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Submission to

House Standing Committee on the Environment and Energy

Inquiry into the current circumstances, and the future need and potential for dispatchable energy generation and storage capability in Australia

Summary

Nuclear energy is widely used in many countries where it provides large-scale economic electricity and security of supply as well as reduces carbon emissions and other air pollution. Nuclear power plants provide dispatchable energy and can be operated either as baseload plants or flexibly to load follow.

Australia needs access to all available zero-carbon technologies to meet the challenge of decarbonising the energy system. There is no justification for continuing the historic prohibitions on nuclear power in Australia. These historic prohibitions are to the detriment of regional communities that could benefit from the jobs and investment in nuclear power, and to the broader regional community that could benefit from increased economic activity, reliable and affordable electricity and reduced carbon emissions.

The International Energy Agency analysed different electricity technologies and found that nuclear energy is competitive in terms of the levelised cost of electricity (LCOE) with fossil fuels and renewables firmed with storage.

System costs are also important. Variable Renewable Energy (VRE) sources like wind and solar rely on reliable backup or storage to cover periods, varying from hourly to seasonal, when they are unable to produce their nameplate capacity. This becomes a large extra cost to the electricity from these technologies when they become a large part of the generating capacity. In 2020, the US fleet of nuclear power reactors operated with a capacity factor of 92.5%, compared to 35.4% for wind and 24.9% for solar. Using nuclear energy in conjunction with wind and/or solar can help provide reliable, low carbon energy.

Adding dispatchable nuclear electricity energy to the grid would enhance grid stability and reliability as well as reduce carbon emissions.

The Australian Nuclear Association strongly recommends nuclear energy be recognised as a viable option in Australia's future energy mix. Establishing a framework for introducing nuclear now will enable nuclear power plants to be producing dispatchable carbon free electricity in Australia from the 2030s. Nuclear energy can work with other low carbon technologies to provide reliable, low carbon energy.

Australian Nuclear Association

The Australian Nuclear Association Inc. (ANA) is an independent incorporated scientific institution with members from the professions, business, government and universities with an interest in nuclear science and technology. Many of our members are professional scientists and engineers with considerable experience and expertise in nuclear issues. One of the main aims of the ANA is to communicate the benefits of the peaceful uses of nuclear science and technology based on science.

INQUIRY TERMS OF REFERENCE

A. Current and Future Needs

Australia needs to use all available low carbon technologies including nuclear power to ensure that our future electricity grid is reliable, low carbon, affordable and resilient.

Nuclear power is already widely used in many countries. Many of the larger countries that have introduced targets to achieve net-zero carbon emissions by 2050 or 2060 (e.g. South Korea, China, UK, USA, Europe, Canada) depend on large nuclear power plants and/or have good hydro-electricity plants. The two leading low carbon electricity sources in the world are hydropower and nuclear power[1]. Access to large-scale, continuous generation from hydropower is limited in Australia.

Nuclear power plants produce electricity which can be despatched on demand at the request of grid operators as needed to meet market designs. Dispatchable generators like nuclear can raise or lower power output on command from the grid controllers.

Variable renewable energy (VRE) generators like wind and solar PV are considered non-dispatchable unless they are coupled with storage such as batteries, pumped hydro, molten salt or by other energy storage systems. The additional cost of storage or standby generators must be included in the cost of electricity from VREs. An electricity grid with large amount of VREs requires many generators to load follow or large amounts of storage to provide backup when the VREs are unable to generate energy. **Modern nuclear power plants can operate flexibly and follow load.**

Most of the modern light water nuclear reactors are capable (by design) to operate in a load following mode and change their power level once or twice per day in the range of 100% to 50% (or even lower) of the rated power, with a ramp rate of up to 5% (or even more) of rated power per minute[2].

Despite this capability to load follow, most nuclear power plants around the world have been operated as baseload units. This is because the high fixed capital costs and low fuel costs make it more economic to run the nuclear power plants continuously at their rated power level. With increasing amounts of VREs in an electricity grid, nuclear power plants are being designed and built with increased load following capability.

France and Germany already use the flexible operation capabilities of their nuclear power plants. German plant designs (pressurized water reactors (PWRs) and boiling water reactors

[1] Our World in Data, *Electricity Mix*, https://ourworldindata.org/electricity-mix, Accessed 1 May 2021
[2] Technical and Economic Aspects of Load Following with Nuclear Plants. OECD 2011 https://www.oecd-nea.org/ndd/reports/2011/load-following-npp.pdf

(BWRs)) can change over a large power range and a fast gradient (up to 5% rated electrical output rated electrical output per minute). French power reactors can go from 100% rated thermal power to 30% power and up to 5% rated thermal power per minute return to full power[3]. A 1,300-MW French reactor can increase or decrease its output by 900 MW within about 30 minutes[4].

Small Modular Reactors also have fast load following capabilities; for example the NuScale SMR module can increase from 20% to 100% power in 96 minutes[5].

Legislative prohibitions against nuclear power must be removed.

Notwithstanding the excellent record of nuclear power plants in supplying reliable, affordable and low carbon electricity around the world, Australia has historic legislative prohibitions against nuclear power and other nuclear facilities in the Australian Radiation Protection and Nuclear Safety Act 1998 (ARPANS Act) and the Environment Protection and Biodiversity Conservation Act 1999 (Cth) (EPBC Act). Repealing these prohibitions against nuclear facilities would allow proposals for nuclear power plants to be considered on their merits as part of Australia's energy system.

Vendors cannot offer proposals for nuclear power in Australia nor provide realistic costings when the technology itself is prohibited. Now is the time to remove the Federal prohibitions to allow nuclear to be considered on its merits as part of Australia's energy future.

Much of Australia's coal generation plant is aged and due for retirement in the next decade. Putting nuclear plant near or at locations of retiring coal plant would allow the nuclear plant to benefit from the existing grid connections and provide continuing employment in regional locations.

ANA recommends that legislative prohibitions against nuclear power be removed to allow nuclear to be considered on its merits.

B. Issues Related to System Integration, Connection, and Grid Transmission Requirements.

Nuclear power plants are large-scale generators of reliable low carbon electricity and can be used directly to replace aging and retiring coal plants. Retiring coal plants already have good connection to the grid and assess to cooling water. As well as reducing carbon emissions, nuclear power plants also benefit the environment by reducing other air pollution. Nuclear plants offer a dense source of energy on a small land footprint.

Installing either larger nuclear power plants or the emerging small modular reactors (SMRs) at locations of closed coal plants would maximise the use of existing resources such as the grid, transport systems, cooling resources and most importantly provide jobs for the existing work forces. The construction and operation of nuclear power plants can ensure stable regional communities and local economies in the long term.

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[3] IAEA, *Non-Baseload Operation in Nuclear Power Plants: Load Following and Frequency Control Modes of Flexible Operation* Nuclear Energy Series No. NP-T-3.23 2018

[4] Power magazine, 1 April 2019 https://www.powermag.com/flexible-operation-of-nuclear-power-plants-ramps-up/

[5] NuScale, *Ensuring a Balanced Mix with Advanced Nuclear*, 2020, https://www.nuscalepower.com/newsletter/nucleus-summer-2020/featured-topic-cleaner-energy, Accessed 1 May 2021

Installing nuclear power plants at the sites of retiring coal plants minimises the need for additional transmission lines and is close to the major users of electricity.

Due to the small quantities of fuel used in nuclear plants, there is also significant scope for siting of nuclear plants in a wider range of locations than coal or gas plants. This is because the small quantity of fuel makes the transport of the fuel much easier and more economical than for existing fossil fuel technologies.

C. Existing, New and Emerging Technologies

Nuclear electricity is a very well-established technology with over 18,000 nuclear power plant-years of commercial operation since the first commercial nuclear power plants started in the 1950s[6]. Nuclear power plants are major generators of electricity in most developed and many developing countries.

The nuclear power reactor technology has been continually improved and the modern large nuclear plants are being built in many countries are very reliable. Australia can gain from the experience in operation of nuclear power plants in many countries.

As of April 2021, there were 444 nuclear power plants in service in over 30 countries, and 54 nuclear power plants are under construction[7]. In 2019 nuclear generated approximately 10% of the world's electricity[8], and about 18% of the electricity of OECD countries[9].

Nuclear power plants are very reliable operating at a high capacity factor – in 2018 the global average capacity factor was 79.8%[10] - providing dispatchable electricity 24 hours per day. This figure would be even higher if it wasn't for the fact that more and more nuclear power plants are being used for load following. In 2020, the US fleet of nuclear power reactors operated with a capacity factor of 92.5%, compared to 35.4% for wind and 24.9% for solar[11]. Using nuclear energy in conjunction with wind and/or solar can help provide reliable, low carbon energy. The very low carbon emissions of nuclear power greatly assist countries in meeting international carbon emission commitments.

The reliability of nuclear power plants is enhanced by not requiring continuous delivery of fuel. This means for example that while a 1000 MWe coal plant needs millions of tonnes of coal per year, the equivalent nuclear plant would consume only 25-30 tonnes of uranium fuel. Partial refuelling (a third of the fuel elements) of pressurised water reactors takes place every 18 to 24 months. This requires the plant to be shutdown typically for only about one month. CANDU reactors are refuelled online. The long time between refuelling contributes to the resilience and reliability of nuclear power plants.

Nuclear technologies are evolving.

There is significant work being undertaken internationally in three areas of nuclear technology:

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[6] World Nuclear Association, *Nuclear Power in the World Today*, https://world-nuclear.org/information-library/current-and-future-generation/nuclear-power-in-the-world-today.aspx, Accessed 1 May 2021

[7] *IAEA Database on Nuclear Power Reactors*, https://pris.iaea.org/pris/ Accessed 25 April 2021

[8] World Nuclear Association, *World Nuclear Power Reactors & Uranium Requirements*, https://www.world-nuclear.org, Accessed 25 April 2021

[9] *Nuclear Energy Data 2020 Edition*, OECD Nuclear Energy Agency 2021

[10] *World Nuclear Performance Report 2020.* World Nuclear Association, 2020

[11] US Office of Nuclear Energy, *Nuclear Power is the Most Reliable Energy Source and It's Not Even Close* https://www.energy.gov/ne/articles/nuclear-power-most-reliable-energy-source-and-its-not-even-close, Accessed 1 May 2021

- Small Modular Reactors, typically defined as reactors up to 300 MWe,
- Advanced reactors, including Generation IV reactors, and
- Nuclear fusion technologies.

Examples of some of the work underway, R&D funding, and recent developments are provided in the references in Section F.

Nuclear power plants generate very low carbon clean electricity.

The demand for electricity for private and industrial use, including transport and the developing electric vehicle market, will only increase. Nuclear energy plays a key role in lowering carbon emissions from the energy sector in many countries. The median carbon emissions for the whole nuclear fuel cycle are very low and of the order of 12 grams CO_2/kWh[12]. This low carbon emission is similar to emissions from wind per unit of electricity produced and slightly less than hydro and solar PV. This comparison assumes that methane from hydro is not significant and ignores the emissions from any storage or backup generators required for firming wind and solar generators.

In 2018, nuclear power plants around the world produced 50% more clean electricity than wind and solar combined[13]. In the European Union and USA, nuclear produces more low carbon electricity than hydro[14].

The use of nuclear power plants enables countries to achieve low carbon emissions from electricity generation. For example, nuclear supplied 71% of electricity in 2019 in France, resulting in France having an overall electrical generation carbon emission intensity of 52 grams CO_2e/kWh[15]. This compares to 338 grams CO_2e/kWh for its neighbour Germany, which has a similar sized electricity grid, has invested heavily in VRE technologies, and is closing nuclear plants for domestic political reasons.

D. Comparative Efficiency, Cost, Timeliness of Development and Delivery, and Other Features of Various Technologies.

According to the joint report by the International Energy Agency and the OECD Nuclear Energy Agency on projected cost of generating electricity, nuclear is the dispatchable low-carbon technology with the lowest expected costs in 2025, see Figure 1. Only large hydro reservoirs can provide a similar contribution at comparable costs but remain highly dependent on the natural endowments of individual countries. While gas-based combined-cycle gas turbines (CCGTs) are competitive in some regions, their levelised costs of generating electricity (LCOE) very much depend on the prices for natural gas and carbon emissions in individual regions[16].

[12] IPCC, *Emissions of selected electricity supply technologies (gCO2eq/kWh)*. Table A.III.2, Annex III: Technology-specific cost and performance parameters. In: Climate Change 2014: Mitigation of Climate Change. Contribution of Working Group III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change

[13] *Electricity Information Overview*, International Energy Agency 2019. Page 4.

[14] IEA 2019b *Nuclear Power in a Clean Energy System*, International Energy Agency May 2019

[15] EEA 2020. Greenhouse Gas *Emission Intensity of Electricity Generation.* European Environment Agency, Dec 2020.

[16] IEA/NEA *Projected Costs of Generating Electricity 2020* https://www.iea.org/reports/projected-costs-of-generating-electricity-2020

The LCOE calculations in the IEA/NEA report are based on a levelised average lifetime cost approach, using the discounted cash flow (DCF) method. Costs are calculated at the plant level (busbar), and therefore do not include transmission and distribution costs. The LCOE calculations also do not capture other systemic costs or externalities beyond plant-level CO_2 emissions such as, for instance, methane leakage during the extraction and transport of natural gas. The long potential operating life and low operating costs of nuclear offset the high construction costs.

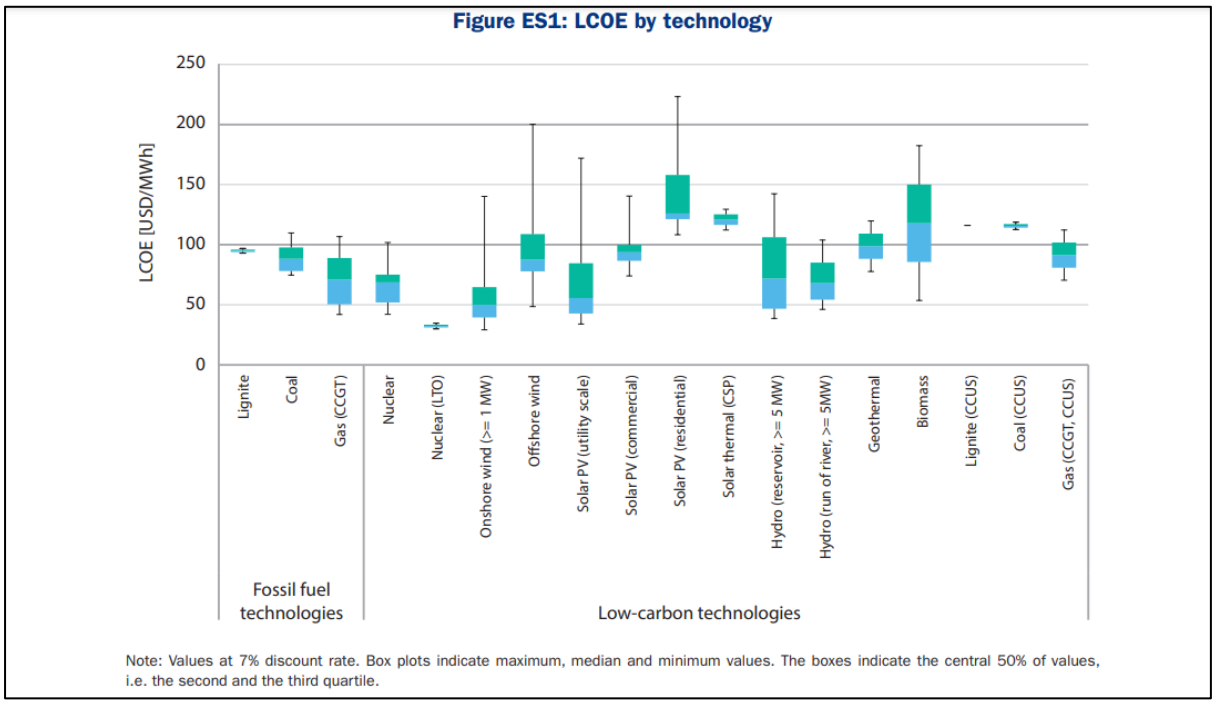

Figure 1. Levelised costs of generating electricity (LCOE) by Technology. Nuclear LTO is Long Term Operation by lifetime extension of existing nuclear plants[17]

Note that this LCOE analysis does not include system costs in a grid operating with significant variable renewable energy (VRE) such as solar and wind. Adding a low cost VREs to the grid requires backup generators or storage available for the times when the VRE is not producing electricity. In addition to this, as greater reductions in carbon intensity are made, every element of a VRE grid will be operating at steadily reducing capacity factors.

The time to build a nuclear power plant has a major bearing on its cost. Although recent construction of some first-of-a-kind power plants in Finland, France and the USA (EPR and AP1000 designs) have experienced delays and cost more than planned, the overall conclusion of the International Energy Agency study stands - in most countries nuclear is economically competitive as a generator of electricity.

The construction times of the EPR and AP1000 nuclear power plants already built and operating in China were much shorter and at lower cost than the first-of-a-kind plants of same design built in Europe and the USA.

The median construction time for nuclear power plants completed between 2011 and 2017 was 68 months from first pouring of concrete to the connection of the unit to the grid[18].

[17] IEA/NEA *Projected Costs of Generating Electricity 2020* https://www.oecd-nea.org/jcms/pl_51110/projected-costs-of-generating-electricity-2020-edition page 14 Fig ES1
[18] IAEA 2019. *Nuclear Power Reactors in the World.* International Atomic Energy Agency, Vienna, May 2019

A recent OECD 2019 report[19] on the costs of decarbonisation highlighted the impact of the variability of wind and solar have on electricity system costs and the cost of the extra backup generators, costly transmission lines and excess capacity required.

Decarbonising Australia's electricity system will need an optimum economic mix of low carbon technologies to work together. Because of their intrinsic variability, the overall system cost of adding large amounts of wind and solar are larger than the sum of their individual plant level costs.

In particular, the OECD 2019 study concludes that:

"… diversity of energy sources drives down total costs of energy in a low-carbon system, whereas taking options off the table – such as nuclear – creates extra costs to society".

It also indicates that:

"… the impacts of decarbonisation targets on the optimal investment policies are not linear and some targets may yield a share of a particular technology e.g. wind, that under a more stringent target may not be present in the optimal mix".

Nuclear power plants are safe and getting safer.

The Chernobyl accident is the only accident in the history of nuclear power generation in which deaths have occurred from radiation. It is important to note that the Chernobyl nuclear power plant type would not have been licenced outside the former Soviet Union.

The Fukushima nuclear accident caused great economic loss and evacuation of large numbers of people. Nevertheless, there is no clear evidence of any deaths attributable to the emission of radiation from the accident that occurred at Fukushima.

As with the aircraft industry, nuclear power plant designs are continually being improved based on the operating experience of current nuclear power plants. The nuclear risk and safety of all operating nuclear plant and new designs were reassessed following the Fukushima accident and where necessary upgraded.

The most significant design improvements in modern large-scale 1 GWe nuclear power plants and Small Modular Reactors (SMRs) are the introduction of safety features which enable these reactors to automatically shut down and remove decay heat using passive controls. This means that modern reactors remain safe without external power supply or human intervention for an extended time.

SMRs, rated from 10 MWe to 300 MWe, are now undergoing regulatory assessment overseas, notably in the US and Canada. SMRs have advanced safety features, are designed to load-follow and their modularity reduces the upfront capital cost making them easier to finance and quicker to operate.

Any nuclear plant to be built in Australia would be a modern design that meets international standards and satisfies stringent regulatory conditions. A nuclear plant built in Australia would be assessed, approved and licensed by the Australian nuclear regulator before construction.

[19] OECD 2019. *The Costs of Decarbonisation: System Costs with High Shares of Nuclear and Renewables*, Nuclear Energy Agency, Organisation for Economic Co-operation and Development, OECD June 2019 NEA No 7299.

E. Applications to Various Scales and Forms of End-Use such as Households, Industry, and Transport

Most nuclear power plants are large-scale generators of electricity. Some designs produce high temperature heat that can be used for industrial applications including production of hydrogen and process heat.

Refer to Section F for more information on Small Modular Reactors and advanced reactors.

F. Australia's Research and Innovation Development Framework and Policies.

Australia can gain by contributing to the innovation associated with international R&D programs on existing and advanced reactors. The Australian Nuclear Science and Technology Organisation (ANSTO) is currently involved in a number of projects in the international nuclear energy arena in the areas of advanced reactors and nuclear fusion, e.g. [20] [21]. In addition, ANSTO is well placed to provide information to the Australian Government on advances in nuclear technologies, including Small Modular Reactors and advanced reactors, e.g. [22] [23] [24].

ANA recommends that ANSTO monitor and consider overseas developments in nuclear power reactors including small modular reactors and enhance Australia's contributions to international projects to develop and prototype advanced reactors.

G. Opportunities for Australia to Grow and Export Dispatchable Zero-Emission Power

Nuclear power plants produce dispatchable zero-emission power, and there is an opportunity to use excess power to be stored in pumped hydro or used to produce hydrogen or desalinate water.

H. Other Relevant Matters, Including Reference to International Examples.

More than thirty countries already benefit from the use of nuclear power plants to provide reliable low carbon electricity as a standard part of their energy system. Australia can benefit from the extensive overseas experience in operating and regulating nuclear power plants when considering whether to add nuclear power to the Australian energy system.

[20] ANSTO, *ANSTO Partners with the World's Largest Engineering Project*, https://www.ansto.gov.au/news/ansto-partners-worlds-largest-engineering-project
[21] ANSTO, *Australia Joins International Collaboration*, https://www.ansto.gov.au/news/australia-joins-international-collaboration
[22] ANSTO, *ANSTO Contributes to International Project to Evaluate Economics of Small Modular Reactors*, https://www.ansto.gov.au/news/ansto-contributes-to-international-project-to-evaluate-economics-of-small-modular-reactors
[23] ANSTO, *Global Development in Small Modular Reactors*, https://www.ansto.gov.au/news/global-development-small-modular-reactors
[24] ANSTO, *What's New in Nuclear Power Technologies*, https://www.ansto.gov.au/news/whats-new-nuclear-power-technologies

Recommendations

The Australian Nuclear Association strongly recommends:

1) **that nuclear energy be recognised as a viable option in Australia's future energy mix. Establishing a framework for introducing nuclear now will enable nuclear power plants to be producing dispatchable carbon free electricity in Australia from the 2030s;**

2) **that legislative prohibitions against nuclear power reactors be removed to allow nuclear to be considered on its merits; and**

3) **that ANSTO monitor and consider overseas developments in nuclear power reactors including small modular reactors and enhance Australia's contributions to international projects to develop and prototype advanced reactors.**