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CSIRO is to be congratulated on the GenCost 2023-24 Consultation Draft. We reviewed the comments and costings on nuclear power (including SMRs) and have little to say other than that it is rigorous. We have just a couple of points to make in this submission.

You might find something of value in a 31-page SMR briefing paper released in mid-2023, titled 'Small Modular Reactors and 'Advanced' or 'Generation IV' Reactor Concepts'. It is online at https://nuclear.foe.org.au/wp-content/uploads/SMR-BRIEFING-PAPER-FOE-AUSTRALIA-2023.pdf

CONSTRUCTION TIMES

Our main concern in the GenCost 2023-24 Consultation Draft is the assumption that SMRs could be built in three years. To test that assumption, we could look at the only two operating SMRs, the twin-reactor high-temperature gas-cooled (HTGR) plant in China, and the twin-reactor floating nuclear plant in Russia. (Neither of these could be called modular – they haven't used modular factory construction techniques – but that is not the point here.)

In 2004, the CEO of Chinergy said construction of the first HTGR would begin in 2007 and it would be completed by the end of the decade, i.e. a 3-4-year construction project.[1] However, construction of the demonstration HTGR did not begin until 2012 (with an estimated construction time of 50 months (4 years and 2 months)[2]) and it was completed in 2021 after repeated delays. This nine-year construction project took more than twice as long as the earlier projected times of 3-4 years or 4 years and 2 months.

The Russian floating plant took 12 years to build.[3] Shortly before construction began in 2007, Rosatom announced that the plant would begin operating in October 2010, but it was not completed until 2019.[4] A 3-4-year construction project became a 12-year project. As the World Nuclear Industry Status Report notes, the construction timeline blew out by a factor of 3.5.

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[1] https://www.worldnuclearreport.org/The-World-Nuclear-Industry-Status-Report-2022-HTML.html#_idTextAnchor147

[2] https://www.worldnuclearreport.org/The-World-Nuclear-Industry-Status-Report-2022-HTML.html#_idTextAnchor147

[3] https://www.worldnuclearreport.org/The-World-Nuclear-Industry-Status-Report-2021-HTML.html#_idTextAnchor013

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

Given those empirical realities, we dispute the assumption in the GenCost 2023-24 Consultation Draft that SMRs could or will be built in as little as 3 years. We understand that GenCost reports entail assumptions about future developments, and we understand that those assumptions are necessarily somewhat arbitrary when empirical evidence is slight.

Another way into this problem is to consider the solid empirical evidence regarding large reactors. The latest edition of the World Nuclear Industry Status Report has a detailed discussion on this issue.[5] The Status Report notes than 10 countries completed 66 reactors over the decade 2013–2022 with an average construction time of 9.4 years.

CSIRO might reasonably use that 9.4-year figure as the working assumption for SMRs. It is empirically based with respect to large reactors, and it fits the only empirical data with respect to SMRs, i.e. the 9-year and 12-year SMR construction projects in China and Russia.

Assumptions that construction times will be shortened for SMRs assume the existence of factories producing identical reactor components in large quantities at rapid speed – this is the essential concept behind SMRs. But no such factories exist. None. Moreover, no country, company or utility is building or has any concrete plans to build any such factories. It is nothing more than wishful thinking. That being the case, it can reasonably be assumed that SMRs will take as long to build as large reactors, i.e. an average of 9.4 years.

If CSIRO still wishes to build some optimistic assumptions into your assessments and calculations, we would suggest something like a 6-year SMR construction build time instead of the wildly improbable 3 years. Of course it is also an option to consider a range of possible timelines (e.g. 6-9 years).

On another point, we have no quibble with the assumption of a 30-year lifespan for SMRs. No SMRs have ever been built, none are being built now, and we believe that none will ever be built in which case they have a 0-year lifespan. As noted above, neither of the two operating SMR plants (in China and Russia) are truly SMRs. If CSIRO is inclined to adjust the estimated 30-year lifespan in light of furious, unhinged attacks from the nuclear lobby and the Murdoch/Sky press, or for other reasons, it might be instructive to note that the mean age of all power reactors closed from 2018–2022 was 43.5 years as noted in the latest edition of the World Nuclear Industry Status Report.[6]

LEARNING RATES

We think that the assumptions about SMR learning rates need to be adjusted.

There is zero empirical evidence of learning rates for SMRs, i.e. there have been no attempts to build on prior experience. *NucNet* reported in 2020 that China's State Nuclear Power Technology Corp. dropped plans to manufacture 20 HTGRs after levelised cost of electricity estimates rose to levels higher than a conventional pressurised water reactor such as

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[5] https://www.worldnuclearreport.org/The-World-Nuclear-Industry-Status-Report-2023-HTML.html#_idTextAnchor056

[6] https://www.worldnuclearreport.org/IMG/pdf/wnisr2023-v1-hr.pdf

China's Hualong One.[7] Likewise, the World Nuclear Association states that plans for 18 additional HTGRs at the same site as the demonstration HTGR have been "dropped".[8]

Russia is building more floating nuclear plants, but not in large numbers, and not using modular factory construction techniques – so there is no reason to assume anything more than marginal cost reductions if any.

A significant learning rate assumes that large number of SMRs will be built. But that is not the case according to expert opinion:

- The prevailing scepticism about SMRs is evident in a 2017 Lloyd's Register report based on the insights of almost 600 professionals and experts from utilities, distributors, operators and equipment manufacturers.[9] They predict that SMRs have a "low likelihood of eventual take-up and will have a minimal impact when they do arrive".[10]
- Dr. Ziggy Switkowski – who headed the Australian Government's nuclear review in 2006 – noted in 2019 that "nobody's putting their money up'' to build SMRs and "it is largely a debate for intellects and advocates because neither generators nor investors are interested because of the risk."[11]
- 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."[12]
- *World Finance* reported in October 2018 that "while SMRs are purported to be the key to transforming the nuclear sector, history has painted a troubling picture: SMR designs have been in the works for decades, but none have reached commercial success."[13]
- Former World Nuclear Association executive Steve Kidd wrote about SMR "myths" in 2015: "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."[14]
- Likewise, American Nuclear Society consultant Will Davis said in 2014 that the SMR "universe is rife with press releases, but devoid of new concrete."[15] Nothing has changed in the past decade.
- 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.[16]

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[7] https://www.nucnet.org/news/progress-and-status-in-the-race-for-commercialisation-2-4-2020
[8] https://www.world-nuclear-news.org/NN-First-vessel-installed-in-Chinas-HTR-PM-unit-2103164.html
[9] http://info.lr.org/techradarlowcarbon
[10] http://www.world-nuclear-news.org/EE-Nuclear-more-competitive-than-fossil-fuels-report-09021702.html
[11] https://www.afr.com/politics/federal/no-investment-appetite-for-nuclear-switkowski-20190805-p52dwv
[12] https://www.nuclearenergyinsider.com/international-smr-advanced-reactor
[13] https://www.worldfinance.com/markets/nuclear-power-continues-its-decline-as-renewable-alternatives-steam-ahead
[14] https://www.neimagazine.com/opinion/opinionnuclear-myths-is-the-industry-also-guilty-4598343/
[15] http://ansnuclearcafe.org/2014/02/13/carem-25-carries-torch-for-smr-construction/
[16] http://1.nuclearenergyinsider.com/LP=362

The South Australian Nuclear Fuel Cycle Royal Commission's final report in 2016 identified numerous hurdles and uncertainties facing SMRs, including:[17]

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

There is no likelihood of SMRs being built in large numbers in the foreseeable future. That being the case, the assumptions about learning rates in the GenCost 2023-24 Consultation Draft are at best wildly improbable, at worst impossible, and should be adjusted.

Last but not least, we note the *negative* learning rate that has afflicted nuclear power in key markets. If learning rates were to be demonstrated, that would most likely be in the countries with the largest numbers of reactors, i.e. the USA and France. But a negative learning rate has clearly been demonstrated in both those countries.

Indeed the latest construction projects in the USA and France demonstrate a negative learning rate on steroids:

- The only current reactor construction project in France is one EPR reactor under construction at Flamanville. The current cost estimate of €19.1 billion (A$31.6 billion) is nearly six times greater than the original estimate of €3.3 billion (A$5.5 billion).[18] (Lower cost estimates cited by EDF and others typically exclude finance costs.) Construction of the Flamanville EPR reactor began in Dec. 2007 and it remains incomplete over 16 years later.[19] The last reactor startup in France was in the last millennium (1999).
- In the US, the only current reactor construction project is the Vogtle project in Georgia (two AP1000 reactors, of which one is complete). The latest cost estimate of $34 billion (A$52.1 billion) for two reactors (2.2 GW) is more than double the estimate when construction began – $14-15.5 billion.[20] In 2006, Westinghouse said it could build an

[17] https://nuclear.foe.org.au/wp-content/uploads/NFCRC_Final_Report_Web_5MB.pdf
[18] https://www.worldnuclearreport.org/The-World-Nuclear-Industry-Status-Report-2022-HTML.html#_idTextAnchor042
[19] https://pris.iaea.org/PRIS/CountryStatistics/ReactorDetails.aspx?current=873
[20] https://www.worldnuclearreport.org/The-World-Nuclear-Industry-Status-Report-2022-HTML.html#_idTextAnchor086

AP1000 reactor for as little as $1.4 billion[21], 12 times lower than the current estimate for Vogtle.

There are exceptions to the pattern of negative learning rates, but these case studies are troubling:

- South Korea's nuclear industry has been rocked by industry-wide corruption scandals involving cost-cutting with safety significance.[22]
- China's nuclear power program suffers from inadequate nuclear safety standards, inadequate regulation, lack of transparency, repression of whistleblowers, world's worst insurance and liability arrangements, security risks, and widespread corruption.[23]

For literature on nuclear power's negative learning rates, see

Grubler, Arnulf. 2010. "The costs of the French nuclear scale-up: A case of negative learning by doing." Energy Policy. vol. 38, no. 9. 2010/09/01/. pp. 5174-5188. *https://www.sciencedirect.com/science/article/pii/S0301421510003526*

Krause, Florentin, Jonathan Koomey, David Olivier, Pierre Radanne, and Mycle Schneider. 1994. Nuclear Power: The Cost and Potential of Low-Carbon Resource Options in Western Europe. El Cerrito, CA: International Project for Sustainable Energy Paths. *http://www.mediafire.com/file/kjwo9gjwtj5p11t/nuclearpowerbook.pdf*

Koomey, Jonathan, & Nathan Hultman, "A reactor-level analysis of busbar costs for US nuclear plants, 1970–2005," Energy Policy, 2007, vol. 35, issue 11, 5630-5642, http://www.sciencedirect.com/science/article/pii/S0301-4215(07)00255-8

And various other papers:
2007, https://pubs.acs.org/doi/10.1021/es0725089
2007, https://iopscience.iop.org/article/10.1088/1748-9326/2/3/034002/pdf
2012, https://www.imperial.ac.uk/media/imperial-college/research-centres-and-groups/icept/Cost-estimates-for-nuclear-power-in-the-UK.pdf
2019, https://link.springer.com/chapter/10.1007/978-3-658-25987-7_5

[21] https://www.nytimes.com/2006/07/16/magazine/16nuclear.html
[22] https://wiseinternational.org/nuclear-monitor/887/nuclear-monitor-887-17-june-2020
https://www.wiseinternational.org/nuclear-monitor/844/south-koreas-nuclear-mafia
[23] http://www.wiseinternational.org/nuclear-monitor/796/chinas-nuclear-power-plans-safety-and-security-challenges