Nuclear For Climate Australia

Submission to: House Select Committee on Nuclear Energy

Robert Parker 13th November, 2024

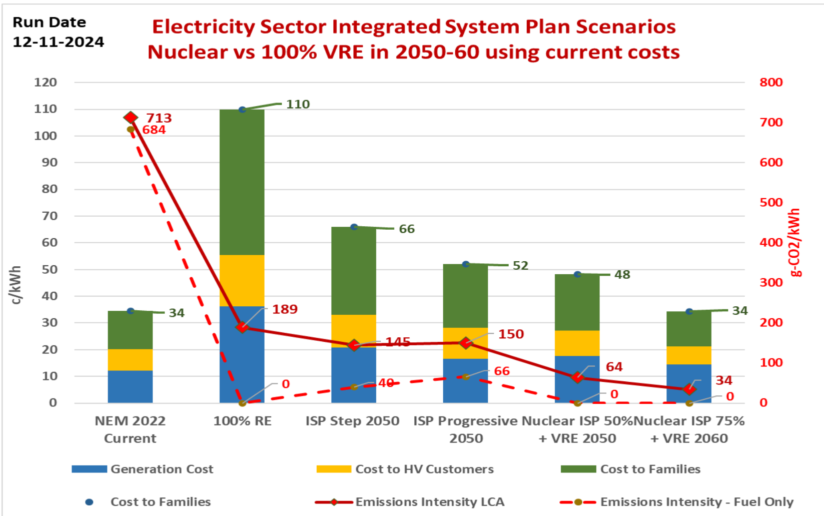
Nuclear Energy is Essential to Meeting the National Electricity Law

Executive Summary

The key theme of this submission which is outlined in Sections 2 and 3 makes the case that only by using baseload nuclear energy, as our dominant form of electricity generation, can we provide ultra low carbon emissions while at the same time providing the lowest cost form of generation.

In Section 2 we provide the results of six electricity generation scenarios. These compare the NEM situation in 2022 with 100% “Renewables”, AEMO’s Step Change and Progressive Change scenarios and 50% and 75% nuclear generation options.

Full Life Cycle Analysis parameters are used to calculate the emissions of all scenarios. The two nuclear options have the lowest system costs and only the 75% nuclear is ultra-low carbon. The 100% Renewable, Step Change and Progressive Change fail to achieve either low or ultra-low emissions and therefore do not provide a solution that meets the requirements of the National Electricity Law. The results are shown in the following Figure 1 from the report.



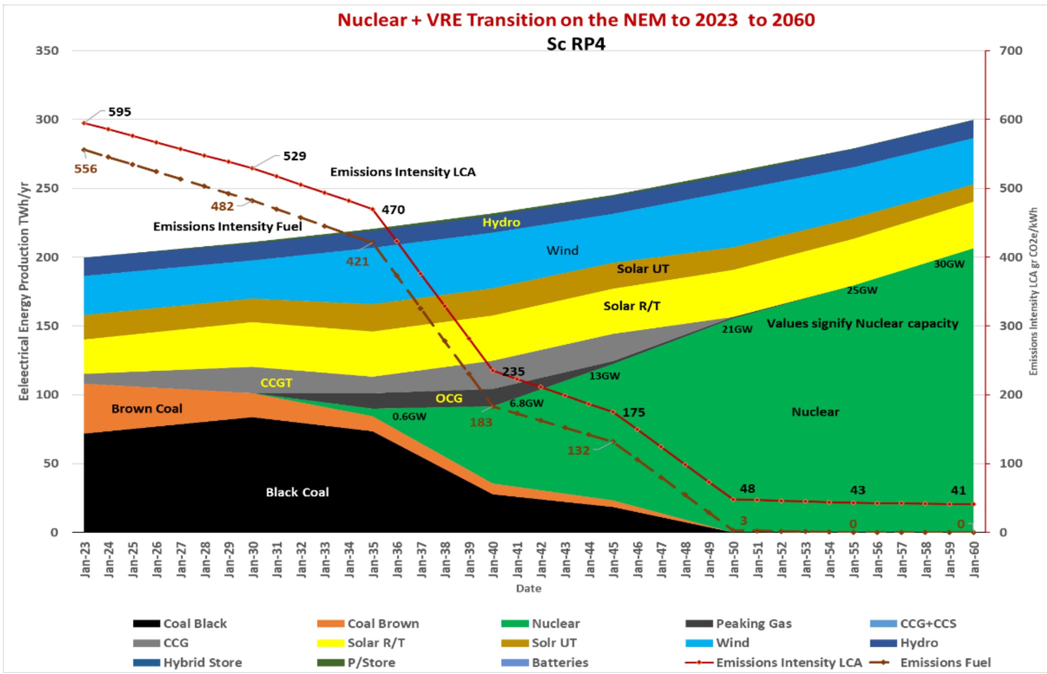
Based on these results the National Electricity Objective as stated in the National Electricity Law (NEL) cannot be met unless a system based on high levels of nuclear energy is deployed. The NEL is in direct conflict with the laws preventing nuclear energy production contained in the ARPANS and EPBC Acts

This leads to the nuclear energy implementation timeline shown in the next image which is Figure 5 in the main report.

1. The nuclear roll out is completed in 2060 with 30 GW of installed nuclear capacity using AP1000 large plants and i-SMR small plants. Other options such as APR1400 and BWRX 300 could also be used. The plants operate at 79% capacity factor in 2060.

3. Installed wind is 18.4GW, Grid solar – 8.8 GW and roof top solar is 26.3GW. This is similar to current levels.

4. Emissions intensity in 2060 on an LCA basis is 41 g CO2/kWh & cost to consumers is 38.5 c/kWh. Emissions in 2050 are 48 gr CO2/kWh (LCA), 3 gr CO2/kWh Burned Fossil Fuel (BFF) or about 1/3rd that of the Step Change Scenario in the same year.



A bar chart showing fourteen plant locations together with plant types and precedent activities is included in Figure 6. Also included is a comparison of the speed of this programme with the achievements in other nations – it's a conservative and achievable target.

In Section 4 the report details the huge materials consumption associated with a system dependant on wind and solar. The energy transition was intended to herald a more sustainable future however attempting to achieve this with wind and solar will only result in a massive increase in materials consumption. These materials will litter the landscape and their end of life retrieval is neither certain nor affordable.

A 100% "Renewable" system uses between 5.1 and 6.2 times more materials over an 80 year period than a nuclear based system. If the term "Renewable" is to mean anything at all it is best reserved for nuclear energy

Section 5 of the report deals with water demand and cooling of nuclear power plants. Research by the United Nations Economic Commission for Europe finds that nuclear power plants use similar of slightly lower amounts of cooling water compared to coal plants. Data from EPRI in the US indicates similar levels or slightly more is used in nuclear plants. This report notes that in Australia siting of plants on the coast using sea water cooling in close proximity to large load centres is the ideal solution. Cooling using once through cycles from large cooling ponds as was used at Liddell power plant would also be environmental prudent.

Section 6 deals primarily with seismic risk. Australia is seismically stable being similar to the stability of eastern and central USA and far from unstable plate boundaries. Recent tremors in the Hunter region or in Gippsland or the 1989 Newcastle earthquake pose no safety risk to the safe operation of nuclear power plants.

It is entirely feasible and accords with precedent that the NEM can achieve true ultra low emissions electricity at a cost of about ½ that of a system reliant on wind, solar, hydro and gas backup. Such a nuclear energy system would contain 21 GW of nuclear energy plants built by 2050 and total 30GW by 2030. The plants would be located at 14 sites within Queensland, New South Wales, Victoria and South Australia.

1. Introduction

The purpose of this submission is to address the items listed for attention by the House Select Committee on Nuclear Energy. This has been appointed to specifically inquire into and report on the consideration of nuclear power generation, including deployment of small modular reactors, in Australia.

Thirteen subject areas have been identified. Not all have been addressed as this would make this submission too long. Many were addressed properly in the South Australian Royal Commission into the Nuclear Fuel Cycle.

Items covered in this submission focus closely on a plan for a Nuclear Energy rollout across the NEM requiring 30GW of nuclear energy generators to be installed by 2060.

1. deployment timeframes; Refer Section 3 A Nuclear Plan for the NEM
2. fuel supply, and transport of fuel; Not addressed
3. uranium enrichment capability; - Not Addressed
4. waste management, transport and storage; Not Addressed
5. water use and impacts on other water uses; Refer Section 5 Cooling Water Demand
6. relevant energy infrastructure capability, including brownfield sites and transmission lines;
   Refer Section 2 Conforming to Laws requiring Ultra Low Carbon Generators
   Section 3 A Nuclear Plan for the NEM
7. Federal, state, territory and local government legal and policy frameworks;
   Refer Section 2 Conforming to Laws requiring Ultra Low Carbon Generators
8. risk management for natural disasters or any other safety concerns;
   Refer Section 6 Natural Disaster Risk
9. potential share of total energy system mix;
   Refer Section 2 Conforming to Laws requiring Ultra Low Carbon Generators and:
   Refer 3 A Nuclear Plan for the NEM
10. necessary land acquisition; Not Addressed
11. costs of deploying, operating and maintaining nuclear power stations;
    Refer 3 A Nuclear Plan for the NEM
12. the impact of the deployment, operation and maintenance of nuclear power stations on electricity affordability; Refer 3 A Nuclear Plan for the NEM
13. any other relevant matter.
    a. Materials consumption comparison and sustainability;
       Refer Section 4 Materials Consumption is minimised with nuclear energy.

2. Conforming to Laws requiring Ultra Low Carbon Generators

This section refers to the following items for consideration:

6. Relevant energy infrastructure capability, including brownfield sites and transmission lines

7. Federal, state, territory and local government legal and policy frameworks;

9. Potential share of total energy system mix;

We outline the failure of all jurisdictions at the Federal, State and Local government level to comply with the National Electricity Law (NEL) by not embarking on ultra-low emissions electricity production. As our results show this can only be provided on the NEM when nuclear generation is the dominant source. We outline how the current laws that prevent nuclear energy are in conflict with the NEL

From the Australian Energy Market Commission document "Emissions targets statement under the national energy laws" all states and territories are committed to "Net Zero by 2050" economy wide. This applies to transport, electricity generation, agriculture, waste handling, heavy and light industry and industrial processes.

It's easier to decarbonise the electricity sector than other sectors because:

- the sources of generation are stationary and
- we have the established transmission and distribution system in place that can feed ultra-low carbon energy to consumers and
- Successful International precedent exists

Electricity production must facilitate carbon reductions in other sectors such as:

1. Transport sector via battery charging or the production of zero carbon liquid fuels,
2. Industrial sector using hydrogen in processes such as steel making,
3. Industrial processes through the replacement of fossil fuels with electricity.

For example, given the difficulties in decarbonising the agricultural sector and many industrial processes, electricity production must be ultra-low carbon to minimise overhang from the other sectors.

That means that the electricity system must have an emissions intensity of less than 50 g-CO_2/kWh measured on a Life Cycle Analysis basis (LCA). LCA takes account of embodied emissions incurred through the mining, manufacturing processes and plant construction. Burned Fossil Fuel (BFF) analysis accounts only for CO_2 and other Green House Gases (GHG) arising from the combustion of fossil fuels

2.1 Achieving Ultra Low Emissions and Cost

In brief we compared six scenarios to determine the lowest cost ultra-low emissions scenario. The scenarios were:

1. A control which used an energy mix similar to that of the NEM in 2022,
2. A 100% renewable system which contains no fossil fuel backup,
3. The AEMO Step Change Scenario in 2050,
4. The AEMO Progressive Change Scenario in 2050,
5. Nuclear Integrated System Plan – 50% Nuclear,
6. Nuclear Integrated System Plan – 74% Nuclear,

Our analysis reveals that in the case of scenarios 2, 3 and 4, which rely heavily on wind and solar, very high levels of spillage and/or curtailment occur. In effect not all energy can be used leading to high costs due to low capacity factors, equipment redundancy and low utilisation of transmission.

The tool we used to carry out these comparisons was the Electric Power Consulting ty Ltd "Power System Generation Mix Model". An example of the application of the model is contained in the EPC modelling of the AEMO Draft 2024 ISP that was released in December 2023. This can be viewed at this link:

https://www.epc.com.au/wp-content/uploads/EPC-Submission-on-the-2024-Draft-ISP-20240216-Final.pdf

Emissions factors used for generators in the model are shown in "Table 1 Emissions Factors and Parameters used in Scenario Modelling".

Table 1 Emissions Factors and Parameters used in Scenario Modelling

Generator Type Description	Life Years	Carbon Fuel T/MWh	Carbon Embedded T/MW	Carbon Embedded Storage T/MWh
Pumped Storage	60	0	0	119
Solar PV Behind LV Meter	15	0	2,614.00	0
Solar PV	25	0	2,614.00	0
Wind	25	0	875.65	0
Open Cycle Gas	25	0.661	2.27	0
Hydro	60	0	0	119
Battery HV Storage	30	0	0	360
Battery LV Storage	15		0	600
Black Coal Existing	35	0.899	0	0
Combined Cycle Gas	35	0.426	2.27	0
Brown Coal Supercritical	35	1.203	0	0
Nuclear	60	0	2,680.00	0

The emissions factors used are measured in T/MW and T/MWh and some explanation is needed to for these units:

- For constructed plant or equipment the embodied carbon dioxide is reported as of tonnes per megawatt (T/MW). This fixed amount is disbursed over every unit of energy (MWh) that the plant and equipment produce over their service life.
- For fuel burned in a fossil fuelled plant the emissions are reported as tonnes of carbon dioxide produced from burning to produce a MWh of electrical energy, namely T/MWh.
- For constructed storages such as batteries or pumped hydro we also use tonnes of carbon dioxide per MWh (T/MWh) but in this case the unit relates to the construction and size of the storage which is measured in MWh. So for example, how many tonnes of carbon dioxide were produced to build the capacity of a battery or pumped storage facility to store a MWh of energy.

The value of 2,614 T/MW for solar PV has a significant impact on the overall emissions intensities calculated for each scenario, especially for high levels of "Renewables". It was obtained from recent analysis done by Seaver Wang of the Breakthrough Institute at this link:

Solar PV GHG calculation, head-to-head - Google Docs

The value of 2,614 T/MW was used to reflect the near total dominance of Chinese manufactured solar panels in the Australian market. Throughout the Chinese manufacturing process very high levels of electricity is generated using coal power.

For this report the costs of generators were obtained from the CSIRO GenCost report except for nuclear energy which used:

- A$10,000/kW overnight capital cost. Increased from GenCost value of $8,655/kW
- A$8.16/MWh fuel allowance in line with Nuclear Energy Institute values
- A$31 allowed for operations and maintenance in line with Nuclear Energy Institute values

The comparative cost and emissions performance of each scenario was modelled and is summarised in Figure 1

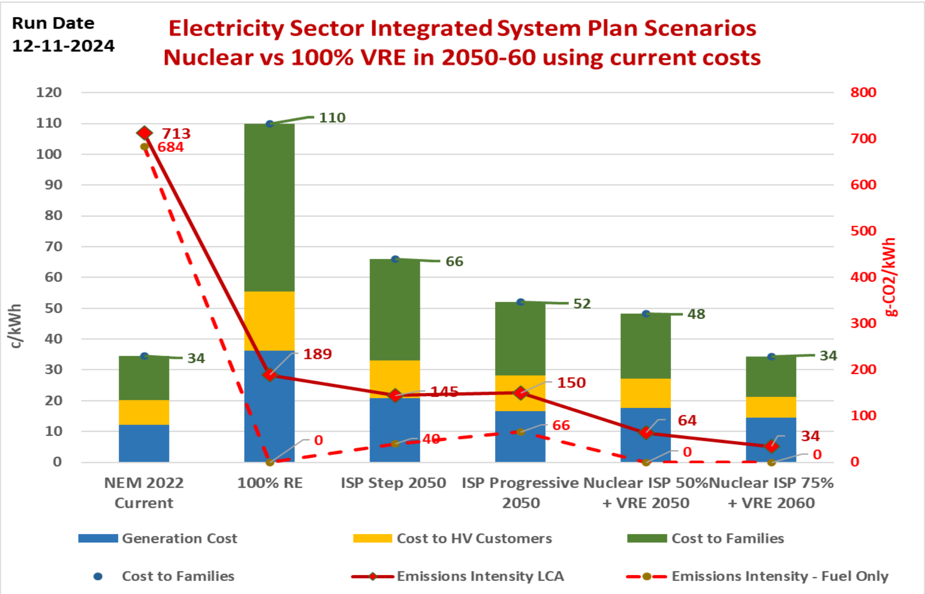


Figure 1 - Nuclear and Renewable Energy Scenarios

2.2 Explanation of Graph shown in Figure 1:

1. The left-hand axis shows electricity costs in c/kWh while the right-hand axis shows system emissions intensity in g-CO_2/kWh on a Life Cycle Analysis basis.
2. On each column blue represents cost of system generation, yellow represents extra cost for high voltage users getting energy from high and medium voltage transmission such as large industry and urban electric train systems.
3. Green represents the extra cost to distribute energy from the High Voltage transmission system through to low voltage users such as general industry, small business and residential users.
4. The dashed red line and data points are the emissions intensity derived from fossil fuel burning for each scenario. Burned Fossil Fuel (BFF) analysis
5. The continuous red line and data points are the total system emissions intensity using Life Cycle Analysis (LCA) for each scenario.

Of the low carbon options the two nuclear scenarios have the lowest system costs and only the 75% nuclear is ultra-low carbon. The 100% Renewable, Step Change and Progressive Change fail to achieve either low or ultra-low emissions and therefore do not provide a solution that meets the requirements of the National Electricity Law.

The reasons are shown in the following three images.

2.2 Step Change Scenario fails to achieve low emissions or low costs

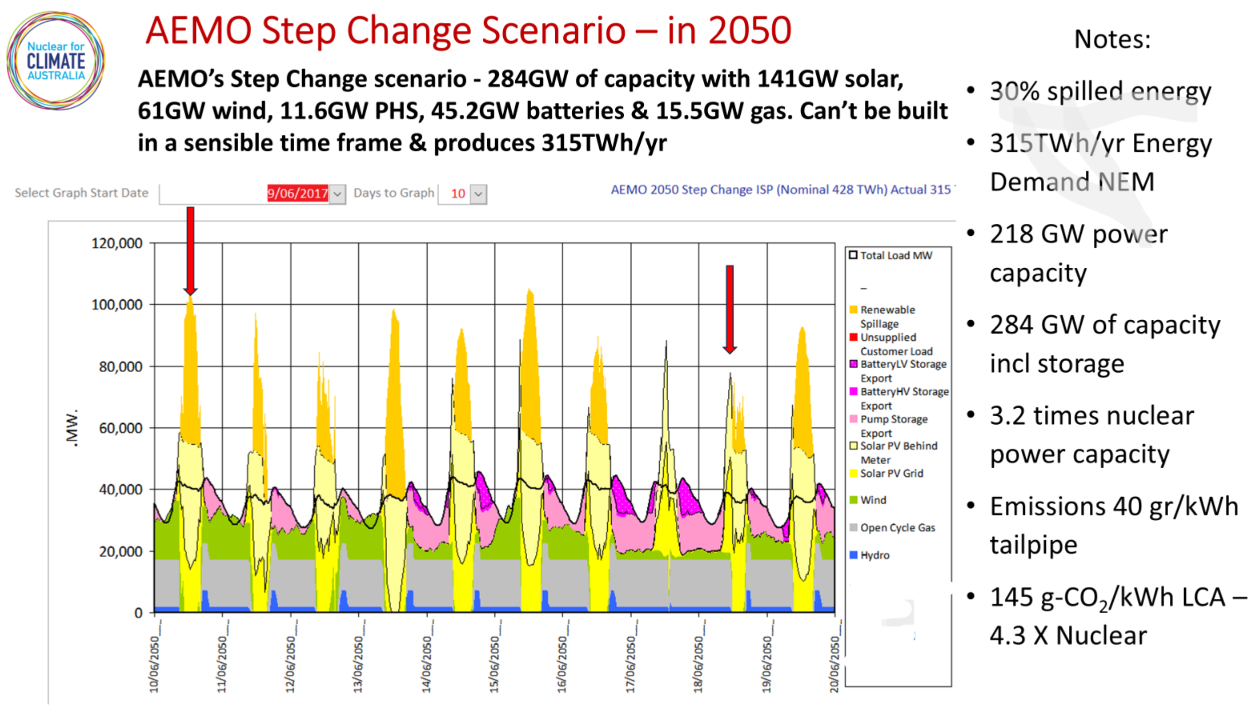


Figure 2 - Step Change Energy Graphic

Figure 2 - Step Change Energy Graphic shows a ten day period in a June month. The thick black wavey line represents the traditional NEM load pattern, dark blue represents hydro, grey is gas,

green is wind, pink represents battery and pumped storage and the two yellow tones represent roof top and grid solar PV. Orange above PV represents spillage/curtailment.

Under the red arrow on the right-hand side we have a day when the system meets load with no spillage because wind output is very low. Under the left-hand red arrow wind has returned, storage is minimised and spillage is very large. This demonstrates some of the fundamental reasons why wind and solar based systems fail both emissions and cost minimisation.

These are:

1. Large amounts of redundant generation and storage are required to cope with fluctuating wind and solar output. In effect we have a very large “overbuild”.
2. Collapse of capacity factors caused by redundancy drives up embodied emissions especially from installed solar PV and gas backup to around 145 g-CO_2/kWh. This is a mediocre emissions result and can’t be described as “low carbon”.
3. Expansion of the High and Medium Voltage transmission grid has inefficient levels of utilisation due to fluctuating outputs from Renewable Energy Zones. This drives up network costs.
4. Very high levels of installed battery and pumped storage have low capacity factors and very high costs and embodied emissions.
5. Spillage/curtailment of 30% of generation occurs with the Step Change scenario. AEMO claim its possible to reduce this impact by sophisticated load management and price inducements however its highly dependent on behavioural change and compromised industrial demand.

2.3 100% Wind, Solar and Hydro Scenario fails to achieve low emissions or low costs

A popular aim exists of achieving a 100% renewable decarbonised grid. In Figure 3 we show a 10 day period with 100% wind, solar and hydro. Gas backup is removed from the system which is now totally reliant on wind, solar and hydro.

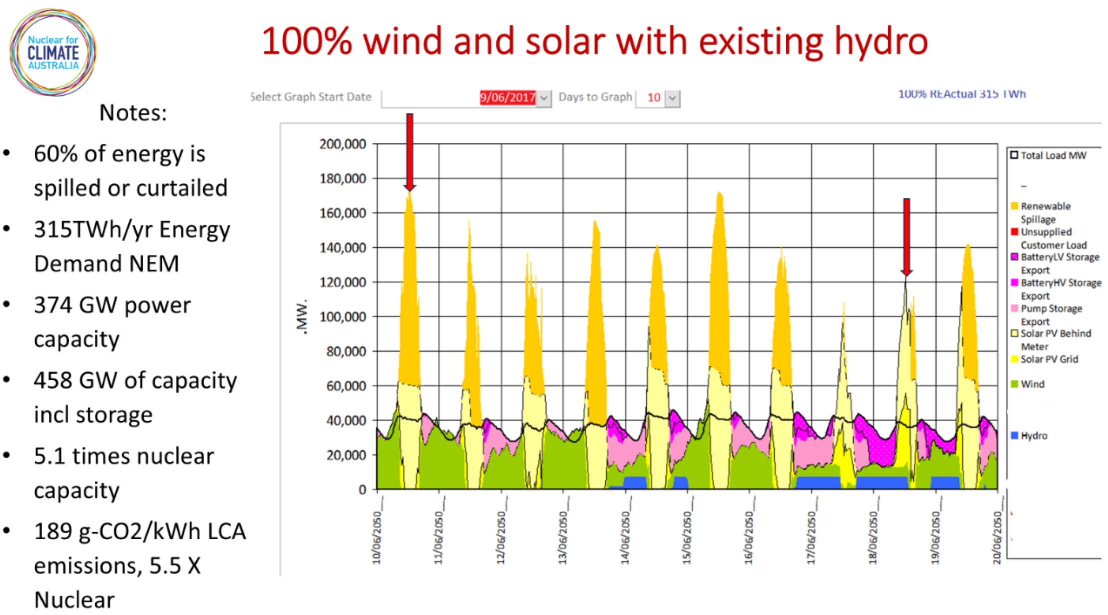


Figure 3 - 100% "Renewable Energy" Graphic

Costs rise massively due to very large increases in redundancy, storage, distribution and transmission. We now have 5.1 times more capacity connected to the grid compared to an equivalent nuclear scenario and 60% of energy is curtailed or spilled. With these huge amounts of connected generation and storage the emissions intensity remains stubbornly high at 189 g-CO_2/kWh on an LCA basis despite the removal of fossil fuel backup from the system.

In effect it is impossible to meet the requirements of the National Electricity Law (NEL) by relying on a system powered exclusively by wind, solar and hydro.

2.4 75% nuclear scenario with wind, solar and hydro achieve ultra-low emissions at economic costs

Reference is made to Figure 4 - 75% nuclear energy with wind, solar and hydro.

This scenario contains 33.5 GW of installed nuclear capacity operating at 81% capacity factor. Assumed NEM demand is 315 TWh per year compared to the current value of approximately 200TWh/year.

The costs of nuclear power plants used in this analysis are:

- A$10,000/kW overnight capital cost.
- A$8.16/MWh fuel allowance
- A$31 allowed for operations and maintenance
- 6% Annual Discount Rate,

For this example the calculated LCOE for nuclear energy is A$140/MWh at 81% capacity factor

Emissions on an LCA basis have dropped to 34 g-CO2/kWh. The retail cost to consumers is 34 c/kWh is ½ that of the Step Change Scenario and 1/3rd that of the 100% wind, solar and hydro option.

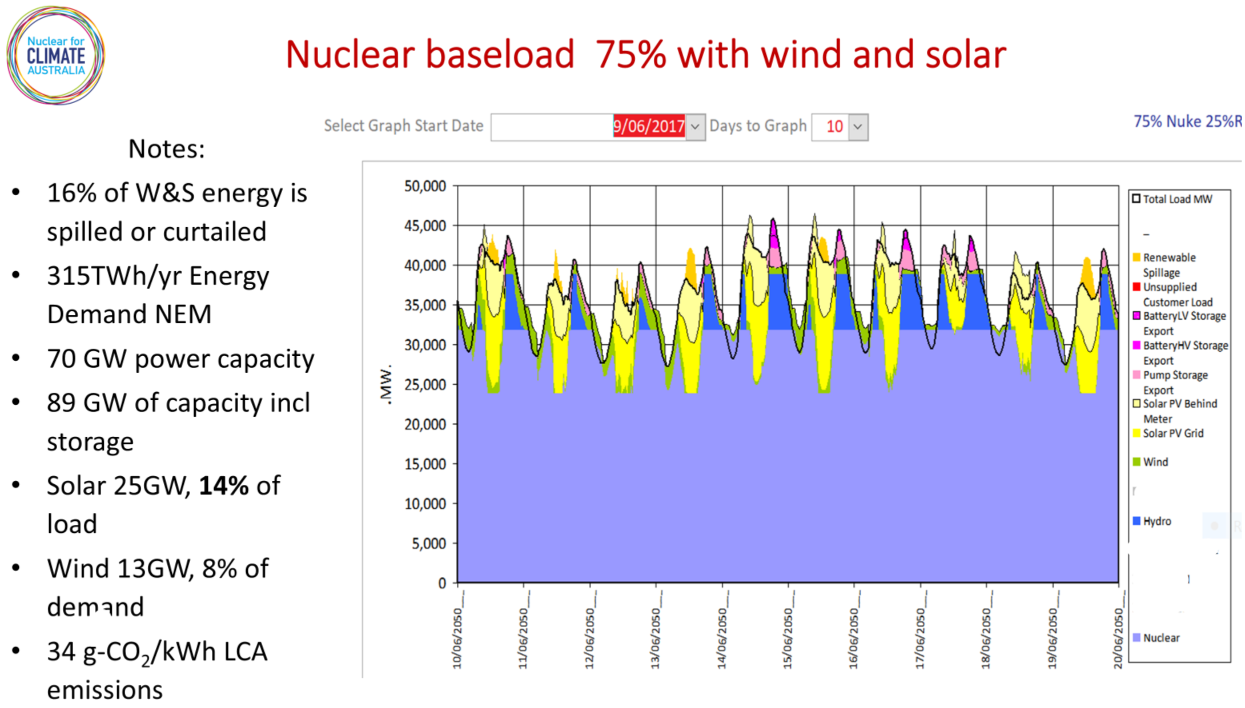


Figure 4 - 75% nuclear energy with wind, solar and hydro

2.5 Conclusions from Section 2

1 Federal, State, Territory and local government legal and policy frameworks requiring decarbonisation with 100% reliance on wind, solar and hydro will not provide a decarbonised grid capable of achieving "Net Zero" emissions. They do not meet the requirements of the National Electricity Law (NEL).

2 A grid powered predominantly by nuclear energy will meet the requirements of the NEL. This law is however in conflict with laws that prevent nuclear energy in Australia such as the Australian Radiation Protection and Nuclear Safety (ARPANS) Act and the Environmental Protection and Biodiversity Conservation (EPBC) Acts. The anti nuclear provisions of both these acts put them in direct conflict with "Net Zero" environmental ambitions.

3 To achieve an ultra low emissions grid, on an LCA basis, requires the amount of nuclear energy generation to exceed about 60% of total generation. Further increases in nuclear energy generation beyond this amount up to around 80% continues to reduce overall grid supply costs.

3 A Nuclear Plan for the NEM

In this section we address the deployment time frame for nuclear energy on the NEM.

A proposed timeline for the roll out of a nuclear energy plan is shown in Figure 5 - A Nuclear Energy Transition for the NEM. The assumed NEM load in 2050 is 260 TWh/yr and in 2060 is 300 TWh/yr. This approximates to the AEMO Progressive Change Scenario and is based on anticipated population growth plus electrification of our motor vehicle fleet and increased industrial electrification.

Relevant parameters are:

1. Roll out is completed in 2060 with 30 GW of installed nuclear capacity using AP1000 large plants and i-SMR small plants. Other options such as APR1400 and BWRX 300 could also be used.
2. Plants operate at 79% capacity factor in 2060.
3. Installed wind is 18.4GW, Grid solar – 8.8 GW and roof top solar is 26.3GW. This is similar to current levels.
4. Emissions intensity in 2060 on an LCA basis is 41 g CO_2/kWh & cost to consumers is 38.5 c/kWh
5. Emissions in 2050 are 48 gr CO_2/kWh (LCA), 3 gr CO2/kWh Burned Fossil Fuel (BFF) or about 1/3rd that of the Step Change Scenario in the same year.
6. The nuclear scenario removes all fossil fuel plants more quickly than both AEMO's Step Change and Progressive Change Scenarios. Coal plants stop in 2049 while in the AEMO Progressive Change they remain in place at 1.5GW together with 15.5 GW of Open Cycle gas. Step Change still has 24.8 GW of gas in 2050.
7. Gas consumption is minimised to prevent the construction of stranded assets and minimise electricity costs.

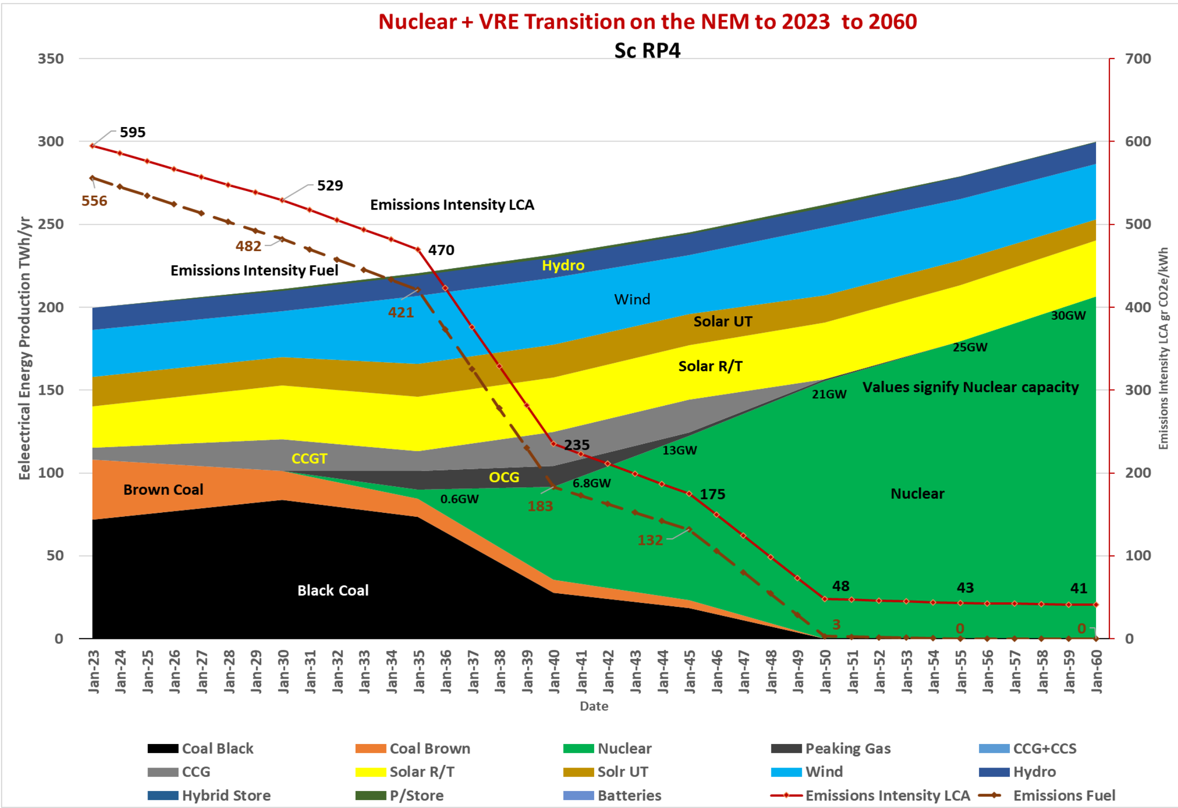


Figure 5 - A Nuclear Energy Transition for the NEM

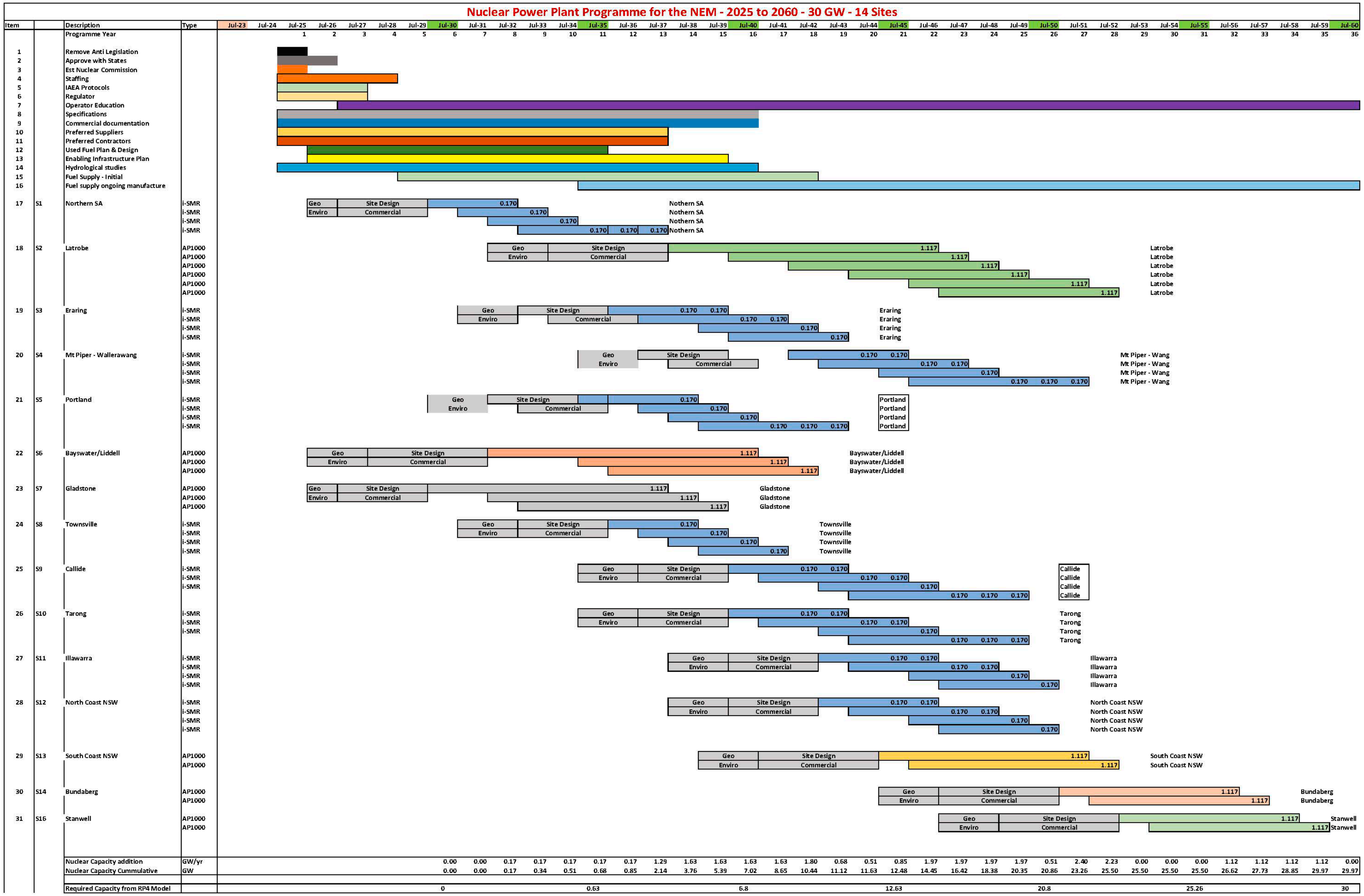


Figure 6 - Bar Chart showing locations, plant sizes and deployment time frames for 30GW of Nuclear Power plants on the NEM

Claims that nuclear "takes too long" and "we have no time to wait" are without foundation. The speed of deployment of our prosed nuclear scheme is shown in Figure 6. Seven of the ten fastest non-hydro deployments are all nuclear.

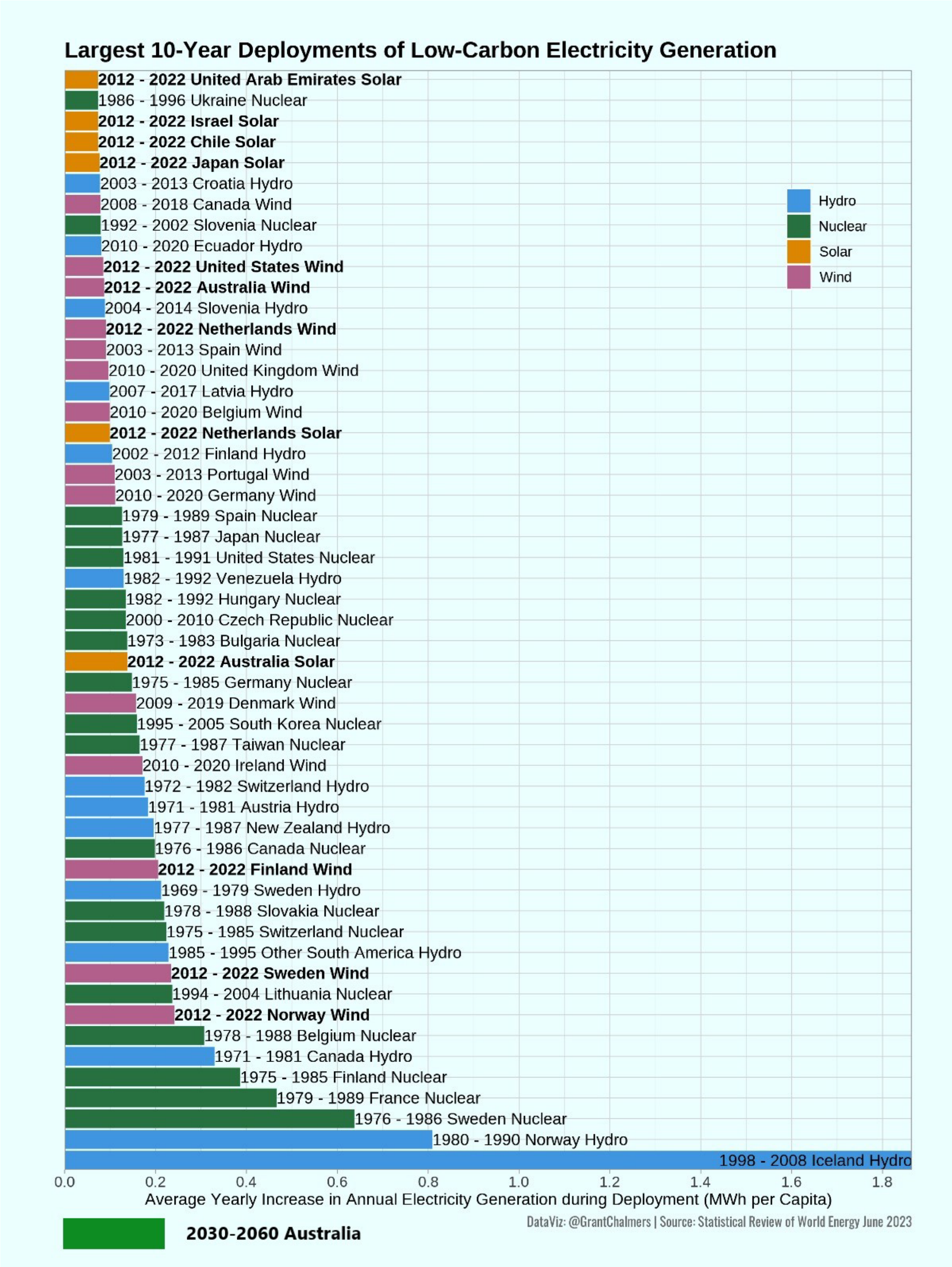


Figure 7 - Proposed Australian Low Carbon deploymenst compared to International precedent

A real world example of the low carbon success of nuclear energy happens every day with the comparison of French electricity emissions with its neighbour in Germany shown in Figure 8 German vs French Electricity sector Emissions.

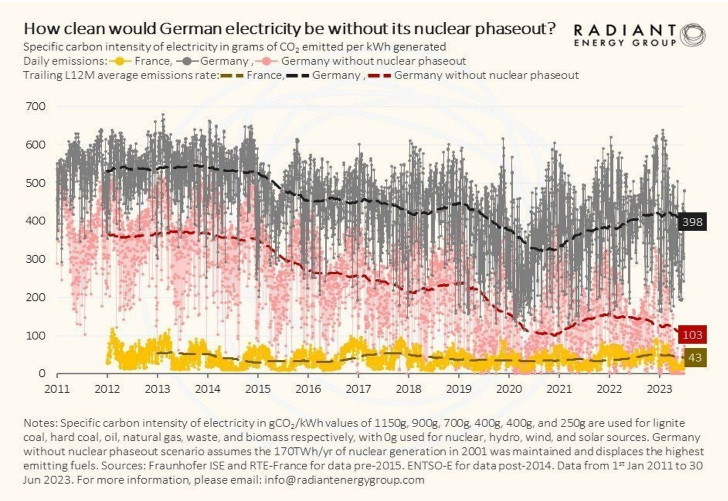


Figure 8 German vs French Electricity sector Emissions

Conclusions from Section 3

1 A proposed timeline for the roll out of a nuclear energy plan is shown in Figure 5 - A Nuclear Energy Transition for the NEM. The assumed NEM load in 2050 is 260 TWh/yr and in 2060 is 300 TWh/yr.

2 Installed Nuclear capacity is 21GW in 2050 and 30GW in 2060

3 Emissions in 2050 are 48 gr CO2/kWh (LCA). 3 gr CO2/kWh Burned Fossil Fuel (BFF) or about 1/3rd that of the Step Change Scenario in the same year.

4 The nuclear scenario removes all fossil fuel plants more quickly than both AEMO's Step Change and Progressive Change Scenarios. Coal plants stop in 2049 while in the AEMO Progressive Change they remain in place at 1.5GW together with 15.5 GW of Open Cycle gas. Step Change still has 24.8 GW of gas in 2050.

3 Claims that nuclear "takes too long" and "we have no time to wait" are without foundation. The speed of deployment of our prosed nuclear scheme is shown in Figure 6 is 1/3rd that of the Swedish Programme and ½ that of the French. It has quite modest and achievable targets.

4 A real world example of the low carbon success of nuclear energy happens every day with the comparison of French electricity emissions with its neighbour in Germany shown in Figure 7 German vs French Electricity sector Emissions. No nation has ever achieved ultra low emissions low cost electricity by relying exclusively on wind and solar. Germany has driven itself into recession on the back of its closing of 17GW of ultra low carbon nuclear power plants.

4 Materials Consumption is minimised with nuclear energy.

In this section we deal with the highly important issue of materials consumption and sustainability:

13. any other relevant matter.

The energy transition was intended to herald a more sustainable future however attempting to achieve this with wind and solar will only result in a massive increase in materials consumption. These materials will litter the landscape and their end of life retrieval is neither certain nor affordable.

We have compared the materials use of two scenarios each producing 315TWh/yr over an 80 year life in Table 2 - Materials used in Nuclear Energy system vs 100% wind and solar. That period was chosen because it can be expected that modern nuclear power plants such as the AP1000 will last for 80 years while wind generators will last for 30 years and solar PV for 25 years.

To arrive at these values in Table 2 we used recent data from the "Updated Mining Footprints and Raw Material Needs for Clean Energy - Challenges and opportunities for managing energy transition mining impacts" by Wang, Cook, Stein, Lloyd and Smith of the Breakthrough Institute. Its available at this link:

https://thebreakthrough.org/issues/energy/updated-mining-footprints-and-raw-material-needs-for-clean-energy

We then applied the materials used in wind, solar, nuclear and batteries to the amount of generating and storage capacity used in a 100% "Renewables" scheme on the NEM to a comparable Nuclear Energy scheme. We used the amount of equipment required in the comparison from values obtained in scenarios modelled by Nuclear For Climate Australia and Electric Power Consulting

Advocates for wind and solar frequently claim that components from these "Renewable" schemes are recyclable. This potential is limited by the energy and cost inputs required to recycle these components especially where:

a) they are located far from their place of manufacture and;
b) the costs of recovery are incurred in economies that have higher labour and equipment inputs than the place of extraction, refining and manufacture.

Nevertheless the degree to which recycling can occur was handled by looking at both the initial materials load for each system with the subsequent rebuild. Even if 100% of the Wind and Solar system could be recycled its initial materials load of 191 Million tonnes is 5.1 times that of the nuclear system with 37 million tonnes.

At the end of the day, materials consumption in manufactured items is a good proxy for comparative costs. This reinforces our finding that a nuclear energy based system is ½ to 1/3rd the cost of a "Renewables" system. Given the large amounts of materials used with wind and solar it begs the question – What Does Renewable Mean?

Table 2 - Materials used in Nuclear Energy system vs 100% wind and solar

Description	Capacity GW	T Millions of tonnes used	Materials Multiple
100% RE at 80 yr	**431.4**	**380**	**380/62 = 6.2 times nuclear at 80 years assuming no recycling**
100% RE Initial	**431.4**	**191**	**191/37 = 5.1 times nuclear for Initial buildout**
Nuke Option 80yr	99.2	**62**	1.0 Nuclear build out with RE components renewed
Nuke Option Initial	99.2	37	1.0 Initial nuclear + RE components

In Figure 9 shown next, the brown columns show the initial materials load of a 100% RE system and orange above brown shows the contested amount that possibly could be recycled to some degree. Likewise the dark and light green show the ranges for the nuclear system.

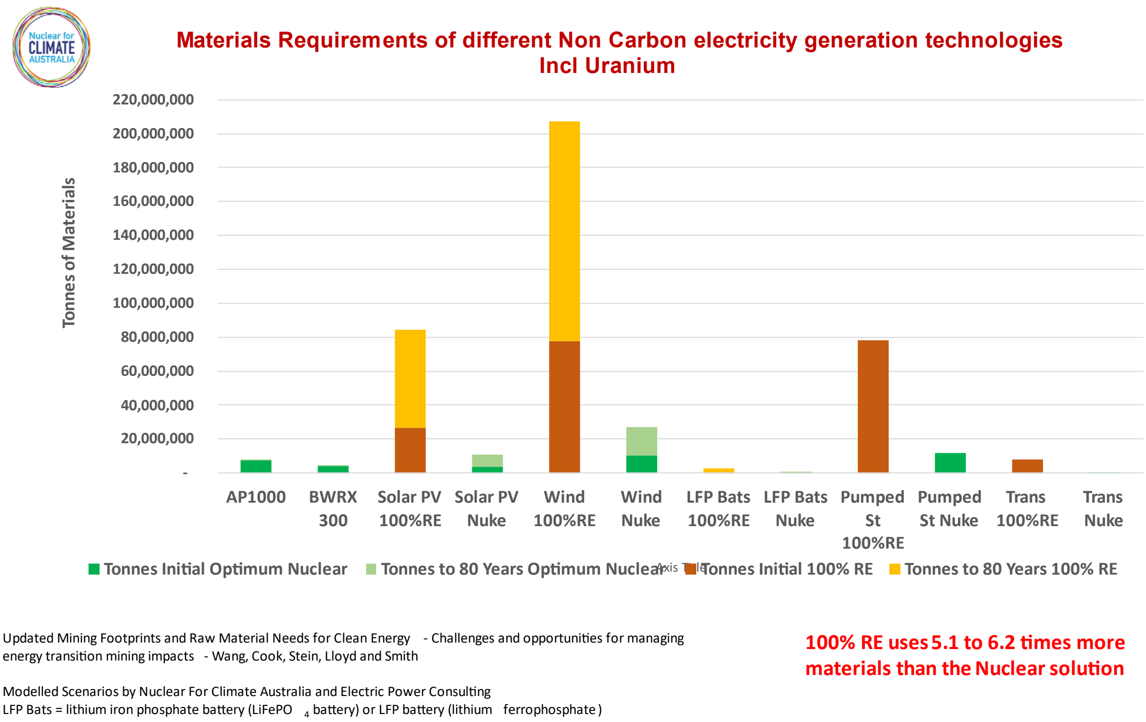


Figure 9 Comparison of materials used in 100% wind and solar scheme with a nuclear dominated scheme

Conclusions from Section 4

1 The energy transition was intended to herald a more sustainable future however attempting to achieve this with wind and solar will only result in a massive increase in materials consumption. These materials will litter the landscape and their end of life retrieval is neither certain nor affordable.

2 **Table 3 - Materials used in Nuclear Energy system vs 100% wind and solar**

Description	Capacity GW	T Millions of tonnes used	Materials Multiple
100% RE at 80 yr	**431.4**	**380**	**380/62 = 6.2 times nuclear at 80 years assuming no recycling**
100% RE Initial	**431.4**	**191**	**191/37 = 5.1 times nuclear for Initial buildout**
Nuke Option 80yr	99.2	**62**	1.0 Nuclear build out with RE components renewed
Nuke Option Initial	99.2	37	1.0 Initial nuclear + RE components

3 A 100% "Renewable" system uses between 5.1 and 6.2 times more materials over and 80 year period than a nuclear based system.

4. If the term "Renewable" is to mean anything at all it is best reserved for nuclear energy

5 Cooling Water Demand

Nuclear power plants have greater flexibility in location than coal-fired plants due to fuel logistics. This reduces their potential to compete for valuable water resources.

Nuclear power plants use water for cooling for two purposes:

- To convey heat from the reactor core to the steam turbines.
- To remove and dump surplus heat from this steam circuit.

For nuclear or coal plants, the larger the temperature difference between the internal heat source and the external environment where the surplus heat is dumped, the more efficiently the plant operates, This means its best to site power plants alongside very cold water. Coastal locations are excellent.

5.1 Steam cycle heat transfer

For the purpose of heat transfer from the reactor core, the water is circulated continuously in a closed loop steam cycle and hardly any is lost. It is turned to steam by the reactor in order to drive the turbine to make electricity, and it is then condensed and retuned under pressure to the reactor in a closed system. A very small amount of make-up water is required in any such system. The water needs to be clean and pure.

5.2 Cooling to condense the steam and discharge surplus heat

The second function for water is to cool the system to condense the low-pressure steam and recycle it. As the steam is condensed back to water, the surplus (waste) heat needs to be discharged to the air or to a body of water. This is a major consideration in siting power plants, and in the UK siting study in 2009 for nuclear plants all recommendations were for sites within 2 km of abundant water – sea or estuary.

This cooling function to condense the steam may be done in one of three ways:

1. Direct or "once-through" cooling.
2. Recirculating or indirect cooling.
3. Dry cooling which is not considered to be a viable option for the current types of nuclear power plants.

Due to the heat loss through combustion gases in the stack, simple-cycle coal plants have a lower heat rejection load through the condenser and cooling system than simple-cycle nuclear plants. However, they also have water needs for scrubbing and coal ash handling, which reduces the difference between water needs for nuclear and coal-fired plants. The basic difference, estimated by the US Electric Power Research Institute (EPRI) as typically 15-25%, is not significant enough to be a factor in making a selection between nuclear and coal.

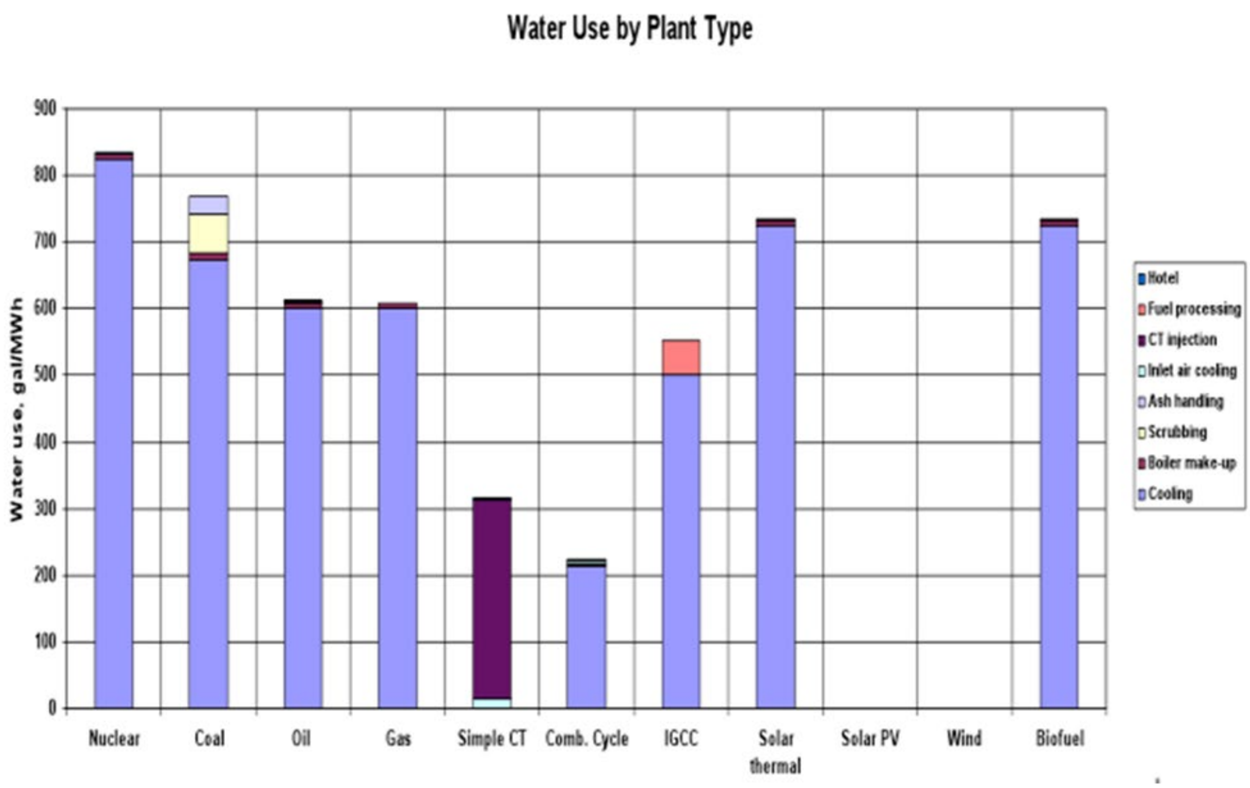


Figure 10 - EPRI study, 2010 NB US gal = 3.79 litres

5.3 Lifecycle Water Requirements of all generators

The united Nations Economic Commission for Europe examined the Life Cycle water use of all generators as shown in Figure 11. This shows that nuclear energy uses similar or slightly less water than coal generators such as pulverised and supercritical coal plants. The use of CCS with fossil fuel plants drives up their water demand substantially. Base water demand for nuclear is 2.4 M^3/MWh.

Figure 44 **Lifecycle water requirement regional variations for year 2020. Variability is explained by several factors: electricity mix (all regions), methane leakage rates (fossil fuels), load factors (renewables). Nuclear power is modelled as a global average except for back-end.**

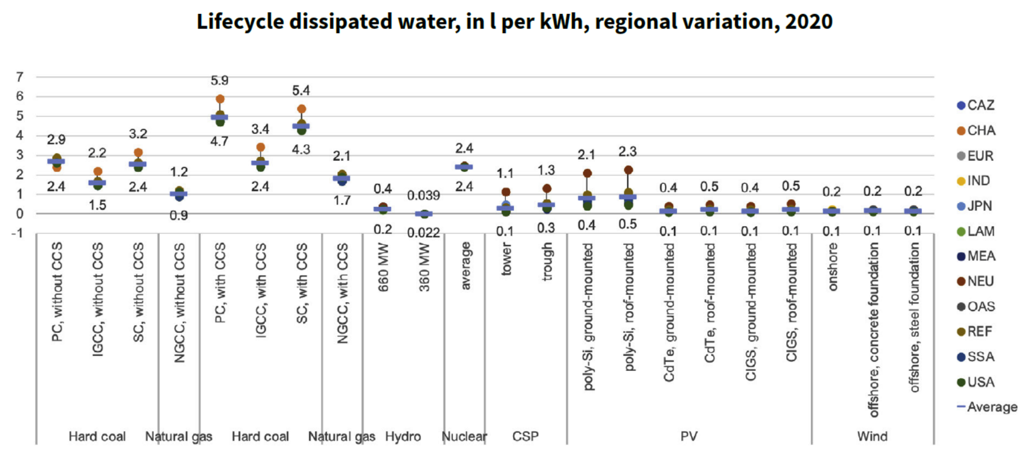


Figure 11 Life Cycle Dissipated Waer use from UNECE Report

5.4 Direct or once-through wet cooling

If a coal or nuclear plant is next to a large volume of water (big river, lake or sea), cooling can be achieved by simply running water through the plant and discharging it at a slightly higher temperature. There is then hardly any consumption or depletion on site, though some evaporation will occur as it cools downstream. The amount of water required will be greater than with the recirculating set-up, but the water is withdrawn and returned, not consumed by evaporation. In the UK the water withdrawal requirement for a 1600 MWe nuclear unit is about 90 cubic metres per second (7.8 GL/d).

Many nuclear power plants have once-through cooling (OTC), since their location is not at all determined by the source of the fuel, and depends first on where the power is needed and secondly on water availability for cooling. Using seawater means that higher-grade materials must be used to prevent corrosion, but cooling is often more efficient. In a 2008 French government study, siting an EPR on a river instead of the coast would decrease its output by 0.9% and increase the kWh cost by 3%.

Any nuclear or coal-fired plant that is normally cooled by drawing water from a river or lake will have limits imposed on the temperature of the returned water (typically 30°C) and/or on the temperature differential between inlet and discharge.

5.5 Recirculating or indirect wet cooling

Where a power plant does not have abundant water, it can discharge surplus heat to the air using recirculating water systems which uses the physics of evaporation.

Cooling towers with recirculating water are a common visual feature of power plants, often seen with condensed water vapour plumes. Sometimes it is possible to use simply a pond, from which hot water evaporates.

Most nuclear power (and other thermal) plants with recirculating cooling are cooled by water in a condenser circuit with the hot water then going to a cooling tower. This may use either natural draft (chimney effect) or mechanical draft using large fans (enabling a much lower profile but using power). The cooling in the tower is by transferring the water's heat to the air, both directly and through evaporation of some of the water. In the UK the water requirement for a 1600 MWe nuclear unit is about 2 cubic metres per second (173 ML/d), this being about half for evaporation and half for blow-down.

Figure 12 - Chinon B France with low profile forced draft cooling towers

Credit: EDF/Marc Mourceau

Cooling towers consume water, with up to $3m^3$ being evaporated for each Megawatt hour (MWh) produced.

Cooling towers with recirculating water reduce the overall efficiency of a power plant by 2-5% compared with once-through use of water from sea, lake or large stream, the amount depending on local conditions.

Water evaporating from the cooling tower increases the concentration of impurities in the remaining coolant. Some bleed – known as "blowdown" – is needed to maintain water quality, especially if the water is recycled municipal wastewater to start with - as Palo Verde, Arizona. Here some 220 ML/day of treated sewage is pumped 70 km from Phoenix, Arizona to the 3-unit 3,875 MWe plant. Evaporation is 76 ML/day per unit, and blowdown 4.7 ML/day at a salinity approx. that of seawater, discharged to evaporation ponds, hence about 2.6 L/kWh is used. It has three mechanical-draft cooling towers for each unit.

Even with the relatively low net water requirement for recirculating cooling, large power plants can exceed what is readily available from a river in summer. The 3,000 MWe Civaux nuclear plant in France has 20 GL of water stored in dams upstream to ensure adequate supply through drought conditions.

A few nuclear plants employ cooling ponds, which are another type of closed-cycle cooling that reduce the evaporative losses associated with cooling towers. A cooling pond has the advantage of transferring a larger percentage of waste heat to the atmosphere via convection or slower evaporation due to lower differential temperatures, reducing the rate of evaporation and thus the rate of water loss relative to cooling towers. Also their environmental impacts are typically less than direct cooling. This would be a very suitable option for nuclear power plants located in the Latrobe Valley where the disused coal pits would create suitable cooling ponds. It can also continue to be used a Liddell Power station using Lake Liddell.

Despite many coal and nuclear plants using wet cooling towers, in the USA electric power generation accounts for only about 3% of all freshwater consumption, according to the US Geological Survey - some 15.2 gigalitres per day (5,550 GL/yr). This would be simply for inland coal and nuclear plants without access to abundant water for once-through cooling. Australian coal-fired power plants consume about 400 GL/yr – the equivalent of Melbourne's water supply.

5.5 Environmental and social aspects of cooling

Each of the different methods of cooling have their own set of local environmental and social impacts and is subject to regulation.

In the case of direct cooling, impacts include the amount of water withdrawn and the effects upon organisms in the aquatic environment, particularly fish and crustaceans.

In the case of wet cooling towers, impacts include water consumption and the effects of the visual plume of vapour emitted from the cooling tower.

Over time, knowledge of these effects has increased, impacts have been quantified and solutions developed. Technical solutions (such as fish screens and plume eliminators) can effectively mitigate many of these impacts but at an associated cost that scales with complexity.

In a nuclear plant, beyond some minor chlorination, the cooling water is not polluted by use – it is never in contact with the nuclear part of the plant but only cools the condenser in the turbine hall.

On the policy side, one US DOE report notes that a major effect of the US Clean Water Act is to regulate the impact of cooling water use on aquatic life, and this is already driving the choice towards recirculating systems over once-through ones for freshwater. This will disadvantage nuclear over supercritical coal, though flue gas desulfurization (FGD) demands for coal will even out the water balance at least to some extent, and any future carbon capture and storage (CCS) will further disadvantage coal.

In France, all but four of EdF's nuclear power plants (14 reactors) are inland, and require fresh water for cooling. Eleven of the 15 inland plants (32 reactors) have cooling towers, using evaporative cooling, the other four (12 reactors) use river or lake water directly. With regulatory constraints on the temperature increase in receiving waters, this means that in very hot summers generation output may be reduced. For instance at Bugey, the maximum increase in water temperature in summer is 7.5ºC normally, and 5.5ºC in summer, with maximum discharge temperature 30ºC (34ºC in summer) and maximum downstream temperature 24ºC (26ºC allowed for up to 35 summer days). For plants using direct cooling from the sea, the allowed temperature increase offshore is 15ºC.

In the USA plants using direct cooling from rivers must reduce power in hot weather. TVA's three Browns Ferry units operate at 50% while river temperature is over 32°C.

With one exception, all nuclear power plants in the UK are located on the coast and use direct cooling. In the UK siting study of 2009 for nuclear new build, all recommendations were for sites within 2 km of abundant water – sea or estuary.

5.6 Future implications of cooling requirements for nuclear power in Australia

Fresh water is a valuable resource in most parts of the world. Where it is at all scarce, public opinion supports government policies, supported by common sense, to minimise the waste of it.

Existing coal plant sites can be retrofitted with nuclear generators to take advantage of existing cooling resources and grid connections. These opportunities are limited and there is no reason to site nuclear power plants away from the coast, where they can use once-through seawater cooling and are generally closer to load centres. Coal plant locations need to be near their fuel supply with over three million tonnes of coal being required per year for each 1000 MWe plant.

"Water consumption by nuclear plants is significant, but only slightly higher than water consumption by coal plants. Nuclear plants operate at a relatively lower steam temperature and pressure, and thus lower cycle efficiency, which in turn requires higher cooling water flow-rates. Coal plants, with higher efficiency, can be cooled with slightly less water" per unit of output, but the difference is small.*

* Cooling Water Issues and Opportunities at US Nuclear Power Plants, Oct 2010, INL/EXT-10-2028.

Generation III+ nuclear plants have higher thermal efficiency relative to older ones, and should not be disadvantaged relative to coal by water use considerations.

Considerations of limiting greenhouse gas emissions will, of course, be superimposed upon the above. US DOE figures show that CO_2 capture will add 50-90% to water use in coal and gas-fired plants, making the former more water-intensive than nuclear.

A further implication relates to cogeneration, using the waste heat from a nuclear plant on a coastline for desalination. A lot of desalination in the Middle East and North Africa already uses waste heat from oil- and gas-fired power plants, and in future a number of countries are expecting to use nuclear power for this cogeneration role.

Conclusions from Section 5 - Cooling

1 For nuclear or coal plants, the bigger the temperature difference between the internal heat source and the external environment where the surplus heat is dumped, the more efficiently the plant operates, <u>This means its best to site power plants alongside very cold water. Coastal locations are excellent.</u>

2 The latest research from the United Nations Economic Commissions for Europe indicates that nuclear plants use similar or slightly less water than coal plants. Data from the USA indicate sthey use a bit more water for cooling than coal plants. The basic difference, estimated by the US Electric Power Research Institute (EPRI) as typically 15-25%, is not significant enough to be a factor in making a selection between nuclear and coal.

3 Nuclear plants can also employ cooling ponds, which are another type of closed-cycle cooling that reduce the evaporative losses associated with cooling towers. A cooling pond has the advantage of transferring a larger percentage of waste heat to the atmosphere via convection or slower evaporation due to lower differential temperatures, reducing the rate of evaporation and thus the rate of water loss relative to cooling towers. Also their environmental impacts are typically less than direct cooling.

4. Cooling ponds would be a very suitable option for nuclear power plants located in the Latrobe Valley where the disused coal pits would create suitable cooling ponds. It can also continue to be used a Liddell Power station using Lake Liddell and needs to be investigated for other coal plant sites where open cut coal pits have created large potential reservoirs.

6. Natural Disaster Risk

6.1 Earthquakes

Recent tremors in the Upper Hunter near Singleton created a flurry of ill-informed comment about the dangers of earthquakes to the safe operation of nuclear power plants in Australia.

Nuclear plants are designed to shut down for operational reasons when ground vibration exceeds a certain level – generally 0.3g where "g" is the gravitational constant of 9.8m/sec^2. In essence, the ground acceleration from earthquakes in Australia including the 1989 Newcastle earthquake is not high enough to shut a plant down let alone cause any structural damage. The level at which any actual structural damage occurs is much higher and nuclear plants in seismically active regions in Asia are typically exposed to earthquakes of around 7 in the Richter scale without significant damage.

Recently Nuclear For Climate Australia participated in hosting a nuclear energy information evening in Morwell in the Latrobe Valley. In preparation we spoke with Professor Andrew Whittaker who is a distinguished expert on seismicity and nuclear power plants in the United States.

In Figure 13 Comment From Professor Andrew Whittaker notes that:

Latrobe Valley poses no siting problem for AP1000 and advanced reactors: earthquakes, floods, bushfires, extreme winds

Expectation is safe construction and operation of nuclear power plants, even under very rare, extreme natural hazards Identical to operating plants in the US.

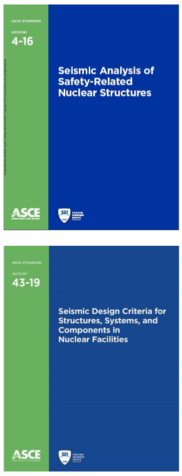
He also notes that:

Seismicity in Australia is similar to that in Central and Eastern United States: far from plate boundaries

> *In CEUS, 87 operating reactors at 51 sites in 25 states*
>
> *AP1000 units, Vogtle 3 and 4, new additions to the US operating fleet*

We note that the same stability applies to any nuclear power plant constructed in Australia. The country is seismically stable. Prudent measures would be taken in siting plants to avoid close proximity to fault lines such as those shown in Figure 14 Fault features in the Gippsland Region

Earthquakes and nuclear power plants



Technical reference on nuclear civil structures
- **Andrew Whittaker, PhD, S.E., F.ASCE, F.SEI, F.ACI, M.ANS**
- **SUNY Distinguished Professor, Department of Civil Engineering, University at Buffalo**
- **Chair, ASCE Nuclear Standards Committee, 2015– present**
- **Member, White House Working Group, Nuclear Deployment and Project Delivery**

Whittaker education
- **B.S., Civil Engineering, University of Melbourne, 1977**
- **M.S., Civil Engineering, University of California, Berkeley, 1985**
- **Ph.D., Civil Engineering, University of California, Berkeley, 1988**

ASCE Nuclear Standards Committee
- **Writes ASCE standards for NRC- and DOE-regulated nuclear structures**
- **ASCE 4-16, ASCE 43-19**

Seismicity in Australia is similar to that in Central and Eastern United States: far from plate boundaries
- **In CEUS, 87 operating reactors at 51 sites in 25 states**
- **AP1000 units, Vogtle 3 and 4, new additions to the US operating fleet**

Standard US and international practice
Probabilistic seismic hazard assessment (PSHA) to determine earthquake shaking used for design
Geotechnical investigations to characterize site conditions and support, trenching across faults to characterize history
If AP1000 in the Latrobe Valley, ground shaking with return period (RP) of 50,000 years used for design, no damage accepted. Contrast with other infrastructure, RP = 500 years and significant damage accepted

Latrobe Valley poses no siting problem for AP1000 and advanced reactors: earthquakes, floods, bushfires, extreme winds
Expectation is safe construction and operation of nuclear power plants, even under very rare, extreme natural hazards
Identical to operating plants in the US

Figure 13 Comment From Professor Andrew Whittaker

Folds, kinks and warp features in Gippsland region

Neotectonic Features

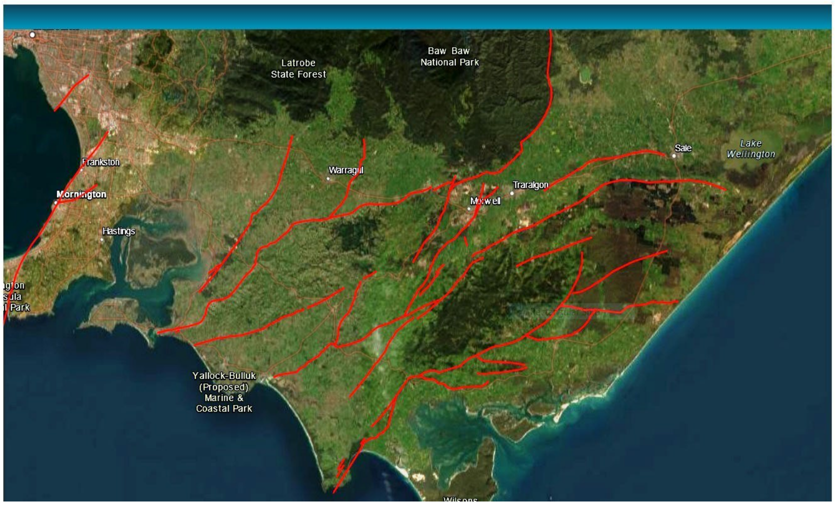


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Figure 14 Fault features in the Gippsland Region

7 Conclusion

The National Electricity Objective as stated in the National Electricity Law (NEL) cannot be met unless a system based on high levels of nuclear energy is deployed. The NEL is in direct conflict with the laws preventing nuclear energy production contained in the ARPANS and EPBC Acts

Systems based exclusively on wind, solar and hydro cannot achieve deep decarbonisation in order to conform with jurisdictions aiming for “Net Zero”.

As reported in The Australian on 13th November 2024, Australian Energy Market Operator chief executive Daniel Westerman says natural gas will be the “ultimate backstop” for keeping the lights on because weather-dependent generators can’t deliver consistent power. He stated gas would be essential to ensure the reliability of the eastern grid to 2050 and beyond, as the cost of trying to cover long periods of low wind and solar generation without it would be prohibitive.

Westerman has stated that “We will have batteries, we’ll have pumped hydro, but we’ll have times, like we’ve seen earlier this year, where there’s not much wind and there’s not much sun, and the gas-fired power stations are really required to back up the reliability of the grid. They’re there as the ultimate backstop.”

This failure of wind and solar to power our grid economically and achieve ultra low emissions is due to:

- high levels of embodied carbon,
- high random variability of weather patterns,
- the collapse in capacity factors when wind and solar have high penetration rates on the grid.
- requirement for the continued backup of the “renewable” energy plants with fossil fuels.

These conclusions are supported by the very large amounts of material required to deploy wind and solar which are four to five times greater than required by a nuclear based system.

It is entirely feasible and accords with precedent that the NEM can achieve true ultra low emissions electricity at a cost of about ½ that of a system reliant on wind, solar, hydro and gas backup. Such a nuclear energy system would contain 21 GW of nuclear energy plants built by 2050 and total 30GW by 2030. The plants would be located at 14 sites within Queensland, New South Wales, Victoria and South Australia.