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The Advantages of Safe Nuclear Power for a Reliable, Affordable and Low-Emissions Power System in Victoria

A Submission by SMR Nuclear Technology Pty Ltd to the Victoria Legislative Council's Environment and Planning Committee, February 2020

INTRODUCTION AND EXECUTIVE SUMMARY

By repealing its 37-year legislative ban on uranium mining and nuclear power, Victoria will have the opportunity of establishing a completely new industry in the State, bringing highly-skilled job opportunities and long-term environmental, technological, economic and social development benefits that will flow to its entire population.

The new industry could start in a regional location with the planning and development of a Small Modular Reactor (SMR), one of the modern world's safest and most advanced, low-emissions nuclear power plants. The development benefits would extend progressively to energy-dependent and associated industries in other regions and throughout the State.

For the short and long run, Victoria must keep its power system running. It could be suicidal for the State economy to close down its coal-fired fleet prematurely. This submission does not go into how this task should be managed but explains the pivotal role that nuclear power could play in the future Victoria power system and in the wider Victoria economy.

It should be acknowledged at the outset that there may be an important continuing role for gas-fired and coal-fired power generation, utilising technologies such as High-Energy, Low-Emissions (HELE) generation and Carbon, Capture, Use and Storage (CCUS).

In the long run, however, there may be only four practical technologies available for low-emissions power systems: hydro, solar PV, wind and nuclear power.

Nuclear power is the only one of these that is not weather-dependent.

Nuclear power is already making a vital contribution to reliable, affordable and low-emissions power systems in 30 other countries.

Modern Small Modular Reactors (SMRs) are designed to be inherently safe.

SMRs are likely to be a game-changer for Victoria power system planning, replacing obsolete power generators that may be closed down over the next 30 years.

Power industry infrastructure is more valuable to the State economy than other forms of infrastructure, such as transport, because of its return on investment and flow-on effects in regional development.

1. Reliability

Modern nuclear power plants are reliable, dispatchable and safe, with capacity factors in excess of 90%.

SMRs with unit outputs of between 60 and 720 MW would be particularly suitable for the Victoria power system. SMRs have features that will enable them to work effectively in a power system that has variable renewables.

The leading US example is the NuScale SMR. Up to twelve 60 MW modules can be accommodated in one power plant to provide a gross output of 720 MW. The NuScale plant is specifically designed to automatically adjust its output to compensate for the variable generation from wind turbines.

The safety features of modern SMRs are elaborated further in section 5 below.

2. Affordability

Modern SMRs could be the lowest cost generation available in Australia because of their contribution to power system reliability.

The final cost of individual plants will depend on location-specific factors determined during feasibility studies. However, as with wind and solar energy, nuclear costs are coming down due to simpler and standardised design; factory-based manufacturing; modularisation; shorter construction time and enhanced financing techniques.

The 'whole of system' advantages of nuclear power has important strategic implications for the NEM and the entire economy. (See section 7 for further details)

3. Lower Emissions

Nuclear power will contribute to Australia overcoming its lack of success to date in significantly reducing emissions from electricity generation.

Australia's annual emissions from electricity generation for the year to June 2014 were 179.4 million tonnes CO_2-e (National Greenhouse Gas Inventory).

Five years later, and after billions of dollars spent on wind and solar, Australia's annual emissions from electricity generation for the year to June 2019 were 179.9 million tonnes CO_2-e.

Australia has one of the world's highest emission intensities, typically 820 kg CO_2-e /MWh (Finkel Review). Countries with low emissions intensities either have large hydro resources (Norway) or have nuclear as part of their energy mix (France, Belgium).

Nuclear makes a significant contribution to reducing emissions from electricity generation worldwide.

In 2018, 2,563 TWh was generated by nuclear power reactors worldwide, saving over 2 billion tonnes CO_2-e emissions (World Nuclear Association). Also in 2018, nuclear generated more electricity than solar and wind combined.

In 2015/16, Australia exported 8,417 tonnes of uranium oxide concentrate (ASNO Annual Report) which would have generated ~280 TWh and saved the recipient countries more than 250 million tonnes CO_2-e, yet Australia does not take advantage of this valuable resource.

Nuclear has zero operating emissions and whole of life cycle emissions comparable with renewables.

Nuclear power, like wind and solar, has zero operating emissions. The South Australia Nuclear Fuel Cycle Royal Commission examined in detail the whole of life cycle emissions for different electricity generation technologies. The median value for nuclear is 12kg/MWh, the same as wind. Solar is slightly higher at 18-50 kg/MWh.

The Finkel Review reported a very large difference between low-emissions technologies (wind, solar, hydro, nuclear) that have zero operating emissions and the lowest intensity fossil technology, CCGT, that has an operating emissions intensity of 370 kg/MWh.

4. System Planning

With the repeal of the legislative ban, it should be feasible to develop an initial 360 MW SMR nuclear generator by 2030 and up to 3000 MW by 2040.

The construction and operation of a nuclear power plant in Victoria is presently prohibited by the Nuclear Activities (Prohibitions) Act 1983

The prohibition was put in place at a time when there was no real appreciation of the contribution that modern, safe nuclear power plants could make to energy security, affordability and emissions reduction.

In May 2016, the South Australia Nuclear Fuel Cycle Royal Commission recommended that prohibitions at the federal level be removed:

> *Recommendation 8 - Pursue removal at the federal level of existing prohibitions on nuclear power generation to allow it to contribute to a low-carbon electricity system, if required.*

The legislative prohibitions preclude any serious consideration of the merits of nuclear power generation in Australia. SMR vendors will not treat Australia as a potential market whilst the prohibitions remain.

Although government reports have repeatedly endorsed the merits of "technology neutrality"in power system planning, the legislative prohibitions have prevented its accomplishment.

System reliability, as well as affordability and lower emissions, beyond 2030 can be underwritten by including load-following nuclear generation in the generation mix and allowing all technologies to compete with each other.

Modern SMRs could make a vital contribution to Australia's needs for reliable, low-emissions, affordable energy.

Without repeal of the legislative ban, Australia's power system will continue to be constrained at great cost to the economy.

5. Safety

Nuclear energy has the lowest incidence of death and accidents amongst all energy production technologies, comparable to renewables. It is many times lower than fossil fuels.

Following the accident at the Chernobyl nuclear power plant in the Ukraine in 1986, the nuclear power industry became what we believe from a safety point of view to be the most highly regulated industry in the world. In this regard, the Convention on Nuclear Safety (CNS) came into force in 1994, laying down the fundamental principles for the protection of individuals, society and the environment from the harmful effects of ionising radiation.

The CNS has 152 Member States, including Australia. Under the CNS, each country must establish safety regulations for nuclear power.

Australia's safety regulations are laid down by Commonwealth law and are enforced by the Australian Radiation and Nuclear Protection Agency (ARPANSA) for Commonwealth entities.

In 2013, the UK Tyndall Centre for Climate Change, in a report for Friends of the Earth, found that:

> *"… overall the safety risks associated with nuclear power appear to be more in line with lifecycle impacts from renewable energy technologies and significantly lower than for coal and natural gas per MWh of supplied energy".*

In 2016, the South Australia Nuclear Fuel Cycle Royal Commission concluded that safety was not a basis for ruling out nuclear power in Australia.

Modern SMRs are designed to be inherently safe, avoiding Chernobyl-type or Fukushima-type accidents.

SMRs can be installed below ground level. This protects them from external hazards and unauthorised access. The reactor building is able to withstand aircraft impact.

The NuScale module sits in a large "swimming pool" enabling the reactor to be cooled indefinitely without attention.

Modern SMR designs have now become a game-changer for nuclear safety. Although traditional reactors are safe, SMRs take safety to a new level of "walk-away safety". For example, the NuScale SMR does not require any operator action, backup electrical supplies or water supplies and would have survived even the Fukushima accident. The passive safety systems enable the reactor to be cooled indefinitely without attention - "indefinite cooling time".

The US Nuclear Regulatory Commission (NRC) has confirmed that the NuScale plant does not require any emergency electrical generators to keep the plant safe. The NuScale SMR is the first nuclear reactor design to have achieved this accreditation.
The turbine condensers for modern SMRs can be air cooled and do not require large quantities of water. They do not need to be located near a river or on the coast.

Australia has a world-class nuclear regulator, the Australian Radiation Protection and Nuclear Safety Agency (ARPANSA). Provision for high-level community participation in its regulatory functions, in fashion with the US, the UK and Canada, may nonetheless be appreciated by the general public in Australia.

6. Environmental Issues

i) Emissions

Fossil fuelled energy production not only has short-term health impacts relating to accidents and air pollution; there are also the long-term, environmental impacts relating to climate change. Signs of this are already starting to show, with extreme weather events, reduced rainfall, sea level rise, etc.

Australia must utilise every safe, low-emissions technology to reduce its emissions. Nuclear is a safe, low-emissions technology that should be included in the energy mix in Australia, as it is already in 31 other countries, with four new countries with nuclear power reactors presently under construction.

No country has achieved a low level of emissions without nuclear and/or hydro.

ii) Process Heat

Emissions reductions are required in all areas of energy production and use. Industry commonly uses coal or gas for process heating. Modern nuclear reactors can produce process heat which can reduce emissions from industry. Wind and solar cannot provide process heat. Nuclear power not only reduces emissions from electricity generation, but also provides a pathway to emissions reductions in many other industries.

Australia is looking at hydrogen as a key fuel for the future. This relies on the efficient and economic production of hydrogen. In his address to the Press Club on 12 February 2020, Chief Scientist Alan Finkel stated that "There's a nearly A$2 trillion global market for hydrogen come 2050, assuming that we can drive the price of producing hydrogen to substantially lower than A$2/kg." Process heat increases the efficiency of hydrogen production. Renewables cannot produce process heat, but nuclear reactors do, particularly the Gen IV types like the Terrestrial Molten Salt Reactor which supplies process heat at 600^{o}C for high temperature electrolysis. This enables hydrogen production at a cost comparable to steam methane reforming, but with low emissions and a cost less than one third of renewable energy electrolysis (Terrestrial submission 260 to Federal Nuclear Inquiry).

iii) Energy Density

Renewables, for example wind and solar, are very low energy density technologies, that is, the physical quantity of plant required for a given output is very high. The amount of concrete and steel in a wind turbine is more than 10 times the quantity in a nuclear power plant for a given output. The Victoria Numurkah solar plant has 373,839 PV panels but produces only 112 MWe (AEMO Generation Information).

iv) Land Area

Wind and solar require large areas. For example, the new 112 MWe Victoria Numurkah solar plant occupies 515 hectares. This can be compared to a 720 MWe NuScale plant that occupies only 18 hectares.

v) Waste

The lifetime of a solar plant is around 25 years. By 2016, it had been estimated that 23 million solar panels had been installed in Australia. Reclaim PV (SA) has estimated that 100,000 - 150,000 PV panels every year are faulty and need replacing. The International Renewable Energy Agency (IRENA) has projected that by 2050 there will be up to 78 million tons of PV waste. Parts of PV panels can be recycled, but this requires the panels to be dismantled and the materials separated - an energy intensive process.

By comparison, a 720 MW 12 module NuScale SMR would produce each year only 120m^3 (two shipping containers) of low level waste that is packaged and stored in drums before being transported to a Low Level Waste repository.

The required repository is a simple, near-ground level engineered facility to hold the waste securely, usually in concrete cells, for around 300 years. A NuScale module would also produce only ~1500kg/year of used fuel which is initially stored in cooling ponds and then stored in dry casks on site or reprocessed. The final disposal of the small amount of waste from reprocessing or complete used fuel assemblies will be in a deep geological repository. Construction of this type of facility is in progress in Finland and licensing is in progress in Sweden and France.

vi) Noise

Nuclear and PV produce very little noise during operation. Wind turbines produce significant low frequency noise which has an environmental impact and limits their siting.

vii) Weather-dependency

Nuclear power plants operate regardless of the weather. They are designed to continue operating in extreme weather conditions. There are many examples in the USA where nuclear power plants have continued to supply electricity in extreme weather conditions, when other electricity generators have failed. PV panels can easily be damaged by storms and particularly by hail.

Renewables, by contrast, are totally weather-dependent. The output from a wind turbine rapidly decreases as the wind drops. Although this can be forecast to some extent, the drop can sometimes be quicker than expected. For example the AEMO report into conditions on 10 February 2017 (the very hot day in NSW) identified that the wind dropped faster than forecast, leading to a shortage of supply. According to AEMO, of more concern is the total cut-off of supply from a wind turbine when the high wind protection operates. In windy conditions, the turbine can suddenly de-load without warning. South Australia has over 1,600 MW of wind turbines, but the total output can be <10% for several days during calm conditions. The total output of **all** the wind farms in the NEM was less than 20% of their installed capacity for 2,760 hours (32%) during 2017.

7. The Economics of Small Modular Reactors (SMRs)

There is one new SMR operating in Russia and two under construction worldwide[1]. However these are all prototypes and are not typical of a modern commercial SMR. The economics of SMRs is therefore based on estimates.

[1] Russia 70 MW floating SMR, Argentina 27 MW Carem, China 211 MW Shandong Shidaowan HTR-PM

CSIRO/AEMO GenCost 2018 Report

This report has been widely taken as evidence that "nuclear is three times more expensive than renewables". CSIRO commissioned GHD to provide the technical analysis for their report.
GHD produced a LCOE figure for an SMR of $250-$325/MWh. However this was based on:

- $16,000/kW overnight cost. The source of this figure is given as the World Nuclear Association. The WNA do not recognise this figure which is not in any of their reports and they confirm that they were not consulted on this matter (WNA submission 259 to the 2019 Federal Nuclear Inquiry).

- 300 MW Gen IV reactor constructed in 2035. Gen IV is the next generation of advanced reactors, currently in the R&D stage. The most likely SMR to be deployed in Australia would be a Gen 111+ light water reactor based on existing known technology

The $16,000/kW figure is clearly not appropriate for a SMR that would most likely be deployed in Australia. The WNA stated in their Federal submission "We can therefore say categorically that the figure of $16,000 AUD/kW is not in concordance with current international expectations".

More up to date costs

IEA World Energy Outlook 2018 gives the average capital cost of new nuclear in the USA as US$5,000/kW.
The 2017 SMR Start report[2] estimates SMR capital costs of US$4,600 - $5,150/kW.

Fluor (the international engineering company) has recently carried out a "bottom up" detailed cost estimate of the NuScale 720 MWe 12 module plant. This estimate conforms to the American Association of Cost Engineers class 4 cost estimates and is based on over 14,000 line items priced using Fluor's extensive cost data or actual vendor quotes. For a Nth of a Kind plant (that would most likely be deployed in Australia) the cost[3] is US $3,600/kW equivalent to ~ A$5,300 at current exchange rates. However much of the work (civil, electrical, balance of plant) would be resourced locally.

Large scale solar PV capital cost in the GenCost 2018 report is $1,500/kW at ~25% capacity factor. Levelised to the NuScale 95% capacity factor, this equates to $ 5,700/kW for large scale solar PV. Nuclear capital costs are competitive with large scale solar PV even without including firming costs.

It would be appropriate to compare the LCOE cost of nuclear with firmed VRE.
The CSIRO/AEMO Gen Cost 2018 report fig 4-2 (page 28) shows the LCOE in 2020 for solar

[2] SMR Start, September 2017, The Economics of Small Modular Reactors, http://smrstart.org/wpcontent/uploads/2017/09/SMR-Start-Economic-Analysis-APPROVED-2017-09-14.pdf
[3] NuScale submission to the NSW Standing Committee on State Development Nuclear Inquiry

PV firmed with 6 hrs pumped hydro energy storage (PHES) as $95-$130/MWh. A nuclear LCOE of ~$100/MWh would therefore be competitive with firmed solar.

The SMR Start report shows a LCOE of US$70-$90 for an investor owned utility and US$62-$70 for a municipal owned utility in the USA.
Projected LCOE costs in Canada[4] are CDN$58-$90/MWh.

Modern SMRs look to be competitive with firmed VRE. Certainly the "nuclear is three times more expensive than renewables" is not true for the SMRs that are about to be deployed in the USA and would most likely be deployed in Australia.

The costs of SMR deployment in Australia will only be accurately determined by a feasibility study, but indications from the USA are that SMRs will be competitive with firmed renewables.

Given their operating life of 60-80 years, it is likely that SMRs will be Australia's lowest-cost generation source.

In looking at the economics of different power generation options, it is essential to understand the distinction between generation costs and power system costs and to adjust for the low capacity factors, additional transmission cost and firming costs of renewable energy forms.

Electricity needs to be available on demand, 24 hours a day, 7 days a week and in all weather conditions (as explained under Weather-dependency above).

Nuclear is available 24 hours a day but solar, for example, may only be available for a third of the time each day. You must therefore multiply the generation cost of solar three times to get the same amount of electricity. Even then, it may not be available at the times of the day when it is required.

Although the generation costs of wind and solar are lower than nuclear, the true cost to the power system is higher. This is due to:

(i) their low capacity factor,
(ii) additional transmission costs and
(iii) firming costs.

Modelling by the Australian consultancy Electric Power Consulting of Kiama in 2018 showed that the cost of a system with 100% renewables would be more than 4 times the cost of a system where coal was replaced by nuclear [5].

A recent authoritative report (2019) by the OECD-NEA explains why the cost of electricity is increased by a high percentage of variable renewable energy (VRE) in the system[6].

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[4] Canadian Small Modular Reactor Roadmap, November 2018, https://smrroadmap.ca/wpcontent/uploads/2018/11/SMRroadmap_EN_nov6_Web-1.pdf
[5] Electric Power Consulting https://epc.com.au/index.php/nem-model/

8. Construction Time

Nuclear power plants were traditionally very large in order to capture economies of scale. In many cases, this has caused construction delays and increased costs. Modern SMRs will be factory-built and the complete reactor module is transported to site and installed with minimum on-site work. This reduces site construction time and the risk of expensive delays.

The actual time of construction of an SMR is planned to be around 36 months. This would be preceded by a period of around 4 years for community consultation, site selection, feasibility studies, environmental and development approvals and arranging financial facilities, making a total development period of around 7 years after the law is changed to lift the prohibition on nuclear power.

9. "Load Following" and Grid Operation

Modern SMRs are designed to "load follow" and can support weather-dependent renewables. They do not need to be connected to the grid for safety. On loss of grid, the NuScale modules can remain in operation and are then ready to contribute to re-establishing the grid. If a NuScale SMR had been operating in South Australia at the time of the September 2016 State blackout, the grid could have been restored quicker than it was. However, if an SMR **had** been operating in South Australia at the time, it is unlikely that the State blackout would have occurred.

10. Decommissioning

There is extensive experience of decommissioning nuclear power plants, with more than 140 decommissioned worldwide. After operations cease, the fuel and coolants are removed. This takes about 2 years and removes the major radiation hazards - 99% of the radioactivity is in the used fuel. The plant buildings are then dismantled and the site remediated, leaving a greenfield site that can be reused.

There is an excellent example of decommissioning a research reactor in Australia. ANSTO's Moata research reactor at Lucas Heights operated from 1961-1995. The used fuel was removed after shutdown and sent back to the USA. In 2009/10 the reactor was completely dismantled. The concrete shielding was cut with a diamond saw and checked for radiation levels. Most of the concrete was able to be moved to landfill as industrial waste. The cost of dismantling was $4.15m. Considering that Moata operated for 34 years and laid the foundations of nuclear research in Australia, the cost of decommissioning is clearly a small proportion of the total project cost.

[6] The Costs of Decarbonisation: System Costs with High Shares of Nuclear and Renewables, NEA No7299, 2019

11. Flow-on Benefits

The first NuScale SMR is planned to be sited near Idaho Falls, USA. This will be a 12 module, 720 MWe plant. The Idaho Department of Labour has forecast that the SMR will generate 12,800 local jobs during construction and 1,500 during operations.

The 1,000 direct construction jobs would create or support an additional 11,800 jobs through "inter-industry" trade and local services for the new workforce. NuScale expects direct construction jobs to peak at 1,100 employees and this would last for much of the three year site build.

The new plant will also support long term employment in Idaho Falls. NuScale expects the plant to directly employ 360 workers when it is online and the Department of Labour expects this will support 1,500 local jobs, equating to annual revenues of US$389 for local industry in this regional area.

12. Conclusions

In the modern era, the nuclear industry is transforming itself to meet contemporary community expectations. In particular, modern SMRs are designed to be inherently safe and will provide reliable, affordable and low-emissions power for 60-80 years.

If the legislative prohibitions on nuclear facilities can be repealed, Small Modular Reactors (SMRs) could be developed and become be a game-changer in Victoria power system planning, progressively replacing obsolete power generators in the Victoria power system as they close down over the next 30 years.

Power industry infrastructure is arguably more valuable to the economy than transport infrastructure because of its flow-on benefits to other parts of the economy.

The development of nuclear power generation in Victoria would lead to the establishment of an entire new industry with long-term environmental, technological, economic and social development benefits for the people of Victoria and its internal regions. These benefits would flow on progressively to other industries.

SMR Nuclear Technology Pty Ltd has been pleased to provide this submission to the Victoria Environment and Planning Committee and stands willing to expand on these and any other issues that the Committee may wish to raise in evidence to the Committee.

Tony Irwin
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