Submission
No 61

INQUIRY INTO URANIUM MINING AND NUCLEAR FACILITIES (PROHIBITIONS) REPEAL BILL 2019

Organisation: Bright New World

Date Received: 18 October 2019

bright new world

Stable Climate. Rich Nature. Prosperous Humanity.

Submission to

Standing Committee on State Development

Uranium Mining and Nuclear Facilities (Prohibitions) Repeal Bill 2019

18 October 2019

Table of Contents

Executive Summary ***3***

1. Environmental case ***7***

1.1 Low emissions technology **7**

1.2 Environmental impacts **9**

1.2.1 Material use 9
1.2.2 Waste 10
1.2.3 Water use 12

1.3 Health impacts **13**

1.3.1 Radiological impacts 13
1.3.2 Clean air benefits 16

1.4 Nuclear safety **16**

1.4.1 Three Mile Island & David Besse, PWR 17
1.4.2 Fukushima-Daiichi & Onagawa, BWR 18

2. Economics ***19***

2.1 Capital cost **19**

2.1.1 Overnight capital cost trends 19

2.2 Levelised cost of nuclear **21**

2.2.3 CSIRO & AEMO GenCost 2018 Nuclear cost error 23

2.3 System and Wholesale Costs **24**

2.3.1 OECD NEA 24
2.3.2 System costs of all low-carbon sources 25
2.3.3 Australian analysis 27
2.3.4 Waste management services 28

2.4 Policy considerations **29**

3. Community ***30***

3.1 Community engagement **30**

3.2 National consensus **30**

References ***32***

Appendix A – GenCost 2018 review ***36***

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Executive Summary

Bright New World welcomes the Standing Committee on State Development inquiry into the repeal of the uranium mining and nuclear facilities prohibitions in New South Wales. The *Uranium Mining and Nuclear Facilities (Prohibition) Repeal Bill 2019* is a timely bill to ensure that New South Wales has the opportunity to develop a suite of low carbon technologies.

Bright New World is a not-for-profit environmental NGO based in South Australia. We believe that human prosperity and environmental conservation can work together rather than in conflict. Our core ethos is: Stable Climate, Rich Nature, Prosperous Humanity.

A key component is access to affordable plentiful energy that is low carbon and low impact to the environment. One of the technology sources that affirms this, and our core ethos more broadly, is nuclear power.

Australia is the only G20 member state to not actively construct or operate nuclear power. Italy is the only other member with a nuclear prohibition, but theirs was put to the Italian public in a referendum after the accidents at Chernobyl and Fukushima, understandably with these accidents in mind the result was “no”.

The nuclear prohibitions that exist today are the main impediment for an in-depth analysis into nuclear power in Australia. Discussions with nuclear vendors and Australian institutions all indicate the prohibition as the limiting factor to undertake detailed feasibility and market assessments. The committee has already heard from the Australian Energy Market Operator (AEMO) that nuclear is not considered or taken seriously in market planning due to the prohibition.

There have been three major inquiries into nuclear power in the past two decades. The House of Representatives Standing Committee on Industry and Resources (November 2006), Uranium Mining Processing and Nuclear Energy Report (UMPNER; December 2006), and South Australian nuclear fuel cycle royal commission (May 2016).

All three were in depth processes that heard from a wide variety of stakeholders both for and against, addressed the terms of reference for this committee, and assessed every aspect of the nuclear fuel cycle.

All three of these inquires recommended for Australia to lift the prohibitions on nuclear power at the Federal and State level. These prohibitions still remain, and they are the biggest impediment to understanding the full benefits, opportunities and costs of nuclear in Australia. Dr Ziggy Switowski put it aptly in his submission to the commonwealth committee on the prerequisites for nuclear power in Australia:

> *“We should not make decisions in 2019 based upon legislation passed in 1999 reflecting the views of 1979”*

Bright New World recommends the committee should:

1) **The *Uranium Mining and Nuclear Facilities (Prohibitions) Repeal Bill 2019* be supported**

2) **Support a national effort to proceed with a net zero by 2050 emissions policy**

Otherwise we are putting all our bets on a single pathway with no option for a plan B if we encounter problems. Nuclear is a historically demonstrated pathway to low carbon electricity networks, enabling economy wide benefits in heavy industry with access to plentiful cheap power, while having a low environmental footprint.

The Australian public is open to the prospects of nuclear with polling showing increases in support, along with social media polling indicating a higher result if two options are presented.

It's time for Australia to join the rest of the G20 nations and the OECD in allowing nuclear to have the opportunity to demonstrate its worth to Australia.

The issues paper for this inquiry poses a variety of questions pertaining to the opportunities and risks of uranium mining and nuclear power. In this submission Bright New World will address the questions pertaining to nuclear power and associated facilities. The following are our abridged responses with further detail in the body of this submission.

Question 1: Does the 'Energy Trilemma' framework of security, equity and environmental sustainability capture the key energy issues facing NSW? What other factors should be considered?

The energy trilemma of energy security and reliability, affordability and low carbon as outlined in the Finkel Review are the result of having to integrate large amounts of variable renewable generation into an existing network that was not designed for this new technology. There are a range of technologies now that can address parts of this trilemma, however there are two that can address all three, nuclear power and hydroelectricity.

Nuclear has a low environmental footprint, addresses industrial heat requirements, and develops an advanced manufacturing and sciences industry. It has one of the lowest life-cycle emissions intensities of all electricity generation sources.

Further discussion on the low environmental impact on nuclear can be found in sections 1.1 and 1.2, and affordability in sections 2.1 to 2.3.

Question 2: What mix of current technologies will best meet the key energy opportunities and challenges in NSW? How might this change with future technological developments?

It is difficult to predict the final generation mix, however systems modelling can be undertaken to assess the optimum levels of different low carbon generation sources. The categorisation of generation into three distinct categories of firm low carbon, fuel saving (i.e. variable renewable generation) and fast burst (Sepulveda, 2018) demonstrate that a higher network cost in incurred without a proportion of firm low carbon generation (nuclear and hydro).

Further discussion on the particulars of system costs of including nuclear are discussed in sections 2.3.2 and 2.3.3.

Question 5: What are the economic, social and environmental opportunities and risks associated with nuclear energy in NSW?

Nuclear is one of the safest forms of energy development with a low levelised mortality rate, extensive involvement of nuclear operators in international groups (see WANO), designed defence in depth and passive systems, and a commitment to zero harm practices.

Further discussion on the environmental opportunities and risks are discussed in sections 1.1 to 1.3, and economic opportunities in sections 2.1 to 2.3.

Question 6: Under what conditions would nuclear power generation be viable in NSW?

For nuclear power to be viable in NSW there would need to be a future deficit in electricity generation from the NEM. With the planned closures of coal generators in NSW there will exist demand in the future for low carbon generation to meet this future deficit. For nuclear with a high upfront capital investment there will need to exist conditions of investor certainty and predictability to ensure financial viability.

Further discussion on conditions for investment certainty and policies can be found in sections 2.3 and 2.4.

Question 7: What is the optimal investment model to create a nuclear energy industry in NSW? How does the return on investment compare with other energy options?

The committee should seek the input from nuclear power vendors as to the specifics of their projects and investment specifics. De-risking capital is one of the main drivers to deliver an optimal investment model for nuclear power Further discussion can be found in section 2.2.

Question 8: Are private sector financial organisations interested in financing nuclear power projects in NSW should current prohibitions be repealed?

Bright New World has spoken to nuclear vendors and the consistent message from all is that for investment to occur in Australia the prohibitions have to be removed first.

Question 9: How would radioactive waste from nuclear power generation be managed?

Radioactive waste from nuclear power is managed appropriately and effectively for the radiological hazard it poses. The nature of this material is that over time the radiological hazard diminishes. The radiotoxicity of spent nuclear fuel decreases by 90% in the first 100 years out of the reactor. This material can be recycled and reused in fourth generation reactors with the proof of concept tested in the United States during the 1980s and 90s.

Further discussion on the hazard of radioactive waste and recycling can be found in sections 1.2.2 and 2.3.4.

Question 10: What is the current level of support amongst the NSW public for uranium mining and nuclear energy?

Nuclear power in Australia is currently supported by the general public. Recent polling from Roy Morgan in October 2019 showed that there is a narrow majority of those supporting nuclear power, especially considering carbon dioxide emissions. The polling did include a breakdown by state. The national support for nuclear considering carbon dioxide emissions is 51% where the support for NSW in the same context is four points higher at 55%.

Further discussion on polling can be found in section 3.2.

Question 11: If a nuclear energy industry were to be allowed in NSW, what are the optimal regulatory settings to ensure the safe and secure operation of uranium mining, nuclear power generation, and nuclear waste disposal.

The NSW government should look to the regulatory practices and experiences of the South Australian government with respect to uranium mining. In developing a nuclear power sector the NSW government will need to work with the Commonwealth government to establish the correct regulatory settings for the nuclear fuel cycle. The International Atomic Energy agency has a program to assist member states to develop best practice regulatory regimes. This was recently undertaken in the United Arab Emirates to establish their nuclear power generating program. They started with no nuclear regulators in 2007 to beginning to operate four 1400MWe reactors over the next 4 years. Australia has a head start with established radiation protection and nuclear safety regulators.

Question 13: Should nuclear power generation continue to be prohibited in NSW?

No. Bright New World urges the NSW parliament to repeal the prohibitions by supporting the Bill in question. Nuclear is needed in the toolbox to decarbonise out electricity and industrial heat sectors. Leaving it out results in sub-optimal outcomes. It is a position the Intergovernmental Panel on Climate Change (IPCC), Organisation for Economic Co-Operation (OECD) and International Energy Agency's sustainable development scenario all agree on, nuclear needs to be in the mix.

Question 15: What model of community engagement should be used to include the NSW public in decisions about uranium mining and nuclear energy?

Discussed in section 3.1 is a model that is currently being utilised to develop the national radioactive waste management facility. This is a similar model to that used in France and Finland to site their nuclear waste facilities. Informed community consent through a voluntary site nomination process is a model that Bright New World sees as fair and reasonable.

Question 16: What is the best method of including the community in decisions about:

- **a. Location of a nuclear reactor;**
- **b. Nuclear waste disposal; and**
- **c. Nuclear non-proliferation.**

As outlined in the response to question 15 above and discussed in section 3.1, informed community consent through volunteering a site is the best method. The community will have the final determination, however they agree to undertake a consultation process prior to any final determination.

Question 17: What are the other key decisions on uranium mining and nuclear energy that require community engagement?

Inclusion of traditional owners early in the process is paramount to ensuring minimal angst in the local community. Open and transparent communication with all stakeholders is key to ensuring the project proponent gains the trust of the local community in which they wish to operate.

1. Environmental case

1.1 Low emissions technology

The current international climate agreements, Paris Climate agreement of 2015, states that countries must work towards limiting global warming to under 2°C[1]. Studies that look at pathways to achieve these targets conclude that greenhouse gas emissions from electricity generation must fall to near zero.

The Intergovernmental Panel on Climate Change (IPCC), in its Fifth Assessment Report, classifies nuclear energy as a 'mitigation technology'. This is echoed in the recent IPCC special report on global warming of 1.5C where nuclear increases its share of global primary energy in every scenario assessed[2].

The total life-cycle emissions profile of nuclear power is 12g CO_2eq/kWh [3]. A full life cycle analysis considers the entire fuel chain from mining to decommissioning.

This figure is from the National Renewable Energy Laboratory (NREL) in the United States and is the median result of a harmonised dataset. NREL undertook an analysis of hundreds of life-cycle assessments to determine the range of values for nuclear power. Harmonised results reduce the variability in the dataset by aligning common input assumptions across all studies to a consistent set of values.

In addition, based on 32 references providing lifecycle greenhouse gas emissions estimates and 125 estimates that passed the IPCC's literature review screening process[4], the IPCC declared nuclear power as comparable to renewable energy technologies such as wind and solar PV[5]. This information is summarised in the table below.

Technology	Minimum gCO_2-e/KWh	Median gCO_2-e/KWh	Maximum gCO_2-e/KWh
Nuclear (PWR and BWR)	3.7	12	110
Wind (Onshore)	7	11	56
Solar PV (Utility scale)	18	48	180
Concentrated solar thermal	8.8	27	63
Coal (with carbon capture and storage)	190	220	250
Combined cycle gas (with carbon capture and storage	94	170	340

Nuclear power operators also undertake life cycle analyses of their plants. In Switzerland the Paul Sherrer Institut undertook an analysis of the Swiss Gösgen and Leibstadt nuclear plants. Their results found the Gösgen and Leibstadt plants have an emissions intensity of 6g and 10g CO_2eq/kWh respectively[6]. Figure 1 below demonstrates the composition of the emissions intensity for both reactors. The difference is due to the type of reactor, with Gösgen as a Pressurised Water Reactor (PWR) and Leibstadt a Boiling Water Reactor (BWR).

This is also the case for Vattenfall, a major operator of electricity generation assets across Europe. Their assessment of nuclear plants under their operation (Forsmark and Ringhals in

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[1] (United Nations Framework Convention on Climate Change, 2015)

[2] (Masson-Delmotte, 2018)

[3] (Warner, 2012)

[4] (Moonaw, et al., 2011)

[5] (Schlomer, et al., 2014)

[6] (Zhang, 2018), p. 45

Sweden) found the emissions intensity of those plants to be 5g CO_2eq/kWh. The total emissions intensity for Vattenfall's European generation fleet is presented in figure 2.

This data shows the majority of emissions intensity for nuclear plants arises from the front end of the nuclear life cycle (mining, conversion, enrichment). When emissions reductions in these sectors are realised, the emissions intensity of nuclear will further decrease. Past improvements have been the transition from gaseous diffusion to centrifugal enrichment.

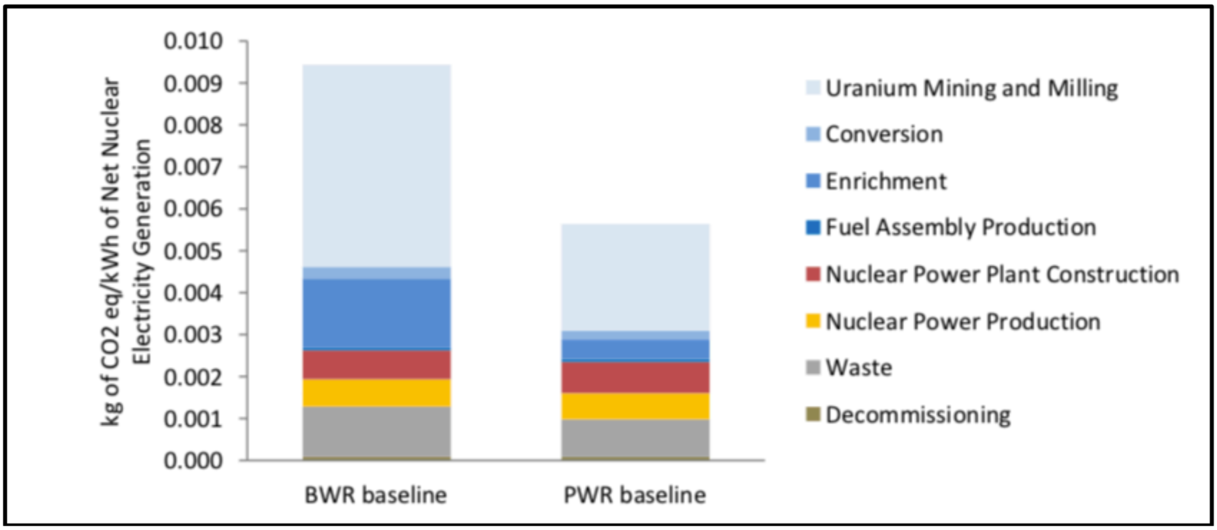


Figure 1 - Emissions intensity of Swiss nuclear power plants

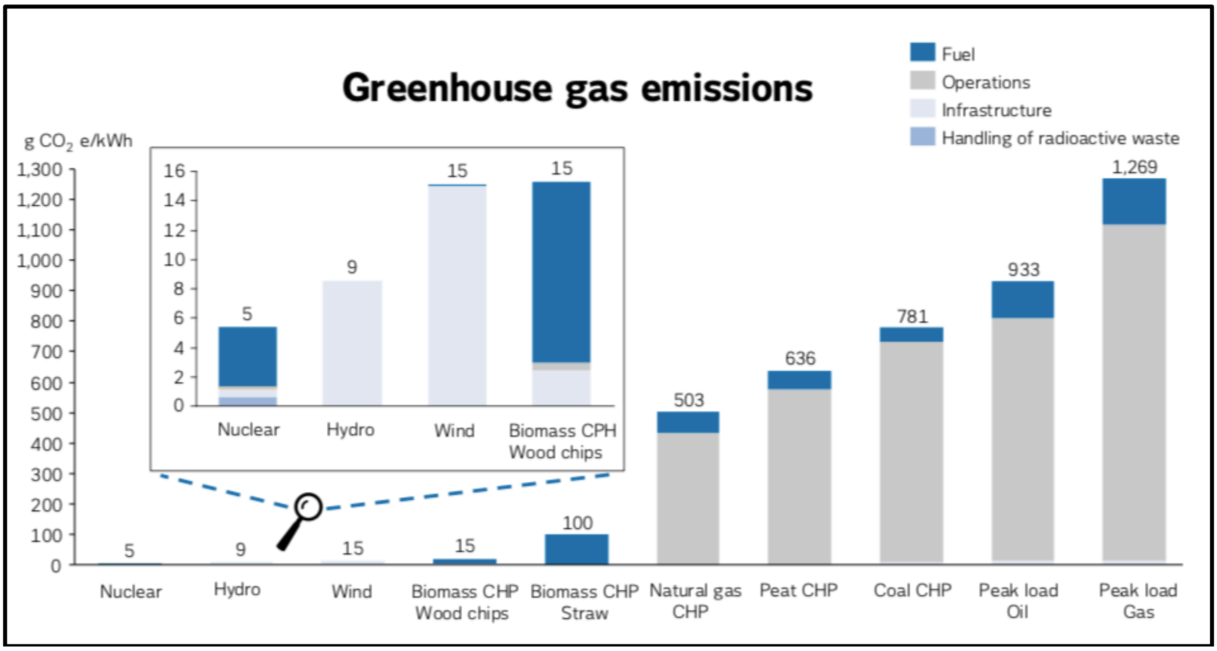


Figure 2 - Emissions intensity of Vattenfall generation assets

Assertions to the contrary that nuclear emissions figures are higher due to studies omitting front or back end fuel cycle components are incorrect. The wide array of studies assessed in the NREL harmonisation and IPCC studies emphasise that all aspects of the nuclear fuel cycle are assessed.

Higher estimates of nuclear emissions intensities involve assumptions on the future grade of uranium ores mined. With lower grades nuclear emissions intensity figure will increase as majority of the lifecycle emissions are in the front end of the nuclear cycle.

The final estimate of this figure could fall in a range of 12 to 110g CO_2eq/kWh[7] depending on emissions in the front end and decreasing grades of uranium ore. However, other steps such as multi-commodity mines (e.g. in South Australia's Gawler Craton; see Olympic Dam) and reprocessing will limit this increase. One other option is the use of fast breeder reactors (FBR) which are commonly included in Generation IV reactor designs. The median life cycle emissions of a FBR are 0.87g CO_2eq/kWh, with a range of 7.7 to 0.78g CO_2eq/kWh[8].

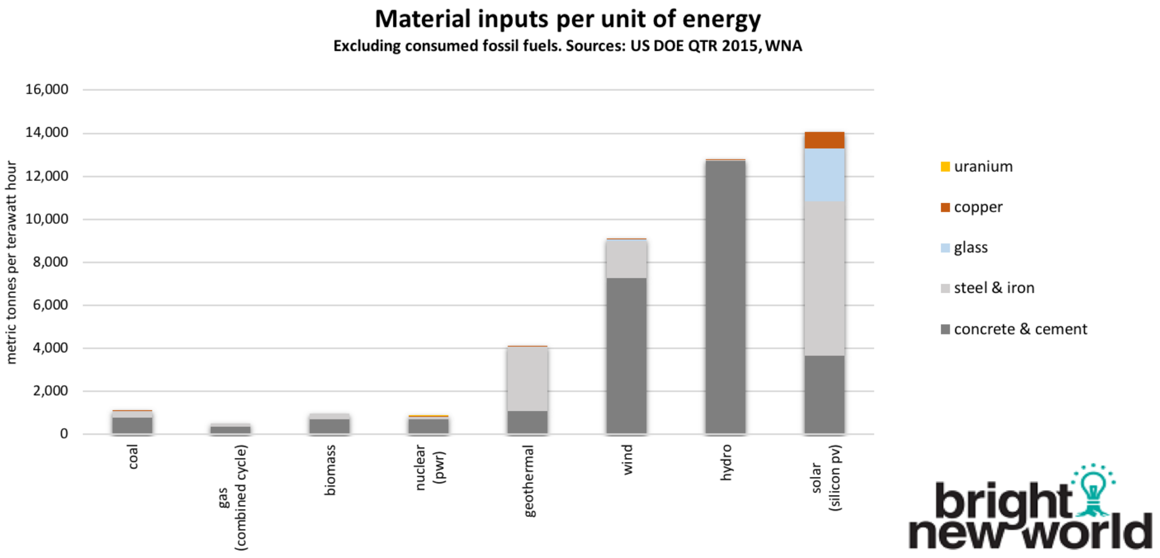
1.2 Environmental impacts

The impact of operating nuclear reactors on the environment is small in comparison to other generation sources. Emissions and physical impact to the environment are some of the lowest of all generation sources.

1.2.1 Material use

Nuclear power has one of the lowest materials input per unit of energy and is the only power generation source that fully encapsulates its waste stream. It is the only generation source that has established industries to recycle wastes from generation (spent nuclear fuel) and facilities to dispose of the material that has no further use.

The Department of Energy in the United States working with the Argonne National Laboratory (ANL) undertook analysis of material inputs for a range of different generation sources. The following graph outlines the material use for different generation sources.



The values for nuclear are as follows using a terawatt hour (1 billion kWh):

Uranium	3 tonnes/TWh
Copper	3 tonnes/TWh
Steel and Iron	150 tonnes/TWh
Concrete and Cement	690 tonnes/TWh

These are the lowest of the low carbon energy choices and demonstrate the large energy density that is associated with nuclear energy. From a project the size of any modern coal power plant, large amounts of low carbon energy can be generated using a low amount of materials per unit of energy produced. This is the definition of sustainable development.

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[7] (Warner, 2012)

[8] *ibid*, p. S-10

Due to the large energy density of uranium, the total output of Australia's uranium mining industry from three mine sites (Olympic Dam, Beverley/Four Mile, and Ranger) was 7,343 tonnes in 2017-18 which can produce 246 TWh of electricity, or 96% of Australia's electricity generation[9].

This means that from a handful of mines we could potentially power all of Australia, this is the definition of low impact development. With modern rehabilitation processes and legal requirements, the long-term impact of these mines can be minimised and returned to nature as evident at the Narbalek mine in Northern Territory[10].

1.2.2 Waste

From nuclear generation there is the by-product of nuclear waste, spent nuclear fuel. Nuclear waste management is a well understood and developed process. From the reactor, spent nuclear fuel is cooled in a pool next to the reactor for at least 5 years,[11] after this it is removed into a dry cask for interim storage (see figure 3), and finally it is moved to either permanent disposal or reprocessing i.e. recycling.

Figure 3 - Dry cask storage at decommissioned Connecticut Yankee Nuclear Power Plant

Spent nuclear fuel is a diminishing hazard as it decays. The radiotoxicity of spent nuclear fuel, as demonstrated in figure 4 decreases by 70% in 10 years and 90% in 100 years. In the United States spent fuel cannisters have been uprated to 100-year lifespans[12].

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[9] (Australian Safeguards and Non-Proliferation Office, 2018)

[10] (Department of the Environment and Energy, 2019)

[11] (Institute of Nuclear Physics and Particle Physics, n.d.)

[12] (Nuclear Regulatory Commission, 2015)

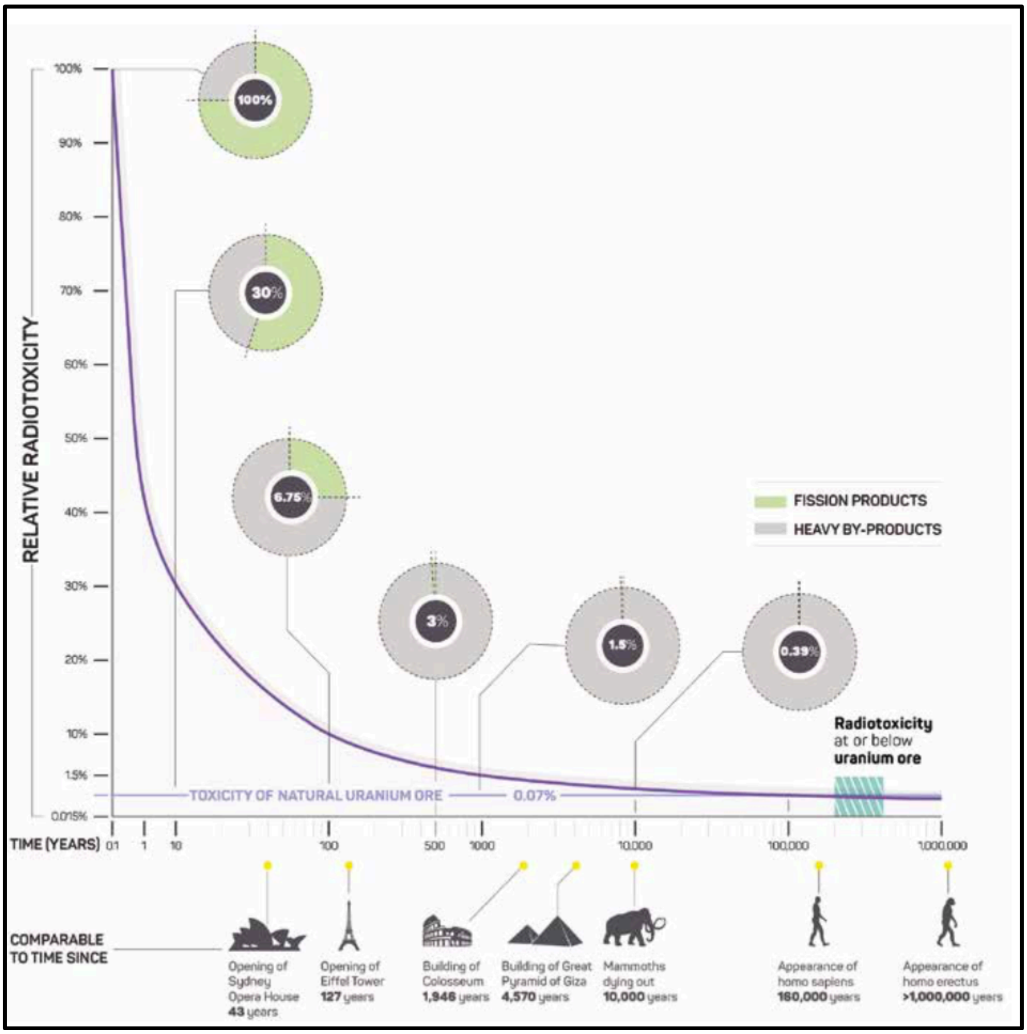

Figure 4 - Radiotoxicity of used nuclear fuel over time, NFCRC 2016

The Nuclear Fuel Cycle Royal Commission's final report extensively assesses the nuclear waste industry and demonstrates there are accepted practices and facilities to manage and handle the waste, with minimal environmental impact.

In the 40 years of nuclear waste transportation in Australia there have not been any accidents during the transport of nuclear material that have caused a significant release of radiation or harm to the environment[13]. Globally this experience is echoed with no significant releases of radiation to the environment from 25,000 cargoes of used fuel since 1971[14].

Nuclear waste from power generation, particularly spent nuclear fuel, is a well understood and managed hazard. It is fully encapsulated, stored, recycled or disposed in purpose-built facilities handled by experts in radiation protection and nuclear safety. With this management, expertise and professionalism, the risk to the public from spent nuclear fuel is negligible.

This is affirmed by the accident scenario modelling in the Nuclear Fuel Cycle Royal Commission, finding that if a cask was lost at sea in South Australia the maximum dose to the public eating seafood locally would be:

> *One thousandth to a billionth of natural background levels*[15]

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[13] (Nuclear Fuel Cycle Royal Commission, 2016), p. 153

[14] (World Nuclear Association, 2017)

[15] (Nuclear Fuel Cycle Royal Commission, 2016), p. 310

Additionally, the risk of any accident occurring resulting in a breach of containment is very low, mainly due to the existing management and operational processes in place to prevent such a breach[16].

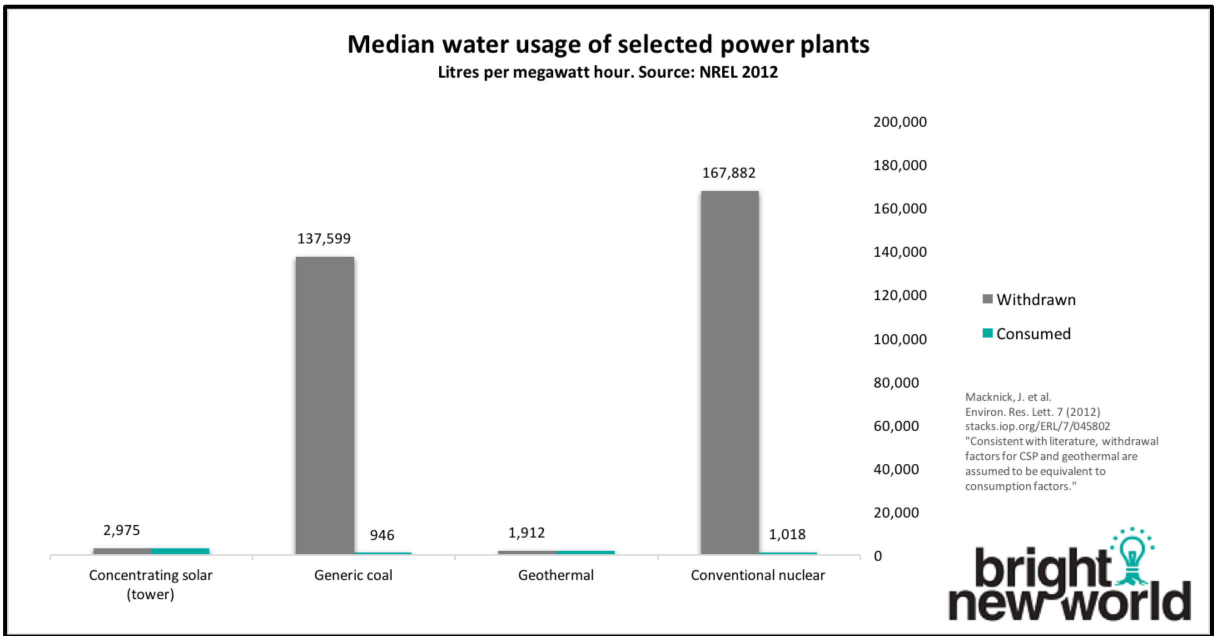
For this energy source, the radiation hazard decreases over time, with the majority of the harm minimising within the capabilities of current storage technology, long term storage is well understood (see Finland and Onkalo), recycling options are available and well established, and this waste is a potential resource for use in Generation IV reactors.

1.2.3 Water use

Australia is a continent where water resources are vitally important for all users. The use of these water sources, particularly potable and irrigation water resources, must be managed to ensure the long-term sustainability of the resource.

Nuclear power, like all thermal electricity generation sources, uses water in the coolant loops of the reactor core and turbine condenser circuits. This water is withdrawn from a body such as the ocean, river or cooling pond, and the majority returned to this water source. Some will be evaporated into the atmosphere; however, this will return in rain, albeit in a geographically different location.

The water use is well understood in nuclear power, and limitations on the use are typically due to maintaining environmental water temperature limits for outflow[17]. Nuclear power withdraws between 95 and 230m^3/MW/hour but consumes between 2 to 4 m^3/MW/hour through cooling ponds and towers[18]. The National Renewable Energy Laboratory in the United States assessed power sources in the US and found nuclear power withdraws 167,882L/MWh and consumes 1,018L/MWh (see figure 5).



Median water usage of selected power plants

Litres per megawatt hour. Source: NREL 2012

Macknick, J. et al.
Environ. Res. Lett. 7 (2012)
stacks.iop.org/ERL/7/045802
"Consistent with literature, withdrawal factors for CSP and geothermal are assumed to be equivalent to consumption factors."

Figure 5 - Water consumption and withdrawals of selected generation sources

Arguments noting nuclear power's large water use – i.e. consumption – as competition for other sectors such as agriculture or potable sources for human use are misunderstood. Nuclear sited on a coastline is not in competition as it can use the ocean for cooling purposes.

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[16] (Nuclear Fuel Cycle Royal Commission, 2016), Appendix L

[17] (Kidd, 2008)

[18] (Nuclear Fuel Cycle Royal Commission, 2016), p. 198

In arid regions and countries such as India, Pakistan, China, Iran, Kazakhstan, Egypt and Saudi Arabia nuclear projects have or are planned with desalination capacity. The Ataku plant in Kazakhstan provided both power and potable water for 150,000 people[19].

Nuclear, through thermal or electricity power, can desalinate water for potable and agricultural uses in Australia. A recent study commissioned by Senator Bernardi published by MIT found a nuclear plant in South Australia paired to a modern desalination plant could cultivate 5,800km2 of arid land into irrigated farmland, similar to that found in Israel[20].

Rather than being a net consumer of water, nuclear power can be a net producer of water. For a country with large arid zones, declining water resources, and ample coastline, the establishment of new water sources powered with plentiful clean energy is a major opportunity to protect and conserve vital water courses in Australia, such as the Murray Darling basin.

1.3 Health impacts

1.3.1 Radiological impacts

The World Health Organisation (WHO) and United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR) are the two most authoritative bodies on the health impacts of nuclear accidents. UNSCEAR was established in 1955 to undertake:

> *"… broad reviews of the sources of ionizing radiation and the effects on human health and the environment. Its assessments provide a scientific foundation for United Nations agencies and governments to formulate standards and programmes for protection against ionizing radiation. It does not deal with or assess nuclear safety or emergency planning issues."*

UNSCEAR collates and assesses reports and measurements from a large group of nuclear and medical experts to determine effects and any required actions. It can be thought of as the IPCC of the radiation effects field of science, where effects are measured, assessed and reviewed by global experts. They work with other UN bodies under the UN Environmental Program such as WHO, FAO, IAEA, CTBTO, and WMO.

Australia has been a member of UNSCEAR since its inception and the current Chair Dr. Gillian Hirth is Deputy CEO of Australian Radiation Protection and Nuclear Safety Agency (ARPANSA). UNSCEAR is responsible for the studies looking into the effects of the nuclear accidents at Fukushima-Daiichi in 2011 and Chernobyl in 1986.

These two reports are the culmination of field studies, medical assessments, radiation and nuclear physicist analyses, and extensive peer review. For the worst accident to befall a western designed reactor, General Electric Mark I BWR, at Fukushima-Daiichi, UNSCER found:

> *No radiation-related deaths or acute diseases have been observed among the workers and general public exposed to radiation from the accident. The doses to the general public, both those incurred during the first year and estimated for their lifetimes, are generally low or very low. No discernible increased incidence of radiation-related health effects are expected among exposed members of the public or their descendants.*

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[19] (World Nuclear Association, 2019)

[20] (Buongiorno, 2018), p.16

Further adding:

> *The most important health effect is on mental and social well-being, related to the enormous impact of the earthquake, tsunami and nuclear accident, and the fear and stigma related to the perceived risk of exposure to ionizing radiation. Effects such as depression and post-traumatic stress symptoms have already been reported.*[21]

An update to this report in 2016 reaffirmed these findings[22]. The 2016 update even took into consideration a study that demonstrated larger incidents of thyroid cancer than initially measured and impacts to other organisms in the exclusion zone. It found the former was based on a flawed analysis and the latter needed to take into consideration other stressors to local fauna populations[23]. In 2017, a symposium of international experts concluded that:

> *doses to the public from the accident in Fukushima were too low to give rise to a discernible excess risk for thyroid cancer.*[24]

Disputed findings of elevated cancers are reported in anti-nuclear publications as references indicating the impacts of Fukushima are more than assessed, but this is not backed up by expert assessment and peer review. The underlying risk of overstating the harm and impact is to increase fear and stigma in the populations effected. It is something unheeded by those wanting to overstate nuclear harm.

The Chernobyl accident was the worst for an uncontained release of radioactive material from a power nuclear reactor. UNSCEAR has undertaken a two-decade long assessment of the effects of Chernobyl and found the observed health effects currently attributable to radiation exposure are as follows:

> *134 plant staff and emergency workers received high doses of radiation that resulted in acute radiation syndrome (ARS), many of whom also incurred skin injuries due to beta irradiation;*
>
> *The high radiation doses proved fatal for 28 of these people;*
>
> *While 19 ARS survivors have died up to 2006, their deaths have been for various reasons, and usually not associated with radiation exposure;*
>
> *Skin injuries and radiation-induced cataracts are major impacts for the ARS survivors;*
>
> *Other than this group of emergency workers, several hundred thousand people were involved in recovery operations, but to date, apart from indications of an increase in the incidence of leukaemia and cataracts among those who received higher doses, there is no evidence of health effects that can be attributed to radiation exposure;*
>
> *The contamination of milk with [Iodine-131], for which prompt countermeasures were lacking, resulted in large doses to the thyroids of members of the general public; this led to a substantial fraction of the more than 6,000 thyroid cancers observed to date among people who were children or adolescents at the time of the accident (by 2005, 15 cases had proved fatal);*

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[21] (UNSCEAR, 2014)

[22] (UNSCEAR, 2016), p.32

[23] *ibid*

[24] (Saenko, 2017)

> *To date, there has been no persuasive evidence of any other health effect in the general population that can be attributed to radiation exposure.*[25]

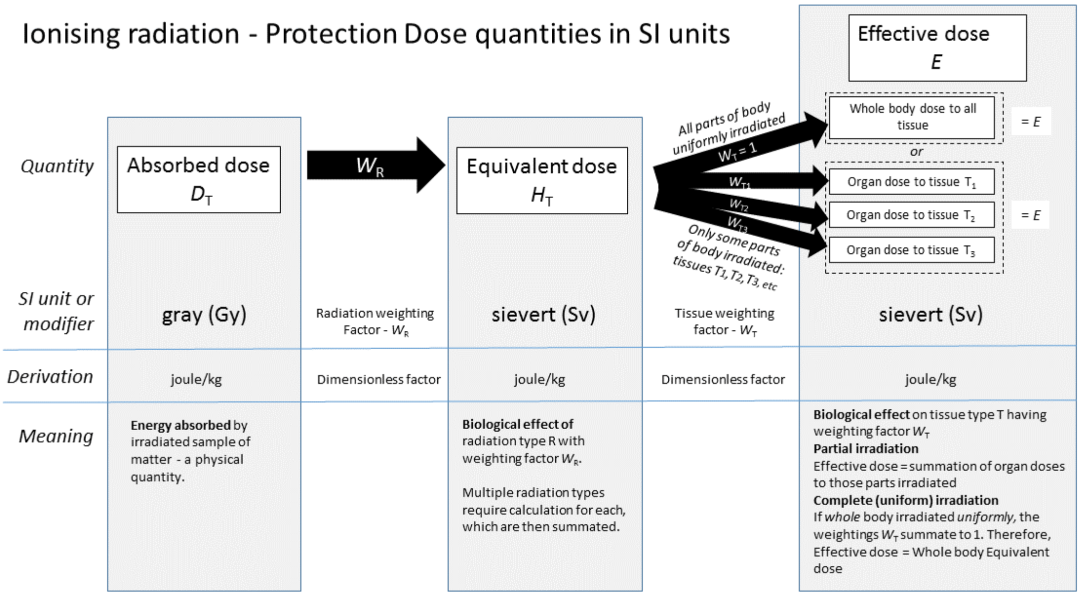
The WHO adding in their overview of the Chernobyl Forum's assessment of the impacts:

> *Alongside radiation-induced deaths and diseases, the report labels the mental health impact of Chernobyl as "the largest public health problem created by the accident" and partially attributes this damaging psychological impact to a lack of accurate information. These problems manifest as negative self-assessments of health, belief in a shortened life expectancy, lack of initiative, and dependency on assistance from the state.*
>
> *"Two decades after the Chernobyl accident, residents in the affected areas still lack the information they need to lead the healthy and productive lives that are possible," explains Louisa Vinton, Chernobyl focal point at the UNDP. "We are advising our partner governments that they must reach people **with accurate information**, not only about how to live safely in regions of low-level contamination, but also about leading healthy lifestyles and creating new livelihoods."*[26] [emphasis added]

Psychological impacts are a real and present danger from nuclear accidents. Overstating the impacts and labelling a population as "contaminated" when their effective doses (see box 1.1) are assessed to have no additional impacts or lower than the worst-case estimations, can lead to undue harm through psychological distress.

Box 1.1

Radiation impacts can be assessed in different units and can be confusing to understand what is being assessed. The following flowchart outlines the process to understand an absorbed dose (Gray) to equivalent and effective dose (Sievert).



The attempts to discredit experts in radiological impacts, physicians and nuclear science through conspiracies (see box 1.3), misquoting official sources by focusing on the hazard and

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[25] (UNSCEAR, 2011), p.64

[26] (World Health Organisation, 2016)

omitting the actual impacts to disguise the risk (see box 1.2), or distressful claims by the anti-nuclear lobby add to the harm of an already stressful situation.

1.3.2 Clean air benefits

Nuclear power emits no pollutants in harmful quantities during normal operation such as small particulates (PM2.5 or PM10), gasses (CO_x, NO_x and SO_x) or radioisotopes. Pushker Kharecha and James Hansen assessed the historical and projected deployment of nuclear power globally and calculated the prevented mortality due to avoided harmful emissions. Their assessment found (emphasis added):

> *global **nuclear power has prevented an average of 1.84 million air pollution-related deaths** and 64 gigatonnes of CO2-equivalent (GtCO2-eq) greenhouse gas (GHG) emissions that would have resulted from fossil fuel burning. On the basis of global projection data that take into account the effects of the Fukushima accident, we find that **nuclear power could additionally prevent an average of 420 000−7.04 million deaths** and 80−240 GtCO2-eq emissions due to fossil fuels by mid-century, depending on which fuel it replaces.*[27]

This is also a factor echoed by the Asthma Society of Canada and Bruce Power in their "Clean Air Ontario" report. Due to the continued and refurbished nuclear power and closure of fossil fuel plants in Ontario they have reduced their annual smog days from 53 in 2005 to 0 in 2015. The benefits this will have on the air people breathe living in greater Toronto and Ontario will lead onto other benefits society wide[28].

Box 1.2

During the South Australian Nuclear Fuel Cycle citizen jury processes, the anti-nuclear groups published a briefing note on the maritime impacts of spent fuel importation. The following quote is the one published by anti-nuclear campaigners and the red in square brackets is the full quote from the source cited. (Nuclear Port Brief, D. Noonan, 2016):

> *The Final Report Concludes: "...if a cask was lost at sea and was irrecoverable, there is a potential for some members of the public consuming locally sourced seafood to receive a very small dose of radiation [However, the maximum annual dose expected would be a thousandth to a billionth of natural background levels]"*
>
> *A further Jacobs MCM desk top Concludes that radioactivity that escapes from an unrecovered and degrading cask is expected "to be diluted in thousands of cubic kilometres of seawater [so that the risks it poses to people and the environment are negligible]"*

This clearly demonstrates the removal of the actual risk to the public by anti-nuclear campaigners to play on the misperceptions of radiological harm.

1.4 Nuclear safety

The nuclear accidents discussed above, Chernobyl and Fukushima, are two incidents that are widely discussed along with Three Mile Island as reasons not to develop nuclear power. While the risk of a nuclear meltdown leading to radiological releases is very low, the impacts can be quite severe in property loss and psychological impacts.

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[27] (Kharecha, 2013)

[28] (Bruce Power & Asthma Society of Canada, 2016)

Box 1.3
There is a claim by anti-nuclear commentators to discredit the findings of the World Health Organisation (WHO) by stating they cannot report on the effects of atomic radiation because of an agreement with the International Atomic Energy Agency. The agreement cited states:

Article I – Co-operation and Consultation

1. *The International Atomic Energy Agency and the World Health Organization agree that, with a view to facilitating the effective attainment of the objectives set forth in their respective constitutional instruments, within the general framework established by the Charter of the United Nations, they will act in close co-operation with each other and will consult each other regularly in regard to matters of common interest.*
2. *In particular, and in accordance with the Constitution of the World Health Organization and the Statute of the International Atomic Energy Agency and its agreement with the United Nations together with the exchange of letters related thereto, and taking into account the respective co-ordinating responsibilities of both organizations, it is recognized by the World Health Organization that the International Atomic Energy Agency has the primary responsibility for encouraging, assisting and co-ordinating research on, and development and practical application of, atomic energy for peaceful uses throughout the world* ***without prejudice to the right of the World Health Organization to concern itself with promoting, developing, assisting, and co-ordinating international health work, including research, in all its aspects.***
3. *Whenever either organization proposes to initiate a programme or activity on a subject in which the other organization has or may have a substantial interest, the first party shall consult the other with a view to adjusting the matter by mutual agreement*

Anti-nuclear commentators will refer to the last paragraph as evidence the WHO cannot undertake radiological impacts without first getting approval from IAEA. However, it ignores the prior section that notes the WHO can act “without prejudice” (emphasis in bold).

While these accidents receive the most attention and have been assessed and discussed widely, the committee should also look to the incidents that have occurred at other nuclear power facilities of the same type and technology where it was successfully managed and contained.

Below we will discuss two incidents and incidents at similar plants that are relevant to the committee, Pressurised Water Reactors and Boiling Water Reactors. Chernobyl is not discussed as the RMBK reactor type should never be considered for use in Australia.

1.4.1 Three Mile Island & David Besse, PWR

Three Mile Island (TMI) is the only major meltdown incident of a nuclear power reactor in the United States. Due to a loss of coolant incident, cooling to the reactor core resulted in a partial meltdown of the core and the loss of the reactor.

Radiological releases to the environment were contained within the designed containment structures of the plant (see figure 6[29]), resulting in a small release of radioactive noble gasses to the environment. The effective dose to the public was 0.08mSv (equal to a chest x-ray)[30].

However, while many people remember TMI, the incident at the David Besse nuclear power plant, a sister plant to TMI, two years prior is never recognised. The plant operators at David Besse experience the same loss of coolant accident that occurred TMI and they responded in the same manner. The David Besse operators took actions outside of their training but based on their expert knowledge of reactor operations. They saved their reactor core[31].

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[29] (International Atomic Energy Agency, 1982)

[30] (World Nuclear Association, 2012)

[31] (Derivan, 2014)

The issue was how the incident at David Besse was communicated to the reactor operators and designers. It is a major reason why an organisation such as the World Association of Nuclear Operators was established. It is an organisation with 120 members operating 430 nuclear reactors worldwide. This body exists to maximise safety and reliability of nuclear plants by operators working together to assess, benchmark, and improve performance through mutual support, exchange of information and emulation of best practices[32].

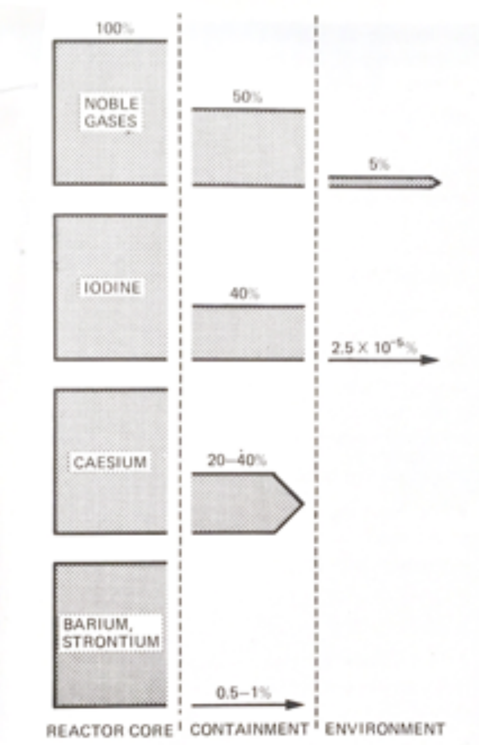

FIG.41. Schematic illustration of the leakage of radioactive substances (percentages of initial amounts in the reactor core) from the reactor fuel at Three Mile Island through the first barriers (fuel cladding and primary system, and containment respectively). Only noble gases reached the environment in any significant amount.
Source: Report of Swedish National Institute of Radiation Protection, Stockholm, Dec. 1979.

Figure 6 - Radioactive releases from Three Mile Island, IAEA 1982

1.4.2 Fukushima-Daiichi & Onagawa, BWR

The nuclear accidents at Fukushima Daiichi and Onagawa nuclear plants occurred during the Tohoku earthquake and tsunami in March 2011. Both nuclear plants are a Boiling Water design by General Electric.

Onagawa was located closer to the epicentre of the Tohoku earthquake and received beyond design basis ground acceleration twice that that experienced at Fukushima-Daiichi[33,34]. Both plants were assessed after prior earthquakes and found to have no damage.

When these plants received a beyond design basis ground acceleration from the earthquake movement they automatically tripped off or SCRAM. For both incident reports by the IAEA the plants operated as designed to this point.

The difference between the two plants was the design of the sea wall to prevent water intrusion. At Onagawa the designers pushed for a 14.8m seawall as opposed to the drafted 12m seawall. Fukushima-Daiichi's was designed to 5.7m and the Tsunami that inundated the plant was estimated to be 14m[35].

The different experiences between these two plants demonstrates two key aspects of nuclear safety design; adequate designs for environmental impacts common to the region and the robustness of nuclear plant design. The latter can be summed up by the experts report from the IAEA into the Onagawa nuclear power plant after experiencing the largest earthquake and tsunami to hit a nuclear power plant:

> *The Structures Team concluded that the structural elements of the NPS were remarkably undamaged given the magnitude and duration of ground motion experienced during this great earthquake.*[36]

These accidents are used as examples to not develop nuclear, however there are other cases where the operation, design and experience during an accident scenario demonstrate that nuclear can be operated safely.

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[32] (World Association of Nuclear Operators, 2019)
[33] (International Atomic Energy Agency, 2012)
[34] (TEPCO, 2011)
[35] (Japan Today, 2012)
[36] (International Atomic Energy Agency, 2012)

2. Economics

The following section will consider the economics of nuclear power on three key areas; overnight capital costs (OCC), levelized cost of electricity (LCOE) and overall system costs. These three areas demonstrate the capital cost of a nuclear plant (OCC), its total cost including financing, operating and decommissioning (LCOE) and the modelled wholesale cost of electricity in a network of other generators (system cost).

2.1 Capital cost

2.1.1 Overnight capital cost trends

The overnight capital cost of nuclear represents the cost of the nuclear generation plant minus financing costs. This is useful to understand trends in the capital cost of nuclear without the differing jurisdictional financing costs. As these costs are only realised at the finalisation of a project.

A study by Lovering, Yip and Nordhouse in 2016[37] undertook an analysis of overnight capital costs of nuclear to understand trends in the capital of nuclear. Of their analysis of 349 nuclear reactors across several countries the trend in cost escalation in the United States is not consistent with the continual cost de-escalation in South Korea.

This is crucial for the committee to understand as there exists jurisdictional variation in the capital cost of nuclear deployment in several countries. Figure 7 highlights the historical trends in nuclear deployment across several countries. The full study has detailed datasets on historical OCC figures.

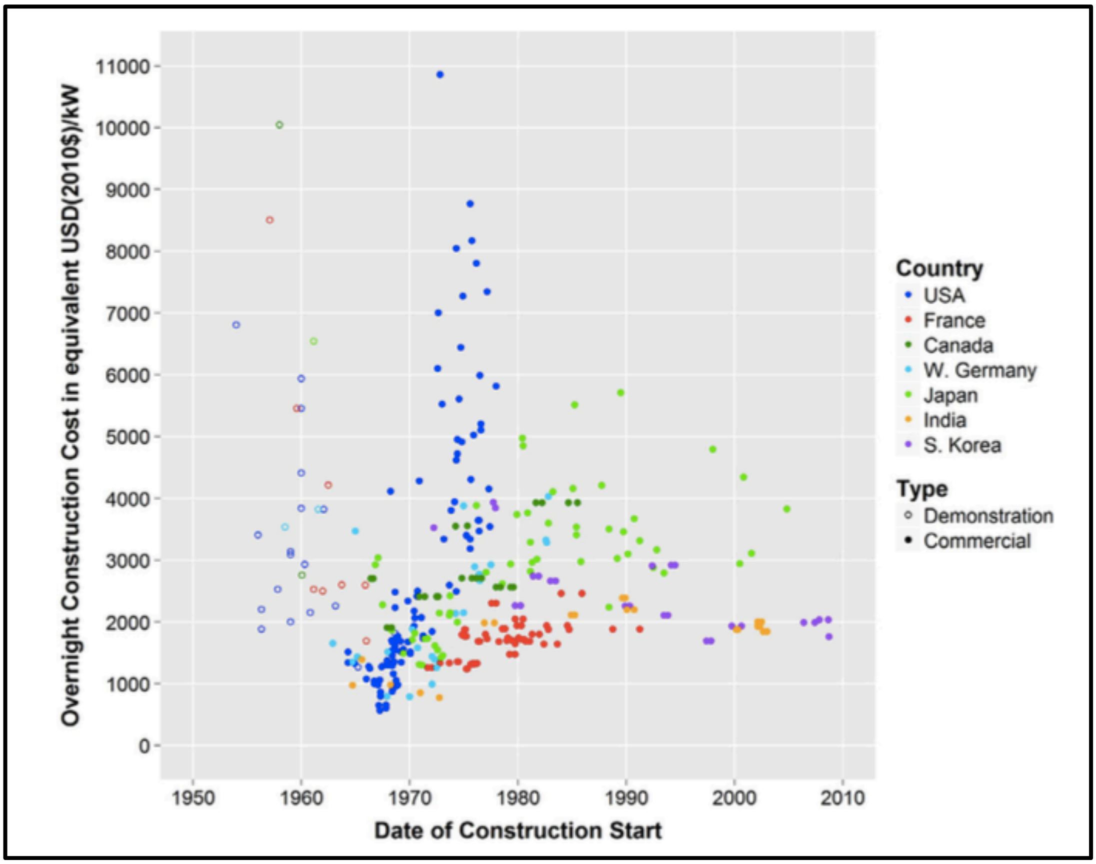

Figure 7 - Overnight Capital Costs of nuclear from Lovering, Yip and Nordhouse (2016)

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[37] (Lovering, 2016)

Overnight capital costs can also be determined for SMRs based on vendor assessments of their reactors. The Canadian SMR roadmap[38] assessed 47 different SMR capital cost estimates and 17 large scale nuclear reactors (>1GWe). Figure 8 demonstrates a wide array of capital cost estimates for different SMR types (presented in Canadian Dollars; 1CDN = 1.11AUD).

The committee should note that there are only a handful (n=3) of references where the SMR capital cost is close to the GenCost 2018 figure (see section 2.2.3 & Appendix A), but none are referenced in the GenCost 2018 report.

In discussions with Small Modular Reactor (SMR) vendors, it has been noted a benchmark for capital costs for a single plant of multiple units should be close to AU$4 billion which will be attractive to private investment. Large scale nuclear power plants, where the capital cost is in the tens of billions will require public-private investment models.

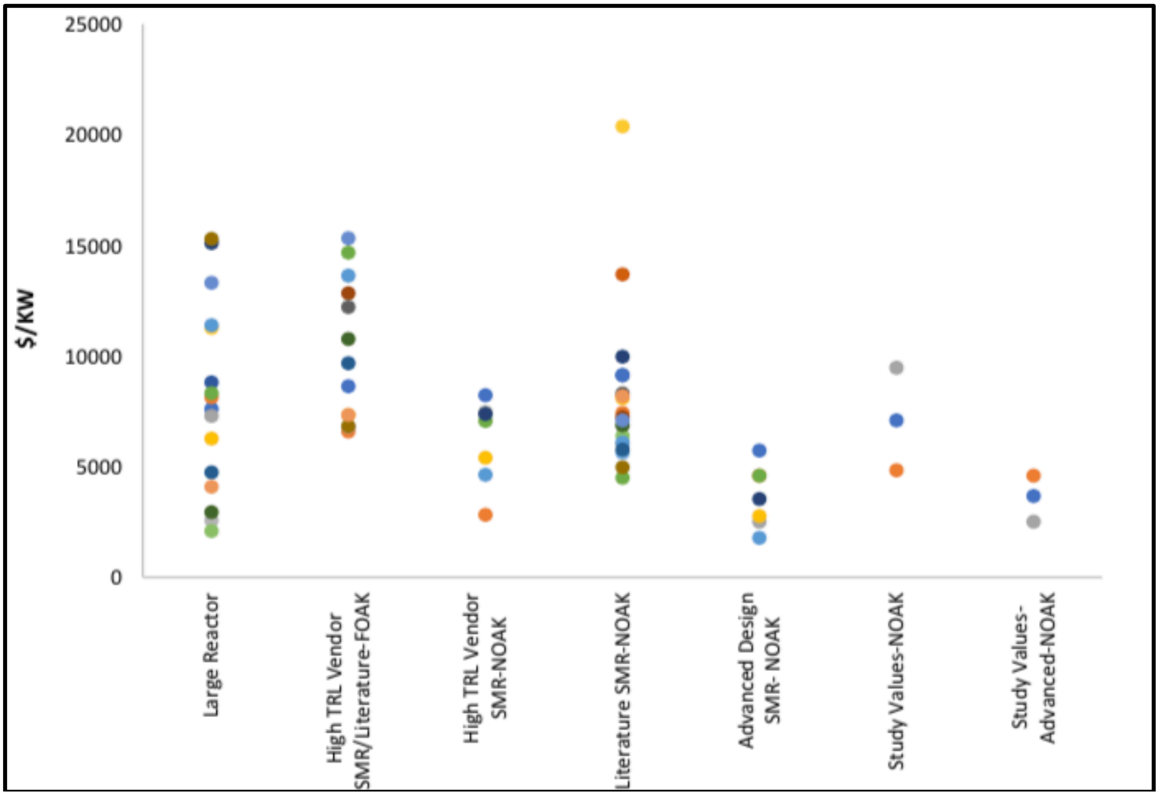

Figure 8 - SMR capital costs in CAD (= 1.11 AUD), SMR Roadmap, 2018

The attractiveness of SMRs is in their modularity and lower capital cost per unit compared to large nuclear plants. As below discussed, the majority of the financial risk for nuclear is in the upfront costs. To be able to deploy nuclear in smaller amounts helps to reduce financial risk, and flexibility to add capacity as the grid requires.

The Energy Options Network in 2017 undertook an analysis of advanced reactor designs and had input from several reactor vendors to the costs of their plant. Their analysis determined that the capital costs for all participating companies averaged US$3,782/kW[39]. The analysis also determined the levelised cost of electricity (discussed further in section 2.2) and operating costs (see figure 9). The key takeaway is that for these advanced reactor designs the capital cost is a major determinant of the levelized cost of electricity.

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[38] (SMR Roadmap, 2018)

[39] (Energy Options Network, 2017)

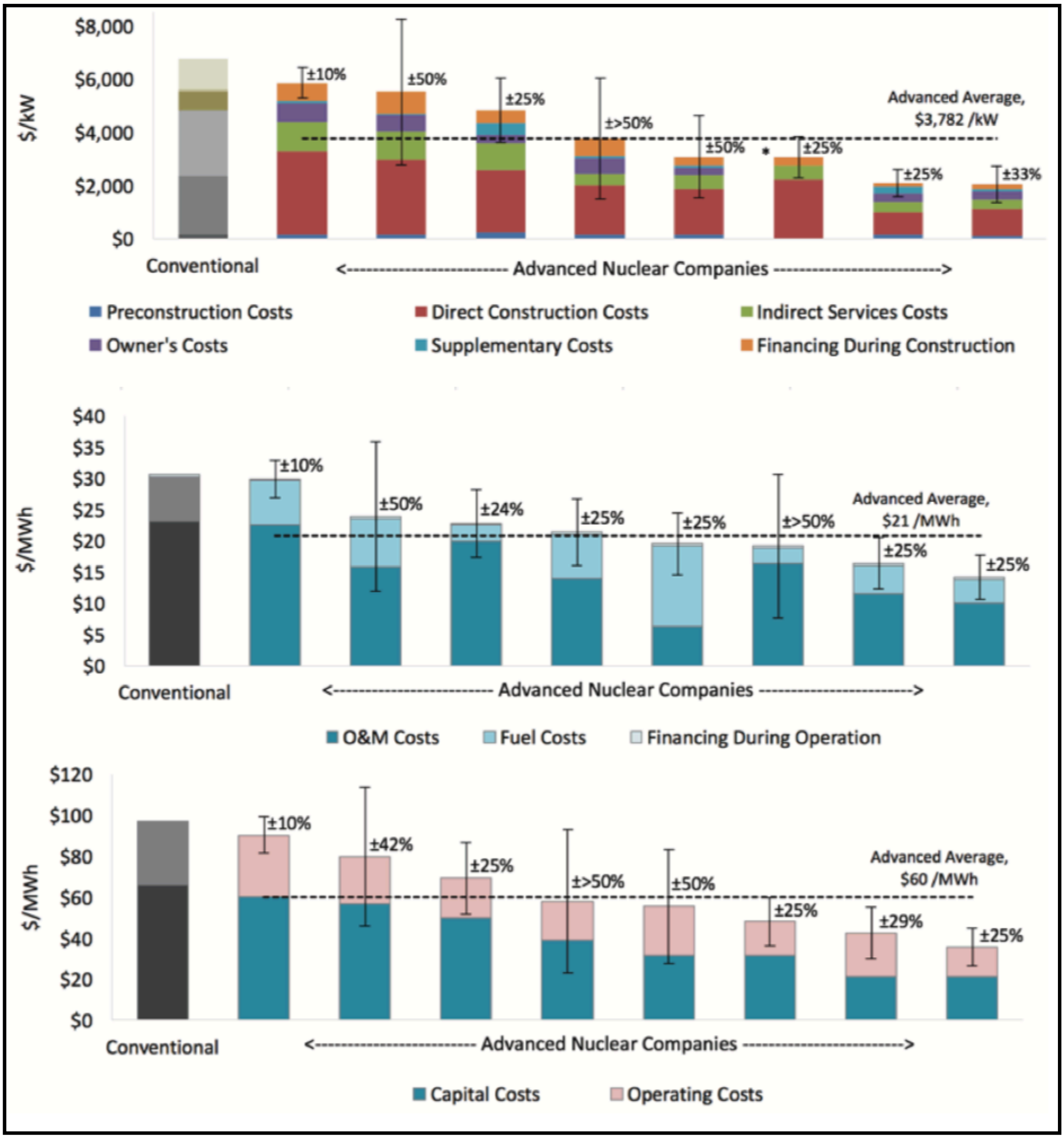

Figure 9 - Energy Options Network: Capital cost, Operating cost and Levelised cost (USD)

2.2 Levelised cost of nuclear

The committee will be aware and have evidence presented to it on the levelised cost of electricity (LCOE) of nuclear and other sources. Levelising costs of nuclear and other generation sources enables us to compare different generation sources on the same basis. Comparing variable renewable generation (solar and wind) with conventional generation (thermal generation) should take into consideration differences in dispatch characteristics.

The LCOE of nuclear is heavily impacted by the cost of capital. This can comprise of up to 75% of overall LCOE of a SMR or gigawatt scale nuclear plant[40]. De-risking the financing

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[40] (Nuclear Fuel Cycle Royal Commission, 2016), p. 62

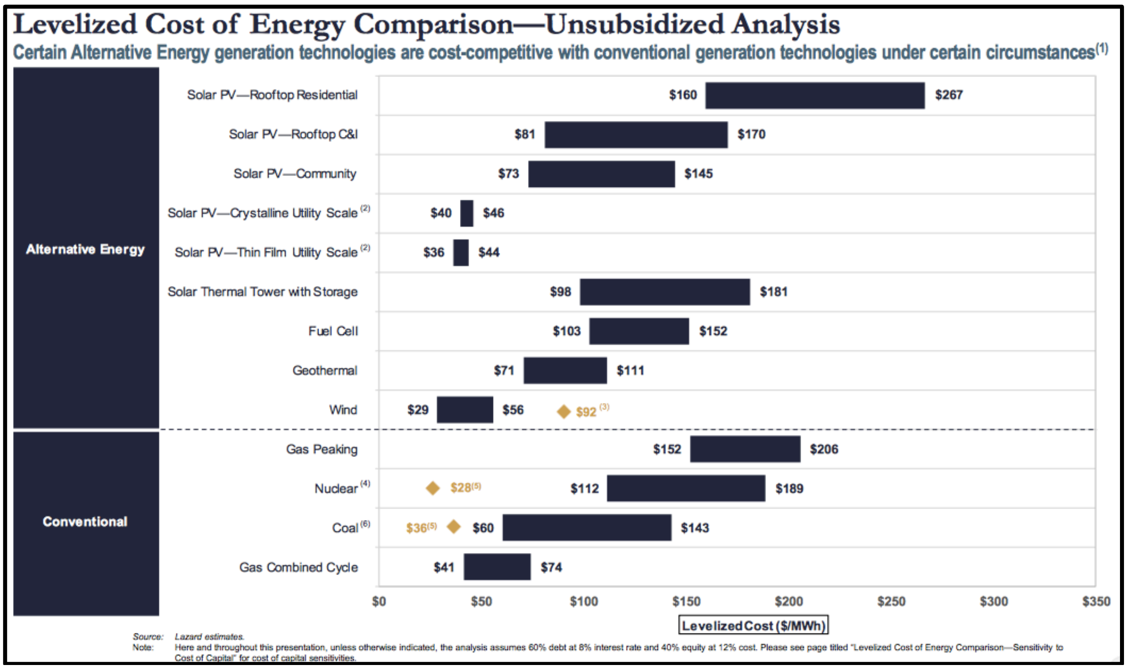
phase of nuclear deployment has the ability to lower the LCOE of nuclear to acceptable levels for investment. The sensitivity to cost of capital can be as much as US$55/MWh[41].

The Nuclear Fuel Cycle Royal Commission assessed reactors that could be commercially deployed and found that `LCOE of nuclear is impacted by the capital and finance costs. With an 8% reduction in capital or finance obtained at 7% nuclear could be viable in South Australia at current costs[42].

The Canadian Government SMR roadmap outlines strategies to de-risk the cost of capital through private-public partnerships. Such strategies can include loan guarantees, preferred interest rates, power purchasing agreements, or production tax credits (e.g. LGCs). A change in the discount rate applied to a SMR development from 9% to 6% lowered the LCOE of nuclear by A$26/MWh[43].

An analysis of United States SMR deployment has shown the introduction of a production tax credit (i.e. LGC), loan guarantee, and tax incentives can reduce the LCOE of a SMR by A$24/MWh[44].

Another source of information on levelised cost of nuclear is the reports published by consultation firm Lazard. For their LCOE results they assume 60% debt at 8% interest rate and 40% equity at 12% cost, however they caution comparing LCOE results from thermal generators such as coal, gas and nuclear to variable sources such as wind and solar[45]. The results of their LCOE analysis are presented in figure 10[46].



Levelized Cost of Energy Comparison—Unsubsidized Analysis

Certain Alternative Energy generation technologies are cost-competitive with conventional generation technologies under certain circumstances(1)

Source: Lazard estimates.
Note: Here and throughout this presentation, unless otherwise indicated, the analysis assumes 60% debt at 8% interest rate and 40% equity at 12% cost. Please see page titled "Levelized Cost of Energy Comparison—Sensitivity to Cost of Capital" for cost of capital sensitivities.

Figure 10 - Lazard estimates of the LCOE of different energy sources, 2018

They key piece of information in their charts that is not discussed when comparing the cost of electricity from nuclear to other sources, is the fully depreciated nuclear price denoted by a

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[41] (Lazard, 2018)

[42] (Nuclear Fuel Cycle Royal Commission, 2016), p. 220

[43] (SMR Roadmap, 2018)

[44] (SMR Start, 2017)

[45] This is due to the different dispatch operations of variable renewable energy that is weather dependent, and thermal plants that's based on the availability of fuel.

[46] (Lazard, 2018)

golden diamond. Nuclear plants are licensed for 40 years in the US, and some are having licence extensions to 60 and 80 years[47]. Thus, the lifespan of a reactor can be as high as 80 years, when LCOE calculations are typically done over 30 years due to depreciation limits.

Hence after year 30 based on LCOE calculations there is the prospect of nuclear power producing power at US$36/MWh. This is reaffirmed by the the Columbia nuclear power plant in Washington State, US. This plant, commissioned in 1984, is a 1.1GW plant, produces 8,128 GWh annually, and cost US$7.63billion to construct (2018 USD)[48].

Over the past half-decade, the plant's economic operation has come under scrutiny to determine whether it provides value for consumers. The Bonneville Power Administration, similar to the Australian Energy Market Operator, concluded it provides "unique firm, baseload, non-CO2 emitting with predictable costs for ratepayers". The predictable cost is 3c/kWh (USD)[49].

The committee should consider the two generational lifespan of a nuclear power plant that while initially may have a higher LCOE than other sources, it can provide a wholesale cost that is comparable to present day coal generation in Australia when the costs are fully sunk.

2.2.3 CSIRO & AEMO GenCost 2018 Nuclear cost error

CSIRO publishes the annual report 'GenCost'. The 2018 edition of GenCost was released as a collaboration with the Australian Energy Market Operator (AEMO). This document is used as an authoritative source to compare and assess the costs of different generation sources. The stated premise of the report is as follows[50]

> *This GenCost project is the result of a collaboration between CSIRO and AEMO, together with stakeholder input, to deliver an annual process of updating electricity generation costs. CSIRO and AEMO have both committed their own resources to deliver the project with the aim of increasing the likelihood of delivering the continuity that was not achieved in predecessor studies. Wide stakeholder engagement and transparency are also built into the project design. The main workshops and other engagement supporting this activity were held in August through November 2018… The projection methodology is grounded in a global electricity generation and capital cost projection model recognising that cost reductions experienced in Australia are largely a function of global technology deployment.*

Bright New World has reviewed the document and its supporting work[51] for the treatment of SMR nuclear technology. The results are not consistent with 'wide stakeholder engagement and transparency' and certainly not presenting results that are a function of 'global technology deployment'.

The stated capital expenditure ($16,000/kW) and levelised cost of electricity for SMR nuclear is indefensible and does not withstand scrutiny. Given the reliance many Australian stakeholders place on this report, and the trust placed in AEMO and CSIRO, this section of the GenCost work requires urgent revision, from suitable qualified professionals, to inform current political conversations in Australia. A breakdown of the CSIRO/GHD assessment of SMR capital costs is attached in appendix A.

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[47] (Nuclear Regulatory Commission, 2019)
[48] (Energy Information administration, 2012)
[49] (Conca, 2018)
[50] (Graham, 2018) p. v
[51] (GHD, 2018)

2.3 System and Wholesale Costs

The above discussion on nuclear capital costs and assessment of LCOE demonstrates two methods to analyse a nuclear power plants financial feasibility. However, a more important measure is to analyse these figures in the context of a modern-day network with other generators. These analyses will determine a system cost of electricity which can be compared to the wholesale cost of electricity of a network, like the National Electricity Market.

2.3.1 OECD NEA

The OECD Nuclear Energy Agency has published reports looking at the system cost of grids with nuclear power. The most recent study assesses system costs (see figure 11) with high shares of nuclear and renewable energy. It compares the analysis of four variable renewable energy scenarios for a system with a low emissions intensity of 50g CO_2/kWh across several scenarios[52].

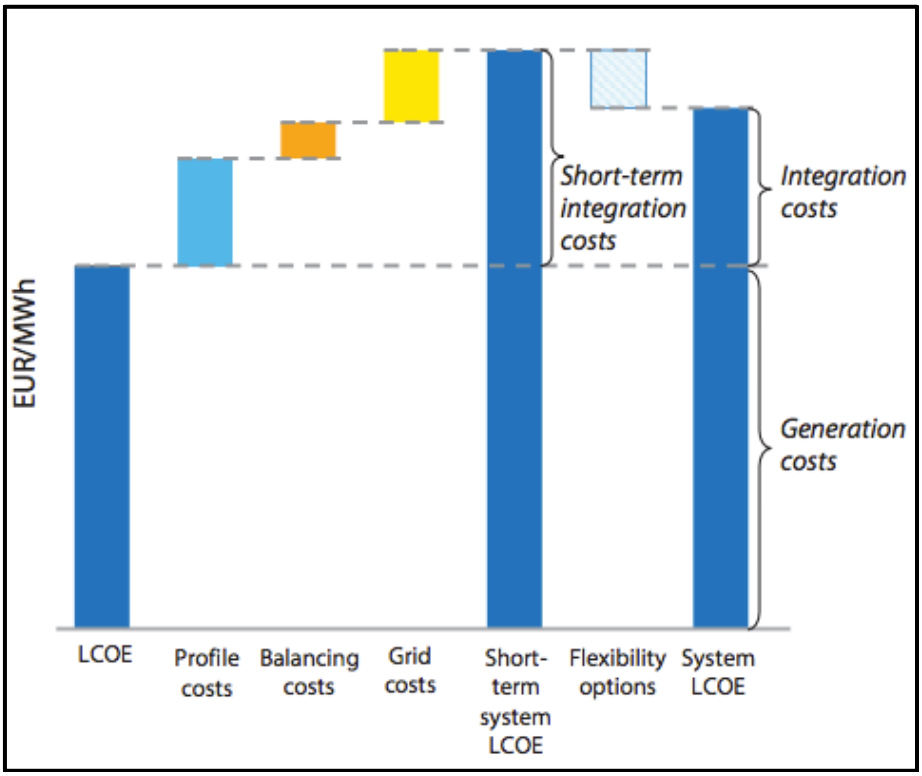

Figure 11 - Illustration of system cost, OECD 2015

The study defines a policy framework for achieving emissions reductions in a least-cost manner, it outlays five pillars for this framework:

> *1) Setting a robust price for carbon emissions;*
> *2) Short-term markets for efficient dispatch and revealing the system value of electricity;*
> *3) Regulation for the adequate provision of capacity, flexibility and infrastructures for transmission and distribution;*
> *4) Mechanisms to enable long-term investment in low-carbon technologies, including the reform of existing mechanisms; and,*
> *5) The internalisation of system costs wherever practical and necessary.*

With higher penetrations of variable renewable generation (VRE) the system costs also increase. At 75% VRE the profile, balancing and grid costs are US$50/MWh on top of the

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[52] (Organisation for Economic Co-operation and Development, 2019)

LCOE of the generation sources (see figure 12). Total costs of electricity provision at these higher scenarios are up to US$70 billion per year. The report concludes:

> *If OECD policy makers want to achieve such a deeply decarbonised electricity mix they must foster vigorous investment in low-carbon technologies such as nuclear energy, VRE and hydroelectric power. Where hydroelectric power is constrained by natural resource endowments, nuclear and VRE remain the principal options.*

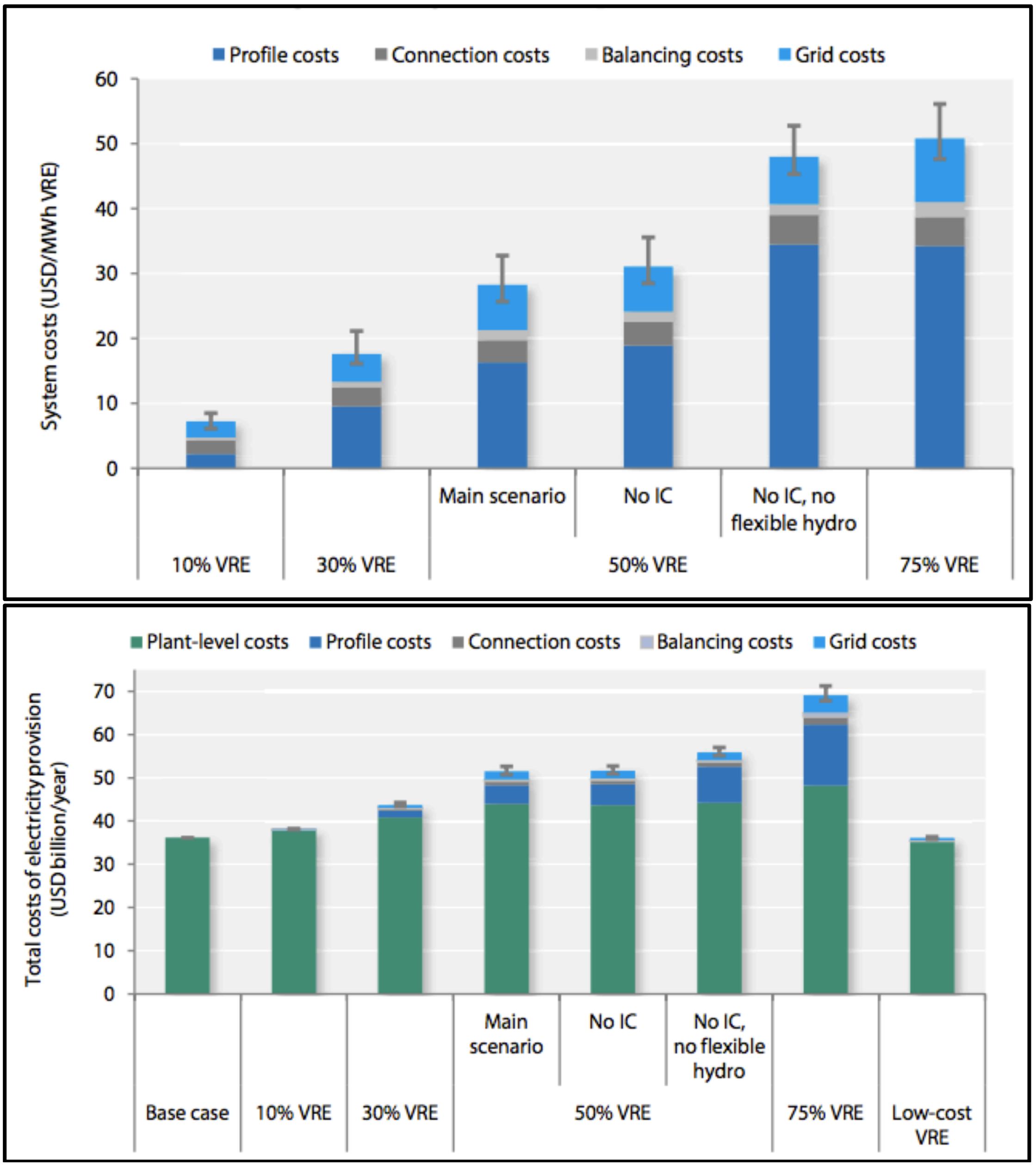

Figure 12 - System costs and costs of electricity provision

2.3.2 System costs of all low-carbon sources

A study conducted by researchers from MIT found that a system with variable renewable energy, firm and flexible generation provides the lowest average cost of electricity for the two energy market systems. These systems represented a typical northern and southern United States network (New England and Texas ERCOT).

This study assessed nearly 1,000 cases covering different CO2 levels, uncertainties, and geographical differences in demand, and renewable resource potential[53]. The study also re-classed low carbon generation into three categories rather than historical definitions based on the load they are dispatched into. These are fuel saving variable renewable energy resources, fast burst balancing resources, and firm low-carbon resources (see figure 13)[54].

The study determined that a lower system cost is established with a mix of all three sources of electricity generation. That excluding out firm low-carbon generation, such as nuclear, can lead to higher system costs when deeper cuts to emissions are targeted. To achieve the commitments in the Paris Agreement and limit electricity sector emissions to near zero a balanced mix of all generation classes must be deployed (see figure 14).

The core analysis determined that the cost of full decarbonisation without firm low carbon sources is 11 to 105% higher in the southern system[55,56]. With conservative assumptions on the cost of firm-low carbon sources and very-low cost assumptions for wind, solar and energy storage the result is similar with the non-firm option being higher in system cost than without[57].

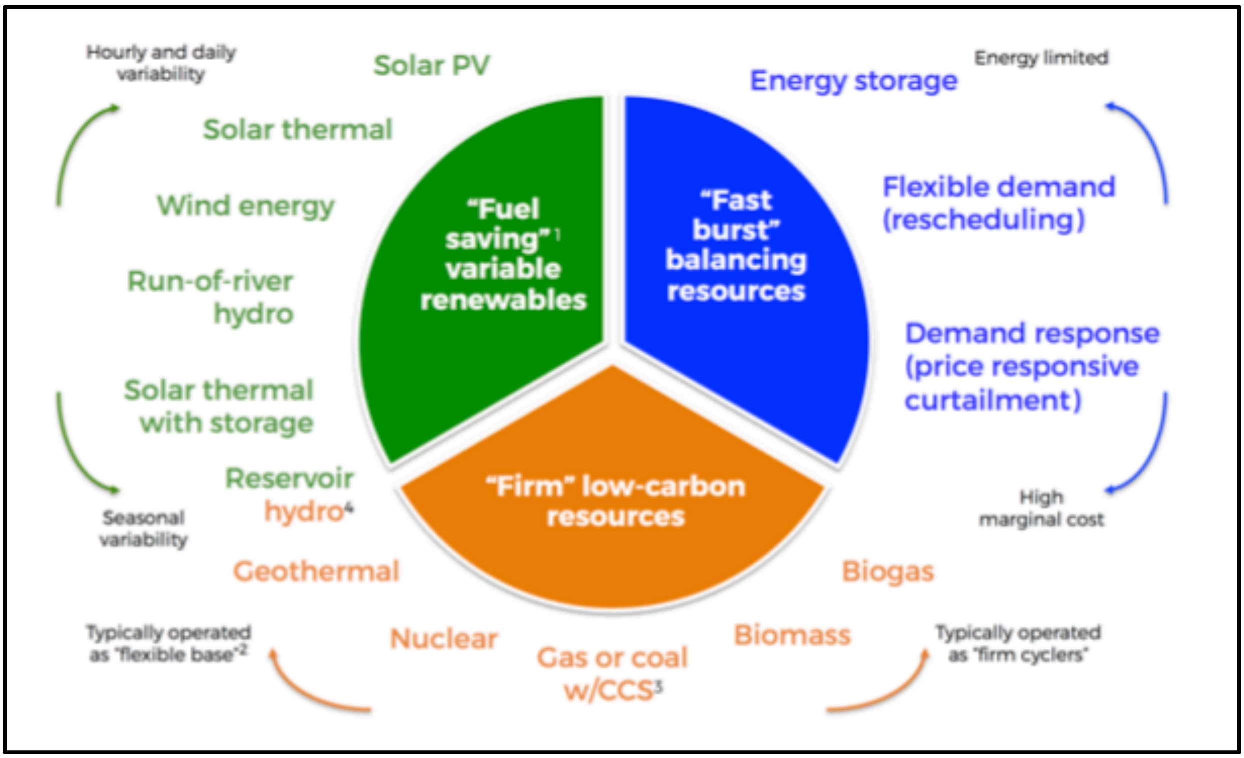

Figure 13 - Taxonomy of resources in a low carbon power system, Sepulveda et al.

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[53] (Sepulveda, 2018)

[54] (Sepulveda, 2018), p. 2

[55] *ibid*, p. 5

[56] The southern system is representative of the Texas ERCOT system. The geographical location of this system with respect to global latitudes is similar to the Australian NEM.

[57] *Ibid*, p. 7

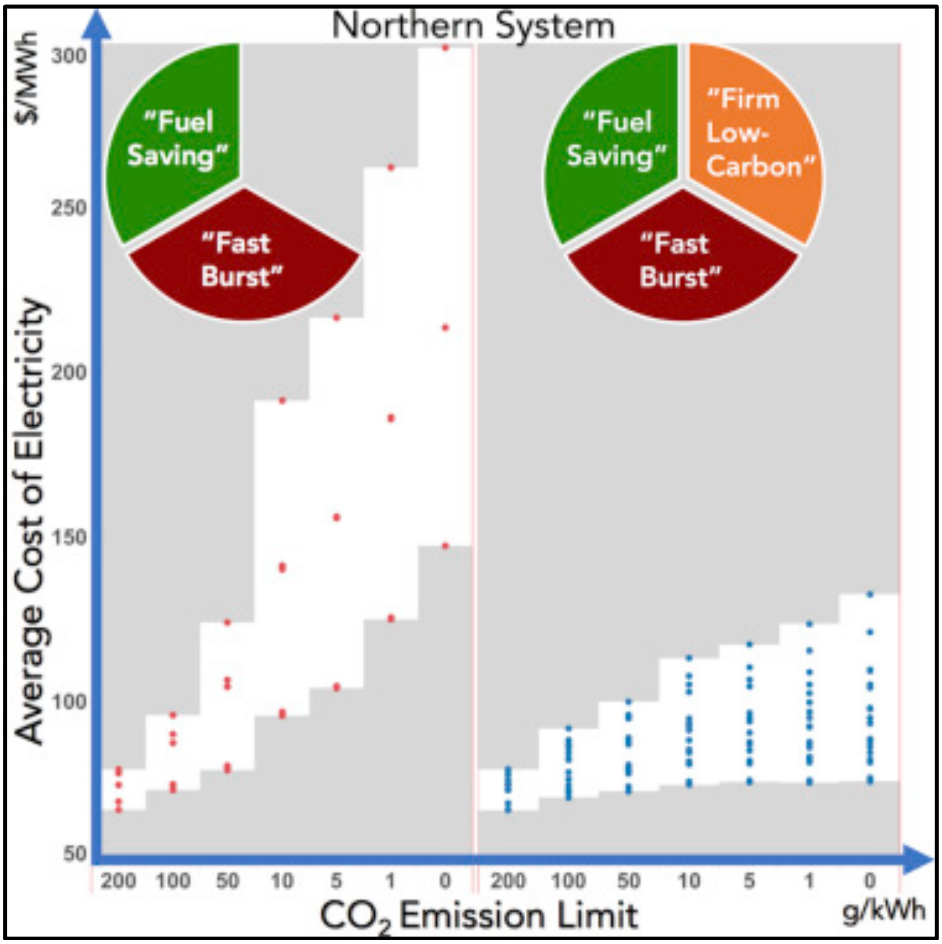

Figure 14 - Comparison of cost of electricity and carbon dioxide limits, Sepulveda et al.

2.3.3 Australian analysis

Bright New World founder Dr. Ben Heard published an industry white paper with Frazer-Nash Consultancy on the likely whole-of-system costs of nuclear deployment in Australia - "Identifying the role for nuclear power in Australia's energy transition"[58]. It is one of the first Australian centric reports to look beyond the cost of nuclear sent out and understand the whole of system cost of nuclear integrated with renewable energy in the NEM.

The white paper details three scenarios covering predicted cost reductions in renewable energy technologies. Results from these modelled scenarios detail the overall system average levelised cost of electricity and the average emissions intensity of the system. It is a first for many NEM modelling reports as it demonstrates the predicted cost of wholesale electricity for a given emissions intensity.

The study found a wholesale levelised cost sent out of $85-95/MWh (AUD, 2020) and a NEM emissions intensity of less than 100gCO2-e/kWh. It incorporates 15GW of nuclear, 12.5GW of wind, 8.3 GW of solar, and 18.6 GW of Gas. With an optimised generation portfolio of 59% nuclear, 14% gas, 17% wind and 10% solar[59].

In other words, this is the creation of a new nuclear sector, a doubling of wind generation, a doubling of gas, and several orders of magnitude growth in solar. At the time of writing NEM wholesale average costs for the year range between $80 to 110/MWh. This would entail a

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[58] (Dr. Heard, 2018)

[59] *ibid*

system in the future where Australia exceeds its emission reduction targets for a wholesale price similar to today.

2.3.4 Waste management services

During the Nuclear Fuel Cycle Royal Commission in South Australia, former Senator Sean Edwards and Dr Ben Heard published a paper on a potential project to take spent nuclear fuel, as the Royal Commission found to be an opportunity, and recycle it in a fourth-generation reactor developed by GE-Hitachi[60].

The proposal was to use a technology developed in the United States at the Idaho National Laboratory (INL). At INL the Experimental Breeder Reactor-II was built. It operated for 29 years, proving the concept for the reactor.

One of the benefits of this type of reactor was its fully passive shutdown feature during accident conditions. In 1986 the operators ran two loss of coolant accident simulations on the reactor, similar to Three Mile Island and Fukushima accidents, and the reactor shut itself down with no operator input[61]. Figure 15 (Cao, 2016) shows the actual data traces from the IFR under these test conditions.

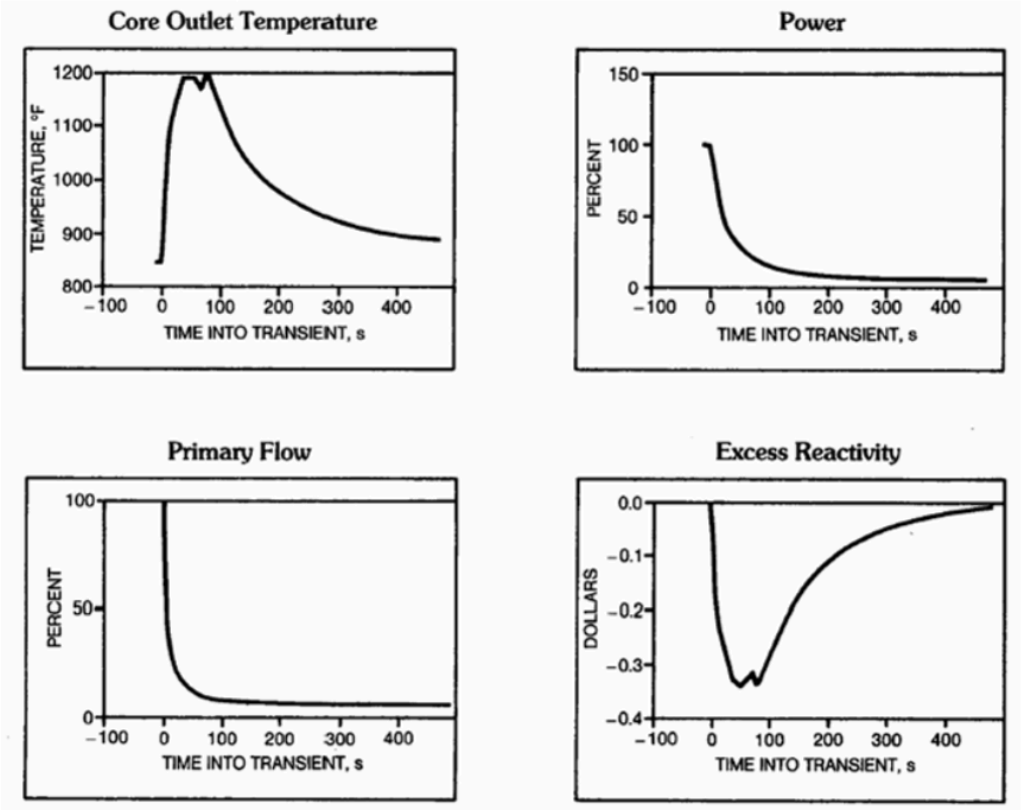

Figure 15 - Integral Fast Reactor loss of coolant test data

Using the updated version of the EBR-II, the GE-Hitachi PRISM reactor, the proposal to reprocess the fuel using a pyro-processing technology and burning the long lived nuclear isotopes in the PRISM reactor, meant the reactor could reduce the long-term disposal requirements for the spent fuel, recycle existing stocks of spent nuclear fuel, and provide electricity and high temperature heat.

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[60] (Dr. Heard, 2015)

[61] (Till, 2011), p. 147-149

In this proposal as the fuel is waste from other reactors (spent fuel) the cost of the fuel is effectively negative, as the sender of the spent fuel is paying for the recipient to manage the waste. The study by Sen. Edwards and Dr. Heard showed that the power and heat from the reactor can be set at any price as the operator is receiving income from the spent fuel they take custody of. Under assumptions of offering "free electricity" the NPV for the proposal remains positive in majority of scenarios[62].

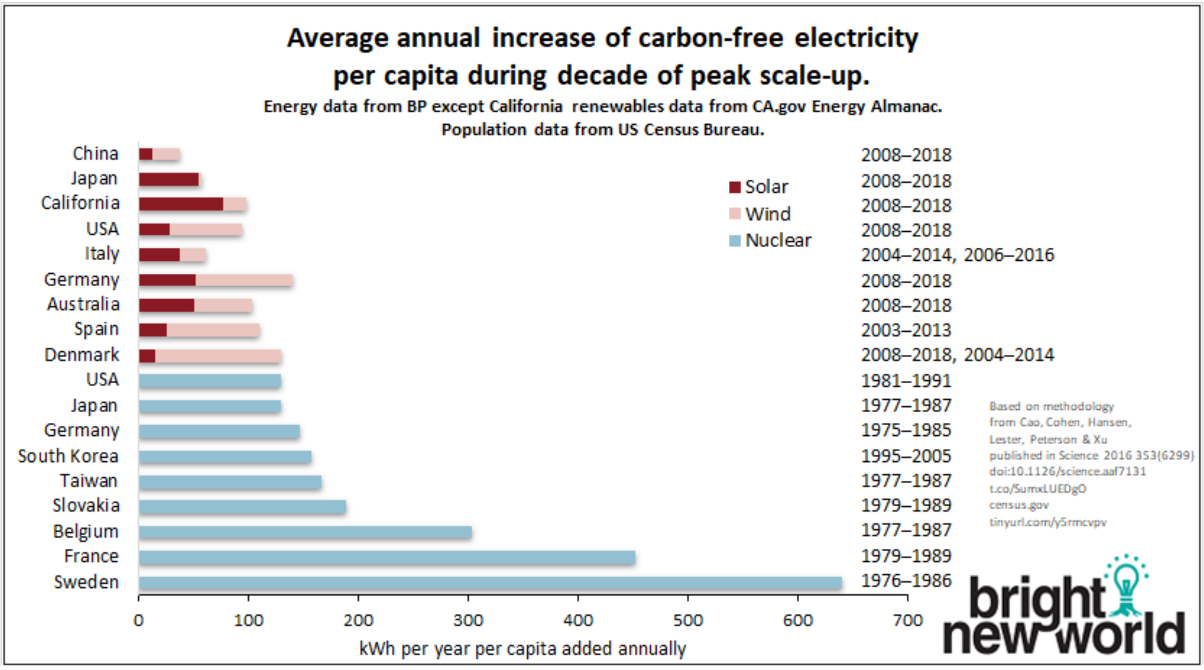
What this proposal demonstrated is there are other innovative options using technologies that have gone through extensive R&D processed that can add value through other services such as waste management, recycling, low carbon industrial heat and cheap electricity. The latter two are essential to attract new industries with energy intensive processes, such as metal smelting and refining.

2.4 Policy considerations

For the same cost of electricity today (see 2.2.3) Australia can exceed its Paris commitments and reach an electricity network with an emissions intensity on par with joining the likes of Ontario, Sweden, and France that all have sub 100g CO2-e/kWh emissions intensities.

Excluding firm low-carbon energy choices in the development of a low carbon electricity network can result in higher costs as emission intensity targets reach zero. A "net zero by 2050" policy can be realised in Australia. A policy with this target date provides ample time for nuclear to be developed alongside renewable energy. Similar to what the United Kingdom is achieving with their "net zero by 2050" policy, or what Ontario has already achieved with renewables hydro and nuclear.

Historical deployment rates of low carbon energy per capita demonstrate that including nuclear in the decarbonisation of electricity networks is fast on a kilowatt per capita basis. A review of historical deployment rates for the fastest decades of deployment for renewables and nuclear was undertaken by Cao et al. (2016). The following graph, updated by Bright New World to reflect recent Australian and Danish renewable deployment rates, highlights the speed in which nuclear can add large amounts of low carbon energy per capita.



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[62] (Dr. Heard, 2015), p. 34 & p. 36

3. Community

3.1 Community engagement

There is a persistent request during these nuclear inquiries as to where nuclear power will be sited. It is a request borne from an outdated policy where projects are announced and defended from opposition. These top down approaches may work for some developments, however for projects with complex concepts that require public engagement they will result in reactionary responses based on emotive reasoning.

Bright New World urges the committee to reject requests for naming sites for nuclear power, until there has been enough time for the Australian public to first understand what is being proposed. A methodology Bright New World prefers is for general siting conditions to be communicated as per IAEA guidelines[63], a proponent to describe their project, and call for community nominations for sites that meet IAEA siting criteria. Once communities have volunteered the proponent and the community can undertake an in-depth consultation process.

This process is similar to that of the national radioactive waste management facility process. While there have existed tensions in the community, the level of information provided, the voluntary process, and community compensation for undergoing the consultation have resulted in a community that is able to make an informed decision.

This is a process that was also recommended by the South Australian Nuclear Fuel Cycle Royal Commission in their final report[64]. The “Know Nuclear” campaign was the first step in the process to establish an informed community.

3.2 National consensus

There exists presently the national consensus to remove the prohibitions on nuclear power. Polling conducted by Essential Media in June 2019 has shown a 4% increase on a 2015 poll for nuclear support in Australia; 44% support and 40% opposed with the remainder undecided[65].

Roy Morgan released a poll in October 2019 on Australian views on nuclear power. The poll reported a 16% increase in support from 2011 and showed higher support when carbon dioxide emissions are considered (51%)[66]. The polling for NSW showed higher support for nuclear power than the national score (45% vs 51%).

Polling conducted by the South Australian Chamber of Mines and Energy (SACOME) in 2016 found a similar level of support with 45% support, 25% neutral and 30% opposed[67]. This poll also asked the respondents perception of the communities’ feelings towards nuclear power.

It found an inverse relationship with 45% of respondents noting the communities’ feelings were negative towards nuclear power and only 14% said “positive”[68]. This is an important finding by SACOME in their polling. It can support the notion that while people think everyone else is opposed, in actual fact they are supportive.

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[63] (International Atomic Energy Agency, 2019)

[64] (Nuclear Fuel Cycle Royal Commission, 2016), p. 171

[65] (Dalton, 2019)

[66] (Roy Morgan, 2019)

[67] (South Australian Chamber of Mines and Energy, 2015)

[68] *ibid*

This is becoming more visible on social media from news media organisations asking viewers what their views are on nuclear power. For example:

- The Feed on SBS's Viceland asked its followers in October 2018 via Facebook whether Australia should lift its ban on nuclear power. The poll had 13,300 respondents and the result was 61% yes[69].
- ABC Brisbane conducted a similar poll in March 2019 via Facebook asking should Australia consider nuclear power, 7,000 responded and 57% said yes[70].
- Channel 9 News did the same on their Facebook page in August 2019 asking should Australia turn to nuclear power, 25,300 responded and 65% said yes[71].

Internationally when people have been confronted with the choice to ban nuclear or allow development, they have overwhelmingly chosen to keep nuclear.

- In Taiwan a referendum to remove the early closure of their plants was put forward. Taiwanese residents voted to support the motion, keeping the plants open and removing the early closure policy [72]
- In Arizona voters rejected a motion to close the Palo Verde nuclear plant, and in 2016 Illinois and New York prevented plants from closing prematurely[73].
- In 2017 a South Korean Citizens Jury went from 60 per cent opposed to 60 per cent in favour after discussing merits of the nuclear fuel cycle[74].

Data is showing Australian's are more open to nuclear power than perceived, especially calling for the prohibition on nuclear power to be lifted. When people have been asked internationally to vote to close their nuclear plants they have voted against those motions.

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[69] (SBS Viceland, 2018)

[70] (Australian Broadcasting Corporation, 2019)

[71] (Channel Nine, 2019)

[72] (Shellenberger, 2018)

[73] (Ballotpedia, 2018)

[74] (Patel, 2017)

References

Australian Broadcasting Corporation, 2019. *ABC Brisbane.* [Online]
Available at: https://www.facebook.com/abcinbrisbane/posts/10157242918659669
Australian Safeguards and Non-Proliferation Office, 2018. *Australia's Uranium Production and Exports.* [Online]
Available at: https://dfat.gov.au/about-us/publications/corporate/annual-reports/asno-annual-report-2017-18/html/section-2/australias-uranium-production-and-exports.html
Ballotpedia, 2018. *Arizona Proposition 127, Renewable Energy Standards Initiative (2018).* [Online]
Available at:
https://ballotpedia.org/Arizona_Proposition_127,_Renewable_Energy_Standards_Initiative_(2018)
Bruce Power & Asthma Society of Canada, 2016. *Clean Air Ontario.* [Online]
Available at: https://www.brucepower.com/wp-content/uploads/2016/12/140411_CleanAirOntario_R003.pdf
Buongiorno, J. S. N. R. L., 2018. *Potential applications of the modern nuclear fuel cycle to (South) Australia,* s.l.: Massachusetts Institute of Technology.
Cao, J. e. a., 2016. China-U.S. cooperation to advance nuclear power. *Science,* 353(6299), pp. 547-548.
Channel Nine, 2019. *9 News Australia.* [Online]
Available at: https://www.facebook.com/9News/posts/2725697980811355
Conca, J., 2018. *Forbes.* [Online]
Available at: https://www.forbes.com/sites/jamesconca/2018/10/08/the-little-reactor-that-could-wa-state-nuclear-plant-continues-to-break-records/#15a20cdc2af1
Dalton, D., 2019. *Poll shows support for nuclear energy rising.* [Online]
Available at: https://www.nucnet.org/news/poll-shows-support-for-nuclear-energy-rising-6-2-2019
Department of the Environment and Energy, 2019. *Uranium mining in the Alligator Rivers Region.* [Online]
Available at: https://www.environment.gov.au/science/supervising-scientist/supervision/arr-mines/narbalek
Derivan, M., 2014. *TMI operators did what they were trained to do.* [Online]
Available at: http://ansnuclearcafe.org/2014/04/23/tmi-operators-did-what-they-were-trained-to-do/#sthash.xTgH9CKr.dpbs
Dr. Heard, B., 2015. *Transforming our economy. Cleaning our energy. Sustaining our future,* Adelaide, Australia: Sen. Sean Edwards.
Dr. Heard, B., 2018. *Identifying the role for nuclear power in Austrlaia's energy transition,* Adelaide: Frazer-Nash Consultancy.
Energy Information administration, 2012. *Nuclear and Uranium: State Nuclear Profiles.* [Online]
Available at: https://www.eia.gov/nuclear/state/archive/2010/washington/
Energy Options Network, 2017. *What will advanced nuclear power plants cost?.* [Online]
Available at: http://www.innovationreform.org/wp-content/uploads/2018/01/Advanced-Nuclear-Reactors-Cost-Study.pdf
Fthenakis, V. M. & Kim, H. C. K., 2007. Greenhouse gas emissions from solar electric and nuclear power: A lifecyle analysis. *Energy Policy,* 35(4).

GHD, 2018. *AEMO costs and technical parameter review Report Final Rev 4 9110715,* s.l.: Australian Energy Market Operator.
Graham, P. H. J. F. J. &. S. O., 2018. *GenCost 2018: Updated projections of electricity generation technology costs,* Newcastle: CSIRO.
Institute of Nuclear Physics and Particle Physics, n.d. *Radioactivity: spent fuel storage.* [Online]
Available at: radioactivity.eu.com/site/pages/IS_Spent_fuels.htm
Intergovernmental Panel on Climate Change, 2014. *Climate Change 2014: Fifth Assessment Synthesis Report of the Intergovernmental Panel on Climate Change ,* Geneva: Intergovernmental Panel on Climate Change.
International Atomic Energy Agency, 1982. *Nuclear Power, the Environment and Man.* Vienna: IAEA.
International Atomic Energy Agency, 2012. *IAEA expert team concludes mission to onagawa NPP.* [Online]
Available at: https://www.iaea.org/newscenter/pressreleases/iaea-expert-team-concludes-mission-onagawa-npp
International Atomic Energy Agency, 2012. *IAEA mission to Onagawa nuclear power station to examine the performance of systems, structures and components following the great east japanese earthquake and tsunami.* [Online]
Available at: https://www.iaea.org/sites/default/files/iaeamissiononagawa.pdf
International Atomic Energy Agency, 2019. *Siting of Nuclear Power Plants.* [Online]
Available at: https://www.iaea.org/topics/siting
Japan Today, 2012. *Onagawa nuclear plant remarkably undamaged: IAEA.* [Online]
Available at: https://japantoday.com/category/national/onagawa-nuclear-plant-remarkably-undamaged-iaea
Kharecha, P. &. H. J., 2013. Prevented Mortality and Greenhouse Gas Emissions from Historical and Projected Nuclear Power. *Environmental Science and Technology,* Volume 47, pp. 4889-4895.
Kidd, S., 2008. *Cooling of plants: a constraint on growth?.* [Online]
Available at: https://www.neimagazine.com/opinion/opinioncooling-of-plants-a-constraint-on-growth
Lazard, 2018. *Levilised cost of energy analysis - version 12.0.* [Online]
Available at: https://www.lazard.com/media/450784/lazards-levelized-cost-of-energy-version-120-vfinal.pdf
Lovering, J. Y. A. &. N. T., 2016. Historical construction costs of global nuclear power reactors. *Energy Policy,* Volume 91, pp. 371-382.
Masson-Delmotte, V. e. a., 2018. *Summary for Policy Makers: Global Warming of 1.5°C,* s.l.: Intergovernmental Panel on Climate Change.
Moonaw, W. et al., 2011. Annex II: Methodology. In: O. Edenhofer, et al. eds. *IPCC Special Report on Renewable Energy Sources and Climate Change Mitigation.* Cambridge and New York: Cambridge University Press.
National Renewable Energy Laboratory, 2014. *Natural Gas-Fired Generation Results – Life Cycle Assessment Harmonization.* [Online]
Available at: http://www.nrel.gov/analysis/sustain_lca_ngas.html
[Accessed 8 February 2017].
Nuclear Fuel Cycle Royal Commission, 2016. *Nuclear Fuel Cycle Royal Commission Report,* Adelaide: s.n.

Nuclear Regulatory Commission, 2015. *Dry Cask Storage.* [Online]
Available at: http://www.nrc.gov/waste/spent-fuel-storage/dry-cask-storage.html
[Accessed 26 July 2015].

Nuclear Regulatory Commission, 2019. *Status of Subsequent License Renewal Applications.* [Online]
Available at: https://www.nrc.gov/reactors/operating/licensing/renewal/subsequent-license-renewal.html

Organisation for Economic Co-operation and Development, 2019. *The costs of decarbonisation: System costs with high shares of nuclear and renewables,* Paris, France: OECD NEA.

Patel, S., 2017. *Citizens' Jury Recommends Resuming Nuclear Construction in South Korea.* [Online]
Available at: https://www.powermag.com/citizens-jury-recommends-resuming-reactor-construction-in-south-korea/

Roy Morgan, 2019. *A narrow majority of Australians want to develop nuclear power to reduce carbon dioxide emissions.* [Online]
Available at: http://www.roymorgan.com/findings/8144-nuclear-power-in-australia-september-2019-201910070349

Saenko, V. T. G. &. Y. S., 2017. Meeting report: the 5th International expert symposium in Fukushima on radiation and health. *Environmental Health,* 16(3).

SBS Viceland, 2018. *The Feed.* [Online]
Available at:
https://www.facebook.com/thefeedsbsviceland/posts/734252793575096?__xts__%5B0%5D=68.ARBAjdrrOZvNNq0DYwO_SDSRIA_C_0v4HNV4K8wGH05CWRvOe8UVEHgsAUe2a0CVjwj5Nq6MQmBn6a8RnTfoKa8ibDqy18iwqXx76CjkmhhzCAmAigc6KjTEnChAYpti8bRTZhOJFK-2zjX524jgtM4uw80xU7qm-MCdLzcdNo1

Schlomer, S. et al., 2014. Annex III: Technology-specific cost and performance paramters. In: B. Edenhofer, et al. eds. *Climate Change 2014: Mitigation of Climate Change. Contribution of Working Group III to the Fifth Assessment Report of the IPCC.* Cambridge and New York: Cambridge University Press.

Sepulveda, N. e. a., 2018. The Role of Firm Low-Carbon Electricity Resources in Deep Decarbonisation of Power Generation. *Joule,* Volume 2, p. 18.

Shellenberger, M., 2018. *Pro-Nuclear Activists Win Landslide Electoral Victory In Taiwan.* [Online]
Available at: https://www.forbes.com/sites/michaelshellenberger/2018/11/24/pro-nuclear-activists-win-landslide-electoral-victory-in-taiwan/#7b8d388729a0

SMR Roadmap, 2018. *Economic and Finance Working Group,* s.l.: Canadian Nuclear association.

SMR Start, 2017. *The Economics of Small Modular Reactors,* s.l.: SMR Start.

South Australian Chamber of Mines and Energy, 2015. *Consolidated Submission to Nuclear Fuel Cycle Royal Commission,* Adelaide: SACOME.

TEPCO, 2011. *The detected acceleration at Fukushima Daiichi/Dani sites.* [Online]
Available at:
https://web.archive.org/web/20180725111529/https://isterre.fr/IMG/pdf/acceleration_data_tentative_estimate_.pdf

Till, C. &. C. Y., 2011. *Plentiful Energy: The story of the Integral Fast Reactor.* s.l.:Library of Congress.

United Nations Framework Convention on Climate Change, 2015. *Paris Agreement.* [Online] Available at: http://unfcc.int/files/essential_background/convention/application/pdf/english_paris_agreement.pdf

UNSCEAR, 2011. *Sources and Effects of Atomic Radiation,* New York: United Nations.

UNSCEAR, 2014. *Sources, effects and risks of ionizing radiation: UNSCEAR 2013 report.* [Online] Available at: https://www.unscear.org/docs/publications/2013/UNSCEAR_2013_Report_Vol.I.pdf

UNSCEAR, 2016. *Developments since the 2013 unscear report on the levels and effects of radiation exposure due to the nuclear accident following the great east-japan earthquake and tsunami ,* New York: United Nations.

Warner, E. &. H. G., 2012. Life Cycle Greenhouse Gas Emissions of Nuclear Electricity Generation. *Industrial Ecology,* 16(1), p. 19.

World Association of Nuclear Operators, 2019. *Our History.* [Online] Available at: https://www.wano.info/about-us/our-history

World Health Organisation, 2016. *Chernobyl: the true scale of the accident.* [Online] Available at: https://www.who.int/mediacentre/news/releases/2005/pr38/en/

World Nuclear Association, 2012. *Three Mile Island Accident.* [Online] Available at: https://world-nuclear.org/information-library/safety-and-security/safety-of-plants/three-mile-island-accident.aspx

World Nuclear Association, 2017. *Transport of Radioactive Materials.* [Online] Available at: https://www.world-nuclear.org/information-library/nuclear-fuel-cycle/transport-of-nuclear-materials/transport-of-radioactive-materials.aspx

World Nuclear Association, 2019. *Desalination.* [Online] Available at: https://world-nuclear.org/information-library/non-power-nuclear-applications/industry/nuclear-desalination.aspx

Zhang, X. &. B. C., 2018. *Live Cycle Assessment (LCA) of Nuclear Power in Switzerland,* Villigen, Switzerland: Paul Scherrer Institut.

Appendix A – GenCost 2018 review

Capital Expenditure

The main concern, which is by far the most material assumption, lies in the extraordinary capex assumption of $16,000 kW installed, with zero learning to 2050. GHD offers a premise that they must look to advanced designs with a strong business case. Given that, a capex of $16,000 kW installed, which is a profoundly weak commercial case, is contradictory to the premise. No developer would have been able to advance SMR designs as they have done if their data suggested $16,000 kW would be their price point. This simply doesn't make sense. Examining the references for the GHD section on nuclear, they selected a capex without any:

- industry consultation from advanced reactor developers, or
- referencing of independent studies that have put effort into answer this question (see attachments)

The capex has a with a vague reference and no link ('World Nuclear Association'). We have perused the page for small modular reactors at the WNA site and spoken to them directly. The $16,000/kW figure does not appear on their website or in their documentation.

Figures are provided for the NuScale SMR of US$4200 per kW. That price would need to be tripled to yield AU$16 K per kW. While its plausible NuScale is overly optimistic about their product, it's unlikely they would be wrong by a factor of three. That company has received of both extensive government funding through competition and a lot of private capex, and they have sold the first 150 MW of their first plant in Idaho.

This is certainly the biggest concern. The capex appears to be taken from nowhere, for an unspecified reactor, with no relevant references. The figure is contradicted by studies that are following these developments and figures from SMR developers that look likely to deploy in the 2020s. The capex has benefitted from no industry consultation.

Regarding the absence of any cost reduction over time, CSIRO state:

> *The flat trend arises because, while nuclear is assigned a learning rate to recognise the potential for further improvements in the technology, they do not experience significant changes in costs due to the limited scope to double global cumulative capacity.*

This is perplexing. SMR is a new class of technology with new vendors. Traction of any single vendor with orders will lead to rapid doubling of global cumulative capacity. CSIRO appears to have bundled SMR with generic nuclear, when the premise of the work by GHD is that SMR is its own class of technology. The notion that factory-produced reactors would have zero-learning defies manufacturing experience. While the uncertainty in any learning might be very high given the absence of experience to date, some greater analytical effort is required than we see in GenCost 2018.

Confusion of reactor types

GHD states 'There are approximately 50 generation III+ designs currently being constructed around the world'. Relatively few of the reactors currently under construction are Generation III+. We are concerned non-specialists are tackling quite a specialised topic.

Inappropriate constraint on reactor types

GHD states:

> *Noting that this legislation must be repealed in order to begin the development of a nuclear power plant, it is highly likely that development of Gen III+ reactors will happen not happen before 2030 in Australia, and that*

> *Australia will seek to construct a Gen IV reactor which may address safety concerns of the public and have an economical business case.*

This statement is unreferenced. We are unclear on what basis GHD makes presumptions about what unknown future investors might or might not seek to develop in the event that nuclear power was relieved of its prohibitions. We suspect the authors are not clear on the distinctions between the generations of nuclear designs and how this might impact investment.

The afore-mentioned small modular reactor from NuScale, for example, is not a Generation IV design (given it uses the well-known light water reactor fuel cycle with solid uranium oxide fuel). However, it has already resulted in profound changes in regulations from the Nuclear Regulatory Commission regarding its safety profile, including that it requires no external back up power supply and no emergency planning zone. It is an entirely plausible choice of design for Australia. The same can be said of the Rolls Royce SMR. While small in size, there is nothing in the fuel cycle to suggest it is Gen IV.

Probable error about unit size

On assumed unit size, GHD references:

> *'World Nuclear Association - Largest Small Modular Reactor (SMR) size. Smaller sizes likely to be prohibitively expensive to generate a positive IRR'.*

This is potentially misleading. There are many smaller unit sizes that will be aggregated into larger power plants – that's a critical aspect of the commercial model for advanced small modular reactors. Only some have single units of 300 MWe. If GHD applied that as a constraint, this is an error. Referring to NuScale again, that unit size is only 60 MWe, but with initial intentions to deploy in arrays of 12 units for a power plant of 720 MWe. The Terrestrial Energy IMSR is 192 MWe and might be deployed in arrays with multiple such units. It's an understandable error for non-specialists.

Erroneous reference for construction time

Construction time is assumed 260 weeks (5 years) based on Moreira, J. M. L., & Carajilescov, P. (2011). That paper is a retrospective review of pressurised water reactors in the established nuclear nations. That is close to irrelevant for the SMR commercial model. The commercial model of advanced small reactors is factory construction of units with high quality control, delivered to site by rail/road, and placed in-situ with balance of plant. No SMR developer is working on the basis of 5-year construction. This would also raise the LCOE considerably compared with a more probable 3 three years on the basis of what those bringing SMR to market are actually devising.

No validation of fixed and operating costs

The fixed and variable operating costs are simply cited as "World Nuclear Association". That is not adequate as these costs (while less material than capex for nuclear) are material for levelized cost of electricity. There is no clear indication of which fourth generation SMR this is referring to.