-sector funding has been scant and taxpayer funding has generally been well short of that required for SMR construction projects.[118] For example, South Korea designed a 'SMART' SMR and in 2015 Korea Atomic Energy Research Institute said it wanted to build a demonstration plant to operate in 2017.[119] That plan was abandoned – domestic construction of SMART SMRs "is not practical or economic" according to the World Nuclear Association.[120]

Large taxpayer subsidies might get some projects – such as the NuScale project in the US[121], or the Rolls-Royce mid-sized reactor project in the UK[122] – to the construction stage. Or they may join the growing list of abandoned SMR projects:

- The French government abandoned the planned 100–200 MW ASTRID demonstration fast reactor in 2019.[123]
- Babcock & Wilcox abandoned its Generation mPower SMR project in the US despite receiving government funding of US$111 million.[124]

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[110] https://energypost.eu/slow-death-fast-reactors/
[111] https://www.world-nuclear.org/information-library/current-and-future-generation/fast-neutron-reactors.aspx
[112] https://www.neimagazine.com/features/featurebrest-is-best/
https://www.powermag.com/nuclear-first-work-starts-on-russian-fast-neutron-reactor/
[113] 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
[114] https://bellona.org/news/nuclear-issues/2015-05-perpetual-search-perpetuum-mobile
[115] https://tass.com/economy/1300401
[116] https://en.wikipedia.org/wiki/List_of_small_modular_reactor_designs
[117] https://www.advancednuclearenergy.org/product/advanced-reactors-turning-the-corner
[118] https://wiseinternational.org/nuclear-monitor/872-873/no-one-wants-pay-smrs-us-and-uk-case-studies
[119] https://www.powermag.com/small-modular-reactors-speaking-in-foreign-tongues/
[120] https://www.world-nuclear.org/information-library/country-profiles/countries-o-s/south-korea.aspx
[121]
https://d3n8a8pro7vhmx.cloudfront.net/oregonpsrorg/pages/21/attachments/original/1600287829/EyesWideShutReport_Final-30August2020.pdf?1600287829
[122] https://www.nuclearconsult.com/wp/wp-content/uploads/2019/07/Prospects-for-SMRs-report-2.pdf
[123] https://www.reuters.com/article/us-france-nuclearpower-astrid/france-drops-plans-to-build-sodium-cooled-nuclear-reactor-idUSKCN1VK0MC
[124] https://wiseinternational.org/nuclear-monitor/872-873/mpower-obituary

- Transatomic Power gave up on its molten salt reactor R&D in 2018.[125]
- MidAmerican Energy gave up on its plans for SMRs in Iowa in 2013 after failing to secure legislation that would require rate-payers to partially fund construction costs.[126]
- 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.[127]
- The UK government abandoned consideration of 'integral fast reactors' for plutonium disposition in 2019[128] and the US government did the same in 2015.[129]

A failed history of small reactor projects. A handful of recent construction projects, most subject to major cost overruns and multi-year delays. And the possibility of a small number of SMR prototype construction projects over the next decade. Clearly the hype surrounding SMRs lacks justification. Informed scepticism was evident in a February 2017 *Lloyd's Register* report based on "insights and opinions of leaders across the sector" and the views of almost 600 professionals and experts from utilities, distributors, operators and equipment manufacturers.[130] The report stated that the potential contribution of SMRs "is unclear at this stage, although its impact will most likely apply to smaller grids and isolated markets." Respondents predicted that SMRs have a "low likelihood of eventual take-up, and will have a minimal impact when they do arrive".[131]

Likewise, 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.[132] And 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."[133]

[125] https://wiseinternational.org/nuclear-monitor/867/nuclear-news-nuclear-monitor-867-15-october-2018
[126] https://pauldeaton.com/2013/06/04/iowa-pulls-the-plug-on-nuclear-power/
[127] https://www.reuters.com/article/us-terrapower-china/bill-gates-nuclear-venture-hits-snag-amid-us-restrictions-on-china-deals-wsj-idUSKCN1OV1S5
[128] Appendix 3, https://nuclear.foe.org.au/wp-content/uploads/2019-Federal-Nuclear-Inquiry-Joint-ENGO-Submission-Final.pdf
[129] Ibid.
[130] https://www.lr.org/en/latest-news/technology-radar-low-carbon/
[131] https://www.world-nuclear-news.org/EE-Nuclear-more-competitive-than-fossil-fuels-report-09021702.html
[132] http://1.nuclearenergyinsider.com/LP=362
[133] https://www.nuclearenergyinsider.com/international-smr-advanced-reactor

4. IMPLICATIONS FOR AUSTRALIA

4.1 Large, conventional reactors

The 2006 Switkowski inquiry initiated by the Howard government estimated the cost of electricity from new reactors at A$40–65 / MWh.[134] That is approximately one-quarter of current estimates. Lazard's October 2021 report on levelised costs of electricity gives these figures:[135]

	Levelised cost of electricity US$ / MWh
Nuclear	131–204 (A$186–289)
Wind – onshore	26–50
Solar PV – rooftop residential	147–221
Solar PV – rooftop commercial and industrial	67–180
Solar PV – community	59–91
Solar PV – crystalline utility scale	30–41
Solar PV – thin film utility scale	28–37
Solar thermal tower with storage	126–156
Geothermal	56–93

Note that although the nuclear cost is comparable to rooftop residential solar PV, the latter does not require large downstream costs such as transmission from a power plant.

In 2009, Dr. Ziggy Switkowski said that the construction cost of a 1,000 MW power reactor in Australia would be A$4–6 billion.[136] Again, that is approximately one-quarter of the current cost estimates for reactors under construction in Western Europe and the US (and one-sixth of the cost of the Flamanville reactor in France).

Lazards provides these capital cost comparisons in its October 2021 report:[137]

	Capital cost per kilowatt
Nuclear	US$7800–12800 (A$11,100–18,200)
Wind – onshore	US$1025–1350
Solar PV – rooftop residential	US$2475–2850
Solar PV – rooftop commercial and industrial	US$1400–2850
Solar PV – community	US$1200–1450
Solar PV – crystalline utility scale	US$800–950
Solar PV – thin film utility scale	US$800–950
Solar thermal tower with storage	US$6000–9090
Geothermal	US$4325–5575

[134] http://pandora.nla.gov.au/tep/66043
[135] https://www.lazard.com/media/451881/lazards-levelized-cost-of-energy-version-150-vf.pdf
[136] https://www.theaustralian.com.au/opinion/a-clean-and-green-way-to-fuel-the-nation/news-story/92aabe042acb3ef3ffdbdfacc65631bf
[137] https://www.lazard.com/media/451881/lazards-levelized-cost-of-energy-version-150-vf.pdf

Dr. Switkowski used to be the most prominent public supporter of nuclear power in Australia but he said in 2018 that the window for large-scale nuclear power in Australia has closed[138] as renewable energy sources are now cheaper and the cost differential continues to widen.[139]

Indeed one of the few points of agreement in Australia's nuclear debate is that large-scale nuclear power is not a viable option. A 2019 federal parliamentary Environment and Energy Committee inquiry[140] was controlled by Coalition MPs who were, in principle, exceedingly 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").[141] Committee chair Ted O'Brien said "Australia should say a definite 'no' to old nuclear technologies".[142]

The Committee's report called for a partial repeal of legal bans to permit the development of "new and emerging nuclear technologies" including SMRs, but that was quickly ruled out by the federal government.[143] The Coalition government continues to rule out repealing legal bans or pursuing nuclear power, as does the Labor Party.

4.2 Small modular reactors and the Minerals Council's disinformation campaign

There is unanimous or near-unanimous agreement that there is no place for large, conventional nuclear power reactors in Australia, but there is ongoing promotion of SMRs. The nuclear industry and some of its supporters continue to present SMR cost projections which are implausible and self-serving at best; dishonest at worst.

Particular note should be made of implausible, self-serving company estimates dressed up as credible, independent estimates.

For example the Minerals Council of Australia (MCA) claims that "robust estimates" using "conservative assumptions" suggest that SMRs will produce power at a cost of A$64–77 / MWh by 2030.[144] However the "robust estimates" using "conservative assumptions" are nothing more than self-serving, implausible company estimates. Moreover, company estimates are falsely described as "independent" in the MCA report.

The MCA bolsters its SMR cost claims with reference to the Energy Information Reform Project (EIRP), which purports to have conducted a 'standardized cost analysis of advanced nuclear

[138] https://www.theage.com.au/business/the-economy/australia-has-missed-the-boat-on-nuclear-power-20180111-p4yyeg.html
[139] https://www.smh.com.au/business/the-economy/safety-risks-stall-nuclear-role-in-australia-s-energy-mix-20180125-p4yyvj.html
[140] https://www.aph.gov.au/Parliamentary_Business/Committees/House/Environment_and_Energy/Nuclearenergy
[141] https://www.aph.gov.au/Parliamentary_Business/Committees/House/Environment_and_Energy/Nuclearenergy/Report
[142] https://www.aph.gov.au/About_Parliament/House_of_Representatives/About_the_House_News/Media_Releases/Nuclear_Energy_-_Not_without_your_approval
[143] https://www.adelaidenow.com.au/technology/parliamentary-committee-recommends-lifting-ban-on-modern-nuclear-power-technology/news-story/503887977515479052l1b5a49cf3786f
https://www.smh.com.au/politics/federal/taylor-rejects-call-for-partial-lift-of-nuclear-power-ban-20191213-p53jsf.html
[144] https://reneweconomy.com.au/small-nuclear-reactors-huge-costs/

technologies in commercial development'.[145] In fact, the EIRP 'study' just collates self-serving, implausible company estimates and presents them with this qualification: "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."

And again the MCA conflates serious analysis with propaganda in its submission[146] to the 2019 federal parliamentary nuclear inquiry, claiming that SMRs could generate electricity for as little as A$60 / MWh based on a report by the Economic and Finance Working Group (EFWG) of the Canadian government-industry 'SMR Roadmap' initiative.[147] Yet the EFWG paper assumes rapid deployment of SMRs from a standing start, then 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, not serious analysis.

Moreover the MCA is selective: among the many EFWG cost estimates it excludes is the C$162.67 (A$181) / MWh estimate for power from a first-of-a-kind 300 MW on-grid SMR or, at the upper end, the estimate of C$894.05 (A$994) / MWh for power from a first-of-a-kind 3 MW remote community SMR.

The MCA is engaged in a systematic disinformation campaign regarding SMRs and nuclear power more generally. MCA member companies such as BHP and Rio Tinto should fix the problem or withdraw from the MCA.

4.3 Serious SMR analyses

The key point made by all serious analysts of SMRs is that they 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 material inputs and staffing, and a number of other costs including waste management and decommissioning will be proportionally higher. It is highly unlikely that potential savings arising from serial factory production of reactor components would make up for those diseconomies of scale; and in any case there is no serial factory production of SMR components. Cost reductions arising from mass production of SMRs are entirely speculative, whereas cost increases arising from diseconomies of scale are certain – they are built into the very concept of SMRs.

In the 2000s, nuclear interests and advocates lied incessantly about the costs of large, conventional reactors and the same deceit is now evident in relation to SMRs as discussed by Dr. Mark Cooper:[148]
"The vendors and academic institutions that were among the most avid enthusiasts in propagating the early, extremely optimistic cost estimates of the "nuclear renaissance" are the same entities now producing extremely optimistic cost estimates for the next nuclear technology. We are now in the midst of the SMR hype cycle.

- *Vendors produce low-cost estimates.*
- *Advocates offer theoretical explanations as to why the new nuclear technology will be cost competitive.*
- *Government authorities then bless the estimates by funding studies from friendly academics."*

[145] https://www.innovationreform.org/wp-content/uploads/2018/01/Advanced-Nuclear-Reactors-Cost-Study.pdf
[146] https://www.aph.gov.au/DocumentStore.ashx?id=8f16efb2-f05a-43a8-8d7f-a7c61df2fa97&subId=670566
[147] https://smrroadmap.ca/wp-content/uploads/2018/12/Economics-Finance-WG.pdf
[148] https://www.nirs.org/wp-content/uploads/reactorwatch/newreactors/cooper-smrsaretheproblemnotthesolution.pdf

Conspicuously absent from the MCA's disinformation campaign is any mention of serious, independent assessments of SMR economics.

A study by WSP / Parsons Brinckerhoff, commissioned by the South Australian Nuclear Fuel Cycle Royal Commission, estimated costs of A$225 / MWh for SMRs based on the NuScale design.[149] The MCA states that SMRs won't find a market unless they can produce power at a cost of A$60–80 / MWh[150] – about one-third of the independent cost estimate from WSP / Parsons Brinckerhoff.

The South Australian Nuclear Fuel Cycle Royal Commission concluded in its 2016 report:[151]
"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."

Renewables coupled with storage are cheaper than SMRs. The CSIRO provides these estimates in its 2020 GenCost report:[152]

	Low and high estimates (2020) A$ / MWh
Nuclear – small modular	258–338
Wind + 2 hrs battery storage	84–107
Wind + 6 hrs pumped hydro storage	92–117
Solar PV + 2 hrs battery storage	88–133
Solar PV + 6 hrs pumped hydro storage	101–151

In its 2021 GenCost report, CSIRO provides these 2030 cost estimates (among others):[153]

- Nuclear (SMR): A$128–322 / MWh
- 90% wind and solar PV with integration costs: A$55–80 / MWh

The 2021 CSIRO GenCost report states:[154]
"The results for the additional costs for increasing variable renewable shares are used to update and extend our LCOE [levelised cost of electricity] estimates. We expand the results for 2030 to include a combined wind and solar PV category for different VRE [variable renewable energy] shares. We have also removed the wind plus storage and solar PV plus storage categories that were included in GenCost 2018 and GenCost 2019-20. These were always designed to be temporary estimates until a better approach was available. In GenCost 2019-20, for 2030, the simple approach of adding 2 or 6 hours storage added $19 to $106/MWh to the cost of variable renewables for an unspecified share of generation.
"With the new approach the additional costs to support renewables are estimated at $6 to $19/MWh depending on the VRE share. As such, the previous approach was too conservative. While it did not consider transmission and synchronous condensers, which are important additional costs, it over-

[149] http://nuclearrc.sa.gov.au/app/uploads/2016/05/WSP-Parsons-Brinckerhoff-Report.pdf
[150] 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
[151] https://nuclear.foe.org.au/wp-content/uploads/NFCRC_Final_Report_Web_5MB.pdf
[152] https://doi.org/10.25919/5eb5ac371d372
[153] https://publications.csiro.au/publications/publication/PIcsiro:EP2021-0160
[154] Ibid.

estimated the need for storage and, in total, over-estimated the additional integration costs that might be associated with variable renewable generation.
"Variable renewables (wind and solar PV) without transmission or storage costs are the lowest cost generation technology by a significant margin. From 2030, the new estimates on additional costs associated with increasing variable renewable generation confirms that they are also competitive when transmission, synchronous condenser and storage costs are included."

An analysis by pro-nuclear researchers from Carnegie Mellon University's Department of Engineering and Public Policy, published in 2018 in the *Proceedings of the National Academy of Science*, concluded that to develop an SMR industry in the US, "several hundred billion dollars of direct and indirect subsidies would be needed to support their development and deployment over the next several decades".[155] 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.[156]

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.[157]

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 would be 30% more expensive than that from large reactors, because of diseconomies of scale and the costs of deploying first-of-a-kind technology. Its optimistic SMR cost estimate is US$107–155 (A$151–219) / MWh.[158]

A 2015 report by the International Energy Agency and the OECD Nuclear Energy Agency predicted that electricity from SMRs will be 50−100% more expensive than that from large reactors, although it held out some hope that large-volume factory production could reduce costs over time.[159] The report further stated that "generation IV technologies aim to be at least as competitive as generation III technologies … though the additional complexity of these designs, the need to develop a specific supply chain for these reactors and the development of the associated fuel cycles will make this a challenging task." In other words, at best Generation IV reactors aim to compete with current − economically failing – reactors, and even realising that goal will be "challenging."[160]

A 2020 report by the International Energy Agency and the OECD Nuclear Energy Agency states:[161]
"SMRs propose cost and risk reductions with factory built construction and higher affordability of the projects. Nevertheless, while some of these benefits have been documented in other industries, they still need to be proven in the nuclear sector. The construction of first prototypes may materialise some of the announce [sic] benefits of SMRs and thus accelerate their commercial viability. Government support is also essential on this front."

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[155] https://www.pnas.org/content/115/28/7184
[156] http://www.pnas.org/content/early/2018/06/26/1804655115, https://www.eurekalert.org/news-releases/800347
[157] https://www.energy.gov/ne/downloads/report-examination-federal-financial-assistance-renewable-energy-market
[158] 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
[159] https://www.oecd-nea.org/jcms/pl_14756/projected-costs-of-generating-electricity-2015-edition, https://www.oecd-nea.org/upload/docs/application/pdf/2019-12/7279-proj-costs-electricity-2015-es.pdf
[160] For discussion see http://www.wiseinternational.org/nuclear-monitor/810/nuclear-advocates-fight-back-wishful-thinking
[161] https://www.oecd-nea.org/upload/docs/application/pdf/2020-12/egc-2020_2020-12-09_18-26-46_781.pdf, https://www.oecd-nea.org/jcms/pl_51110/projected-costs-of-generating-electricity-2020-edition

In other words, SMRs are stuck at the starting gate and will remain there without taxpayer funds; and cost reductions might or might not materialise if some SMRs are built.

A 2014 study published in *Energy and Power Engineering* concluded that fuel costs for integral pressurised water SMRs are estimated to be 15–70% higher than for large light-water reactors, and points to research indicating similar comparisons for construction costs.[162]

SMRs "are still far too expensive and less scalable than renewables, and do not address fundamental nuclear safety and nuclear waste issues", S&P Global Ratings noted in a 2019 report.[163]

Dr. Ziggy Switkowski 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."[164] Likewise, Australian academic Barry Brook states: "SMRs are currently uneconomic, being caught in a Catch-22 situation. In theory, they might be cheaper and faster to build than large LWRs, if one settled on a standard design and made them in a tooled-up factory. But until the bulk orders are flowing, such factories are hard to justify and finance. Unfortunately, everyone wants to build the second one."[165]

Former World Nuclear Association executive Steve Kidd wrote about SMR "myths" in 2015:[166]
"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."

William Von Hoene, senior vice-president at US energy and nuclear giant Exelon, said in 2018 that SMRs are "prohibitively expensive".[167]

4.4 Australia's energy future

A further indication of the dim prospects for nuclear power in Australia was that several conservative governments and parties contributed submissions to a 2019 federal nuclear inquiry opposing nuclear power – the SA Liberal government[168], the Tasmanian Liberal government[169], and the Queensland Liberal-National Party[170] – while none contributed submissions supporting nuclear power. 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

[162] https://www.scirp.org/journal/PaperInformation.aspx?PaperID=45669
[163] https://www.euractiv.com/wp-content/uploads/sites/2/2019/11/Energy-Transition_Nuclear-Dead-And-Alive_11-Nov.-2019.pdf
[164] https://www.afr.com/politics/federal/no-investment-appetite-for-nuclear-switkowski-20190805-p52dwv
[165] https://bravenewclimate.com/2020/09/21/ama-1/
[166] https://www.neimagazine.com/opinion/opinionnuclear-myths-is-the-industry-also-guilty-4598343/
[167] 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
[168] https://www.aph.gov.au/DocumentStore.ashx?id=1519c7ea-3f47-47a0-a65d-97d691827bf0&subId=671226
[169] https://www.aph.gov.au/DocumentStore.ashx?id=69cdc369-9b09-477f-ba35-2b9ec182774a&subId=670563
[170] https://www.aph.gov.au/DocumentStore.ashx?id=5c2cf4df-5ef7-420c-86f3-eee32033fa3f&subId=669992

expensive than renewables backed up with energy storage.[171] 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."[172]

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 pace-setter: wind and solar supplied 62% of local power generation over the past 12 months, wholesale prices were the lowest on the mainland at an average of $48 per megawatt-hour MWh, and grid emissions have fallen to a record low.[173] South Australia 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.[174]

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.

[171] 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
[172] https://www.parliament.vic.gov.au/epc-lc/article/4350
[173] https://reneweconomy.com.au/cheaper-cleaner-more-reliable-the-stunning-success-of-south-australias-renewable-transition/
[174] https://reneweconomy.com.au/renewables-to-supply-69-pct-of-australias-main-grid-by-2030-government-projections-show/

5. NUCLEAR POWER'S LOOMING DECLINE

5.1 The Era of Nuclear Decommissioning

Nuclear power's contribution to global electricity supply fell from a peak of 17.5% in 1996 to 10.1% in 2020, while renewables have grown steadily to reach 29% in 2020.[175]

In 2020, a record 256 GW of renewable capacity were added to the world's power grids compared to a net gain of 0.4 GW of nuclear capacity (and a net decline of nuclear power generation by 3.9%).[176] This year will be another record-setting year for renewables, with 290 GW installed so far[177], and nuclear power has flatlined yet again with the small number of reactor start-ups matched by permanent closures.[178]

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.[179] There is one big difference between the current situation and the situation 30 years ago: the reactor fleet was young then, but 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[180]). The average age of the world's reactor fleet continues to rise, and by mid-2021 reached 30.9 years.[181] The mean age of the 23 reactors shut down between 2016 and 2020 was 42.6 years.[182]

A decade ago, it seemed that growth was possible – but those hopes were quickly dashed. This table captures the birth and death of the short-lived nuclear 'renaissance':[183]

	2002–07	*2008–13*	*2014–20*
Global power reactor construction starts	24 in 6 yrs	59 in 6 yrs	31 in 7 yrs
Annual average	4.0	9.8	4.4

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.[184]

Reactor construction starts need to match closures just for the industry to maintain its 30-year pattern of stagnation, yet annual construction starts have averaged just 4.4 since 2014.

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

[175] https://www.worldnuclearreport.org/The-World-Nuclear-Industry-Status-Report-2021-HTML.html
[176] Ibid.
[177] https://www.theguardian.com/environment/2021/dec/01/renewable-energy-has-another-record-year-of-growth-says-iea
[178] https://pris.iaea.org/PRIS/
[179] Ibid.
[180] https://smithharroff.com/the-nuclear-workforce-gap-dealing-with-the-impending-silver-tsunami/
[181] https://www.worldnuclearreport.org/The-World-Nuclear-Industry-Status-Report-2021-HTML.html
[182] Ibid.
[183] 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
[184] https://www-pub.iaea.org/MTCD/Publications/PDF/RDS-1-38_web.pdf

over the past 30 years. Significant growth is inconceivable. The 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.[185] The IAEA's current low-growth projection is for a 7% decline by 2030.[186]

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.[187]

5.2 Nuclear phase-out policies

The number of countries planning to phase-out nuclear power steadily grows and now includes:

- **Germany**: Eleven reactors have shut down since the 2011 Fukushima disaster and the final six reactors will be shut down by the end of 2022.[188]
- **Belgium**: The country's seven ageing reactors will all be closed by the end of 2025.[189]
- **Taiwan**: Final reactor closure scheduled for 2025.[190] Four reactors were shut down from 2018 to 2021 and only two remain operational.[191] In 2019, Taipower ruled out completing the 2.7 GW Lungmen nuclear plant.[192]
- **Spain**: Nuclear power capacity is expected to decline from 7.1 GW in 2020 to 3 GW in 2030 with the final reactor closure in 2035.[193]
- **Switzerland**: The government accepted the results of a 2017 referendum which supported a ban on new reactors and thus a gradual phase-out is underway.[194] The Mühleberg reactor was shut down in 2019 and most or all of the remaining four ageing reactors are likely to be shut down over the next decade.
- **South Korea**: Long-term (2060) phase-out policy with concrete actions already taken 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. The current plan is to reduce the number of reactors from a peak of 26 in 2024 to 17 in 2034.[195]

[185] 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
[186] https://www.iaea.org/publications/15028/energy-electricity-and-nuclear-power-estimates-for-the-period-up-to-2050
[187] https://reneweconomy.com.au/era-nuclear-decommissioning-13370/
[188] https://www-pub.iaea.org/MTCD/Publications/PDF/cnpp2017/countryprofiles/Germany/Germany.htm
https://www.world-nuclear.org/information-library/country-profiles/countries-g-n/germany.aspx
[189] https://www.world-nuclear-news.org/Articles/Belgian-nuclear-phase-out-an-irreversible-loss-PM
[190] https://www.powermag.com/taiwan-shuts-another-reactor-as-part-of-nuclear-free-goal/
[191] https://www.world-nuclear.org/information-library/country-profiles/others/nuclear-power-in-taiwan.aspx
https://www.powermag.com/taiwan-shuts-another-reactor-as-part-of-nuclear-free-goal/
[192] https://www.world-nuclear.org/information-library/country-profiles/others/nuclear-power-in-taiwan.aspx
[193] https://www.power-technology.com/comment/spain-nuclear-power-phase-out/
[194] https://www.swissinfo.ch/eng/muehleberg-nuclear-plant--_switzerland-proceeds-with-historic-nuclear-shutdown-/45449072
[195] https://wiseinternational.org/nuclear-monitor/887/nuclear-monitor-887-17-june-2020

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.[196] Italy (1990), Lithuania (2009) and Kazakhstan (1999) have already phased out nuclear power. Several countries began construction of a power reactor but never operated one – Austria, Cuba, Libya, Poland and North Korea[197] (although North Korea uses an 'experimental power reactor', based on the British Magnox design, to produce plutonium for weapons). Over 80% of the world's countries have never operated nuclear power plants (158/195 countries or 81%).

5.3 Other countries

As noted above in this paper (section 2), nuclear power is in crisis in the US and Western Europe. The status of nuclear power in a number of other key countries is briefly summarised here.

Japan

Japan's nuclear industry has been decimated in the aftermath of the 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.[198] Of Japan's pre-Fukushima fleet of 54 reactors, just 10 have restarted, more than twice that number have been permanently shut down, and the fate of the remaining reactors remains undecided.[199]

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$1,011 billion or A$1.0 trillion).[200] Indirect costs – such as replacement power for shuttered reactors, and lost tourism revenue – also amount to hundreds of billions of dollars.[201] Direct and indirect costs combined far exceed A$1 trillion (and Chernobyl was also a trillion-dollar disaster[202]).

China

China's nuclear power program has stalled twice over the past decade – after the 2011 Fukushima disaster and again in late 2016.[203] Currently, 52 reactors account for 4.9% of national electricity generation, with another 14 under construction.[204] The most likely outcome over the next decade is

[196] https://www.worldnuclearreport.org/WNISR2019-Assesses-Climate-Change-and-the-Nuclear-Power-Option.html
[197] https://en.wikipedia.org/wiki/Nuclear_power_phase-out
[198] https://pris.iaea.org/PRIS/CountryStatistics/CountryDetails.aspx?current=JP
[199] https://www.bloomberg.com/news/articles/2021-06-23/japan-restarts-first-nuclear-reactor-since-2018-amid-hurdles
[200] https://www.jcer.or.jp/english/accident-cleanup-costs-rising-to-35-80-trillion-yen-in-40-years
[201] https://www.wiseinternational.org/nuclear-monitor/836/economic-impacts-fukushima-disaster
[202] https://globalhealth.usc.edu/wp-content/uploads/2016/01/2016_chernobyl_costs_report.pdf
[203] https://wiseinternational.org/nuclear-monitor/871/china-rescue
[204] https://pris.iaea.org/PRIS/CountryStatistics/CountryDetails.aspx?current=CN

that a small number of new reactor projects will be approved each year, well short of previous projections and not nearly enough to match the decline in the rest of the world. Over the past decade (2011 to 2020), reactor construction starts averaged just 2.1 per year.

This table captures the birth and death of the short-lived nuclear 'renaissance' in China:[205]

	2000–07	*2008–10*	*2011–20*
Average annual power reactor construction starts	0.9 (7 in 8 years)	8.3 (25 in 3 yrs)	2.1 (21 in 10 yrs)

Former World Nuclear Association executive Steve Kidd noted in 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."[206] Those negative factors include delays and cost overruns – for example the two EPR reactors at Taishan were five years behind schedule and 40% over-budget.[207]

The 2020 comparison is striking: 2 GW of nuclear power capacity were added compared to 135 GW of renewables.[208] Solar and wind combined generated twice as much electricity as nuclear power in China in 2020 and the gap continues to widen.[209]

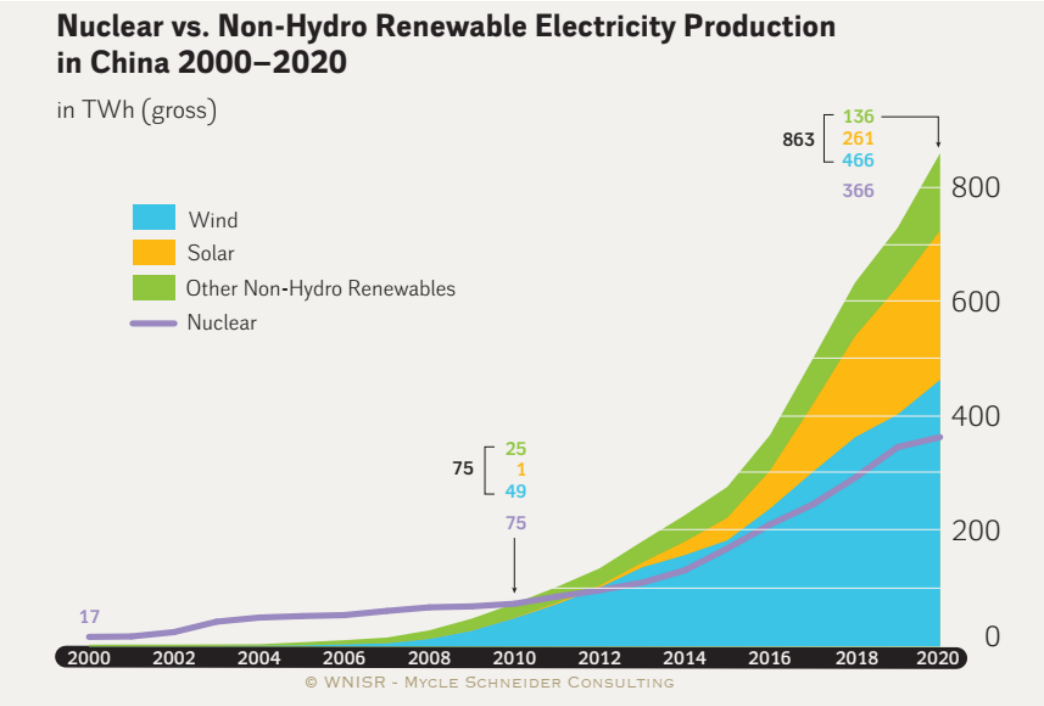
Little independent information is available on nuclear costs in China – although the strong preference for renewables gives a strong indication as to relative costs. The following factors reduce nuclear costs but increase risks:

- Numerous insiders have warned about inadequate nuclear safety standards.[210] 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.[211]
- China's nuclear regulatory agency is not independent[212] and it is understaffed.[213]
- China's nuclear program lacks transparency[214] and there are repressive controls on the media and social media / the internet.[215]
- Whistleblowers who raise concerns about inadequate nuclear safety standards have been persecuted.[216]
- China has the world's worst nuclear insurance and liability arrangements.[217]

[205] https://pris.iaea.org/PRIS/
[206] http://www.neimagazine.com/opinion/opinionnuclear-in-china-where-is-it-heading-now-6275899/
[207] https://www.worldnuclearreport.org/The-World-Nuclear-Industry-Status-Report-2019-HTML.html#_idTextAnchor071
https://www.worldnuclearreport.org/The-World-Nuclear-Industry-Status-Report-2018-HTML#lien141
[208] https://www.worldnuclearreport.org/The-World-Nuclear-Industry-Status-Report-2021-HTML.html#_idTextAnchor021
[209] Ibid.
[210] https://www.chinadialogue.net/article/show/single/en/5808-Chinese-nuclear-di
[211] 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
[212] http://www.eurekalert.org/pub_releases/2011-06/acs-cni062211.php
[213] https://www.world-nuclear.org/info/Country-Profiles/Countries-A-F/China--Nuclear-Power/
[214] http://www.bloomberg.com/news/2014-06-18/french-nuclear-regulator-says-china-cooperation-lacking.html
[215] http://en.rsf.org/china-china-12-03-2012,42077.html
[216] https://www.hrichina.org/sites/default/files/PDFs/CRF.1.2006/CRF-2006-1_Sun.pdf
[217] http://www.globaltimes.cn/content/856971.shtml

- Security risks[218] (in particular those associated with China's fast reactor program[219]) including 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".[220]

China's plans to establish a nuclear export industry are near-dormant[221] and its hopes to build reactors in the UK have been dropped for various reasons including cybersecurity concerns.



Source: World Nuclear Industry Status Report, 2021.

India

India's leaders have for decades promised a massive nuclear power expansion but it never happens. Currently, 23 reactors account for 3.3% of national electricity generation, with another six reactors under construction.[222] In the decade from 2011 to 2020, there were just four power reactor construction starts.[223]

Russia

In Russia, 38 power reactors supply 20.6% of total electricity generation, with three reactors under construction and just three power reactor construction starts in the decade from 2011 to 2020.[224]

[218] http://ntiindex.org/countries/china/
[219] https://www.belfercenter.org/publication/security-risks-chinas-nuclear-reprocessing-facilities
[220] http://blog.transparency.org/2014/12/03/asia-pacific-growing-economies-growing-corruption/
[221] https://www.worldnuclearreport.org/The-World-Nuclear-Industry-Status-Report-2021-HTML.html#_idTextAnchor021
[222] https://pris.iaea.org/PRIS/CountryStatistics/CountryDetails.aspx?current=IN
[223] https://pris.iaea.org/PRIS/
[224] https://pris.iaea.org/PRIS/, https://pris.iaea.org/PRIS/CountryStatistics/CountryDetails.aspx?current=RU

South Korea

As noted previously, South Korea's government has a long-term (2060) phase-out policy with concrete actions already taken 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.[225] The current plan is to reduce the number of reactors from a peak of 26 in 2024 to 17 reactors in 2034.[226] As of November 2021, 24 reactors produce 29.6% of total electricity generation with four under construction.[227]

South Korea's nuclear industry has been rocked by industry-wide corruption scandals.[228] Other than the 2009 contract to supply four reactors to the UAE (also mired in scandal[229]), 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[230] and Toshiba[231]) despite offers of billions of dollars of British taxpayer subsidies.

The South Korean nuclear industry's business model is to sacrifice safety in order to improve economics. The CEO of French nuclear utility Areva likened Korea's AP1400 reactor design to "a car without airbags and safety belts."[232] 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 the above-mentioned safety problems with an EPR reactor in China).

[225] https://www.wiseinternational.org/nuclear-monitor/844/south-koreas-nuclear-industry-model-others-follow
[226] https://wiseinternational.org/nuclear-monitor/887/nuclear-monitor-887-17-june-2020
[227] https://pris.iaea.org/PRIS/CountryStatistics/CountryDetails.aspx?current=KR
[228] https://wiseinternational.org/nuclear-monitor/887/nuclear-monitor-887-17-june-2020
https://www.wiseinternational.org/nuclear-monitor/844/south-koreas-nuclear-mafia
[229] https://wiseinternational.org/nuclear-monitor/887/nuclear-monitor-887-17-june-2020
[230] https://www.theguardian.com/business/2019/jan/17/hitachi-set-to-scrap-16bn-nuclear-project-anglesey-wales
[231] https://www.theguardian.com/environment/2018/nov/08/toshiba-uk-nuclear-power-plant-project-nu-gen-cumbria
[232] Nucleonics Week, 22 April 2010, 'No core catcher, double containment for UAE reactors, South Koreans say'.