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Over Reactor

The economic problems with nuclear power

Nuclear generators are high cost compared with other forms of power. They require extensive safety regulations and extensive government subsidies. Nearly all face cost blow outs and most face delays, taking years to build, sometimes more than a decade.

In existing nuclear nations, nuclear power is stagnating or going backwards, with companies in distress being bailed out. New designs like 'Small Modular Reactors' are still economically speculative and far from deployment. Funding, regulating and building nuclear in Australia is likely to take even longer than it takes in other countries.

Nuclear events are essentially uninsurable; risks are borne by the public. Nuclear power is water intensive and heat-vulnerable, a particular concern in Australia.

The energy transition in Australia requires high levels of *flexibility*, not baseload. Nuclear power is often offline. The falling costs of renewables and storage, and increasing demand response, make nuclear power unnecessary for Australia.

Submission

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Summary

The fundamental problem facing nuclear power is its high cost. This is widely understood throughout the peer-reviewed literature and several key concerns are presented in this report.

Nuclear power is more expensive than other forms of electricity generation. Nuclear power analysts have concluded “nuclear energy is never profitable” and “nuclear new-build is simply not competitive under ordinary market economy rules anywhere”. Nuclear power plants are built with extensive government intervention and subsidies.

For nuclear power to be feasible, a carbon price is necessary, but far from sufficient. Renewable energy is the cheapest form of new generation in Australia. When paired with storage renewable energy is competitive with other new build energy, and will continue to get cheaper

Nuclear is slow to build, often delayed and faces cost blowouts. Nuclear power plants finished in the last ten years took on average a decade to build. A nuclear power plant in Australia could take twice that long to build. There would need to be a robust and likely lengthy process to establish regulation, skills and supply chains. Even with required government policy and funding, it may not be possible to operate a nuclear power plant in Australia until 2040.

Nuclear costs escalate over time. Despite decades of experience and billions in research and development funding, nuclear power has a history of becoming more expensive. Other energy technologies get cheaper over time; renewable energy and storage have plummeted in cost and are likely to continue to do so.

Nuclear power is stagnating or going backwards in existing countries. The global nuclear reactor fleet is aging, few reactors are being built, nuclear companies are going bankrupt or face distress, generation is flat globally, and flat or declining in many nuclear nations. The UK’s *Hinkley C* provides a cautionary tale of the vast costs to the public from building new nuclear. Meanwhile renewable energy is booming. The experience of existing nuclear should be an economic warning to Australia.

New nuclear power technologies are economically speculative. “Small modular reactors” (SMR) and “generation IV” technologies are barely demonstrated, much less deployed. SMR vendors promise lower costs from lower risk and new economies of scale. Yet SMRs face numerous *diseconomies* of scale, and uncertainties about design

and regulation. A wide range of analysts are sceptical, including many supporters of nuclear power.

Optimistic SMR projections claim operations should commence in existing nuclear states by 2030. Australia is in no position to meet such schedules, and they are based on problematic assumptions. Other nuclear technologies are even further off, at best. Little OECD research and development spending on energy is directed to nuclear.

Nuclear power is uninsurable. Financial service organisations will not insure against nuclear accidents. If developers of nuclear power stations were forced to insure the full costs of nuclear accidents, nuclear power would be completely uncompetitive. Insurance policies from some of Australia's major insurers contain specific text regarding nuclear disasters. None of the major Australian insurers will insure your home, car or possessions against a nuclear event.

Nuclear power is water-intensive and heat vulnerable. Nuclear reactors require large volumes of water for cooling and are vulnerable to heat, a problem in Australia due to droughts and heatwaves, which are getting longer and more extreme.

Nuclear power waste disposal still does not exist. High-level radioactive waste material must be stored securely for tens of thousands of years, but no country has implemented a long-term solution.

Nuclear power lacks a social licence. Few Australians support nuclear power, most oppose it, and most do not want to live near a nuclear power plant.

Nuclear power is often offline. While promoted as a reliable and consistent power source, nuclear power faces unplanned outages impacting power reliability and requiring other sources of flexibility.

Nuclear power is not needed. Renewable generation combined with demand management and storage can meet Australian energy needs. Australia needs flexible power not baseload. While some nuclear power plants operate with some flexibility, there are safety limits, as well as economic limits. Increasing renewable energy is already challenging nuclear power plants in existing countries.

Introduction

The House Committee on the Environment and Energy is currently undertaking an Inquiry into "the circumstances and prerequisites necessary for any future government's consideration of nuclear energy generation including small modular reactor technologies in Australia."[1]

It is common for nuclear power proponents to argue nuclear power 'could' be economically feasible if various conditions are met. For example, a spokesperson for Australian Nuclear Science and Technology Organisation (ANSTO) recently said

> If Australia did want to expand into nuclear energy technologies, there would be a number of options to consider in the future, including small modular reactors and Generation IV reactors, which **could be feasible if the policy, economic settings and technology were right and public support was in place**.[2]

Such statements draw attention to the wide range of preconditions *not* in place.

The Senate Inquiry's terms of reference include:

> a. waste management, transport and storage,
> b. health and safety,
> c. environmental impacts,
> d. energy affordability and reliability,
> e. economic feasibility,
> f. community engagement,
> g. workforce capability,
> h. security implications,
> i. national consensus[3]

The fundamental challenge facing nuclear power in Australia is economics.

While the other issues are considerable and important, even if they are addressed nuclear power would be challenged by its economics.

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[1] House Committee on the Environment and Energy (2019) *Terms of Reference – Nuclear Inquiry* https://www.aph.gov.au/Parliamentary_Business/Committees/House/Environment_and_Energy/Nuclearenergy/Terms_of_Reference

[2] Bold added, Latimer (2019) *Australia has 'missed the boat' on nuclear power* https://www.theage.com.au/business/the-economy/australia-has-missed-the-boat-on-nuclear-power-20180111-p4yyeg.html

[3] House Committee on the Environment and Energy (2019) *Terms of Reference – Nuclear Inquiry*

Indeed, addressing the many problems with nuclear power is a key reason why nuclear power plants are slow and costly to build, why costs have escalated over time, and why existing nuclear power generation has stagnated or gone backwards in many countries.

Establishing a nuclear power industry in Australia would be a very slow and costly endeavour. It would require large public subsidies. It is still entirely speculative whether new technologies can avoid the cost issues of previous generations. Nuclear power would likely face sustained public opposition. It is also unnecessary.

The Australia Institute is grateful for the opportunity to submit its views to the Committee. Hopefully following the Committee's comprehensive Inquiry, the national debate on nuclear energy can be settled once and for all.

Nuclear power is expensive

New build nuclear power costs more than other forms of new electricity generation. Renewable energy is the cheapest form of new generation in Australia.

"Nuclear new-build is simply not competitive under ordinary market economy rules anywhere."[4]

That is according to the 2018 *World Nuclear Industry Status Report* (WNISR), a comprehensive independent analysis of global nuclear reactor construction, operation and decommissioning, endorsed by the Bulletin of Atomic Scientists.

The high costs of nuclear power are widely recognised throughout the peer-reviewed academic literature as the main obstacle to new-build nuclear energy.[5] Even many nuclear advocates acknowledge nuclear power is prohibitively expensive.[6]

A recent paper modelled new build nuclear energy under a wide range of reactor costs and revenues. It found that "nuclear energy is never profitable".[7] It relies everywhere on state intervention and significant public finance.

Nuclear reactors and associated supply chains are large and complex. They are potentially very dangerous and so must comply with comprehensive safety regulation.

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[4] Schneider and Froggatt (2018) *The World Nuclear Industry Status Report 2018,* p 25. https://www.worldnuclearreport.org/IMG/pdf/20180902wnisr2018-lr.pdf

[5] Cooper (2014) *Small modular reactors and the future of nuclear power in the United States*, in *Energy Research & Social Science* vol.3 pp 161–177 https://doi.org/10.1016/j.erss.2014.07.014

Khatib and Difiglio (2016) *Economics of nuclear and renewables* in *Energy Policy,* vol.96. pp 740-750. https://doi.org/10.1016/j.enpol.2016.04.013

Thomas (2019) *Is it the end of the line for Light Water Reactor technology or can China and Russia save the day?* in *Energy Policy*, vol.125, pp 216-226 https://doi.org/10.1016/j.enpol.2018.10.062

[6] Morgan et al. (2018) *US nuclear power: The vanishing low-carbon wedge*, in *Proceedings of the National Academy of Sciences,* vol. 115, no.28, pp 7184-7189 https://www.pnas.org/content/115/28/7184

Gattie (2018) *A strategic policy framework for advancing U.S. civilian nuclear power as a national security imperative* in The Electricity Journal https://doi.org/10.1016/j.tej.2017.12.002

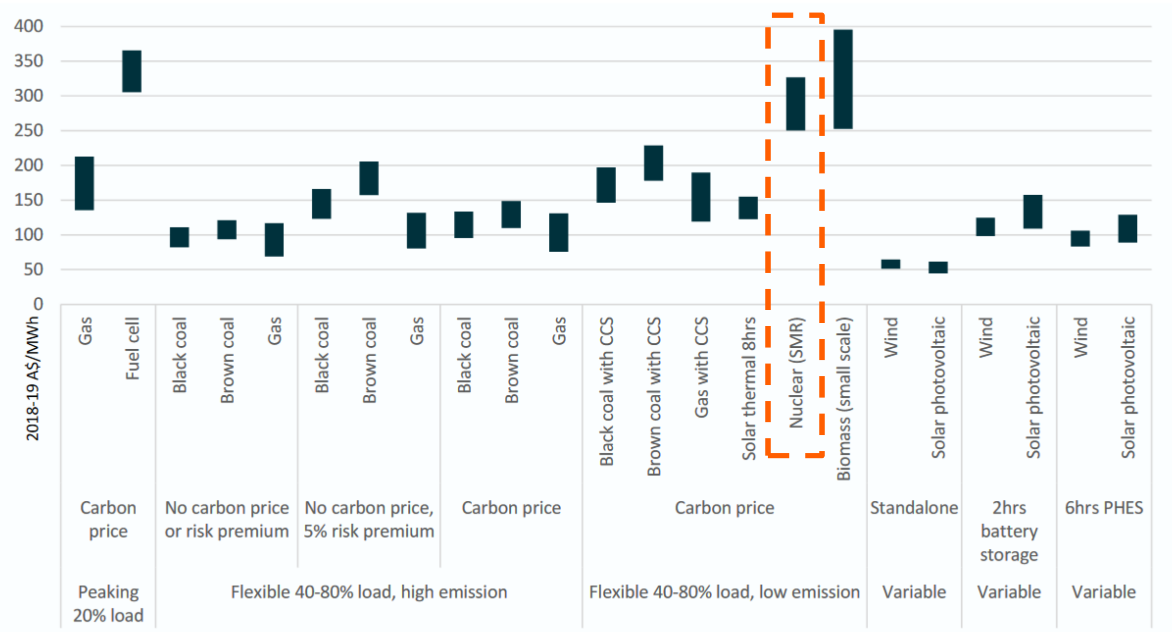
[7] Wealer et al. (2019) *High-Priced and dangerous: nuclear power is not an option for the climate-friendly energy mix*, DIW Weekly Report. https://www.diw.de/documents/publikationen/73/diw_01.c.670581.de/dwr-19-30-1.pdf

Reactors take a long time to build. Construction times and costs frequently blow out. They require extensive government support. Even existing reactors in existing nuclear power states are struggling. This should serve as an economic warning to Australia.

The 'levelised cost of energy' (LCOE) is a common approach to compare the cost of power from different forms of generation. LCOE essentially divides all up-front and operational costs by the units of electricity generated over the project's economic life.

In Australia, the *GenCost 2018* report from CSIRO and the Australian Energy Market Operator (AEMO) assess LCOEs for new build generation presently and in future decades. They find solar and wind are the lowest cost new generation and nuclear power is among the highest. Nuclear power is at least twice as expensive as even solar thermal with 8 hours of storage in each of the decades forecast.[8]

Figure 1: *LCOE by technology and category for 2020* (CSIRO & AEMO), nuclear orange



Source: Modified from CSIRO and AEMO (2018) *GenCost 2018,* p 28

The South Australian *Nuclear Fuel Cycle Royal Commission* found "Nuclear power generation would not be commercially viable in SA under current market rules".[9] This conclusion held under a range of wholesale electricity prices,[10] under a strong carbon

[8] Graham et al. (2018) *GenCost 2018,* CSIRO and AEMO. https://publications.csiro.au/rpr/pub?pid=csiro:EP189502

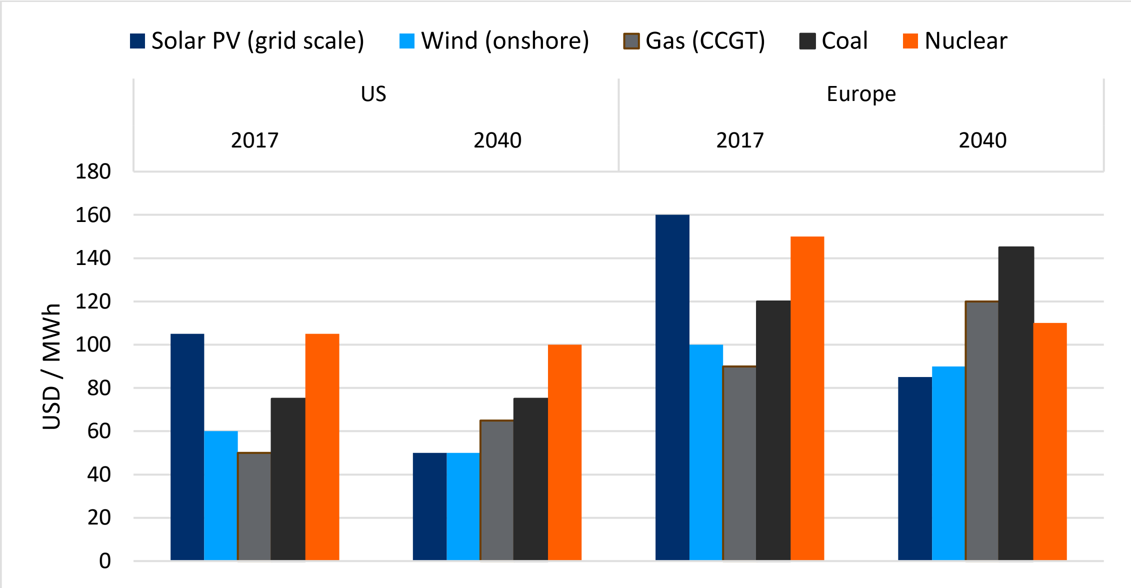
[9] Government of South Australia (2016) *Nuclear Fuel Cycle Royal Commission Report,* p 55. http://nuclearrc.sa.gov.au/

[10] Ibid, p 57, para 7.

price,[11] for proposed new small reactor designs,[12] under expanded interconnection capacity to other states,[13] and under a range of demand scenarios.[14]

A range of authoritative analyses show the LCOE for nuclear energy, in countries like Australia where there are existing nuclear industries, is higher than other energy sources. LCOEs estimated by the International Energy Agency (IEA) are shown for 2017 and projected to 2040, in Figure 2.

Figure 2: LCOEs for energy generation in US and Europe, IEA WEO 2018



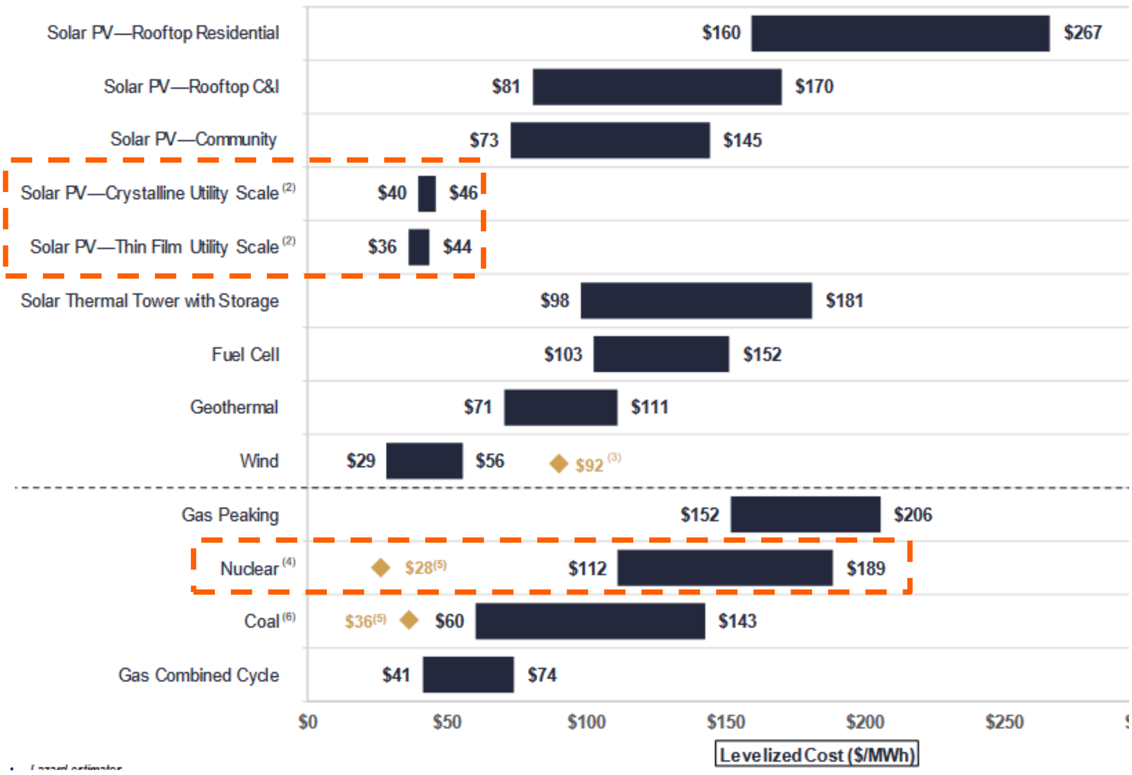
Source: IEA (2018) *WEO,* Appendix 2

Note the IEA's 2017 LCOEs for solar are far higher than other sources and than observed in Australia. IEA's solar projections have for nearly two decades systematically underestimated uptake in the very next year.[15]

[11] Ibid.
[12] Ibid, p 58, para 2.
[13] Ibid, p 58, para 6.
[14] Ibid, p 57, para 7.
[15] Hoekstra et al (2017) *Creating Agent-Based Energy Transition Management Models That Can Uncover Profitable Pathways to Climate Change Mitigation,* in Complexity.

Lazard's LCOE analysis shows nuclear power in the US is far more costly than other sources of energy. Despite being generally operated as baseload, it can be as costly as 'peaking gas' generation.[16] Note Lazard's utility solar LCOEs are *much* lower the IEA's; they are based on recently financed projects.

Figure 3: LCOEs for US generation, unsubsidised, Lazard 2018



Source: Lazard (2018) *Levelized Cost of energy Analysis,* p 2

Lazard also finds utility scale solar PV with storage has a lower LCOE of $108-$140/MWh, equal to or lower than nuclear power, and falling.

Bloomberg New Energy Finance projects cost reductions in solar, wind and batteries driving a large increase in renewables to 62% of global electricity by 2050. Nuclear energy declines slightly as a share of the energy mix.[17] This is under current policies and does not account for future policy.

[16] Lazard (2018) *Lazard's Levelized Cost of Energy analysis.* https://www.lazard.com/media/450784/lazards-levelized-cost-of-energy-version-120-vfinal.pdf
[17] Bloomberg New Energy Finance (2019) *New Energy Outlook 2019.* https://about.bnef.com/new-energy-outlook/

CARBON PRICE NECESSARY, NOT SUFFICIENT

One way of providing policy support to nuclear power is through a carbon price. The Australian Nuclear Association, a peak group for nuclear science and technology in Australia, said reactors “don’t stack up in the current environment unless you have got some direct government intervention or a carbon price.”[18]

Few nuclear political proponents of nuclear power in the current debate are advocating for the introduction of a carbon price.

A carbon price would benefit nuclear over fossil energy, but it would also accelerate uptake of renewables and storage. Renewables and storage are being deployed now and are likely to continue to get cheaper. A carbon price would reduce the opportunity for nuclear even further.

[18] Martin (2019) *Nuclear power doesn’t stack up without a carbon price, industry group says.*

Nuclear is slow to build, often delayed and faces cost blowouts

A nuclear power plant in Australia could take a decade or more to build. First there would need to be long process to establish regulation, skills and supply chains.

Long construction times and delays have plagued the nuclear industry throughout its history. This is a major factor behind cost blowouts. Remedial actions required to fix issues increase costs. Construction delays also increase financing costs as interest accumulates without revenue being earned to pay down debt.

All large infrastructure projects are prone to construction and cost blowouts, but nuclear blowouts are particularly widespread and costly.

Two-thirds of all nuclear power plants currently under construction are already delayed, and nearly half of those had seen *increased* delays in the year to 2017-18.[19]

Nearly all nuclear plants experience cost blowouts. Pressure to avoid delays may itself be a reason costs blow out.[20]

Reactors completing construction over the last decade took on average 10 years to build. Construction times ranged from 4.1 years to 43.5 years.[21]

These figures exclude the many power plants under construction, which have been under construction for 6.5 years on average, with many far from finished.[22] It also excludes the many builds that were cancelled, causing large losses. The figures may also exclude years of design, government and financing negotiations and other preparation.

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[19] Schneider and Froggatt (2018) *The World Nuclear Industry Status Report 2018,* p 18. https://www.worldnuclearreport.org/IMG/pdf/20180902wnisr2018-lr.pdf
[20] Sovacool et al. (2014) "Construction cost overruns and electricity infrastructure: an unavoidable risk?" in *The Electricity Journal*, vol.27 no.4, pp 112-120.
[21] Schneider and Froggatt (2018) *The World Nuclear Industry Status Report 2018.* https://www.worldnuclearreport.org/IMG/pdf/20180902wnisr2018-lr.pdf
[22] Schneider and Froggatt (2018) *The World Nuclear Industry Status Report 2018.* https://www.worldnuclearreport.org/IMG/pdf/20180902wnisr2018-lr.pdf

Given a commercial nuclear generator has never been constructed in Australia, it is likely that build times in Australia would be above the global average.

There would also be a lengthy regulatory debate prior to allowing a project to begin. It is not a matter of simply removing the legislative ban.

Well before a generator starts construction, the Australian government would need to draft and consult on a robust legislative and regulatory framework to regulate the generators and all parts of the supply chain, as well as third-party liability coverage. This would need to be reviewed and passed through Parliament.

There would be extensive public debate about this regulation and public debate about where nuclear power generators would be located. There would need to be financial mechanisms to ensure funding for decommissioning, remediation, monitoring and closure of plants.[23]

Companies and governments would also have to develop the required skilled workforce and supply chains or attract them from overseas.

In short, nuclear power generation for Australia, even with the subsidies required, is not a realistic option for more than a decade and possibly not even for the next.

[23] Government of South Australia (2016) *Nuclear Fuel Cycle Royal Commission Report,* p 106. http://nuclearrc.sa.gov.au/

Nuclear costs escalate over time

Nuclear power generation has a history of becoming more expensive rather than less.

Energy technologies typically become cheaper as they are deployed, due to economies of scale, learning effects and market competition. Nuclear energy has proven different.

One reason for the escalating costs are evolving safety requirements. Another is changing designs. More fundamentally, the industry consists of a small number of large vendors selling a small number of large and very complex assets, which vary in design and must be customised for national and local contexts.[24] In contrast, solar panels are highly modular, mass-produced and quick to deploy, which is driving rapid cost reductions.

There is a sizable literature on nuclear cost escalation:

- In the US, following the early nuclear boom, evolving safety regulation over the 70s and 80s lead to enormous increases in construction costs.[25]
- In France, small cost reductions over deployment of reactor designs were overwhelmed by increases in the move to the next design, or "negative learning by doing."[26]
- Escalation in construction costs occurred in Canada, Germany and India,[27] and in the UK.[28]
- In recent years the LCOE of new-build nuclear in the US has increased again. Lazard finds nuclear LCOEs fell to $95/MWh in 2011 but then rose again to $151/MWh in 2018.[29] At the same time, solar and wind LCOEs plummeted to

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[24] Cooper (2014) *Small modular reactors and the future of nuclear power in the United States* in *Energy Research & Social Science* vol.3 pp 161–177

[25] Lovering, et al. (2016) *Historical construction costs of global nuclear power reactors.* in *Energy Policy*, *91*, p 371

[26] Grubler (2010) *The costs of the French nuclear scale-up: A case of negative learning by doing.* In *Energy Policy*, vol.38 no.9, pp 5174-5188.
Rangel and Lévêque (2013) *Revisiting the Nuclear Power Construction Costs Escalation Curse.* in *International Association for Energy Economics.* http://i3.cnrs.fr/en/workingpaper/revisiting-the-cost-escalation-curse-of-nuclear-power-new-lessons-from-the-french-experience/

[27] Lang (2017) *Nuclear Power Learning and Deployment Rates; Disruption and Global Benefits Forgone* in *Energies* 10, 2169. Doi:10.3390/en10122169

[28] Harris et al. (2011) "Cost estimates for nuclear power in the UK", in *Energy Policy.* https://www.sciencedirect.com/science/article/pii/S030142151300774X

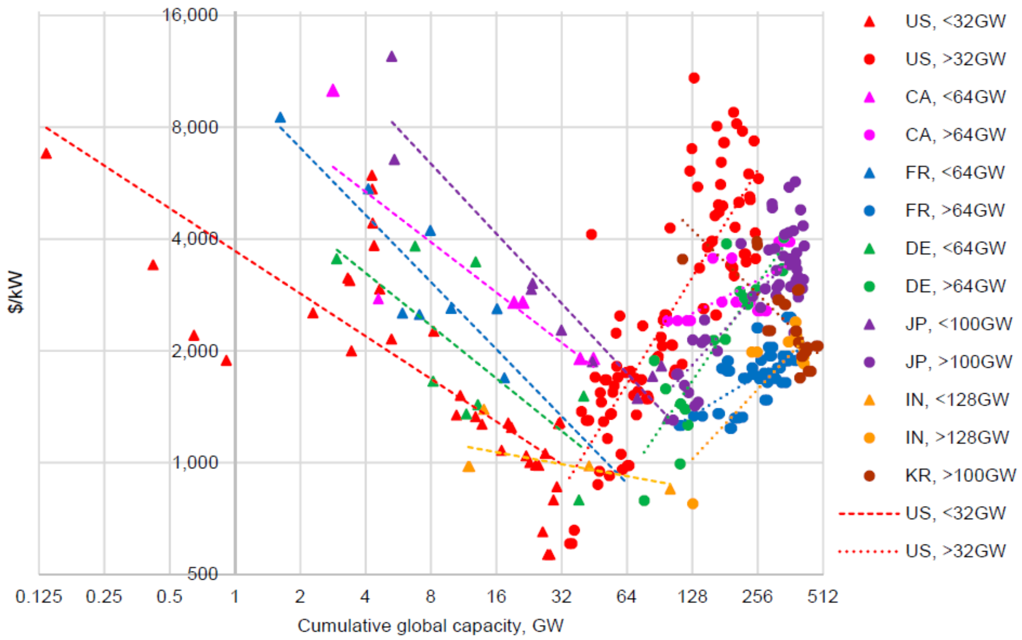
[29] Lazard (2018) *Lazard's Levelized Cost of Energy analysis.* https://www.lazard.com/perspective/levelized-cost-of-energy-and-levelized-cost-of-storage-2018/

$42/MWh and $43/MWh respectively. So too has solar firmed with lithium battery storage, delivering LCOEs of $108-$140/MWh, undercutting nuclear.

- In Japan, there was significant cost escalation from 1975 to 1980, during a period of design improvement, followed by stagnation over three decades since.[30]

Figure 4 below shows construction costs are shown in terms of global installed capacity.[31] While most energy sources get cheaper as more is installed, nuclear energy experienced a dramatic reversal, increasing in most countries as more was installed.

Figure 4: Nuclear overnight construction costs by country, by global capacity

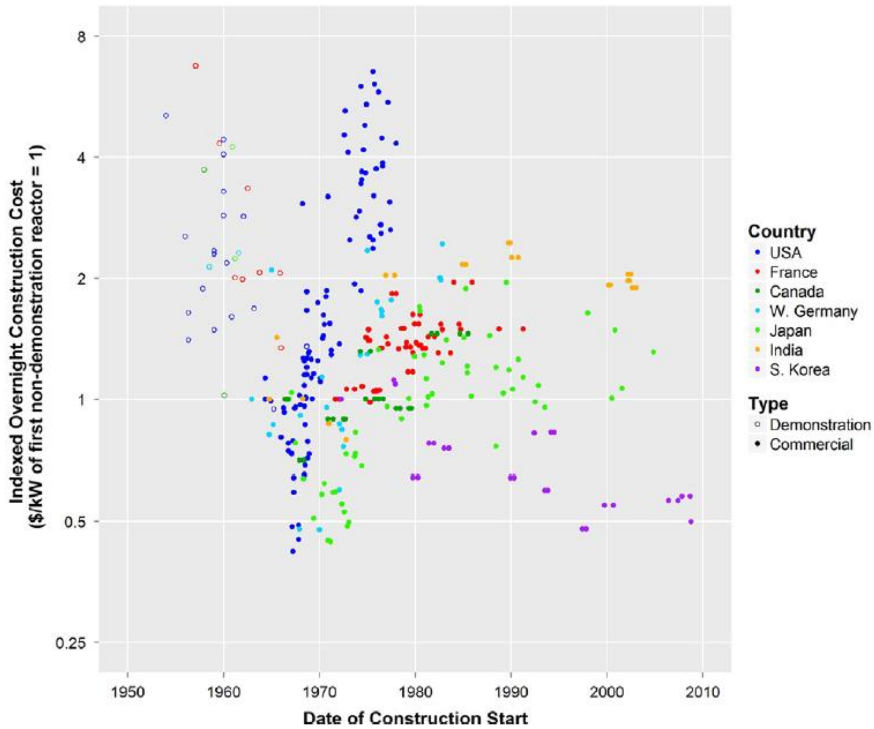


Source: Lang (2017) *Nuclear Power Learning and Deployment Rates; Disruption and Global Benefits Forgone*

Lovering et al. present similar data, in chronological form.[32] The graph clearly shows dramatic cost escalation in all these key countries other than South Korea; the cost escalation has been most extreme in the United States.

[30] Matsuoab and Neib (2019) *An analysis of the historical trends in nuclear power plant construction costs: The Japanese experience,* in *Energy Policy,* vol.124, pp 180-198
[31] Lang (2017) *Nuclear Power Learning and Deployment Rates; Disruption and Global Benefits Forgone*
[32] Lovering, et al. (2016) *Historical construction costs of global nuclear power reactors*

Figure 5: Nuclear overnight construction costs by country, over time



Source: Lovering et al. (2016) *Nuclear Power Learning and Deployment Rates; Disruption and Global Benefits Forgone*, Figure 11

Based on such data, Lovering et al. seek to challenge claims about cost escalation:

> trends in costs have varied significantly in magnitude and in structure by era, country, and experience. In contrast to the rapid cost escalation that characterized nuclear construction in the United States, we find evidence of much milder cost escalation in many countries, including absolute cost declines in some countries and specific eras.[33]

This is a poor outcome of decades of technological development and deployment.

The above graphs display 'overnight construction costs' (OCC) which excludes financing costs. Nuclear plants are capital intensive and prone to delays, which results in financing blowing out. As a result, it is a poor guide to how much nuclear power actually costs to build.

As others argue "there is simply no economic basis" for excluding "cost of capital and the construction duration".[34] Including financing shows even greater cost escalation.

[33] Lovering, et al. (2016) *Historical construction costs of global nuclear power reactor,* p 371
[34] Koomey et al. (2017) *A reply to Historical construction costs of global nuclear power reactors,* in *Energy Policy*, vol.102, p 640

Cautionary tale: UK's *Hinkley C*

Hinkley Point C power station (Hinkley), the first new nuclear plant to be built in the United Kingdom in three decades, is a powerful case study of delays and cost blowouts.

The UK government granted the licence in 2012.[35] The project has already suffered numerous delays and cost blow outs.[36] Construction began in 2018. It is currently due for completion in 2026.

The project enjoys substantial subsidy, which has also blown out. In 2013 the UK Government's estimated the cost to consumers at £6bn over the life of the project.[37] In 2015, the projected whole of life cost was £14.5bn.[38] Just one year later Government projections had the cost ballooning to £37.0bn.[39] By 2017 the Audit Office found the cost to consumers could be as high as £50bn over its operation.[40]

Hinkley's developers are guaranteed a strike price of (£92.50/MWh) for all electricity sold to the market over a 35-year term, via a Contract for Difference, negotiated between the UK Government and the developers.[41] This is more than double the current average wholesale price in the UK, and more than a third higher than the highest monthly average price over the last decade.[42]

The UK National Audit Office found this strike price higher than the price needed for all alternative large-scale renewable power sources in the mid-2020s, including offshore

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[35] BBC (2012) *Hinkley Point nuclear station: Licence granted for site.* https://www.bbc.co.uk/news/uk-england-somerset-20499033
[36] Ambrose (2017) *Cost of Hinkley Point nuclear plant climbs another £1.5bn to over £20bn, as project faces further delay.* https://www.telegraph.co.uk/business/2017/07/03/hinkley-nuclear-costs-climb-almost-20bn-start-delayed/
[37] Ambrose (2018) *Hinkley Point's cost to consumers surges to £50bn.* https://www.telegraph.co.uk/business/2017/07/18/hinkley-points-cost-consumers-surges-50bn/
[38] United Kingdom Government (2015) *DECC Government Major Projects Portfolio data 2015.* https://www.gov.uk/government/publications/decc-government-major-projects-portfolio-data-2015
United Kingdom Government (2016) *DECC Government Major Projects Portfolio data 2016.*
[39] https://www.gov.uk/government/publications/decc-government-major-projects-portfolio-data-2016
[40] Ambrose (2018) *Hinkley Point's cost to consumers surges to £50bn.* https://www.telegraph.co.uk/business/2017/07/18/hinkley-points-cost-consumers-surges-50bn/
[41] United Kingdom Department of Energy and Climate Change and National Audit Office (2016) *Nuclear Power in the UK,* p 32. https://www.nao.org.uk/wp-content/uploads/2016/07/Nuclear-power-in-the-UK.pdf
[42] Ofgem (2019) *Electricity prices: Day-ahead baseload contracts – monthly average (GB).* https://www.ofgem.gov.uk/data-portal/all-charts/policy-area/electricity-wholesale-markets

wind, onshore wind, and large scale solar; the cost of these technologies has fallen further since the contract was first negotiated.[43]

Scientists from Sussex University argue the project is being used to cross subsidise nuclear military capability.[44]

[43] United Kingdom Department for Business, Energy and Industrial Strategy and National Audit Office (2016) *Hinkley Point C,* p 38.
https://www.nao.org.uk/wp-content/uploads/2017/06/Hinkley-Point-C.pdf
[44] Watt (2017) *Electricity consumers 'to fund nuclear weapons through Hinkley Point C'.*
https://www.theguardian.com/uk-news/2017/oct/12/electricity-consumers-to-fund-nuclear-weapons-through-hinkley-point-c

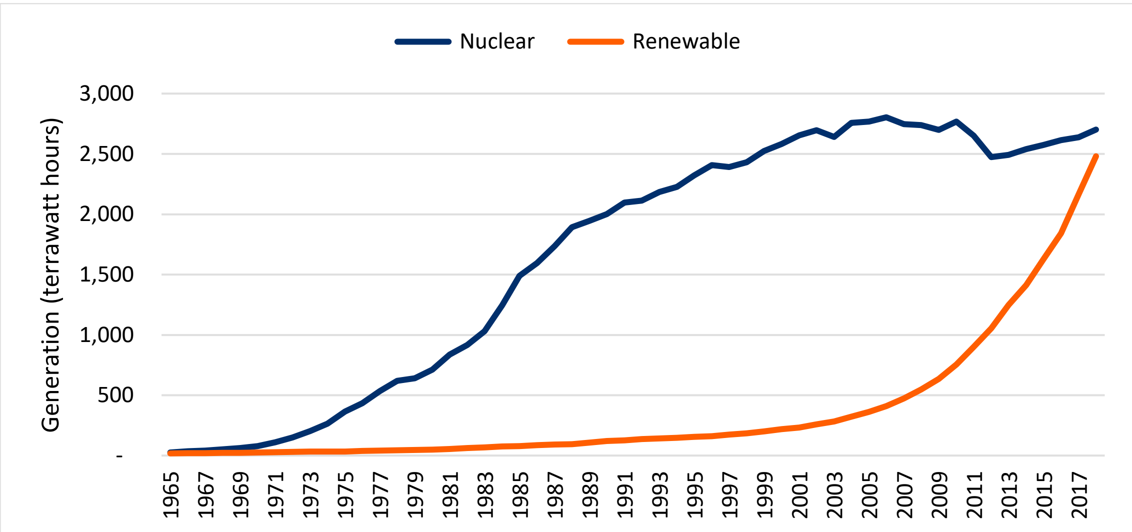
Nuclear power is stagnating or going backwards in existing countries

The global nuclear reactor fleet is aging, few reactors are being built, nuclear companies are going bankrupt or face distress, generation is flat globally, and flat or declining in many nuclear nations.

As a share of global generation, nuclear power has fallen from 17% in 2000 to 10% in 2017.[45] Installations are far below previous decades and plants are closing.

The current global average age of operational nuclear reactors is 30.1 years. Most are over 30 years old. The operational fleet is getting older, with the average age up from 29.3 years in mid-2016.[46] Operating reactors are on average even older than those that have been shut down (25.4 years). The net result is that generation is largely flat.

Figure 6: Global nuclear vs renewable generation



Source: BP (2019) *World Energy Statistics*

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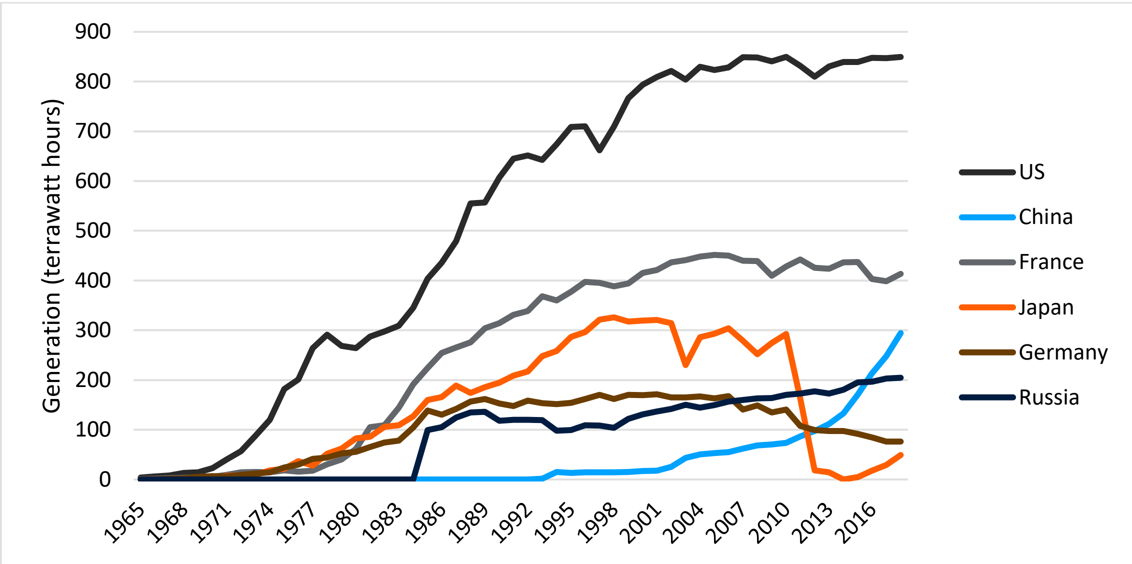
[45] IEA (2018) *WEO*, p 292

[46] Schneider and Froggatt (2018) *The World Nuclear Industry Status Report 2018*

As shown above, the flattening out of global nuclear power generation was punctuated by a sudden decline following Japan's Fukushima disaster and a more recent increase due to new builds in China. Outside of China, nuclear power generation has been flat since 2012. At the same time, there has been a dramatic global increase in renewable energy, which doubled over the last five years and will soon to surpass nuclear generation. This is shown below.

Figure 7 shows nuclear generation in selected countries.

Figure 7: Nuclear generation in selected countries



Source: BP (2019) *World Energy Statistics*

The US launched the nuclear power era in the 1970s and remains the country with the largest total nuclear generation. France has the second largest nuclear generation and has the highest share of nuclear in its electricity mix. Together these countries make up around half of world nuclear generation.

In both US and France, nuclear generation has been flat for two decades, reactors are aging, the industry faces rolling financial crisis and debates focus on whether and how much taxpayer funding to spend to keep the industry going.

In France the average age of operational reactors is now 33 years, while in the US it is 38 years.[47] US reactors are generally licensed for 40 years but some have been extended to 60 years.

[47] Schneider and Froggatt (2018) *The World Nuclear Industry Status Report 2018,* France/US profiles

In the US, the nuclear industry has recently seen the bankruptcy of the Westinghouse Electric Company, a major vendor; the public bail out of two Ohio nuclear plants;[48] the abandonment of the VC Summer plant in 2017 costing the American public billions;[49] and government subsidies to many nuclear plants to keep them afloat.[50] In recent years between a quarter to over half of the US nuclear fleet has been loss making.[51]

In France, following the bankruptcy of AREVA, the majority state-owned nuclear company, the French Government aims to cut electricity produced by nuclear reactors from 75% of total generation to 50% by 2035, and to increase renewable generation.[52] Electricite de France, the publicly owned French utility operating an aging nuclear fleet, is in financial distress and seeking to address this by focusing instead on renewables.[53]

Japan is still struggling to increase its nuclear generation, after the industry was shut down following the Fukushima disaster. A key part of Japan's response to this crisis was a large national energy efficiency program. Japanese nuclear energy generation in 2018 was only at around 17% of pre-Fukushima levels.[54]

Germany announced plans in 2011 to phase out all its nuclear power stations by 2022.[55] Switzerland banned construction of new nuclear power plants as the result of a 2017 referendum.[56]

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[48] Denning (2019) *Ohio's Nuke and Coal Bailout: Throwback Mountain*. https://www.bloomberg.com/opinion/articles/2019-07-24/ohio-house-bill-6-is-a-trip-to-throwback-mountain
[49] Crees (2019) *The failed V.C Summer nuclear project: A timeline*. https://www.chooseenergy.com/news/article/failed-v-c-summer-nuclear-project-timeline/
[50] Schneider and Froggatt (2018) *The World Nuclear Industry Status Report 2018,* p 100
[51] Polson (2017) *Half of America's Nuclear Power Plants Seen as Money Losers.* https://www.bloomberg.com/news/articles/2017-06-14/half-of-america-s-nuclear-power-plants-seen-as-money-losers
Loh (2018) *One-Fourth of U.S. Nuclear Plants Are at Risk of Early Retirement.* https://www.bloomberg.com/news/articles/2018-05-15/one-fourth-of-u-s-nuclear-fleet-is-at-risk-of-early-retirement
[52] Louet and White (2018) *France to cut nuclear energy reliance by 2035: minister*. https://www.reuters.com/article/us-france-nuclearpower/france-to-cut-nuclear-energy-reliance-by-2035-minister-idUSKCN1NN0OK
[53] Trentmann (2019) *French Nuclear Power Producer EDF Plans a Turnaround*. https://www.wsj.com/articles/french-nuclear-power-producer-edf-plans-a-turnaround-11560526991
[54] BP (2018) *Statistical Review of World Energy.* https://www.bp.com/en/global/corporate/energy-economics/statistical-review-of-world-energy.html
[55] BBC (2011) *Germany: Nuclear power plants to close by 2022.* https://www.bbc.com/news/world-europe-13592208
[56] BBC (2017) *Switzerland votes to phase out nuclear power.* https://www.bbc.com/news/world-europe-39994599

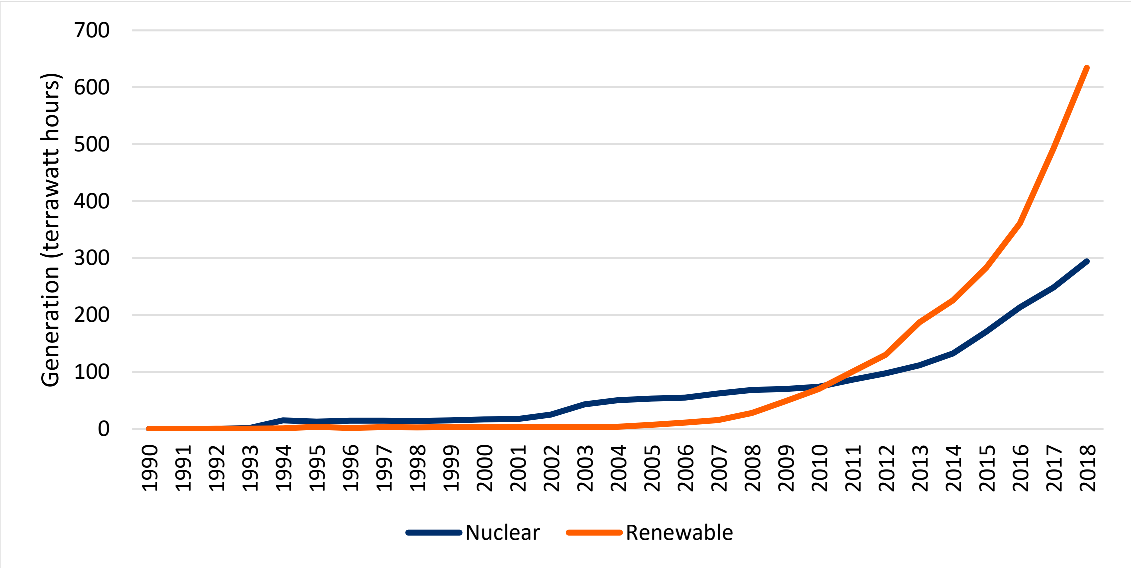
The UK is among few OECD countries seeking to increase nuclear generation. The only project under construction, Hinkley C, has been delayed, is grossly over budget and will cost consumers vast sums.[57] This is discussed above.

China has set ambitious nuclear power targets. 31 power stations have become operational in the last 10 years. However, following Fukushima, no new permits were granted resulting in no new construction post 2016. An article in MIT Technology Review reported

> Officially China still sees nuclear power as a must-have. But unofficially, the technology is on a death watch. Experts, including some with links to the government, see China's nuclear sector succumbing to the same problems affecting the West: the technology is too expensive, and the public doesn't want it.[58]

Since 2010 China has increased renewable energy generation at twice the rate of nuclear power. It now generates over twice as much renewable as nuclear power.

Figure 8: Power generation in China – nuclear vs renewables



Source: BP (2019) *World Energy Statistics*

[57] Green (2019) *Nuclear power exits Australia's energy debate, enters culture wars*. https://reneweconomy.com.au/nuclear-power-exits-australias-energy-debate-enters-culture-wars-47702/

[58] Fairly (2018) *China's losing its taste for nuclear power. That's bad news.* https://www.technologyreview.com/s/612564/chinas-losing-its-taste-for-nuclear-power-thats-bad-news/

New nuclear power technologies are economically speculative

"Small modular reactors" and "generation IV" technologies are far from being deployed. SMRs face numerous inefficiencies, the claimed cost benefits are doubtful, and many analysts are sceptical, despite differing views on nuclear per se. Other new technologies are even further off. Amongst the OECD, nuclear RD&D funding has declined dramatically.

Proponents of nuclear power who accept it is challenged by high costs often point to future costs for "small modular reactors" (SMRs) and "generation IV" reactors.[59]

These technologies remain economically speculative. There is no guarantee they will become available or reduce costs. SMRs or Gen IV reactors would have to show they are different to previous generations, which have been plagued by delays, cost blowouts and cost escalation. There are many reasons to doubt this.

SMRS

SMRs are under construction or have been recently completed in Russia, China and Argentina.[60] Like other forms of nuclear power, these have seen construction delays and cost blow outs.[61]

While touted as new technologies, SMRs have roots in US R&D of the 1950s.[62] Enthusiasm resurged many times since then and vendor hype about SMRs has been with us for decades. [63]

[59] Thomas (2019) *Is it the end of the line for Light Water Reactor technology or can China and Russia save the day?* https://www.sciencedirect.com/science/article/pii/S030142151830716X
[60] EFWG (2018) *Economic and Finance Working Group – Canadian SMR Roadmap*, p 13. https://smrroadmap.ca/wp-content/uploads/2018/12/Economics-Finance-WG.pdf
[61] Green (2019) *SMR cost estimates, and costs of SMRs under construction.* https://wiseinternational.org/nuclear-monitor/872-873/smr-cost-estimates-and-costs-smrs-under-construction
[62] See Weinberg (1956) *Today's Revolution,* in *Bulletin of the Atomic Scientists*, vol.12 no.8, pp 299–302.
[63] Cooper (2014) *Small modular reactors and the future of nuclear power in the United States*

The key promise of small modular reactors is reduced costs through standardisation and economies of scale. They would be factory produced and then deployed more quickly in smaller increments. This will bring about learning effects, simplify construction and enable more favourable financing to bring down costs.

SMRs in fact face numerous and substantial *diseconomies* of scale.[64]

In past decades, small reactors for civilian power generation have been built in many countries – but as demonstration plants, used as stepping stones towards larger, more efficient reactors. "Economics killed small nuclear power plants in the past—and probably will keep doing so".[65] Reactors grew to take advantage of economies of scale, including in material efficiency staffing, safety measures and control systems.

The inefficiencies from being *small* are supposed to be outweighed by the efficiencies of being *modular*. However, in many ways the inefficiencies of scale are amplified. To begin with, a reactor factory is itself a colossal investment requiring a huge financial commitment. The problems of financing large complex assets and the risks of cost blowouts is moved from the individual plant up to the level of the factory.[66]

Securing finance for the factory would in turn require a large order book upfront. Even large vendors like Westinghouse have been unable to secure such orders. Unless many such factories are built, competitive pressures within the industry are likely to be weak.

The economic model for SMRs depends on standardisation across markets of both designs and of regulation. This is something the industry has not to date been able to achieve.[67] It is unclear why smaller reactors would produce a different result.

SMRs promise lower risks from being smaller and from some designs having new 'passive' safety features. SMRs are also claimed reduce safety requirements for site-specific customisation. The hope is such features will reduce regulatory costs.

The claims remain completely untested in practice, and indeed largely untested by regulators. The first SMR design was submitted for licensing in the US in 2017 and the

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[64] Cooper (2014) *Small modular reactors and the future of nuclear power in the United States*
[65] Ramana (2015) *The Forgotten History of Small Nuclear Reactors,* in *IEEE Spectrum,* https://spectrum.ieee.org/tech-history/heroic-failures/the-forgotten-history-of-small-nuclear-reactors
[66] Cooper (2014) *Small modular reactors and the future of nuclear power in the United States*
[67] Wealer et al. (2019) *High-Priced and dangerous: nuclear power is not an option for the climate-friendly energy mix*, in *DIW Weekly Report*. https://www.diw.de/documents/publikationen/73/diw_01.c.670581.de/dwr-19-30-1.pdf

safety review is still ongoing;[68] three other designs are still in pre-application stages.[69] In Canada the first design was submitted for licensing in April 2019.[70]

SMR vendors and proponents are seeking regulatory changes to reduce operator liability and other safety regulations to make them "risk appropriate" or less stringent.[71] Formal regulatory processes are only now starting to consider these issues.

In the US the National Resources Council has ruled it will consider smaller 'emergency planning zones' for SMRs based on a "dose-based, consequence-oriented methodology"; it is still to decide on what zoning will apply.[72]

SMR proponents will need to seek the loosening of numerous safety regulations in this way. It is still unclear what if any regulatory changes will be prudent, or socially acceptable. Changes that are in fact enacted will impact SMRs viability. As with earlier generations, later regulatory changes may be required, further increasing costs.

Widespread scepticism

Many who have examined the economics of SMRs remain sceptical of commercial deployment.

The IEA's 2018 benchmark *World Energy Outlook* does not even mention SMRs.[73]

A more recent IEA report on nuclear power says SMRs are "still at the development stage" and are not yet "technologically mature".[74]

Many scholars are forthright in their criticisms. One concludes "nuclear technology, large and small" has "dismal prospects" and finds it "unsurprising that SMR technology has stumbled getting to the starting gate." [75] Another: "Generation IV, and Small

[68] NRC (2019) *Application Review Schedule for the NuScale Design*. https://www.nrc.gov/reactors/new-reactors/design-cert/nuscale/review-schedule.html
[69] NRC (2019) *Small Modular Reactors (LWR designs).* https://www.nrc.gov/reactors/new-reactors/smr.html
[70] World Nuclear News (2019) *First Canadian SMR licence application submitted.* http://world-nuclear-news.org/Articles/First-Canadian-SMR-licence-application-submitted
[71] EFWG (2018) *Economic and Finance Working Group – Canadian SMR Roadmap*. https://smrroadmap.ca/wp-content/uploads/2018/12/Economics-Finance-WG.pdf
[72] NEI (2018) *NRC Staff Agrees SMRs won't need large EPZs.* https://www.nei.org/news/2018/nrc-staff-agrees-smrs-wont-need-large-epzs
[73] IEA (2018) *WEO* – search for "SMR" and "small modular"
[74] IEA (2019) *Nuclear Power in a Clean Energy System*
[75] Cooper (2014) *Small modular reactors and the future of nuclear power in the United States,* p 174

Modular Reactors are unproven and, at best, a long way from commercial deployment”.[76]

Writing in *Nuclear Engineering International* in 2015, one experienced consultant concluded

> unless the regulatory system in potential markets can be adapted to make their construction and operation much cheaper than for large [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.[77]

An interdisciplinary MIT study found fundamental grounds for scepticism:

> The [nuclear] industry's problem is not that it has overlooked valuable market segments that need smaller reactors. The problem is that even its optimally scaled [i.e. larger] reactors are too expensive on a per-unit-power basis. A focus on serving the market segments that need smaller reactor sizes will be of no use unless the smaller design first accomplishes the task of radically reducing per-unit capital cost.[78]

This comment is especially significant given the study’s broader recommendations about reducing nuclear costs by radically changing the way it plans, manages and builds projects. The report says these are preconditions for any nuclear viability and not an argument in favour of SMRs themselves.

The conclusion that SMRs are unlikely to be deployed commercially is reached begrudgingly even by those arguing for the climate benefits of nuclear:

> Our results reveal that while one light water SMR module would indeed cost much less than a large LWR, it is highly likely that the cost per unit of power will be higher… That vision of the dramatic cost reduction that SMR proponents describe is unlikely to materialize with this first generation of light water SMRs, even at *n*th-of-a-kind deployment.

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[76] Thomas (2019) *Is it the end of the line for Light Water Reactor technology or can China and Russia save the day?*

[77] Kidd (2015) *Nuclear myths – is the industry also guilty?*
https://www.neimagazine.com/opinion/opinionnuclear-myths-is-the-industry-also-guilty-4598343/

[78] Buongiorno et al (2018) *The Future of Nuclear Energy in a Carbon-Constrained World,* p 77.
https://energy.mit.edu/wp-content/uploads/2018/09/The-Future-of-Nuclear-Energy-in-a-Carbon-Constrained-World.pdf

> Because light water SMRs incur both this economic premium and the considerable regulatory burden associated with any nuclear reactor, we do not see a clear path forward for the United States to deploy sufficient numbers of SMRs in the electric power sector to make a significant contribution to greenhouse gas mitigation by the middle of this century.[79]

Even worse prospects in Australia

Existing nuclear states are still unclear how and how much it will cost to demonstrate and deploy SMRs. Australia is in an even poorer position.

The CSIRO and AEMO LCOE projections in Australia noted above include SMRs for nuclear power. They see SMRs remaining more costly than nearly all other sources out to 2040.[80]

In 2018 a group of Canadian utilities, research groups and governments published a ‘roadmap’ for deployment of SMRs in Canada. Economic analysis was conducted by the Economics and Finance Working Group (EFWG), which argues that SMRs could become economically feasible in Canada with substantial government support.[81]

The EFWG argues Canada can “lead” SMR because it has an existing nuclear industry,[82] and reducing costs will require deployment to start with utilities with nuclear power experience.[83]

Australia has neither. According to the Canadian SMR Roadmap, Australia lacks key preconditions for early deployment of SMRs.

The EFWG makes clear SMR technology is still yet to be demonstrated much less deployed:

> Before most SMRs can become commercially viable, the EFWG expects several years of necessary R&D, licensing, and demonstration. Thus, the economic comparison assumes an in-service date of 2030.[84]

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[79] Morgan et al. (2018) *US nuclear power: The vanishing low-carbon wedge,* in *Proceedings of the national Academy of Sciences of the USA.* https://www.pnas.org/content/115/28/7184
[80] CSIRO and AEMO (2018) *GenCost 2018,* pp 28-31. https://www.csiro.au/en/News/News-releases/2018/Annual-update-finds-renewables-are-cheapest-new-build-power
[81] EFWG (2018) *Economic and Finance Working Group – Canadian SMR Roadmap*. https://smrroadmap.ca/wp-content/uploads/2018/12/Economics-Finance-WG.pdf
[82] Ibid., p 36
[83] Ibid., p 29
[84] Ibid., p 16

Even on the EFWG's optimistic analysis, it is reasonable to conclude Australia cannot hope to build SMRs before 2030.

The report also emphasises the large government subsidies, 'risk sharing' and government coordination of 'fleet' development required to induce mass production, and that deployment is more feasible if entities do not have to pay tax.[85]

Despite this, the report uses 'mature' technology costs for its LCOE analysis for the first SMR build. This is just one of many problematic assumptions in the analysis.

GEN IV AND THORIUM

Beyond SMRs, advocates sometimes hold out hope for 'Gen IV' reactors, or thorium as a fuel source.

"Gen IV" is a term for a range of different technologies in various stages of development, some under development for many decades. In 2002 the Generation IV International Forum (GIF), a multilateral forum of nuclear power states, met and agreed to focus on six 'advanced' technologies. It was hoped these may increase efficiency, reduce safety issues and so reduce cost. A decade later, the GIF Technology Roadmap Update conceded reaching commercialisation according to "the original roadmap would have required a multi-year, multi-billion-dollar international commitment" which "was not the case".[86]

Thorium has been considered as a fuel source since the beginning of the nuclear age, however research focused instead on uranium due to its military applications. Since then thorium is touted periodically as an additional or alternative fuel source with possible efficiency, safety and non-proliferation benefits that "could" reduce costs.[87]

The OECD's Nuclear Energy Authority (NEA) outlines knowledge of thorium including possible new risks and vast unknowns. It warns against "simplistic" optimism: "development of new fuels or new reactor concepts is a time – and resource – consuming process likely to span several decades".[88]

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[85] Ibid., p 12

[86] GIF (2014) *Technology Roadmap Update for Generation IV Nuclear Energy Systems,* p 3. https://www.gen-4.org/gif/upload/docs/application/pdf/2014-03/gif-tru2014.pdf

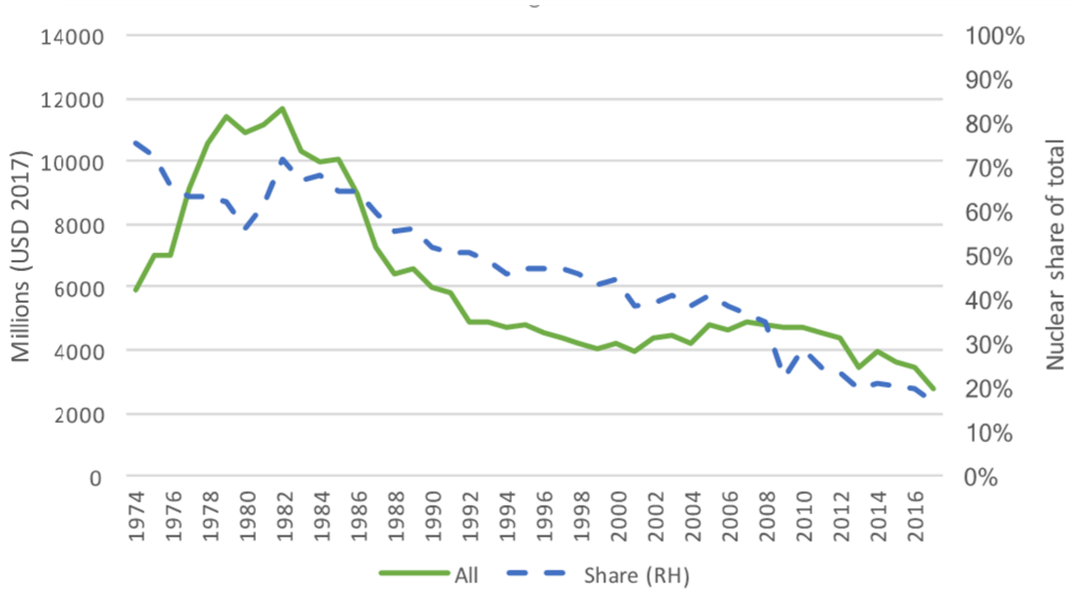
[87] Schaffer (2013) *Abundant thorium as an alternative nuclear fuel: Important waste disposal and weapon proliferation advantages,* in *Energy Policy*, vol.60, pp 4-12

[88] NEA (2015) *Introduction of Thorium in the Nuclear Fuel Cycle,* Nuclear Energy Agency No. 7224, OECD, p 111, https://www.oecd-nea.org/science/pubs/2015/7224-thorium.pdf

LOW OECD RD&D SPENDING ON NUCLEAR

OECD public spending on nuclear energy research, development and deployment (RD&D) was previously dominated by nuclear research but has steadily declined over many decades.[89]

Figure 9: OECD public energy RD&D in nuclear power technology



IEA (2018) *IEA Energy Technology RD&D Statistics*

OECD governments have clearly had other priorities.

Note also that the large increase in nuclear R&D in the late 1970s was the era of cost escalation in OECD countries.

Even with vastly more RD&D, deployment of these new technologies remains speculative, at best far off and not guaranteed.

[89] IEA (2018) *IEA Energy Technology RD&D Statistics*. https://www.oecd-ilibrary.org/energy/data/iea-energy-technology-r-d-statistics_enetech-data-en

Nuclear power is uninsurable

Financial service organisations will not insure against nuclear accidents, even in Australia where there are no nuclear power stations. If developers of nuclear power stations were forced to insure the full costs of nuclear accidents, nuclear power would be completely uncompetitive.

Nuclear power generation has high external costs. This includes future financial liabilities from decommissioning nuclear facilities and disposal of radioactive waste. There are also risks of health and environmental impacts from potential radioactive release.

While the chances of radioactive release are very low, the costs are potentially very high. For example, the Japan Centre for Economic Research calculated the clean-up and disposal following the Fukushima Daiichi Nuclear Power Plant accident will cost up to 80 trillion yen over 40 years (over $105 trillion Australian dollars).[90]

The financial sector is unwilling to insure against the full magnitude of these costs.

Most nuclear power states have laws limiting operator liability for nuclear accidents.[91] The limit means the commercial financial sector is willing to insure costs up to that limit. However, the limit acts as a subsidy: the taxpayer inevitably funds any residual costs or compensation.

In the wake of the Chernobyl nuclear accident, even taxpayers from other countries were forced to pay to reduce the spread of radioactivity.[92]

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[90] Japan Centre for Economic Research (2019) *Accident clean-up costs rising to 35-80 Trillion Yen in 40 years.* https://www.jcer.or.jp/english/accident-cleanup-costs-rising-to-35-80-trillion-yen-in-40-years

[91] For example, see the *Price-Anderson Indemnity Act* in the United States which caps the ceiling liability for power plant operators in the event of an accident and excuses the rest of the supply chain from liability. The US system became the model for other countries.
NRC (2018) *U.S. Nuclear Regulatory Comm'n, Backgrounder: Nuclear Insurance and Disaster Relief 1.* https://www.nrc.gov/docs/ML0327/ML032730606.pdf

[92] Wealer et al. (2019) *High-Priced and dangerous: nuclear power is not an option for the climate-friendly energy mix*, in *DIW Weekly Report*.
https://www.diw.de/documents/publikationen/73/diw_01.c.670581.de/dwr-19-30-1.pdf

A range of studies show liability limits are well below what is required to cover the risk. In 2011 a study, commissioned by the German Renewable Energy Foundation, calculated a risk-appropriate insurance premium to cover third-party liabilities from nuclear power disasters. Requiring insurance to cover the full liability and requiring payout to occur over the 100 years after a disaster would increase the price of nuclear energy by around $0.25-$4.00 per kWh. If the payout were over 10 years, it would increase prices by up to $100 per kWh.[93] A recent French study found "the corporate liability limit currently in force is likely to be inferior to the socially optimal level."[94]

To put this in perspective, in 2018 the Victorian government contracted for over 900 MW of wind and solar capacity at around $56 per MWh, $0.06 per kWh.[95]

If nuclear power operators were made to adequately insure against the risk of nuclear accidents, the insurance premium would make nuclear power utterly uncompetitive.

While Australia does not have a nuclear power generator it has operated reactors for some time for other purposes. It appears even these are uninsurable.

When the Open Pool Australian Lightwater (OPAL) reactor was first commissioned in 1999, the Commonwealth signed a Deed of Indemnity with the Australian Nuclear Science and Technology Organisation (ANSTO). Under the deed, the Commonwealth agreed to guarantee all damages that could be awarded against ANSTO, ANSTO officers and contractors, without limit.[96] Moreover, the Deed requires those seeking compensation to prove negligence, against international conventions on nuclear liability.

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[93] €0.14-€2.36 per kilowatt hour (kWh) based on a 100-year payout period, and up to €67.3 per kWh if paid out over 10 years. Note the report is from 2011. The nominal figures have been converted at the current exchange rate and have not been inflated.
Versicherungsforen Leipzig (2011) *Calculating a risk-appropriate insurance premium to cover third-party liability risks that result from operation of nuclear power plants.* https://www.versicherungsforen.at/portal/media/forschung/studienundumfragen/versicherungsprmiefrkkw/20111006_NPP_Insurance_Study_Versicherungsforen.pdf

[94] Louaas and Picard (2019) *Optimal nuclear liability insurance.* https://hal.archives-ouvertes.fr/hal-01996648/document

[95] Parkinson (2018) *Victoria to support six wind and solar farms after overwhelming response to auction.* https://reneweconomy.com.au/victoria-to-support-six-wind-and-solar-farms-after-overwhelming-response-to-auction-43989/

[96] Australian Nuclear Science & Technology Organisation (1999) *ANSTO Annual Report,* p 60. https://inis.iaea.org/collection/NCLCollectionStore/_Public/31/026/31026677.pdf?r=1&r=1

Tony Wood, former head of ANSTO's Division of Engineering and Reactors, criticised the Deed given "the [OPAL] EIS tells us that the worst accident would have trivial consequences and hence, a close-to-zero payout."[97]

The government indemnity suggests that the insurance industry took a different view.

Insurance policies from some of Australia's major insurers—AAMI, CGU, Allianz, QBE and NRMA—contain specific text regarding nuclear disasters. None of these major Australian insurers will insure your home, car or possession against a nuclear event.[98]

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[97] Tony Wood (2000) *Select Committee for an Inquiry into the Contract for a New Reactor at Lucas Heights*, Official Committee Hansard, p 143. https://www.aph.gov.au/binaries/hansard/senate/commttee/s4346.pdf

[98] Allianz (2017) *Home Insurance Product Disclosure Statement*, p 53. https://www.einsure.com.au/wb/public/openCurrentPolicyDocument/POL1085DIR/$FILE/POL1085DIR.pdf;
Allianz (2018) *Allianz car Insurance Product Disclosure Statement and Policy Document,* p 39. https://www.einsure.com.au/wb/public/openCurrentPolicyDocument/POL891DIR/$File/POL891DIR.pdf;
Allianz (2019) *Allianz Office Pack Policy Disclosure and Policy Document*, p 13. https://www.einsure.com.au/wb/public/openCurrentPolicyDocument/POL963BA_FI/$FILE/POL963BA_FI.pdf;
AAMI (2018) *Comprehensive Car Insurance Product Disclosure Statement,* p 24. https://www.aami.com.au/aami/documents/personal/car/comprehensive/pds-comprehensive-19-6-18.pdf;
AAMI (2018) *Home Contents Insurance Product Disclosure Statement,* p 44. https://www.aami.com.au/aami/documents/personal/home/pds-contents.pdf;
AAMI (2014) *Home Building Insurance Product Disclosure Statement,* p 38. https://www.aami.com.au/aami/documents/personal/home/pds-building.pdf;
AAMI (2017) *Business Insurance Policy Product Disclosure Statement and Policy Wording,* p 23. https://www.aami.com.au/aami/documents/business/business-insurance/pds-pol-word-business.pdf;
CGI (2019) *Motor Trade Insurance Product Disclosure Statement and Policy Booklet*, p 21. https://www.cgu.com.au/sites/default/files/media/personal/pds/motor_insurance_product_disclosure_statement.pdf;
CGI (2019) *Business Pack Insurance Policy*, pp 5-6. https://www.cgu.com.au/sites/default/files/media/business/pds/35a51640-6678-4640-90c6-e355e6db8a86_3.pdf;
CGI (2017) *Accidental Damage Home Insurance Product Disclosure Statement and Policy with Flood Cover,* p 27. https://www.cgu.com.au/sites/default/files/media/personal/pds/Premium_Cover_Accidental_damage_PDS.PDF;
NRMA (2019) *Motor Insurance Product Disclosure Statement and Policy Booklet,* p 58. https://www.nrma.com.au/sites/nrma/files/nrma/policy_booklets/motorcycle_pds_0519_all.pdf;
NRMA (2019) *Home and Contents Insurance Product Disclosure Statement and Policy Booklet,* p 65. https://www.nrma.com.au/sites/nrma/files/nrma/policy_booklets/home_pds_0219_nsw_act_tas.pdf;
NRMA (2018) *Business Insurance Product Disclosure Statement and Policy Booklet,* p 94. https://www.nrma.com.au/sites/nrma/files/nrma/policy_booklets/business_pds_1218_all.pdf;
QBE (2018) *Motor Vehicle Product Disclosure Statement & Policy Wording,* p 45. https://www.qbe.com/au/car-insurance/comprehensive-car-insurance;

For example, AAMI's *Home and Contents Insurance Product Disclosure Statement* provides:

> You are not covered under any section of your policy for damage, loss, cost or legal liability that is caused by, arises from or involves: …
>
> Radioactivity/nuclear materials
>
> - radioactivity or the use, existence or escape of nuclear fuel, nuclear material or waste; or
> - action of nuclear fission including detonation of any nuclear device or nuclear weapon; or
> - any action taken by a public authority to prevent, limit or remedy the actual or threatened release of any radioactive or nuclear materials;
> - any looting or rioting following these incidents.[99]

Even in Australia, even without a nuclear power industry, nuclear disasters are uninsurable.

QBE (2016) *Home Cover Product Disclosure Statement & Policy Wording,* p 60. https://www.qbe.com.au/au/home-insurance/home-contents-insurance

[99] AAMI (2018) *Home Contents Insurance Product Disclosure Statement,* p 44. https://www.aami.com.au/aami/documents/personal/home/pds-contents.pdf

Nuclear power is water-intensive and heat vulnerable

Nuclear reactors require large volumes of water for cooling and are vulnerable to heat, a particular problem in Australia due to droughts and heatwaves, which are getting longer and more extreme.

When based on renewables, decarbonisation pathways can both reduce carbon emissions *and* water use. In contrast, decarbonisation through nuclear expansion increases pressure on water resources.[100]

All thermal generation uses water, but the water requirements of nuclear power stations are 20-83% higher compared to fossil fuel-based power stations.[101] Open loop nuclear power stations withdraw water from an inland water body and circulate it, discharging the warmer circulated water back into the original water body.[102] This can lead to thermal pollution by overheating the local ecosystem, affecting fish and aquatic life.[103] Other nuclear power stations are more water efficient but still require vast quantities of water.

Reliance on water for cooling increases vulnerability to extreme heat. Multiple heatwave-related nuclear power plant shut downs occurred in France in the 2019 summer, as the waters surrounding the plants become too warm to provide a cooling function.[104]

Climate change further exacerbates the pressure on nuclear plants by increasing the intensity and duration of drought and heatwave events. Nuclear power plants across the US and Europe are expected to lose capacity during summer heat due to climate

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[100] Mouratiadou et al. (2018) *Water demand for electricity in deep decarbonisation scenarios: a multi-model assessment*, in *Springer Nature: Climate Change,* vol.147.
[101] Australian Government Department of Parliamentary Services (2006) *Water requirements of nuclear power stations.* https://www.aph.gov.au/binaries/library/pubs/rn/2006-07/07rn12.pdf
[102] Government of South Australia (2016) *Nuclear Fuel Cycle Royal Commission Report,* p 198. http://nuclearrc.sa.gov.au/
[103] Raptis et al. (2016) *Global thermal pollution of rivers from thermoelectric power plants,* in *Environmental Research Letters*. https://iopscience.iop.org/article/10.1088/1748-9326/11/10/104011/pdf
[104] Hird (2019) *France's nuclear electricity production 'threatened by heatwaves'*. http://en.rfi.fr/france/20190726-frances-nuclear-electricity-generation-threatened-heatwaves

change. Australia is already prone to drought and hot summer temperatures. The effects of global warming are set to increase the number of extreme heat days across Australia.

In drought-prone countries like Australia that can ill-afford added pressure on water resources, decarbonisation pathways should be based on generation technologies that induce water savings.

Nuclear power waste disposal still does not exist

High-level radioactive waste material must be stored securely for tens of thousands of years, but no country has implemented a solution.

Around 97% of the waste produced by the nuclear power industry is classified as low- or intermediate-level waste. The remaining 3% is classified as high-level waste (HLW).[105] All waste types are radioactive, but 'high level waste' (HLW) requires permanent geological disposal.

No country has successfully built a deep repository for high-level radioactive waste.[106] Many countries have plans to develop such a repository and one is under construction in Finland. But there is no current example of an operating HLW repository. The global annual production of 34,000m^3 of HLW accumulates in temporary storage.[107]

There have been many proposals and considerable controversy in Australia over the issue of nuclear waste dumps, for various levels of waste, including HLW, resulting in bitter political fights between and within jurisdictions, and staunch community and legal opposition.

In 2016 the *Nuclear Fuel Cycle Royal Commission* held a Citizens' Jury of over 300 randomly selected South Australians to deliberate on expert advice regarding the construction of an HLW repository in SA. Two thirds of the jury concluded: "'no' to the state being a dump due to consent, economics, trust and safety and we should cease spending any further public funds."[108]

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105 World Nuclear Association (2017) *Radioactive Waste – Myths and Realities.* https://www.world-nuclear.org/information-library/nuclear-fuel-cycle/nuclear-wastes/radioactive-wastes-myths-and-realities.aspx

106 Vidal (2019) *What should we do with radioactive nuclear waste?* https://www.theguardian.com/environment/2019/aug/01/what-should-we-do-with-radioactive-nuclear-waste

107 World Nuclear Association (2018) *Nuclear waste inventory (IAEA estimates, 2018).* https://www.world-nuclear.org/information-library/nuclear-fuel-cycle/nuclear-wastes/radioactive-wastes-myths-and-realities.aspx

108 Campbell (2016) *Nuclear Fuel Cycle Royal Commission: SA citizens' jury votes against storing nuclear waste.* https://www.abc.net.au/news/2016-11-06/sa-citizens-jury-vote-against-storing-nuclear-waste/7999262

Nuclear power lacks a social licence

Few Australians support nuclear power, most oppose it, and most do not want to live near a nuclear power plant.

The negative perception of nuclear power plants has proved a major obstacle to their development, and indeed to the continuation of established nuclear industries.[109] The placement of nuclear power stations in Australia is likely to be at least as contentious.

The Australia Institute's 2019 *Climate of the Nation* report found that nuclear power remains greatly divisive in Australia.[110] Asked about their preferred source of energy, 22% placed nuclear in their top three and 11% placed it first, a small increase over the previous year. Yet even more placed it last (34%) and most (59%) placed it in their bottom three, making nuclear about as unpopular as coal. By comparison, three quarters placed solar in their top three; wind, hydro and storage were also more often selected than nuclear power.

Beyond attitudes to the technology itself, there is the question of living near one. 2019 polling by Essential found that only 28% of Australians would be comfortable living close to a nuclear plant. 60% would not.[111]

While all generation options face questions and constraints over location, for nuclear these are exacerbated by the lack of social licence. Nuclear power plants must be built near electrical infrastructure, centres of demand, large quantities of water for cooling purposes and transport infrastructure.[112] Community opposition and potential legal battles pose additional risks to the already lengthy and costly process of developing a nuclear power industry in Australia.

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[109] BBC (2011) *Germany: Nuclear power plants to close by 2022.* https://www.bbc.com/news/world-europe-13592208
[110] Merzian et al. (2019) *Climate of the Nation 2019.* https://www.tai.org.au/content/climate-nation-climate-change-concern-hits-81
[111] Murphy (2019) *Australians' support for nuclear plants rising – but most don't want to live near one*. https://www.theguardian.com/australia-news/2019/jun/18/australians-support-for-nuclear-plants-rising-but-most-dont-want-to-live-near-one
[112] Macintosh (2007) *Sitting Nuclear Power Plants in Australia: Where would they go?* http://www.tai.org.au/sites/default/files/Nuclear%20siting%2040_8.pdf

Nuclear power is often offline

Despite talk of nuclear 'baseload' power, nuclear generators are often offline, subject to significant planned and unplanned outages.

Nuclear generators are not able to generate electricity all the time. Reactors have planned losses during maintenance and refuelling operations. They also have unplanned losses due to breakdowns.

Capacity factor is the ratio of actual generation to total generation if operating at peak capacity over some period.

The International Atomic Energy Agency (IAEA) gives the average capacity factor (called 'load factor') for commercial reactors around the world. Since 1999 the average nuclear capacity factor has been no higher than 83%. It has been around 75% ever since 2012, following Fukushima.[113] There is large variation between countries.[114]

In addition to 'capacity' factors, the IAEA provides data on 'capability' and 'availability'.[115] Both are ratios of possible generation to nameplate maximum and include operation to supply grid stability through ramping. Capability factors exclude planned and unplanned losses that are deemed to be in the generator's control. Capability factors have never been above 85% globally in the last two decades, and fell to 74-76% following Fukushima.[116]

The 'Unplanned Capability Loss Factor' measures unplanned outages as a share of total capacity. Globally it has ranged between 3-6% over the last two decades.[117] Again there are large variations between countries.[118] Over the last three years, unplanned nuclear outages accounted for 2% of capacity in the US, 8% in the UK, 11% in France,

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[113] IAEA (2019) *World Trends in Average Load Factor*.
https://pris.iaea.org/PRIS/WorldStatistics/WorldTrendinAverageLoadFactor.aspx
[114] IAEA (2019) *Unity Capability Factor.*
https://pris.iaea.org/PRIS/WorldStatistics/ThreeYrsUnitCapabilityFactor.aspx
[115] For definitions see: IAEA (2005) *The Power Reactor Information System (PRIS) and its Extension to Non-electrical Applications, Decommissioning and Delayed Projects Information,* in particular Figure 11.
https://www-pub.iaea.org/MTCD/Publications/PDF/TRS428_web.pdf
[116] IAEA (2019) *Unit Capability Factor Trend*
https://pris.iaea.org/PRIS/WorldStatistics/WorldTrendinUnitCapabilityFactor.aspx
[117] IAEA (2019) *World Trends in Unplanned Capability Loss Factor.*
https://pris.iaea.org/PRIS/WorldStatistics/WorldTrendinUnplannedCapabilityLossFactor.aspx
[118] IAEA (2019) *Unplanned Capacity Loss Factor*
https://pris.iaea.org/PRIS/WorldStatistics/ThreeYrsUnplannedCapabilityLossFactor.aspx

and 13% in Switzerland, the latter due largely to 23% lost in 2016. The ongoing closure of nearly all of Japan's fleet post Fukushima is treated as a planned outage.

Nuclear 'availability' is similar to capability, but further excludes losses deemed outside of generator control, namely due to environmental or economic causes, or "fuel coastdown".[119] A further 1-2% of global nuclear capacity has been lost to such factors in recent years.[120]

[119] That is, the "power reduction at the end of the fuel cycle resulting in a release of positive reactivity to compensate for high fuel burnup": IAEA (2005) *The Power Reactor Information System (PRIS) and its Extension to Non-electrical Applications, Decommissioning and Delayed Projects Information*, p 49. https://www-pub.iaea.org/MTCD/Publications/PDF/TRS428_web.pdf

[120] Comparing capability with availability, IAEA (2019) *Energy Availability Factor.* https://pris.iaea.org/PRIS/WorldStatistics/ThreeYrsEnergyAvailabilityFactor.aspx

Nuclear power is not needed

Renewable generation combined with demand management and storage can meet Australian energy needs.

In a world reducing emissions, some argue nuclear energy plays an essential role as a zero-carbon source of energy.

It is essential to distinguish the role of nuclear in existing nuclear states from a possible role in Australia, where there is no industry and a vast renewable energy resource. Debates in existing nuclear states focus on whether or how quickly to phase out the industry, or to subsidise its extension. Any climate or economic argument for extending the life of existing generators is not relevant to the debate in Australia. The lesson for Australia should be extreme caution.

Electricity systems based on high levels of renewable energy are technically and economically affordable. Australia's access to renewable, reliable and low risk energy generation sources, and the rapidly falling cost of energy generation and storage, mean nuclear power generation is simply not necessary.

The Australia Institute has analysed 18 reports published over the past five years and three Commonwealth Treasury reports analysing the economic costs of high levels of abatement, including 100% renewable energy.[121] These studies show high levels of abatement is economically feasible at low cost. Ongoing technology cost reductions in renewable generation, storage and management mean the costs continue to fall.

Integration of higher shares of variable renewables involves additional 'firming' investment beyond generation – including storage, ancillary services and transmission. These costs are however manageable and far lower than the costs of establishing a nuclear power industry.[122]

A major ARENA-funded analysis of dispatchable renewable energy concluded

> a range of proven and affordable options is available to more than adequately cater for significantly increased levels of renewable energy in the Australian

[121] Swann (2019) *A Model Line-up.* http://www.tai.org.au/sites/default/files/P656%20A%20Model%20Line-up%20%5BWEB%5D_0.pdf

[122] Khatib and Difiglio (2016) *Economics of nuclear and renewables*, in *Energy Policy,* vol.96, pp 740-750

> electricity mix, and for an eventual net zero emission technology mix by 2050 as implicitly required by the longer-term goals of the Paris accord.[123]

CSIRO and AEMO find tha wind and solar are already the cheapest form of new generation in Australia and are competitive with conventional energy sources when 'firmed' with storage. They also find that over the next two decades, the time it would take to develop a nuclear industry, wind and solar with storage will be cheaper than or competitive with all other energy sources and up to three times cheaper than nuclear.[124]

NEED FLEXIBLE NOT BASELOAD

Most nuclear reactors are operated in 'baseload' mode, where they provide an almost constant level of supply over the course of each day, regardless of demand or competing supply.

Renewable energy challenges nuclear energy not just through low cost but also by changing market dynamics. As the multilateral nuclear forum GIF states "the increasing share of the renewable resources … are causing unfavourable conditions for nuclear generation".[125]

Increasing 'base cost' wind and solar will create market conditions rewarding *flexibility,* not baseload. In South Australia, the state with the highest renewable share, 'baseload' energy demand is at a 15-year low.[126]

Some nuclear power plants provide flexibility beyond the slow ramping of baseload generators. France and Germany are leaders in the field of flexible nuclear operations and have been designing nuclear power plants to provide variable output, since at least 1992.[127]

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[123] ARENA (2018) *Comparison of Dispatchable Renewable Electricity options: Technologies for an orderly transition*, pp 107, 3. https://arena.gov.au/assets/2018/10/Comparison-Of-Dispatchable-Renewable-Electricity-Options-ITP-et-al-for-ARENA-2018.pdf

[124] CSIRO and AEMO (2018) *GenCost 2018,* p 31. https://www.csiro.au/en/News/News-releases/2018/Annual-update-finds-renewables-are-cheapest-new-build-power

[125] GIF (2017) *Annual Report 2017*, Gen IV International Forum, pp 162, 2. https://www.gen-4.org/gif/upload/docs/application/pdf/2018-09/gif_annual_report_2017_210918.pdf

[126] Saddler (2019) *National Energy Emissions Audit Electricity Update April 2019*, p 4. https://www.tai.org.au/content/national-energy-emissions-audit-april-2019

[127] International Atomic Energy Agency (2018) *Non-baseload Operation in Nuclear Power Plants: Load Following and Frequency Control Modes of Flexible Operation,* p 34, https://www.iaea.org/publications/11104/non-baseload-operation-in-nuclear-power-plants-load-following-and-frequency-control-modes-of-flexible-operation

There are technical and economic constraints on nuclear flexibility. Safety considerations limit how much, often and quickly plants can ramp, which in turn limits economic feasibility with increasing renewables. Nuclear is also challenged by the need to recover high capital costs from lower levels of operation.

Technical flexibility varies during a fuel 'cycle', which is the period between the shut-down and refuelling. A recent study of flexible reactors in France and Germany found they cannot operate flexibly until 2 weeks into a cycle,[128] and towards the end of a cycle, the accumulation of fission products increases the safe minimum operating level, reducing scope for ramping.[129] There are other limits on the ramp rate.

Another recent study showed how increased nuclear flexibility, within technical constraints, can reduce system costs and increase generator revenue. That study considered existing generators and levels of variable renewables similar to those in Australia at present. The increase to nuclear generator revenue was modest at 2-5%.[130] The reduction in capacity factor was also small, down from 100% (within a fuel cycle) down to just 95%.[131]

While the fleet was able to ramp and provide grid stability services, it was still generating at close to full capacity. Such a high capacity factor does not reflect conditions under increasingly high levels of variable renewables. It also does not account for planned and unplanned outages.

DEMAND RESPONSE

Countries using nuclear power use a range of technologies to maintain system reliability. One technology used to in both nuclear and non-nuclear countries is 'demand response'. Demand response involves systems and incentives to reduce demand when this is cheaper or better than increasing generation. The International Energy Agency calls demand response "the sleeping giant of system flexibility".[132]

France has long managed its nuclear-based electricity system through demand response. This is especially important during demand peaks during winter. Consumers

[128] Cany et al. (2018) *Nuclear power supply: Going against the misconceptions. Evidence of nuclear flexibility from the French experience,* in *Energy*, vol.151 https://www.sciencedirect.com/science/article/abs/pii/S0360544218304729
[129] Ibid., p 291
[130] Jenkins et al (2018) *The benefits of nuclear flexibility in power system operations with renewable energy.* in *Applied Energy,* vol.222, p 879. https://www.sciencedirect.com/science/article/pii/S0306261918303180
[131] Jenkins et al (2018) *The benefits of nuclear flexibility in power system operations with renewable energy,* p 877
[132] IEA (2018) *WEO,* section 8.4.3

pay a lower tariff in return for giving the utility remote control over their boilers to moderate or shift demand. The simple ‘ripple control’ signal to turn the heater on or off is sent down the same wires that carry the electric power.

Modern demand response technologies are far more sophisticated. The COAG Energy Council is currently considering a new market rule to enable consumer devices like pool pumps and air-conditioners to be orchestrated by a range of signal technologies to decrease or increase energy consumption, and so improve reliability.

The rise of distributed, variable renewable energy resources will both require and enable more system flexibility. The IEA and Australian energy market agencies say that demand response will be an integral part of this new system model. As demand response and storage are paired with low cost generation supplied by large scale solar PV and wind there will be even less need for baseload technologies such as nuclear or coal.