Submission
No 52

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

Organisation: Nuclear for Climate Australia

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NUCLEAR FOR CLIMATE AUSTRALIA

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Submission to:

NSW Legislative Council Standing Committee on State Development

Inquiry into the Uranium Mining and Nuclear Facilities (Prohibitions) Repeal Bill 2019

Dated: 17th October 2019

Due: 18th October 2019

SUBMISSION SUMMARY

This submission by Nuclear for Climate Australia recommends repeal of the prohibitions in the Uranium Mining and Nuclear Facilities (Prohibitions) Act 1986 No 194 so that nuclear power can be considered on its merits in New South Wales' future energy system. Nuclear for Climate Australia strongly recommends passage of the Uranium Mining and Nuclear Facilities (Prohibitions) Repeal Bill 2019.

The terms of reference include:

> *This inquiry will consider the objectives of the bill, that is, repealing the ban on uranium mining and building nuclear facilities in New South Wales. It is an opportunity to consider if the ban on nuclear power as an energy source is limiting our ability to secure reliable baseload zero emissions power.'*

Nuclear energy can play a central role however we consider the "rules of the game" need to be made clear by:
1) Defining our State and National goals for emissions intensity at a realistic time in the future. Climate change is defining this goal for us as achieving an energy intensity of no greater than 50gr CO2/kWh by 2050.

2) Using the best current or near term technology to achieve that goal within a framework of competitive pricing.

3) NSW support to reconfiguring our National Energy Policy to include five guiding policy pillars

a) The short-term electricity market should be maintained to expose all generators to competitive forces.

b) The use of Carbon pricing is seen as being the most effective means to drive investment in low carbon technologies and reduce emissions to ensure least cost options are deployed. Price to be sufficiently high to drive investment.

c) Develop long-term frameworks for the adequate provision of capacity, flexibility and infrastructures for transmission and distribution.

d) Create appropriate mechanisms for fostering long-term investment in low-carbon technologies if carbon pricing is not a sufficient inducement.

e) Internalise system costs such as connection costs, auxiliary services to exclude "free riders".

The window of opportunity to resolve that nation's energy prices, volatility and emissions intensity is closing. No nation has successfully decarbonised its grid by being significantly reliant on variable wind and solar and Germany is showing this is most unlikely to succeed. For New South Wales and Australia this is a sleepwalk into great uncertainty especially because we have no large cross National grids to help balance generation and demand as occurs in Europe.

Nuclear power has demonstrated, by precedent that it can be deployed quickly, operate economically and can massively reduce carbon emissions. Suitable nuclear plants currently available from South Korea and elsewhere have been identified as suitable.

Small modular reactors may be suitable as and when they become available though care needs to be exercised that these can be delivered to meet the defined goal in the required time frame. We do not need any repeats of the time and cost blowouts of the type associated with defence aircraft procurement.

This submission has identified, using system levelised cost (SLCOE) models in the OECD and within Australia, that nuclear energy provides the least cost means of providing energy especially at deep carbon reductions. 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".

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1.1 OBJECTIVE

Climate change is the most significant threat to our planet today, and yet just three years after the Paris Agreement the world is significantly behind in meeting its climate goals. The latest IPCC report[1] on the impacts of global warming reaching 1.5°C above pre-industrial levels sends a clear warning that this increase may be exceeded by 2030 - 2050.

Nuclear power is recognized as a low-carbon source of energy. According to the IPCC[2], the median lifecycle emissions from nuclear are 12g/kWh, similar to wind energy.

By precedent, nuclear energy must be included in the climate conversation as it is a proven and efficient mitigation technology. Only by rapidly expanding nuclear energy together with renewables and other low carbon sources can we still deliver on the Paris agreement commitments.

1.2 THE ABILITY OF NUCLEAR ENERGY TO REDUCE GREENHOUSE GAS EMISSIONS HAS ALREADY BEEN DEMONSTRATED.

Nuclear energy is available today and is deployable on a large scale, with over 450[3] reactors in operation across 30 different countries. In 2018, the global nuclear installed capacity reached for the first time 400 GWe, accounting for more than 10% of global electricity production and 30% of global low carbon electricity production.

Thanks to nuclear, more than 60 Gt[4] of CO2 emissions have been avoided globally since 1970, equivalent to five years' worth of CO2 emissions from the electricity sector. Nuclear is the second largest source of low-carbon electricity after hydropower.

The European countries which have achieved a rapid reduction in emissions from electricity production (Sweden, Switzerland, France), are those with a large component of nuclear and hydropower. For instance, France, which produces approximately three quarters of its electricity from nuclear, has the lowest per capita emissions of the seven largest industrialized countries (G7).

An analysis[5] of the Swedish nuclear program since 1972 has demonstrated the ability of nuclear power to rapidly decarbonise the electricity system: Swedish emissions per capita decreased by 75% in less than 20 years.

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[1] IPCC special report on the impacts of global warming of 1.5 °C, October 2018

[2] IPCC report 2014

[3] AEA PRIS

[4] IAEA Climate Change and Nuclear Power 2018

[5] China-U.S. cooperation to advance nuclear power, ScienceMag 2016

1.3 The shutting down of nuclear power plants has led to a stagnation of, and even an increase in, greenhouse gas emissions.

Nuclear power plants have been closed in several countries over recent years. Despite the growth of other clean energy sources the result of these premature retirements has been counter-productive for the climate:

In California, Vermont and New Jersey, when nuclear plants have been prematurely shut down, they have been mostly replaced by power plants fuelled by natural gas from shale.

In Germany, despite massive investment in renewable energy (25 billion euros per year), the share of coal, its most polluting energy source, has remained stable and the country will not achieve its climate objectives.

Japan remains the world's largest buyer of liquefied gas due to the fact that the restarting of nuclear reactors is too slow – its electricity producers are even showing an interest in coal.

1.4 International experts have stated that all low-carbon technologies will need to be mobilized in order to stop climate change, including nuclear

The decarbonisation of the electricity sector is central to tackling climate change. Global electricity production accounts for 40% of total emissions and is still dominated by coal and gas (63% of total production).

Decarbonising the electricity sector is a considerable challenge. The latest scenarios set the bar very high, aiming for a total decarbonisation of the electricity system by 2050. At the same time a doubling of electricity consumption is expected due to population growth and the catching-up of emerging countries. Despite massive investments, renewable energies alone are not enough to achieve the decarbonisation required.

International institutions (UN, OECD-IEA[6], EU[7]) believe that all low carbon technologies (renewable, nuclear and CCS) will need to be implemented in order to achieve deep decarbonisation.

This is reflected in the latest IPCC[1] report. The four 1.5°C illustrative pathways in the Summary for Policymakers include more nuclear, with a two-fold to six-fold increase in nuclear production by 2050.

New South Wales can benefit from current and emerging nuclear power plant designs as well as from the considerable international experience accumulated in regulating nuclear power nuclear power plants, taking into account safety, environmental, technical, economic and social factors.

All states are increasingly faced with power prices that are destroying the competitiveness of our manufacturing sector. Together with the urgent need to meet international carbon emission commitments, nuclear is a real option to be part of our energy future and make a very significant contribution to improving energy cost and reliability and lowering carbon emissions of Australia's power system.

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[6] EA ETP 2017 2DS and B2DS scenarios

[7] EUCO30, Pantelis Capros I3 Modelling Sept 2017

1.5 Increasing nuclear power helps to ensure faster and cheaper decarbonisation

Nuclear power is available today in all major greenhouse gas emitting regions: China, the United States, India, Europe and Japan. It represents a real low-carbon alternative to coal, since it also ensures large scale 24/7 electricity production.

The flexibility provided by nuclear power facilitates the development of variable renewable energy while limiting reliance on gas backup. This is already the case today for the French nuclear plants in the Western Europe electricity grid. Most modern Generation III+ nuclear power plants which include SMRs, are designed to enable more favourable load following capabilities.

Abundant low-carbon electricity is the preferred tool for achieving deep decarbonisation scenarios. Electrification of different sectors, such as transport, will be facilitated by cheap electricity: a recent study by the MIT[8] shows that the cost of decarbonising electricity is much lower when the mix includes optimal amounts of nuclear.

The development of future nuclear technologies will enable the decarbonisation of sectors other than electricity, such as industrial heat production.

In 2018, nuclear power plants around the world produced 50% more clean electricity than wind and solar combined [IAE 2019a]. In the European Union and USA, nuclear produces more low carbon electricity than hydro [IAE 2019b].

1.6 Low Environmental Footprint

Uranium is a very energy dense fuel. This means for example that while a 1000 MWe coal plant would consume about 2.6 million tonnes of coal per year, the equivalent nuclear plant would consume only 25 tonnes of uranium.

Partial refuelling takes place every 18 to 24 months. This means that a nuclear power plant releases very little air pollution and there are very limited truck movements to supply fuel. Most nuclear plant has an operating lifetime of up to 60 years.

Nuclear is a large-scale generator which can be a coal replacement technology. Both large scale nuclear power plants and the emerging small modular reactors would maximise the use of our existing power resources such as the grid, transport systems, cooling resources and most importantly the existing work forces. The construction and operation of nuclear power plants can help to ensure stable regional communities and local economies for many decades.

Nuclear power benefits the environmental by reducing carbon emissions and other air pollution but most importantly is the very low environmental footprint of nuclear energy. While this varies greatly between jurisdictions, solar PV is reported to use 11 times the nonrenewable resources of nuclear power plants and wind some seven times. Add in storage in the form of batteries or pumped hydro together with an extended grid and the consumption of non-renewable resources by variable renewables could well be twenty times that of nuclear energy.

This comparison assumes that methane from hydro is not significant and ignores the emissions from any storage or backup generators for wind and solar.

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[8] The Future of Nuclear Energy in a Carbon-Constrained World, September 2018

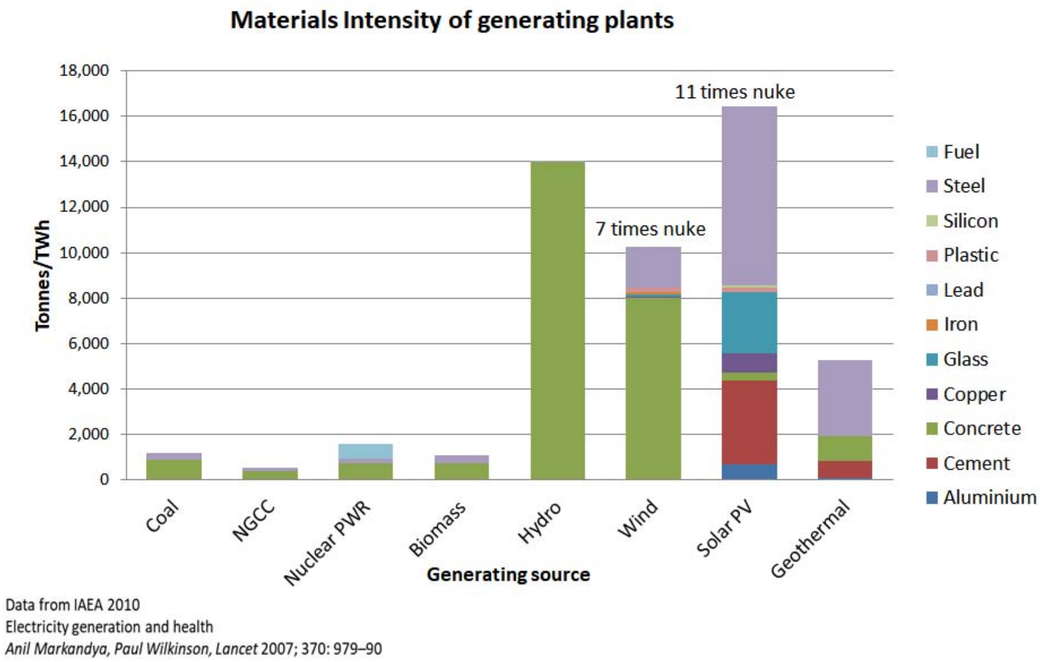

Figure 1 - Materials Intensity of Electricity Generating Plants when constructed

1.7 Prohibitions in New South Wales Legislation Should be Repealed

Notwithstanding that nuclear has a very good record overseas in supplying reliable, affordable and low carbon electricity, the New South Wales Parliament has historic prohibitions against nuclear power and other nuclear facilities in the Uranium Mining and Nuclear Facilities (Prohibitions) Act 1986 No 194.R

The Nuclear for Climate campaign strongly recommends passage of the Uranium Mining and Nuclear Facilities (Prohibitions) Repeal Bill 2019 repealing the prohibition against nuclear facilities.

Vendors cannot consider proposals for using nuclear in Australia nor collaborate in realistic costings when the technology itself is prohibited. Now is the time to remove the NSW prohibitions to allow nuclear to be considered on its merits.

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 benefit from existing grid connections and provide continuing employment in regional locations.

Recommendation: Nuclear for Climate Australia recommends repeal of the prohibitions in the Uranium Mining and Nuclear Facilities (Prohibitions) Act 1986 No 194so that nuclear power can be considered on its merits as part of New South Wales' future energy system. The Nuclear for Climate campaign Association strongly recommends passage of the Uranium Mining and Nuclear Facilities (Prohibitions) Repeal Bill 2019.

References to Environmental Impact

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IAEA 2019. *Nuclear Power Reactors in the World.* International Atomic Energy Agency, Vienna, May 2019

IEA 2015. *Projected Costs of Generating Electricity*, International Energy Agency, Nuclear Energy Agency, Organisation for Economic Co-operation and Development Sept 2015

IEA 2019a. *Electricity Information Overview*, International Energy Agency 2019

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

IPCC 2014: *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

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.

WNA 2019a. *World Nuclear Performance Report 2018.* World Nuclear Association

WNA 2019b. United Arab Emirates country profile. World Nuclear Association

2 Energy Affordability, Reliability and Economic Feasibility

2.1 Summary

Over the period 2022 to 2050 approximately 20,000 MWe of base-load generating plant will need replacement on the National Electricity Market (NEM). There is no national plan for this critical issue. A new electricity generating mix model, the EPC[9] model, has been used to evaluate feasible options for the replacement of these ageing base load generation assets.

A range of options generally focusing on variable renewable energy (VRE) has been widely promoted across the Australian community and media. This has included proposals such as AEMO's Integrates System Plan (ISP). This submission outlines the concept of a system levelized costs of electricity (SLCOE) for both Australian and overseas modelling for coal, gas, nuclear, and renewable generation options for progressive replacement of Australia's electricity generation fleet.

The analysis shows that, when nuclear energy is included in the available options, the electricity costs in deep decarbonisation scenarios are more than halved compared to full VRE systems.

Values of nuclear power plants used in this paper are drawn from two sources:

1. Based on costs of Korean reactors and adjusting for engineering and labour costs in Australia, the overnight cost of nuclear power plants is estimated to be about A$6200/kW or US$4800/kW.
2. Based on data presented by NuScale and extrapolated to Australian conditions we anticipate a cost of US$3,600/kW or A$5,000/kW for an "nth" of a kind.

2.2 Introduction

Over the past two decades the utility of the Australian electricity sector has deteriorated markedly.

Appropriate technology and engineering excellence are crucial to ensuring lowest overall cost, technical standards, and reliable operation every second. Poor choices promoted for the existing and future electricity sector have already led to expensive mistakes that will bedevil many households, businesses and Australian prosperity as a nation for years to come.

This submission recommends a clear strategy for inclusion of nuclear energy in the investigation of future energy options.

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[9] https://epc.com.au/index.php/nem-model/

2.3 The Electricity Sector Investment Dilemma

Electricity sector generation asset replacement for Australia is a policy and planning issue currently left to the market and impacted by subsidies such as LRET. Markets by their competitive nature are incidental to the national interest. The investment problem is driven by a liberalised market that provides no reliable long-term guarantee for return on capital investment for new base load generation. An energy only market where the only chance for plant utilisation and financial return is settled every half hour gives insufficient security or incentive to investors who may wish to provide capital for new dispatchable base load facilities.

Lobbyists have promoted the concept that base-load generation will no longer be required and is an impediment to the more widespread deployment of VRE and "decentralised energy" production. This concept may be true if costs to electricity consumers are of no concern and reliability is of minor importance. Detailed engineering system analysis using the EPC model shows that coal, nuclear or gas base load power will continue to be required for the foreseeable future to underpin the reliable provision of electricity to current technical standards at acceptable cost.

Unpredictable levels of solar and wind power operation will always require quick start backup response, transmission augmentation, and system quality management. This results in higher system wide costs than systems using base load power generation.

2.4 Analysing The Investment Options

A range of energy generating mixes that have been promoted by institutions and individuals have been analysed with the EPC model using load and generation data provided by the Australian Energy Market Operator for each period of 30 minutes over the year 2017. This represents 17,520 data sets analysed for the current and typical future system, winter/summer, day/night electricity load demand pattern using generation combinations available for the Australian electricity sector. This level of analysis picks up the real impact of intermittency of solar and wind generation and what is required to fix this problem.

The system engineering model first matches the actual load demand at each data point with a feasible generation combination to ensure all demand is met at all times. Some proposals are shown to be not operationally feasible. When balance is achieved the final generation mix is costed, transmission, distribution and retail costs are added and a cost to the consumer is calculated.

A minimum cost can be quickly achieved by optimising the generation mix. The model mirrors the actual working of the Australian grid and current National Electricity Market to provide all relevant output values for decision makers. The majority of previous modelling efforts fail to reflect system engineering reality by using averaging concepts for individual generation options. These assumptions smooth over intermittency and asset under-utilisation cost issues. Simplistic economic concepts are unacceptable in real engineering analysis which must account for and manage all extremes. Details of the model used to provide option studies for this paper are available at https://epc.com.au/

The model does not analyse large scale demand management as this is an inappropriate high risk response to inherent system failure particularly for industrial consumers in a modern society.

Apart from nuclear energy, all costing data has been taken from actual capital and operating values outlined in the AEMO Integrated System Plan 2018. Information for the nuclear power option was provided by South Korean government agencies during an intensive study tour of that country's nuclear engineering industry. The Korean costing information was revised by Australian consultants and contractors to ensure compatibility with labour rates and general civil engineering costs currently seen on local major projects.

The comparative costs in terms of US$/kWh are shown in Figure 2 with data taken from the 2018 publication from MIT - The Future of Nuclear Energy in a Carbon-Constrained World. A value of A$6200/kW was used in the EPC model which, after correcting for labour and materials variances became US$4861/kW.

Figure 2 - Overnight Costs of recent nuclear power plantsalso shows the overnight cost of four first-of-a-kind nuclear power reactors being built in USA and Europe and recent builds in South Korea and UAE. A nuclear power reactor for Australia will be a design already built and operating overseas to avoid the first of a king costs and delays. The estimated capital cost of A$6200/kW shows that nuclear would be cost competitive with other forms of generation.

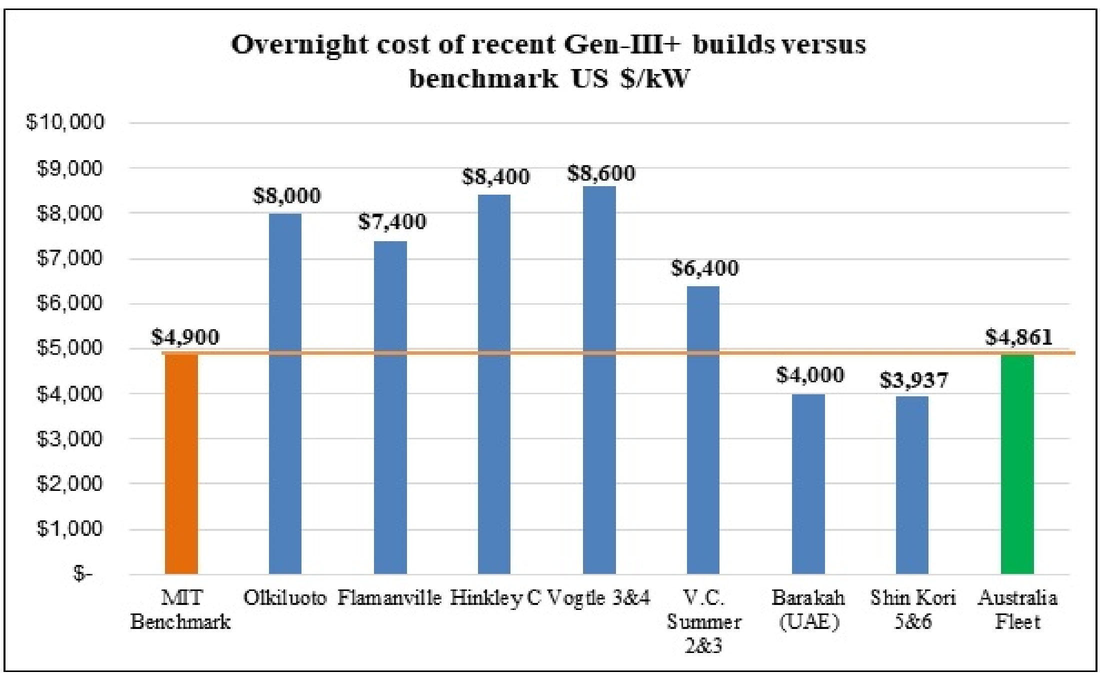


Figure 2 - Overnight Costs of recent nuclear power plants

The EPC model allows financial analysis over a range of discount rates to give an assessment of options for public and private funding.

The historic cost and time reductions achieved by the South Korean nuclear industry underpinned the selection of their costs for use in the OEPC study. Refer Figure 3

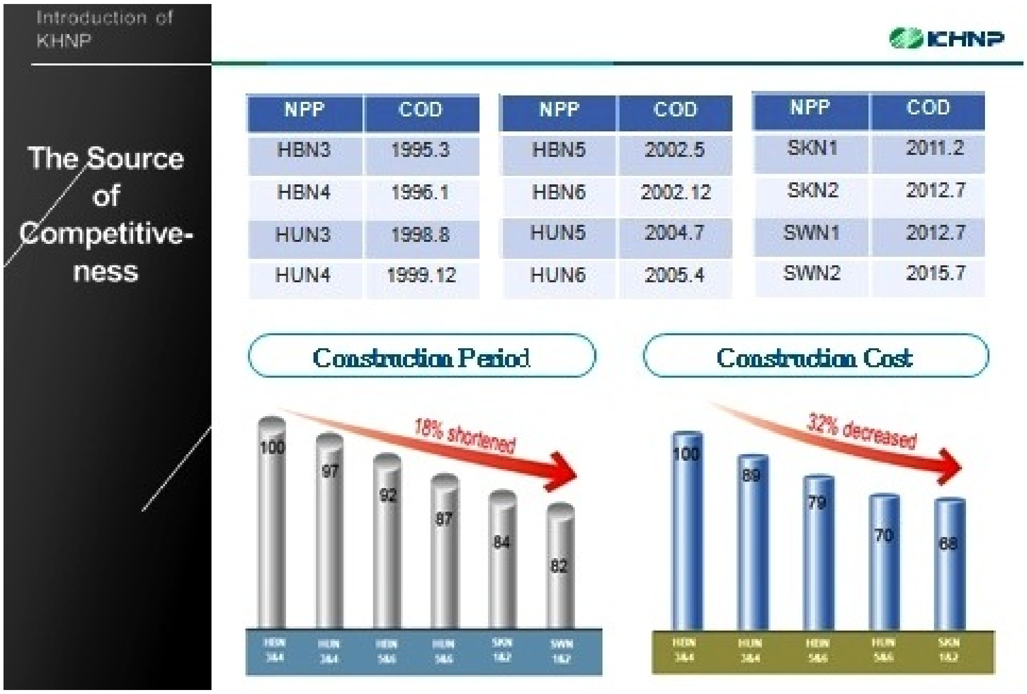


Figure 3 - Historic cost and construction period reductions in Korean nuclear industry

2.5 Analysis Results

Results from a selection of generation options are shown in Figure 4.

Full supporting details are provided in Appendices 1 and 2. These cover the National Electricity Market as it currently operates together with a range of low emissions technologies using gas, renewable solar and wind and nuclear power. The cost of carbon dioxide emission abatement is also calculated.

Figure 5 shows the retail electricity costs of increasing percentages of renewable compared to nuclear electricity sourced in the NEM. Two key factors combine to progressively drive up the cost of solar and wind renewable generation options.

1. The intermittent output requires the provision of quick-start open cycle gas turbine capacity to augment existing hydroelectric capacity and new pumped storage capacity. The use of grid level electrical storage batteries is not currently a viable economic option.

2. As renewable generation increases the transmission costs also markedly increase. Lower capacity factors of renewable energy cause lower utilisation of the transmission network and therefore higher transmission costs. Analysis shows that benefits from wind and solar PV diversity across the NEM are quite marginal and come nowhere near providing a base load capability.

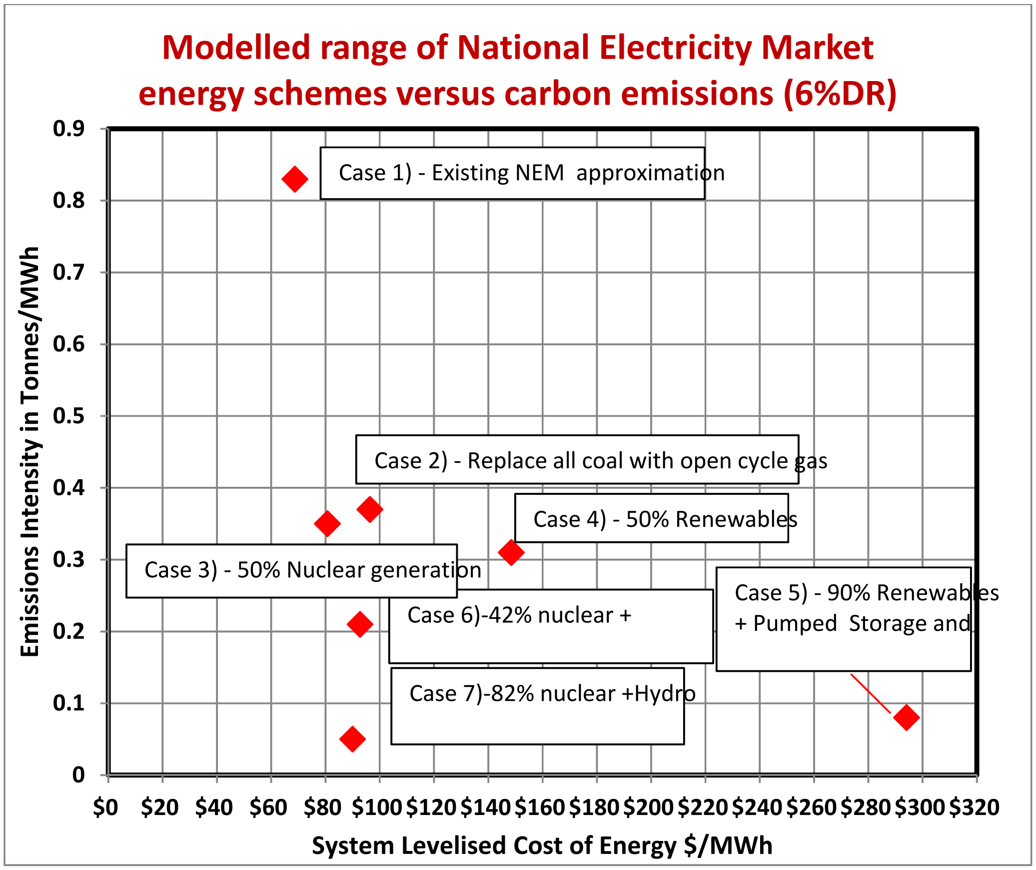


Figure 4 - Cost and Emission outcomes

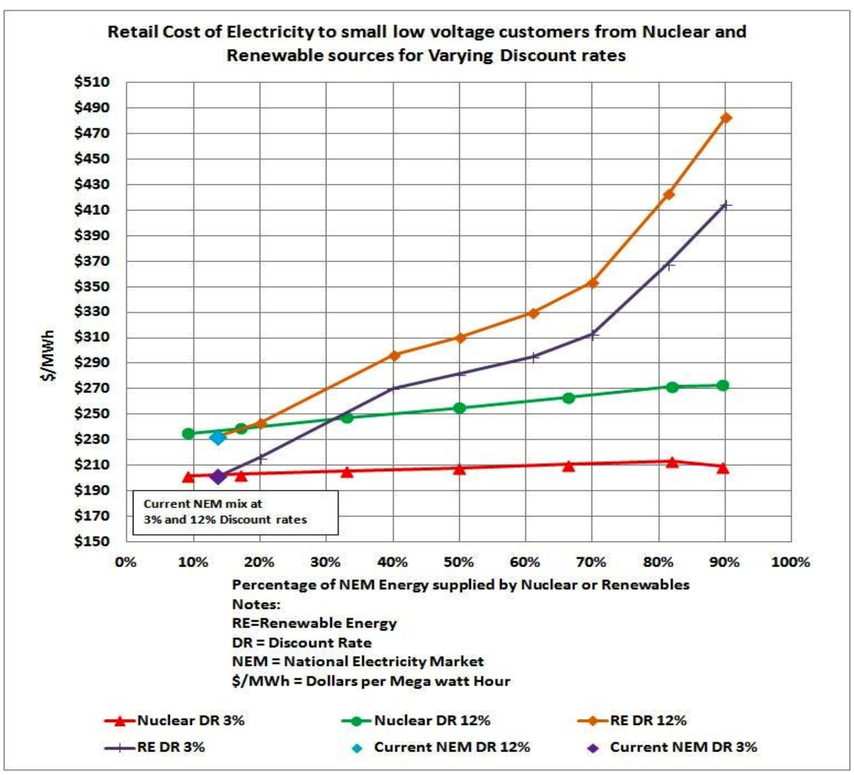


Figure 5 - Nuclear Energy Cost Competitiveness

2.6 The Lowest Cost Lowest Emission Option

This investigation verifies that for deep emissions reductions nuclear power provides the most reliable cost-effective solution. This is verified by experience with very low emissions intensity and costs of electricity generation in France and Sweden compared to that in Germany where very large investments in VRE has been made. Figure 6 illustrates the relative cost of carbon dioxide abatement measures for increasing levels of renewable and nuclear power generation in the NEM

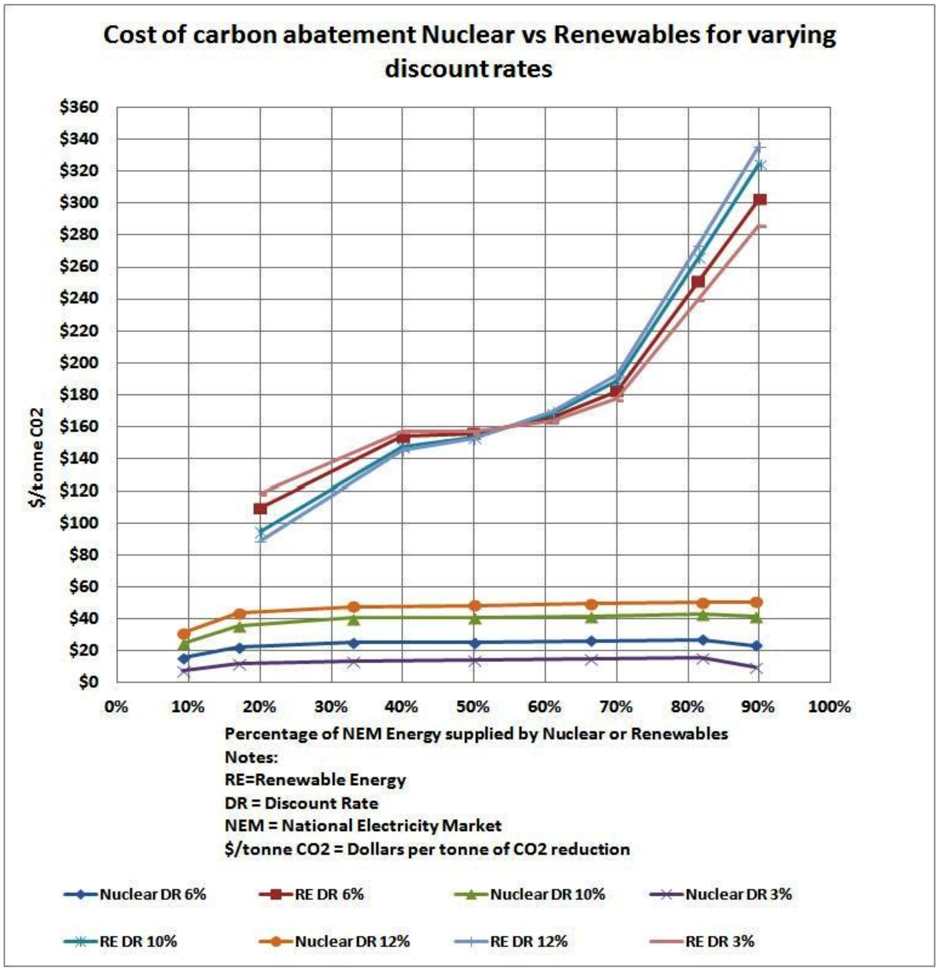


Figure 6 - Carbon Abatement costs comparison, Intermittent Renewables vs Nuclear Energy

OVERSEAS OECD MODELLING

A recent OECD report on the costs of decarbonisation arrived at very similar conclusions to those derived from our Australian EPC analysis. In this case, the OECD study of the Texas system 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 [OECD 2019]. The results of the capacity mix model for ERCOT (Electricity Reliability Council of Texas) with and without nuclear energy are shown in Figure 7. This shows more than a sixfold increase in generating capacity when VRE is the sole option compared to options which include nuclear energy.

The cost implications for these various ERCOT emissions targets are shown in Figure 8.

Decarbonising our 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.

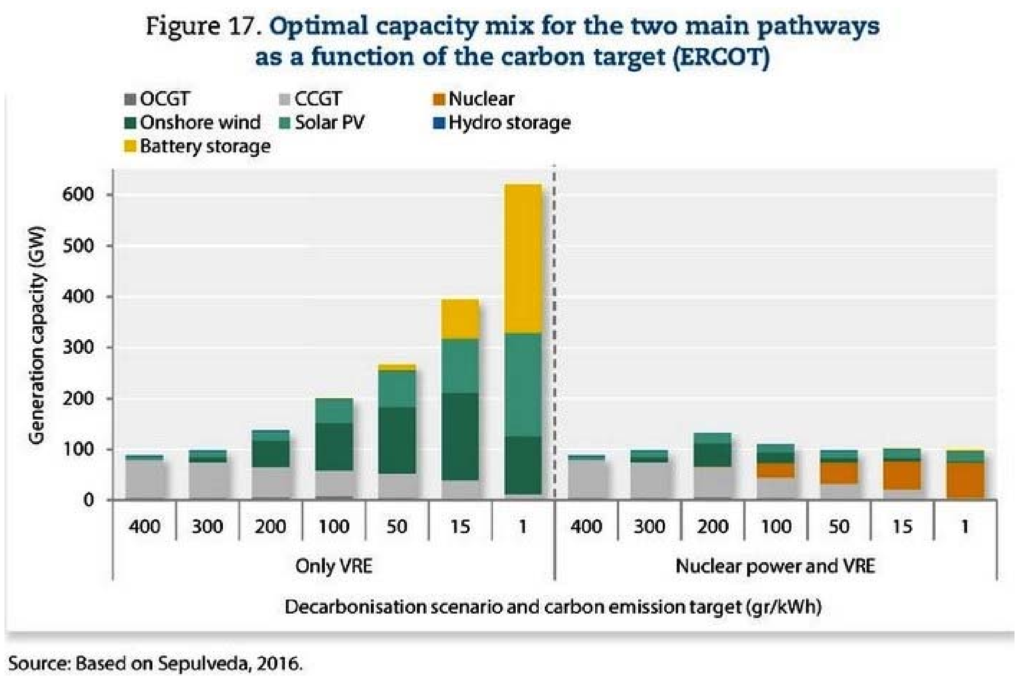
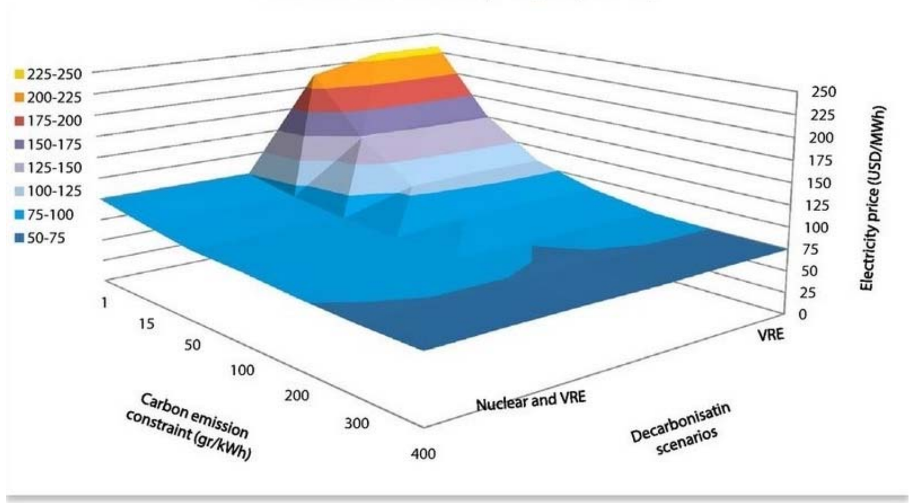


Figure 7 - Impact of capacity mix with and without the inclusion of nuclear energy.

Figure 15. **Average price of electricity as function of pathways and emissions intensity targets (ERCOT)**



Source: Based on Sepulveda, 2016.

Figure 8 - Average Price of Electricity as a function of pathways and emissions intensity targets.

The results of the study carried out on the ERCOT system highlighted in the OECD 2019 analysis can be translated to many similar jurisdictions including that of the NEM. The trends observed when comparing a system that excludes nuclear energy with one that includes nuclear provide valuable insights.

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".

It is therefore important that decarbonisation policies are **not based on pre-specified shares of low-carbon resources in the mix, but rather on ambitious CO2 reduction goals and a pre-specified agenda.** A CO2 price (or a carbon market) is sought as the optimal policy option for efficient decarbonisation; however, in the absence of CO2 markets, support mechanisms should promote all types of low-carbon resources allowing for efficient adaptation among them. [OECD 2019].

For any modelling or policy development in New South Wales collaborative cost analyses need to be carried out directly with reliable vendors such as South Korea who have established track records in successful project implementation.

2.7 The Implementation Program

Management of the transition from coal fired generation directly to nuclear power generation in the National Electricity Market (NEM) needs prompt attention. Measures to provide reliable low cost baseload generation will probably be required to replace Liddell in NSW or Yallourn in Victoria before the first nuclear power units could be commissioned.

The investment failure crisis could be overcome by the provision of minimum 15 year power purchase agreements provided by government to the private sector or alternately by direct investment in the electricity sector by government. The economic analysis illustrates that these two financing options have markedly different financial outcomes for the same asset investment. This leads to system levelised costs for base load private and public investment as noted in Appendices 1 and 2. Inherent in both these possible investment options is the need for electricity supply from both to operate outside of the existing energy only market to ensure full plant utilisation and secure investment return. In one sense both options constitute a payment for long term capacity at lower cost than currently seen in the national energy only market. This underlines the need to institute a capacity market.

The EPC analysis leads to the conclusion that if cost of supply is important, new base load investment should be undertaken directly by government in advance as ageing private generation assets are slated to be retired. This option is already being discussed for some generation capacity such as high efficiency coal and large-scale pumped storage. The most likely plant retirement program is detailed in Figure 9 in this document.

A well-defined government investment strategy for nuclear power will likely stabilise the current market so that price increases driven by plant closures as seen in the past will not be repeated. The continued use of out of market subsidies and inducements for VRE needs to be terminated.

A review of the current base load power station retirement program for the NEM generation assets and information gathered from South Korea indicates the following action proposal. It is recommended that the New South Wales parliament initiate a prompt investigation to build at least 10 GW of nuclear power capacity to replace retiring coal fired plants to be progressively commissioned over the 20 year period 2030 to 2050.

Preliminary costings indicate that the capital cost if 1000MW large scale plants were used would be A$6.2B for each 1000 MWe unit, approximately A$62B in total for a full nuclear power plant fleet in NSW. The program will be completely cost neutral for a generation sale price direct to consumers or through the NEM of 8 cents per kilowatt hour.

Small Modular Reactors (SMR’s) could also be constructed as and when they become available and a blended system may well be the best solution for Australia’s very long grid.

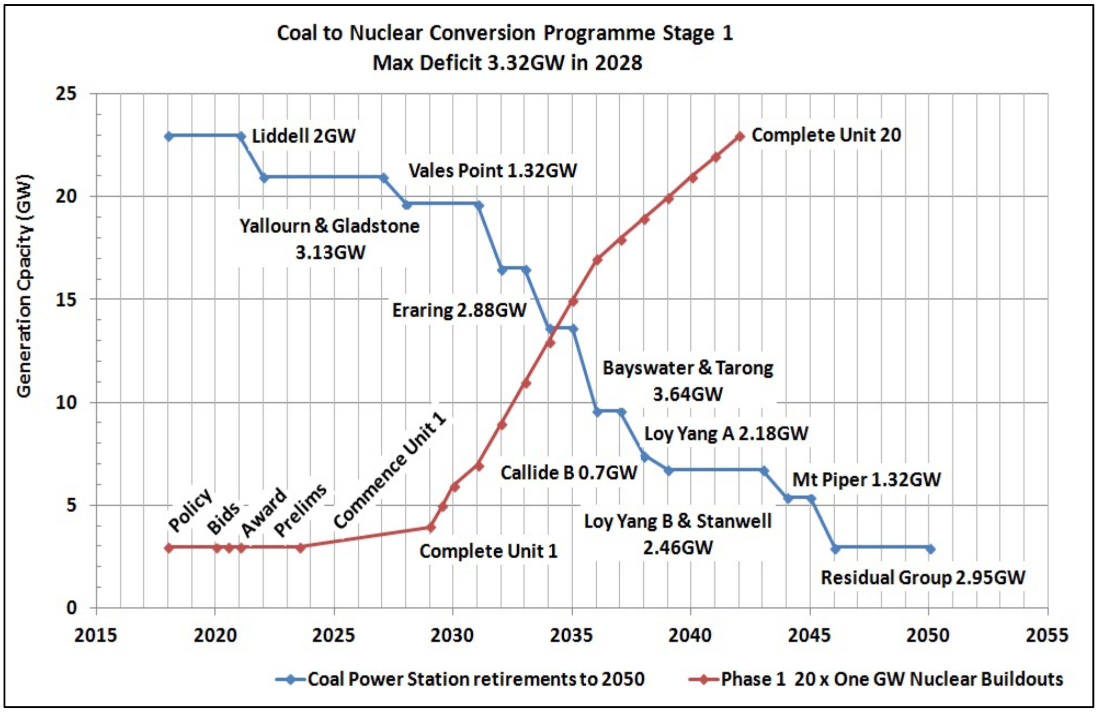


Figure 9 - Coal to Nuclear Transition

Intermittent generation (VRE) as stated earlier is driving up costs and modelling shows that it will continue to do so as highlighted in Figure 5 - Nuclear Energy Cost Competitiveness.

Figure 10, shows the increasing price volatility on the NEM which is being driven by the reduction in the availability of dispatchable generation. This Figure shows the AEMO average monthly wholesale prices in $A/MWh between January 2013 and January 2019 on a state by state basis

These values are then compared with the LCOE of 20GW of nuclear energy capacity installed on the NEM spanning a range of discount rates between 3% and 10%. These values of $105/MWh, $79/MWh and $61/MWh are shown in the three horizontal dotted green lines in Figure 10. They were derived from the EPC model which also shows that 20GW of nuclear capacity will provide 82% of the current annualized NEM demand of 190TWh.

When this 20GW of nuclear capacity is integrated into a system containing solar PV, hydro, pumped storage in the form of Snowy Hydro 2.0 and a small amount of open cycle gas, the System Levelised Cost of Generation (SLCOE) determined by the EPC model is A$87/MWh and the emissions intensity of electricity generation is only 50gr CO_2/kWh.

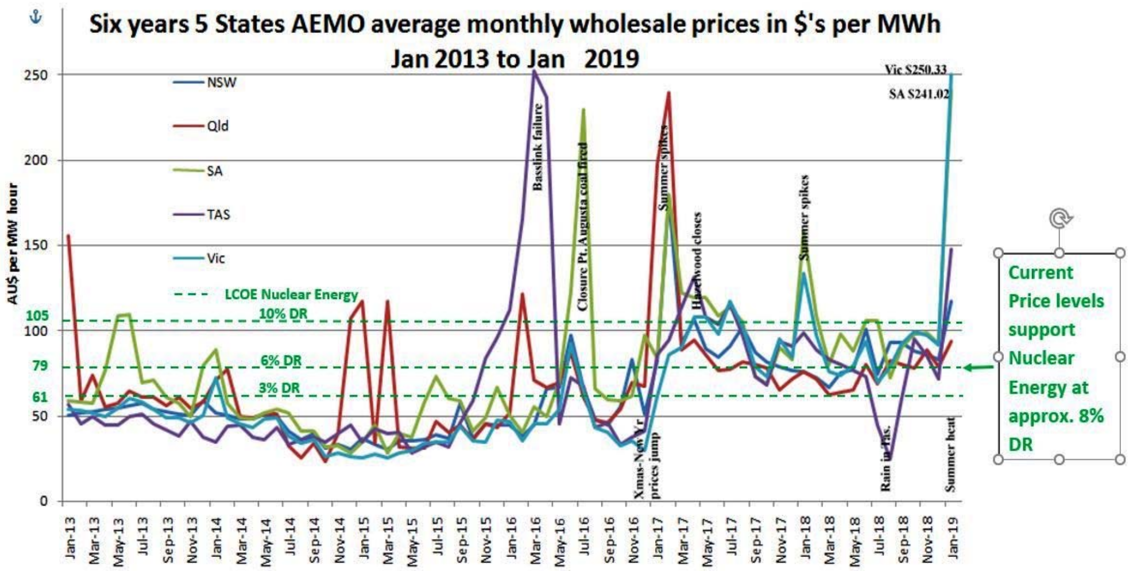


Figure 10 Competitiveness of Nuclear Energy on the NEM

In summary nuclear energy is now economic as a stable, cost competitive, low carbon generating source on the NEM. It should be introduced through a redesigned capacity market to provide long term price stability and accelerated carbon reductions.

3 SUITABLE NUCLEAR POWER PLANTS

Based upon IAEA guidelines[10] a nuclear power plant's power output should not exceed 10% of the minimum demand unless the grid is strongly interconnected to adjacent grids. New South Wales currently has a minimum demand of around 6,000MW but, being well connected to both Victoria and Queensland should be capable of sustaining a 1,000MW sized plant. Grid and switchyard upgrades would be required.

Before the existing large coal fired plants such as Mt Piper with their 500 to 700 MW generating units were built in NSW and Victoria, 500KV transmission lines did not exist. NSW and the other states are now confronting a new power generating system which if based on nuclear fission plants will last for more than sixty years and in all probability a century.

NSW and Australia have an existing energy and emissions generating crisis that needs to be resolved promptly and for this reason the generation units we have targeted come from existing suppliers who can supply now and have a strong commercial incentive to do so.

Therefore, nuclear power plants from South Korea are recommended, namely the APR1000+ pressurised water reactors (PWR). Other similarly sized plants that have been built and exist include China's Hualong One and the Russian VVER 1200.

The Korean APR1000+ units are an updated version of the OPR1000 unit which has a long history of development and world class reliable operation with over 10 units now in operation. Excellent local and export performance has seen recent 1400MWe versions of these units constructed on time and on budget; a factor of the utmost importance for investments of this nature. The larger units although more cost efficient are not suited to the current NEM grid but may be in the future. <u>There is no other nuclear plant option currently available that provides the opportunity for early ordering together with the lowest overall risk profile and value for money at this time.</u>

Currently in Australia Small Modular Reactors are being advocated on the basis that they have safety and cost merits over large scale reactors. The first deployment for NuScale's plant is planned for 2026. GE-Hitachi, whose primary business is concerned with fossil fuel generators, are promoting it's BWRX 300 unit which is claimed to have a deployment cost of $2,000/kW in 2028 or about half the unit cost of NuScale's plant.

Small modular reactor power plants hold out the promise of significant advantage in terms of siting options and factory based manufacture for the future. For use in NSW they must have an established track record in the country of manufacture and this may not occur until the early 2030's

The nuclear industry and electricity supply for South Korea is fully managed by government with minority public shareholding while manufacturing and construction capability is provided by the private sector. Electricity is provided to the nation as a service by the public sector to

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[10] IAEA Nuclear Energy Series No. NG-T-3.8 Electric Grid Reliability and Interface with Nuclear Power Plants

stimulate wealth creation throughout the entire economy. Unfortunately as electricity pricing in Australia now shows the supply of electricity as a tradable commodity is strangling this nation's wealth creation. In South Korea the average electricity price to all consumers is US8c/ kWh. The 30% nuclear power contribution is provided at around US4c/ kWh. This performance model could easily be utilised throughout Australia with the benefit of sharing all financial aspects of the initial investment in the form of a public / private arrangement.

It is recommended that the South Korean Nuclear Industry be approached by the NSW Government to collaborate on a detailed cost analysis. That country is dedicated to supporting progressive local manufacture of future units. Australia already has most of the infrastructure and technical expertise necessary to achieve local construction for later units.

Great care needs to be exercised in any amending legislation to ensure it does not exclude future nuclear power plant developments. For example high temperature gas cooled NPP's such as the HTR-PM being built in China has a nuclear pressure vessel weighing in at 700 tonnes and 25 metres in length. It is roughly twice the size of a 1000MW PWR yet is has been incorrectly described as an SMR. It is suitable for use in hydrogen production especially at steel plants however they are neither small nor modular. They are however inherently safe. Likewise we have other Gen IV designs such as sodium and lead cooled fast reactors or molten salt reactors. Their architecture may or may not be small or modular.

The wholesale adoption of the "SMR" term may become an impediment to future groundbreaking inherently safe nuclear power plants. It is advisable instead to focus attention on the 21st Century high standards of nuclear energy developments as documented in the very large resource base of the IAEA.

3.1 Conclusion

Detailed system engineering and economic analysis has shown that the implementation of a nuclear power investment program provides the lowest cost, lowest emission outcome for NSW's future electricity sector. Nuclear generation units will have an operational life of at least 60 years providing low cost supply of energy for the foreseeable future.

Suitable Nuclear 1GW sized Power Plants are available for installation on the NEM and these could be readily integrated with Small Modular Reactors as and when these become available.

Detailed analysis for these options should begin without delay.

Reports from the study of South Korean nuclear installations are available at https://nuclearforclimate.com.au/

Recommendations:
Nuclear for Climate Australia recommends:

1. ***A detailed cost and feasibility study of the prompt deployment of nuclear energy to include all near term and available types of nuclear power plants. This may include liaising with ANSTO to assist with this work.***
2. ***ARPANSA be given responsibility for licensing, siting and operation of any nuclear power plant in Australia and be given additional resources.***

4 WASTE MANAGEMENT, TRANSPORT AND STORAGE

Nuclear power stations generate a range of radioactive and non-radioactive wastes. There is extensive overseas experience on the safe management of wastes from nuclear power plants and Australia already has a well-developed and effective regulatory regime for the safe and effective management of radioactive waste.

The non-radioactive wastes are similar to those from many large industrial plants and would be readily managed using the waste management infrastructure in the States and Territories.

The radioactive waste from a nuclear power plant would be classified using existing classifications in the Australian Safety Guide on Classification of Radioactive Waste (ARPANSA 2010) RPS20.

This Safety Guide defines six categories of waste

(1) Exempt waste (EW): Waste that meets the criteria for exemption from regulatory control for radiation protection purposes.

(2) Very short lived waste (VSLW): Waste that can be stored for decay over a limited period of up to a few years and subsequently exempted from regulatory control.

(3) Very low level waste (VLLW): Waste that does not meet the criteria of EW, but does need a moderate level of containment and isolation and therefore is suitable for disposal in a near surface, industrial or commercial, landfill type facility with limited regulatory control.

(4) Low level waste (LLW): Waste that is above exemption levels, but with limited amounts of long lived radionuclides. Such waste requires robust isolation and containment for periods of up to a few hundred years and is suitable for disposal in engineered near surface facilities.

(5) Intermediate level waste (ILW): Waste that, because of its content, particularly of long lived radionuclides, requires a greater degree of containment and isolation than that provided by near surface disposal. … waste in this class requires disposal at greater depths, in the order of tens of metres to a few hundred metres.

(6) High level waste (HLW): Waste with activity concentration levels high enough to generate significant quantities of heat by the radioactive decay process or waste with large amounts of long lived radionuclides … Disposal in deep, stable geological formations usually several hundred metres or more below the surface is the generally recognised option for disposal of HLW.

A typical 1000 MW(e) reactor (pressurized water reactor (PWR)) will generate about 100–200 cubic metres of LLW and ILW per year (IAEA 2013, No. NW-T-1.24). Australia already has accumulated almost 5,000 cubic metres of radioactive waste (around the volume of two Olympic size swimming pools). This does not include uranium mining wastes, which are disposed of at mine sites.

There is considerable experience in Australia in managing the storage of low and intermediate level waste, see for example the Safely Guide for the Predisposal Management of Radioactive Waste (ARPANSA 2008). There are numerous radioactive waste stores around Australia and the Commonwealth is currently selecting a site for establishing a National Radioactive Waste Management Facility for the long-term disposal and storage of low and intermediate level radioactive waste.

Such a central facility for managing and disposing of low and intermediate level waste would be beneficial to the operation of a nuclear power plant but is not essential. If in the unlikely event that the national radioactive waste management facility is not operational by the time a nuclear power plant is operational, then waste from the nuclear power plant would be stored in an interim storage facility like the other radioactive waste already existing in Australia.

Nuclear power plants also produce spent fuel or high level waste (HLW) which are solid and emit intense radiation which would be very hazardous if not shielded. Spent fuel from nuclear power reactors and high level radioactive waste are routinely and safely stored and transported in countries with nuclear power.

Existing radiological regulations are suitable for managing spent fuel and high level waste.

Spent fuel discharged from a nuclear power reactor is initially stored in cooling ponds usually on the reactor site. When first removed from the reactor, the spent fuel needs cooling to remove heat generated by the radioactivity in the spent fuel element. The heat generated by the radioactive decay in the spent fuel element decreases over time as the shorter-lived radionuclides decay to be cooled.

The design and regulation of these short term (typically 10 years) storage facilities is part of the design and licensing of the reactor.

Once the heat generation is low enough, the spent fuel can be sent for reprocessing or placed in longer term dry storage facilities. Many nuclear power plants use dry ventilated modules for storing spent fuel after the initial decay period. These modules are very robust and provide full shielding.

A typical operating 1000 MWe PWR generates about 25 to 30 tonnes spent fuel a year. Which is a small quantity and is readily managed.

Spent fuel and high level waste from reprocessing spent fuel need to be stored for 40 to 50 years to allow the decay heat to reduce sufficiently for disposal in a geological facility.

Spent fuel from most power reactor contains partially enriched uranium and plutonium that can be reused in nuclear fuel. Some countries reprocess the spent fuel to extract these resources, while other countries have decided to dispose of the spent fuel directly.

Disposal in a stable geological facility is the preferred disposal option for spent fuel and high level waste. At present, the US Waste Isolation Pilot Plant (WIPP) is the only operating purpose built deep geological facility. Plans for repositories for disposal of spent fuel are well advanced in Finland and Sweden.

An Australian *Code for Disposal Facilities for Solid Radioactive Waste,* ARPANSA 2018] is for low and intermediate level waste. This Code could readily be modified to cover disposal facilities for high level waste. The Australian Code is based on the International Atomic Energy Agency General Safety Guide No. GSG-1 Classification of Radioactive Waste (IAEA 2009) which itself covers high level waste.

New South Wales would have several options if we have spent nuclear fuel, after about 5 to 10 years in the cooling pond.

- Some nuclear fuel suppliers will take back spent fuel
- Spent fuel can be transferred to commercially available dry casks
- New South Wales might establish a deep disposal facility to take spent fuel waste from regional countries, as investigated by the South Australian Nuclear Fuel Cycle Royal Commission,

- For a limited amount of spent fuel, there has been considerable discussion of disposal in deep boreholes.

Figure 11 - Finland's Deep Geological Repository currently under construction.

New South Wales has large areas with very stable geology which could be suitable for deep geological disposal or spent fuel or high level waste.

Summary

New South Wales already has the prerequisites for managing low and intermediate level radioactive waste from a nuclear power program.

Options will be available for managing spent fuel from nuclear power reactors

A decision is needed on which agency will licence and regulate the waste management activities at a nuclear power plant (see also discussion below on Health and Safety).

References for Waste Management:

ARPANSA 2008. *Safety Guide for the Predisposal Management of Radioactive Waste* (2008) Radiation Protection Series No. 16, Australian Radiation Protection and Nuclear Safety Agency (ARPANSA) July 2008.

ARPANSA 2010. *Safety Guide for Classification of Radioactive Waste Radiation* Protection Series Publication No. 20, Australian Radiation Protection and Nuclear Safety Agency (ARPANSA) April 2010.

ARPANSA 2018. *Code for Disposal Facilities for Solid Radioactive Waste*. Radiation Protection Series C-3 Australian Radiation Protection and Nuclear Safety Agency (ARPANSA), October 2018

IAEA 2011. *Disposal of Radioactive Waste*. Safety Standards Series No. SSR-5, Vienna, International Atomic Energy Agency, 2011.

IAEA 2013. *Options for Management of Spent Fuel and Radioactive Waste for Countries Developing New Nuclear Power Programmes.* Nuclear Energy Series No. NW-T-1.24 International Atomic Energy Agency Vienna, 2013.

IAEA 2018. *Status and Trends in Spent Fuel and Radioactive Waste Management,* IAEA Nuclear Energy Series No. NW-T-1.14, Vienna 2018

5 Health and Safety

Australia has a strong regulatory regime for radiological risks. There are seven regulators in Australia, ARPANSA for the regulation of the use of radiation by Commonwealth entities and eight regulators in the States and Territories.

ARPANSA regulates the 20 MW OPAL research reactor at Lucas Heights which is a Commonwealth Facility. ARPANSA also issues permits for import of radioactive substances into Australia and to export high activity substances out of Australia.

Uses of radiation in non-Commonwealth entities are regulated by the State and Territory regulators. National uniformity in regulating the uses of radiation is achieved through the Radiation Health Committee comprising members from ARPANSA and radiation control officers from each State and Territory.

Australia already has a well-established regulatory regime for radiation protection regulations based on the *Fundamentals for Protection Against Ionising Radiation* (2014) and *Code for Radiation Protection in Planned Exposure Situations* (2016). The regulations for radiation protection in the Commonwealth, State and Territories is based on these documents

The existing regulatory regime is adequate for providing radiation protection at a nuclear power reactor, but there is an issue of which regulator would be responsible to a nuclear power plant not owned by a Commonwealth entity.

The State and Territory regulators are responsible to the industrial uses of radioactivity and radiation in their jurisdiction. Internationally most countries, even federal systems like the USA and Canada, have a national regulator for nuclear reactors.

At a national level Australia should designate ARPANSA the regulator of nuclear power plants. This would provide a consistent approach should reactors be proposed in more than one State or Territory and avoids duplication of resources. This would require agreement of the State and/or Territory Governments where the nuclear plant could be located.

Nuclear power plant designs are assessed, approved and licensed by a nuclear regulator before construction. ARPANSA has for many years ably performed its role as Australia's federal nuclear regulator. With more resources and by drawing on international experience in regulating and licensing nuclear power reactors, ARPANSA can apply its experience and knowledge to also regulator nuclear power reactors.

Even including the major accidents in Chernobyl in 1986 and Fukushima in 2011, nuclear power remains among the safest of all generation technologies based on lives lost per unit of electricity produced over the 60 years of commercial operation and over 17,000 total years of operating power nuclear plants.

As with the aircraft industry nuclear power plant designs are continually being improved based on the operating experience of current nuclear power plants. The most significant design improvements in both large scale Generation III and Small Modular Reactors (SMRs) is the introduction of safety features which enable these reactors to automatically shut down and remove decay heat using passive controls. This means that the reactors remain safe without external power supply or human intervention.

Small Modular Nuclear power plants based on factory-built modules rated from 10 MWe to 250 MWe that are now undergoing regulatory assessment overseas. SMRs have advanced safety features, are designed to load-follow and their smaller size reduces the upfront capital cost.

6 Community Engagement and National Consensus

6.1 Current Status

Nuclear energy is undergoing a resurgence of interest in Australia which is evident by inquiries happening at the Federal level and also within the States of New South Wales and later this year in Victoria.

It's being driven primarily by escalating electricity prices and reliability of supply. These pressures if left unchecked will cause harm to householders and will also threaten business and jobs.

Australians are also motivated to a lesser degree by the need to address climate change. This concern underpins the focus on carbon reductions in electricity generation.

A significant ramp up in media engagement and community presentations on nuclear energy is occurring. The issues being raised by the public at these presentations are evolving. Two or three years ago they were reactor safety, radiation and cancer. These days a level of real interest exists in actually how nuclear energy can meet both our economic and environmental needs. Positivity is replacing anxiety.

6.2 Political

Support or at least positive engagement for nuclear energy exists within the "silent majority" and Coalition voters. Within the Labor Party, regional branches behave like the "silent majority" however closer to metropolitan areas, the promise of renewables holds sway.

Within "activist" left of centre voter groups two issues remain very strong.

1. Firstly, nuclear energy represents an existential threat that is promoted by forces that are alien to the values of this group and,
2. Secondly, variable renewables (VRE) can meet our energy demands. Any failings are only short term and will be resolved by new technologies such as batteries or pumped hydro storage. The claimed low carbon virtues of nuclear energy are dismissed out of hand.

Media outlets aligned to these political groups frame their messages to ensure they reinforce the values of the respective camps.

The ongoing sway of the VRE message is very strong and its ultimate expression can be seen internationally in policies such as the German *Energiewende* where despite spending some €150 billion up to 2015, the actual emissions reductions have not lived up to expectations. By 2025 its been estimated by the Düsseldorf Institute for Competition Economics (DICE) that over €520 billion will be spent in the electricity sector alone.

The comparison of the current performance of Germany's policy compared to its nuclear powered neighbour in France can be seen in Figure 12.

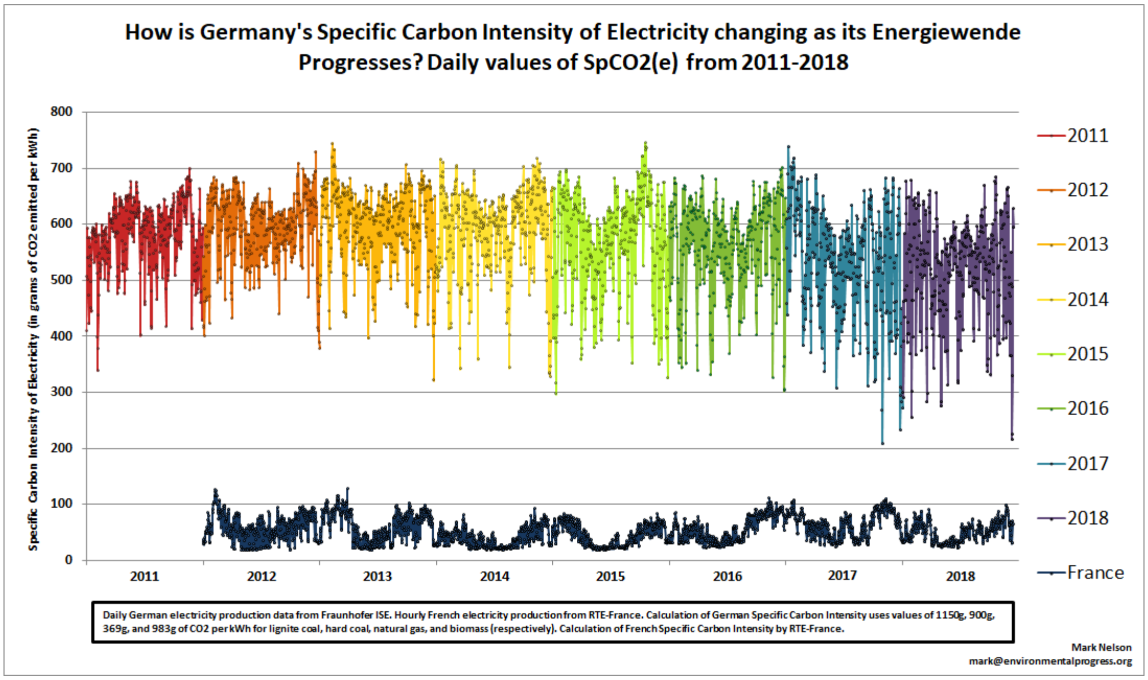

Figure 12 - Germany vs. French electricity emissions intensity

6.3 PROCESS OF ENGAGEMENT

1. *REMOVAL OF BANS ON NUCLEAR ENERGY*. From discussion at public forums this ban operates as a form of censorship on sensible discussion. It appeals only to a minority and is not welcomed.
2. *DETAILED INVESTIGATION OF NUCLEAR ENERGY*. First stage of the introduction of nuclear energy would be a detailed costing and feasibility study carried out either by a private proponent or by Government. Possibly it would fit with the existing role of ANSTO given its existing responsibility to keep Government informed on the advances in nuclear energy. Such an investigation would need to be linked at some stage with a revised national energy policy and adjustments to the design of the market.
3. *COMMUNITY DISCUSSION*. The lessons learned from the South Australian Nuclear Fuel Cycle Royal Commission with community engagement must not be repeated. Rushing to a "Citizens Jury" that lasted over a few weekends was a mistake. Understanding and assimilating the benefits of nuclear energy takes time and people need to become familiar with the issues.

   The chances for a bi-partisan approach may be enhanced by the use of community forums where short term political opportunism can be defused.

4. *KEY ISSUES*
   a. **Nuclear waste** – The means of handling used nuclear fuel is a recurring issue that needs to be handled early on. It will take time for the community to feel confident

with an issue that is readily handled from a technical point of view but which is constantly at the forefront of concerns.

b. **Jobs and communities –** It is best if communities were to self nominate for the establishment of nuclear power plants. The local benefits in terms of education, jobs and community stability and wealth creation need to be clearly identified and promoted.

c. **Environmental Benefits –** Nuclear energy has clear benefits in terms of a very low use of materials compared to VRE and small environmental footprint. Its low emissions have been verified unlike VRE where they are quite speculative as demonstrated in the comparison of France and Germany.

d. **Low and Stable energy cost –** this was discussed in detail in TOR C and D and would be essential in community engagement.

e. Bi-partisanship - Its essential that nuclear energy be approached on a bi-partisan basis. Nuclear power plants could create locally stable communities with trades and professional careers lasting for more than eighty years. These benefits need to be promoted with communities in creating a bi-partisan approach.

Recommendations:
Nuclear for Climate Australia recommends that the New South Wales Government undertake early stage consultations throughout the State's community on:

1) Environmental Benefits of Nuclear Energy

2) Methods of disposal of used nuclear fuel including possible later stage re-use.

3) Contribution of Nuclear Energy to price electricity price stabilization

4) Training and Employment

5) Safety Concerns

7 WORK FORCE AND RESOURCE CAPABILITY

7.1 STRATEGIES FOR WORKFORCE ENGAGEMENT – THE SOUTH KOREAN EXAMPLE

In this section we provide by way of example the method used by South Korea to address its training and recruitment of the workforce for their nuclear energy programme.

An outline of this methodology was contained in the paper entitled "Fourteen lessons learned from the successful nuclear power program of the Republic of Korea" by Sungyeol Choi et al.

This paper presents a very relevant historical roadmap covering the disciplines and procedures brought to bear in the deployment of the South Korean programme.

We then provide a table of the man-hours expended on nuclear power plants in selected countries.

The approach that Australia would take would be highly dependent upon whether a fleet of nuclear power plants was being constructed or just a single unit.

South Korea has 24 reactors providing about one-third of South Korea's electricity from 23 GWe of plant. In 2016 they provided 162TWh of electricity

The Korean government created The Nuclear Energy Program Implementing Organization (NEPIO) which undertook human resources development to provide the manpower needed to execute their national nuclear power program.

The Korean programme initially secured highly skilled manpower and support from overseas institutions in collaboration with the IAEA and the United States industry This prepared the way for domestic education and training programs in the future such as the current KINGS programme near Busan in South Korea. This school now provides graduate skills for nuclear power plant personnel on an International scale.

Figure 13 - KEPCO International Nuclear Graduate School

To secure the required high levels skills, the government offered attractive positions and salaries for qualified personal coming from other fields.

In order to meet the demand for high level expertise not available domestically, foreign experts were invited at all phases of development including the operational phase of the first NPP. The government soon realised that up-to-date education and training could not be effectively provided in Korea and began overseas training for young talent with the International School of Nuclear Science and Engineering (ISNSE). This provided opportunities for overseas education in countries with mature nuclear programmes. This program continued for about 20 years.

To establish a long-term human resources programme the Korean government created quality students due in part to strong government support. The government provided grants to encourage nuclear research in the universities in an effort to stimulate academic involvement with the program.

7.2 Manhours required per Nuclear Power Plant

Lessons can be learned by comparing the labour resources used in different nations and the resultant construction costs. Despite being the innovators of nuclear energy, the United States system has failed to replicate the costs and labour performance achieved in other nations such as South Korea as shown in Figure 14. Not only were South Korean reactors much cheaper but their costs reduced over time[i].

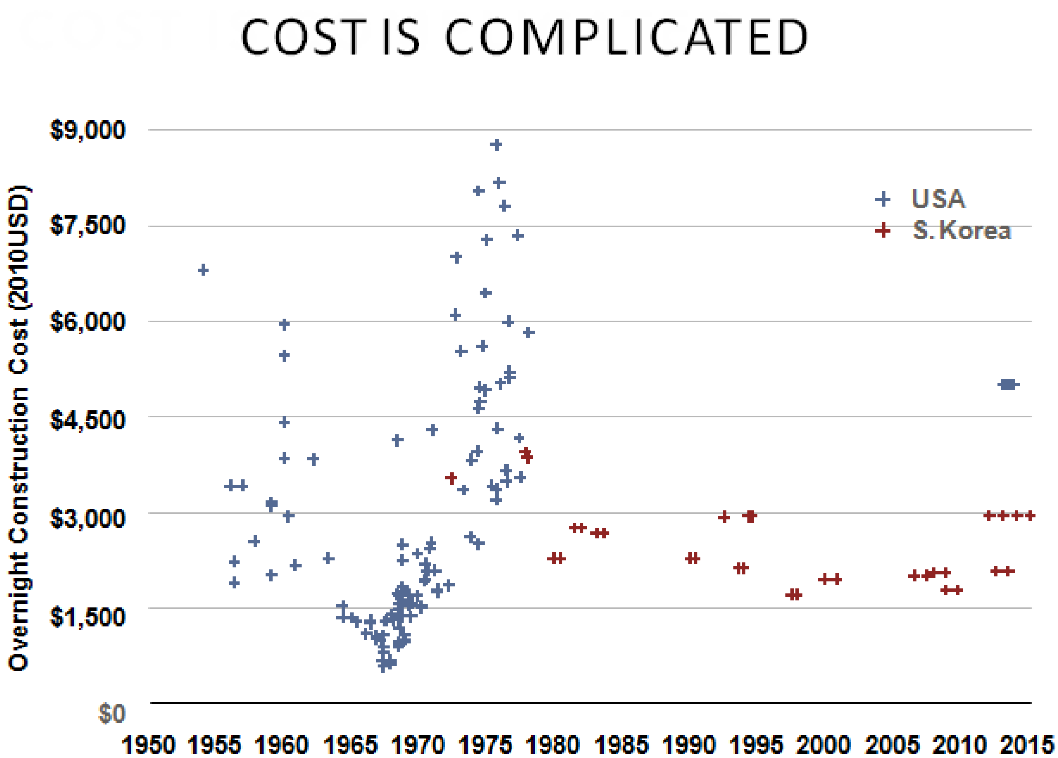

Figure 14 - Relative cost performance of the United States vs. South Korea

The following table shows a very large historical spread of labour resources required for a typical 1000MW nuclear power plant. The difference between the USA and France for virtually identical NPP's is stark. The French programme was carried out under a strong centralised national agenda with multiple plants constructed at each site.

That of the USA was carried out generally with one or two NPP's at each site.

It has been noted that significant cost benefits occur when multiple plants are built at each site.

In the recent UAE Barakah project there was a 40% reduction in the manhours deployed between the first and second units.[ii]

From Nuclear Power in an Age of Uncertainty 1984		
	All 900 to 1000 MW plants	
US	19,160	mhs/MW
W Germany	13,280	mhs/MW
Sweden	12,190	mhs/MW
Japan	13,280	mhs/MW
France	9,670	mhs/MW
Parson Brinkerhoff	**6500 - 9500 man-years for a 1000MW unit**	
	based on 2400hr/yr/man	
Low mhs/MW	High mhs/MW	Median mhs/MW
15600	22800	19200

Recommendations:

Nuclear for Climate Australia recommends that the NSW Government:

1) ***Assess current capacity at our universities and TAFE's to address both graduates and trades people to be employed in the construction and operations of a nuclear power plant fleet.***

2) ***Determine the skills available from off shore to initiate and train up Australian personnel in nuclear skills and construction***

[i] Historical construction costs of global nuclear power reactors by Lovering, Yip and Nordhous

[ii] From WNA