SUBMISSION TO AEMO

Re: CSIRO 2023-2024 GenCost Report

Consultation Draft - December 2023.

Author: Roderick J. Sinclair (BEChem, MEngSci, PhD) as a private individual
5 Eagleview Walk, Doncaster, VIC 3108

Purpose and Scope

It is understood that the purpose of the GenCost Report is to provide cost data for use in developing a plan for the transition and eventual change of electricity generation away from the use of fossil fuels. It is also understood that the configuration of future electricity generation facilities is covered by the AEMO Integrated System Plan and the Optimal Development Path within that plan.

General Objectives and Approach to NZE.

The ultimate objective of the integrated system plan must be to develop an optimum mix of electrical energy generating facilities with zero carbon emissions that will give the lowest overall cost in meeting the expected future energy demand. This may be predominantly from renewable energy sources as appears to be current government policy or can include dispatchable power generation where this has no carbon emissions and includes nuclear or fossil fuel-based generation with carbon capture and storage (CCS).

It is suggested that it is important to define the final integrated system or variations thereof at the outset and then develop the best pathway to reach that end goal from the present energy mix. In that way the additions made to the system during the transition as replacements for closure of fossil fuel generators will be compatible with the final goal. This does not appear to be the approach taken by the present report which focuses more on the progressive changes to the system without a clearly defined longer-term position in view.

One aspect which can be affected by the approach taken is the requirement for energy storage. As long as older coal fired generators are operating, storage requirements need only be of minimal capacity to accommodate the variability of renewable energy generation. This immediate situation will give a false sense of the overall cost of renewables and perhaps lead to unnecessarily high future power costs. (See comments on storage).

The optimum final mix will contain a range of energy generating and storage technologies which will complement each other to provide the lowest overall cost. Each of these technologies has different characteristics and are not necessarily in competition. In this regard direct comparison of separate generating costs or Levelized Cost of Electricity (LCOE) can be misleading.

The problem with the use of LCOE as a comparative tool is that it does not include integration costs such as grid connections and storage requirements, nor does it recognise any excess capacity beyond supplying demand which may be necessary to cover seasonal variations in output. It is suggested that rather than LCOE, the annual cost per kW of capacity for operating a particular facility should be used, and it is the total annual cost of a particular mix of generating and storage facilities derived from the integrated system plan which must be the deciding factor. This will lead to the corresponding cost per kWh of the energy supplied to meet demand and will be minimised for the optimal plan.

In this regard it is suggested that the Gen Cost Report is not the appropriate vehicle for assessing preferred generating methods as it does not include any assessment of the total mix of generating and storage technologies. However, the costs provided should feed into the AEMO Integrated System Plan to enable final energy delivery costs and the optimum mix of technologies to be determined.

The capital cost of renewable installations.

Figures 1 and 2 show the capital cost of installation of utility scale solar PV and on-shore wind from 2010 to the present, and the projection given in the Report under the NZE by 2050 scenario. Generally, the projection appears to be in line with the general trend if the recent increase in costs is ignored.

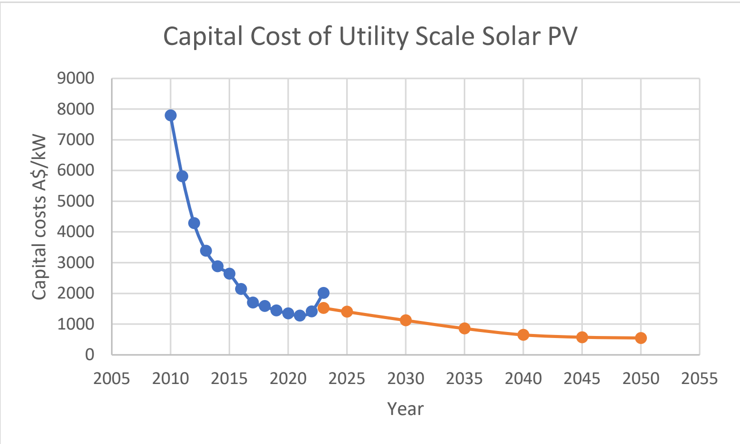

Figure 1

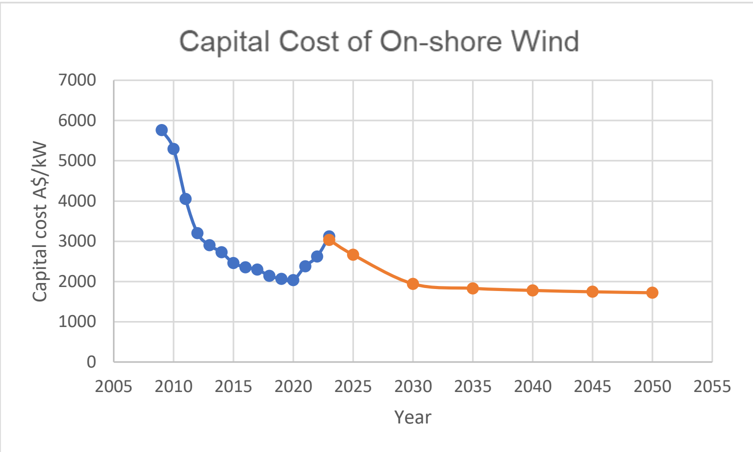

Figure 2

For solar PV the cost of the modules and inverter represented 61% of the total costs in 2010. In 2015 this was 44% and in 2022 was around 35%. The remaining costs represent the cost of land

and permitting, engineering design and installation, and the construction and procurement of racks, cabling and control systems. In past years the cost of these items has not greatly changed and has recently increased due to the cost of steel and other construction materials as well as labour. It is unlikely that the unit cost of these peripheral items will fall significantly in the future, and as indicated in the Report the cost of land may well increase substantially. Any reductions will result from improved performance of the solar panels in terms of power output per unit. However, the cost of the modules and inverters will continue to reduce both due to technology improvement and improvements in manufacturing processes. In this regard it is questioned whether GALLM model separates these two major components in projecting future installation costs.

The same question also applies to onshore wind generation.

The cost of grid connections.

It is understood that the capital cost of a 150 MVA transmission connection is $3.8 million per kilometre, or $25/kW per kilometre. As a typical solar or wind farm is of similar capacity and may require at least 5 km of connection, this would add $125/kW to the capital cost or around 10% to a solar installation and 5% or more to a wind farm. As the most favourable sites are developed first, the connection cost is likely to escalate significantly in time with little or no technology cost improvements. In this regard the cost of connection will become an increasing addition to the cost of renewable energy and by 2050 could represent at least a 30% addition to solar and 15% for wind.

This aspect does not appear to be adequately assessed.

Energy Storage.

If there is total reliance on renewable energy in the future as solar PV, wind and some hydro power generation, there will be a large requirement for energy storage. This will take the form of short-term storage covering variations within a day, and long-term storage covering consecutive days with low levels of sunlight and lack of wind. Short-term storage can be supplied by batteries with rapid response times, and long-term storage will be predominantly pumped hydro energy storage (PHES). The long-term storage will be the major requirement, but both will provide dispatchable energy as and when required and will ensure system flexibility and adequacy.

If the renewable generating capacity is only sufficient to just balance the energy demand, then the associated storage will be at a maximum level and will be excessive, particularly when seasonal variations in output are considered. Modelling based on expected weather patterns and seasonal variations indicates a relationship of the form shown in Figure 3.

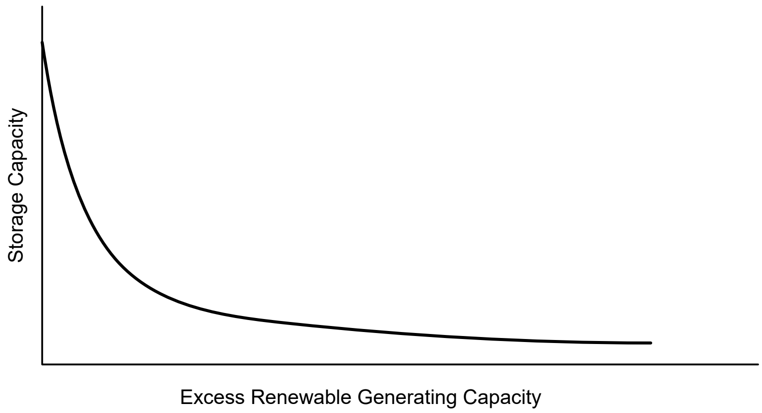

Figure 3

Depending on geographic spread and weather conditions at different times of the year it is likely that the amount of storage required could be of the order of 2% of annual energy demand for a balanced renewable supply, which for Victoria alone would be over 800 GWh or more than twice the capacity of Snowy Hydro 2. As the generating capacity is increased to provide excess, the storage required will be substantially reduced and there will be an optimum position of excess capacity and storage to give the lowest energy supply cost.

An illustration of this effect for Victoria alone with an annual energy demand of 41,200 GWH might be as follows:-

Generating capacity for base load only supply	8.5 GW (Peak power) (5.2 GW average load)
Generating capacity for wind + solar supply (minimum)	15.7 GW
Associated energy storage capacity required (2% demand)	800 GWh
With excess wind + solar capacity (+25%)	19.6 GW
Associated energy storage capacity (0.2% of demand)	80 GWh.

The introduction of steady dispatchable base load generation into the mix will also substantially reduce energy storage required, since that constant level of demand does not have to be met by variable generation sources. Even though the LCOE of base load generation may be higher than renewable supply it can still be justified within the mix by its impact on energy storage reduction. As an illustration, the inclusion of base load generation to provide 50% of the annual energy demand could change the above situation as follows:-

Base load generating capacity	2.6 GW
Wind + solar generating capacity with 25% excess	9.8 GW
Associated energy storage capacity (0.05% of demand)	20GWh

It follows from this that for a given system with a mix of base load generation and renewables, as the percentage of renewable supply increases then the cost of providing that energy will increase due to the proportionally greater storage and connections required, whereas an increase in base load will see a steady or slightly lower cost of energy supply.

It is suggested that a thorough analysis of the storage requirements for the ultimate power generation technology mix needs to be undertaken by modelling energy generation for expected annual weather patterns and seasonal variations. This will provide a basis for evaluating the total cost of energy supply from a fully integrated system of generating, storage, and transmission facilities.

Fuel based generation with CCS

This appears to be proposed as part of the energy mix, if only for peaking supply. It is suggested that reliance on possible carbon capture and storage is high risk and inappropriate for assessment and development of a final energy supply position. The technology has not been successful in capturing all the emissions and has only been applied to any extent using depleted natural gas reservoirs. The concept of underground storage by rock fracturing and injection has been fraught with difficulties and is by no means a reliable or practical technology upon which to base future planning.

Nuclear Power.

This is indeed one technology that will deliver reliable carbon free electrical energy as base load power and has been given only scant attention in the Report and only then in terms of the application of small modular reactors. This is a major deficiency and gives the impression that CSIRO is compliant to the ideological position of the government of the day and is not providing sound well considered advice. It is most disappointing and not at all satisfactory from a supposedly prestigious and unbiased scientific organisation.

The prime reason for consideration of small modular reactors has been to reduce the cost of construction through factory manufacture of reactors and transport to the power station site. There are other advantages such as faster construction times, greater flexibility in plant operation, and ability to retrofit at sites of retired fossil fuel plants. Inherent safety is another major benefit inherent in the design of SMRs. The technology has been well established using highly enriched fuel in applications such as Naval vessels but has only recently been developed for the use of low enrichment level fuels. There has been no operating experience to date and there is a deal of uncertainty in the capital cost. The initial prototype units will necessarily cost more and this needs to be recognised. However, the base line is the cost of conventional reactors and SMRs will not be adopted unless they can reduce costs below this base line.

The possibility of installing conventional reactors in Australia has been dismissed as too large for the relatively small Australian grid to handle (1GW or more in capacity) and challenging for the provision of support infrastructure unless a number are constructed. This observation ignores that fact that there are 10 coal fired power stations presently in operation over 1 GW in capacity with all the necessary infrastructure for a thermal power station already in place. It also denies the experience of many other countries in adding nuclear capacity with less grid capacity or technical expertise within the country. This commentary is gratuitous and only adds to the perception that the report is designed to comply with political preferences.

In relation to the cost of nuclear plant there have been significant problems in recent times with construction cost blowouts and extended construction times, particularly in the USA and some other western nations. The reasons are understood and include excessive permitting delays, changing regulations during both design and construction which have led to the need to rebuild parts of the plant.   The perceived high risk due to these factors has led to high financing costs exacerbated by extended construction times which can more than double the initial estimated cost.   Means of reducing financial risk will be an important part of the funding of any investment in nuclear power generation.

The timing of deployment of nuclear reactors in Australia is also given as a reason to ignore this technology.   If it could be shown that it had a place in the optimum mix of generation technologies for 2050 and beyond this is no reason to reject nuclear technology. Apart from political issues it would certainly be possible to install the first units by 2035, and if indeed SMR technology could be retrofitted to retiring coal fired units it could be implemented sooner.

Historical overnight construction costs expressed in 2010 values for 349 power reactors are illustrated in Figure 4.   For most countries this shows no general trend with time other than the exceptional escalation in costs in the USA in the 1970's resulting from regulatory changes after the Three Mile Island incident. This almost halted new construction in the USA, but other countries were far more successful in restraining costs such as South Korea and France.   This experience has tended to reinforce the view that nuclear energy is too expensive.

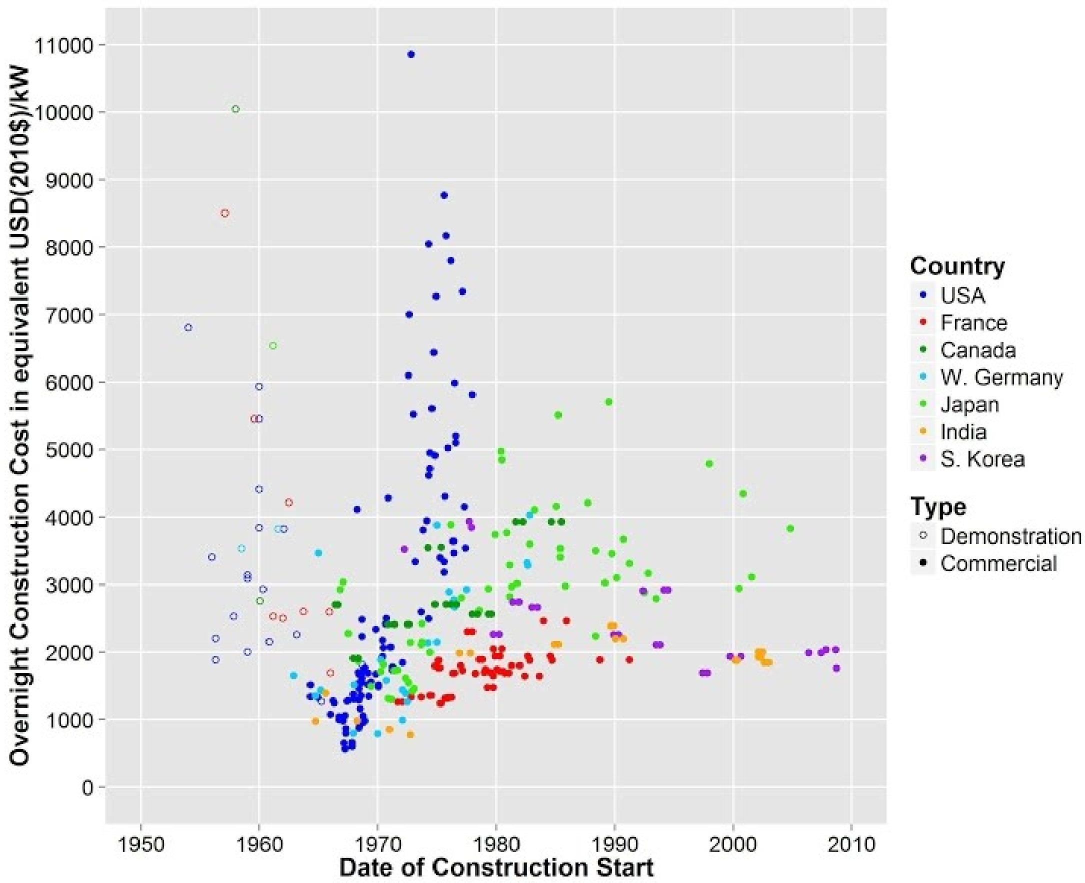

Figure 4.   From "The Breakthrough Institute" and "Energy Policy Vol 91, pp371-382, April 2016 – Elsevier.- Jessica Lovering, Arthur Yip and Ted Nordhaus.

Inflating the costs in Figure 4 from 2010 to 2023 indicates a general range of $2,700/kW to $6,000/kW. OECD figures for the cost of nuclear power plant (as overnight costs – from 2020 edition of the "Projected Cost of Generating Electricity") range from US$2,157/kWe in South Korea to US$6,920 in Slovakia. Costs in China are given as US$2,500/kWe.

The IEA give the following estimate of overnight construction costs based on 2020 values.

Nuclear plant overnight construction costs US$/kWe

Region	2020	2030	2050
European Union	$6,600	$5,100	$4,500
USA	$5,000	$4,800	$4,500
India	$2,800	$2,800	$2,800
China	$2,800	$2,800	$2,500

Source: IEA (2021) Net Zero by 2050: A Roadmap for the Global Energy Sector

Typical costs of large nuclear plants assessed by experts recently indicated a range from US$4,200 to US$6,900/kWe with an average of US$5,300/kWe. Similar sources give the expected cost of SMRs in the range of US$3,000 to US$8,000/ kWe with an average of US$4,200/ kWe.
The development of SMRs is gaining considerable momentum with a range of different designs in a relatively well-advanced state. Attention is drawn to Canada and the report on "A Canadian Roadmap for Small Modular Reactors", which reviews a comprehensive and sound plan for future energy production in Canada. One plant is presently under construction in Ontario using four units from GE-Hitachi (BWRX-300) or 1,200 MW total capacity. The expected cost for a BWRX-300 unit is given by GE-Hitachi as $3,300/kWe.

Rolls Royce in the UK have contracts for supply of a number of 440 MW units at a cost in the vicinity of $6,000/kWe, and Westinghouse will have their AP300 unit available from 2027 at $3,500/kWe.

These figures are far removed from the assumptions made in the report which essentially assesses the cost of the nuclear option at $31,000/KW based on the inflated cost of the one failed NuScale prototype SMR unit of a relatively small 77 MW capacity to be installed in Idaho. No other standard nuclear reactor costs come anywhere near this figure and yet they are not considered and the whole option has been effectively dismissed as too expensive. The costs given in the Report are shown as following a learning curve and declining significantly from the assumed $31,000/kW, whereas major cost reduction has not been the general experience of the industry. Even so the final costs given for 2050 are well above world experience and it is difficult to understand why information from the International Energy Agency (IEA), the Nuclear Energy Agency (NEA), the OECD and other expert sources has not been cited and critically assessed.

A complete revision of this section of the report needs to be made to consider the many nuclear options with consideration of the more recent technologies available, and in line with most of the developed as well as developing world. The IEA expects world nuclear capacity to increase from 413 GW today to 812 GW by 2050 with much of this increase in emerging and developing economies. These decisions are not made without good reason and this needs to be more thoroughly investigated.

The fact that the LCOE of nuclear generation may be higher than the LCOE of renewable generation does not rule it out as a component of the energy mix since its inclusion as base load power supply can dramatically reduce the need for energy storage. As detailed above it is the total energy supply cost including generation facilities, energy storage and grid connections which is the determining factor for whether nuclear generation is a viable component of the mix, and that aspect appears to be completely absent from the report.

It should not be a matter of developing a case for or against nuclear energy, but of presenting a factual account of the associated costs and the implications on other components of the energy supply system.

Hydrogen

Hydrogen will have its place in certain applications such as iron reduction, the production of ammonia and some fuel applications where electrification is not practical. However, the use of green hydrogen for general power generation as has been suggested in the AEMO Integrated System Plan is not considered to be a viable option, largely due to cost and energy efficiency issues.

The electrolytic generation of hydrogen uses close to 50 kWh of electrical energy per kg of hydrogen produced. The heat energy available for practical use by chemical combination with oxygen is 33.3 kWh/kg, and if this is used to generate power using a combustion engine it will produce only around 12 kWh at best. The overall electrical efficiency is then 24%. Alternatively, the use of a fuel cell for direct electricity production will produce around 17 kWh with an overall efficiency of 34%. If hydrogen storage is added this will consume energy for compression at around 5 kWh/kg further reducing energy efficiency to 21.8% and 30.9% respectively.

Use within the electricity generating system is essentially a means of storing energy and that overall efficiency must be compared with other means of energy storage such as batteries and pumped hydro systems with efficiencies of at least 80% to 90%.

Electrolytic production of hydrogen using the alkaline cell technology have been in use for over a century, and certainly on a large scale since the 1940s. The cell stack and power systems represent around 50% to 60% of the capital cost and will experience some cost reductions due to technology improvements. However, the major cost reductions will come from increases in the scale of the equipment as mentioned, and the indicated reductions from $1,700/kW at present to around $700/kW at a scale of 100 MW does appear to be feasible. This may represent a cost of production excluding power costs of $1.45/kg of hydrogen at present, falling to $0.61/kg in the future.

Storage involves compression of hydrogen to pressures of around 700 bar with a cost for 24 hour storage at around $1.28/kg of hydrogen, including the cost of compressors and storage tanks.

Considering energy storage as operating half the time as charging and half the time as discharging, the following Table provides a comparison of hydrogen as a means of energy storage using a combustion engine or gas turbine for energy recovery, with the operation of direct electrical energy storage using a battery.

Storage method	Hydrogen (24 hour)	Battery (24 hour)
Energy recovered from storage	1 MWh	1 MWh
Energy input to the storage system	4.17 MWh	1.136 MWh
Energy lost	3.17 MWh	0.136 MWh
Cost of lost energy @ $50/MWh input cost	$158.5	$6.8
Electrolyser annual cost	$78.1	
Hydrogen compression and storage annual cost	$103.0	
Gas turbine annual cost	$35.0	
Battery annual operating cost		$151.2
Total cost of storage per MWh recovered	**$374.6**	**$158.0**

The cost of using hydrogen generated from renewables to store energy for later conversion back to useful energy is excessively expensive and inefficient compared with other means of direct electrical energy storage and this fact needs to be recognised.

It is also worthy of note that base load nuclear LCOE is likely to be less than $140/MWh which is less than the basic cost of storage alone. In this regard if applied to the maximum degree possible to replace variable renewable energy supply plus storage, it will reduce the overall cost of energy supply.

R. J. Sinclair.
16 January 2024.