SUBMISSION TO

THE AUSTRALIAN FEDERAL PARLIAMENT HOUSE SELECT COMMITTEE ON NUCLEAR ENERGY

INQUIRY INTO NUCLEAR POWER GENERATION IN AUSTRALIA

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Electrical energy represents only 23% of Australia's present energy use. This will need to rise by a factor of at least 3 times to reach zero emissions. If this is to be supplied by renewable energy alone the need for energy storage will be excessive. Energy storage has probably not been adequately addressed and will significantly add to energy costs but can be substantially reduced by using back-up gas turbines and/or by the introduction of base load nuclear generation. There is ample scope to introduce nuclear power up to 2050 and beyond as a replacement for fossil fuels, to cover demand expansion, and as possible replacement for wind and solar facilities as they reach the end of their life.

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There are presently 415 operating nuclear power reactors in 35 countries with 57 presently under construction. Compared with many countries introducing nuclear for the first time, Australia has both the grid capacity and the capabilities to use this technology.

Construction times. Page 7

Most reactors are constructed within 5 to 10 years and the median for all reactors built to date is 6.3 years. Some recent extremes have been due to delays caused by regulatory and design changes and only citing these cases is highly misleading. Small modular reactors could also substantially reduce construction times.

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The importance of construction delays and financing costs is emphasised and has resulted in major cost blow-outs for some recent projects. Such excessive costs have been quoted as a reason not to invest in nuclear power but are not a valid basis for assessment. A well-defined and stable regime for permitting and for regulatory clarity is a necessary first step for a viable nuclear power industry. Given that position, the construction cost for large scale nuclear in

Australia based on well-established designs should average no more than US$5,500/kW or A$8,500/kW.

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Based on a capital cost of A$8,500/ kW the cost of energy from a base load nuclear power station is estimated at $125 per MWh.

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Comparison of the cost of electricity generation only for solar, wind and nuclear (such as by using the Levelized Cost of Electricity – LCOE) is invalid since renewables are highly variable and cannot meet supply requirements. It is essential to compare the total system cost including all energy storage, back-up gas generating facilities and grid connections.
The cost of energy delivered by a system consisting of solar and wind with both short term battery energy storage, long term pumped hydro storage, and gas turbine back-up is estimated at $133 per MWh. The addition of base load nuclear supplying 30% of the energy demand will reduce the overall cost of energy to an estimated $125 per MWh demonstrating that nuclear is clearly economically competitive with renewable supply.

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There are presently 10 coal fired power stations of over 1,000 MW generating capacity with ancillary facilities capable of being replaced with large scale nuclear units. The capacity of large scale units is therefore no impediment to introduction of this technology.

Small modular reactors Page 14.

This technology has been well established for more than 60 years using highly enriched uranium, but only recently has been adapted for low enrichment level fuels. This promises to reduce both costs and construction times and greatly improve flexibility but will only be viable if and when these aims are achieved.

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The public concerns about nuclear energy need to be addressed with an information program using the appropriate expertise.

Appendix 1 Cost estimate details.

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The data and analysis provided in this submission is based on published information from a wide range of sources researched over many years involved in reviewing this subject.

Introduction.

As for the renewable energy sources of wind, solar and hydro, nuclear energy can also provide an abundant source of electrical energy free of carbon emissions, but unlike renewable supply has the advantage that it is a dispatchable supply that can meet demand as required. There are many unjustified concerns and misleading information about nuclear energy which need to be addressed, and it is the purpose of this submission to highlight some of these issues, particularly the opportunity to include nuclear into the energy supply mix and the associated costs.

The future energy mix.

Australia's energy demand is presently around 4,300 PJ per year of which electrical energy supply is close to 980 PJ representing only 23%. The remaining 77% is predominantly sourced from hydrocarbon fuels for transport, agriculture, manufacturing and commerce. At present around 60% of electrical energy also relies on fossil fuels indicating that only 9% of total national energy use is from renewable electrical energy sources.

In order to reach zero emissions by 2050, 93% of the present national energy use must be converted to emission free sources. This will be achieved by electrification of many uses of energy or by the use of alternative fuels such as hydrogen and biofuels. Hydrogen in turn will mainly be produced by electrolysis and will further expand the demand for electrical energy. It is estimated that the present demand for electrical energy will need to increase by a factor of close to 3 times for the same total energy use patterns as at present and ignoring any future growth in energy demand. If this is to be satisfied by renewable energy alone it will require the present level of generation to be increased by a factor of more than 8 times. There is a long way to go which is at odds with the representations made about our progress towards an emission free energy future. It seems that attention is often largely focused on change to the present electricity sector and not on the massive conversion needed in other energy use sectors.

This projected expansion in electrical energy demand will require generated electrical energy to increase from 270,000 GWh per year to over 800,000 GWh per year representing an increase of about 20,000 GWh generated each year up to 2050. This would require the addition of 2.5 GW of thermal generating capacity or 7.5 GW of average renewable capacity each year up to 2050. Over the past five years between 5 and 6 GW of renewable capacity has been installed each year so a significant increase in the rate of installation will be necessary.

Renewable energy is highly variable, not only on an hourly and daily basis but also on a seasonal basis. This will require battery energy storage to handle short term variations and rapid responses, and pumped hydro to handle long term storage. The cost of storing large amounts of energy is much lower for pumped hydro in comparison with batteries but it lacks the rapid response, so both are complementary. The amount of energy storage required to alone provide sufficient security to the supply system is excessive, and hence it has been proposed to also use back-up gas turbine generators. There is an optimum mix of excess wind and solar capacity, energy storage and back-up gas generation. However, gas generation capacity must be relatively large to provide for a large part of the power demand at any one point in time even though it may only operate for short periods.

It is suggested that energy storage capacity requirements have not been adequately addressed probably because there is minimal need at the present time while fossil fired generators are still operating, and consequently the extent of storage capacity required has probably been grossly underestimated. **A full system analysis of this optimum position with renewable generation and the required energy storage capacity needs to be undertaken based on typical climate data and should be widely published for critical review.**

The capacity utilisation of renewable energy sources is low at 20 to 25% for solar and around 30 to 40% for wind, compared with thermal power stations at closer to 90%. This means that replacing present thermal capacity with wind and solar will require capacity to be increased by a factor of around 3 times.

The introduction of base load nuclear supply into the energy supply system will not only replace three times its generating capacity in renewables, but also any associated energy storage and extensive grid connections. In simple terms it is suggested that the addition of energy storage will double the capital cost of renewable capacity alone. Hence the cost of one unit of nuclear capacity would replace 6 times the cost of one unit of average renewable generating capacity. Nuclear base load will also substantially reduce the need for back-up gas generation providing a further cost benefit. Nuclear also provides a much higher level of security to the electricity supply system in the face of growing climate threats.

This would suggest that nuclear should not be dismissed simply by ideological arguments and simplistic cost comparisons but warrants far more serious and detailed consideration. There is indeed every opportunity for large scale nuclear to contribute to this requirement in every year up to 2050 and there is no justification in the argument that it is too late to consider this option or that it will delay the roll-out of renewable energy. Major generating capacity installation is required up to 2050 and in the longer term there will be a growing need to replace existing solar and wind capacity from around 2035 onwards as those facilities reach the end of their useful life.

World nuclear capacity.

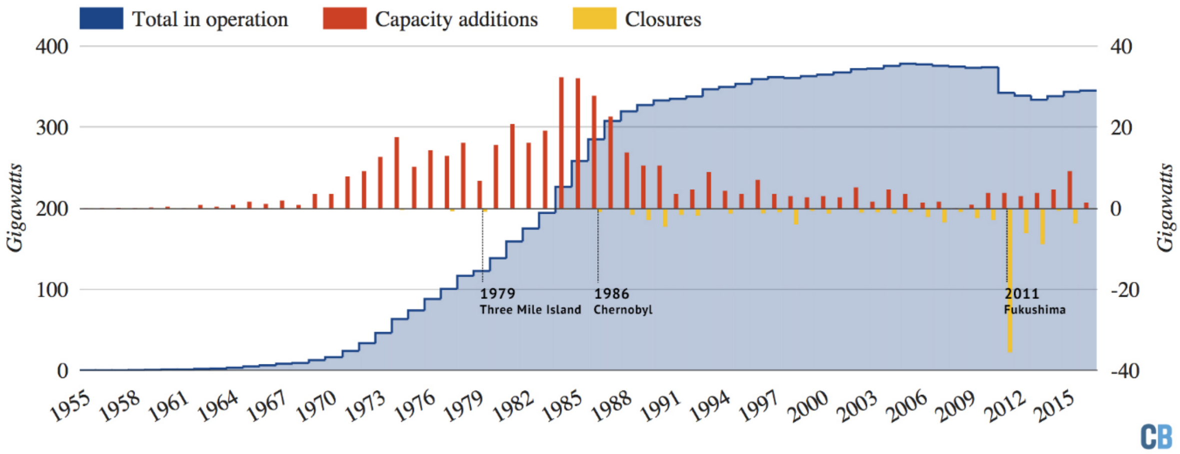
Presently there are 424 nuclear reactors in 35 countries with 415 operating and with little change over the past 30 years.

World Nuclear Power Reactors (June 2023)

Country	Number in operation	Number under construction	Share of total power output
Argentina	3	1	6.3%
Armenia	1	0	31.1%
Bangladesh	0	2	
Belarus	1	1	28.6%
Belgium	6	0	41.2%
Brazil	2	1	2.2%
Bulgaria	2	0	40.5%
Canada	19	0	13.7%
China	55	24	4.9%
Czech Republic	6	0	40.0%
Egypt	0	3	
Finland	5	0	42.0%
France	56	1	64.8%
Hungary	4	0	48.8%
India	19	8	3.1%
Iran	1	1	1.7%
Japan	12 (21 off line)	2	5.5%
Mexico	2	0	4.9%
Netherlands	1	0	3.4%
Pakistan	6	0	17.4%
Romania	2	0	18.9%
Russia	37	3	18.4%
Slovakia	5	1	61.3%
Slovenia	1	0	36.8%
South Africa	2	0	4.4%
South Korea	26	2	31.5%
Spain	7	0	20.3%
Sweden	6	0	28.6%
Switzerland	4	0	32.4%
Taiwan	3	0	9.1%
Turkey	0	4	
Ukraine	15	2	55.0%
United Arab Emirates	4	0	19.7%
United Kingdom	9	2	12.5%
United States of America	94	0	18.5%
TOTALS	**415**	**57**	

Source: International Atomic Energy Association.

The construction of nuclear power stations was greatly affected by three major accidents starting with Three Mile Island in 1979 and has plateaued since the Chernobyl accident in 1986. This resulted in increased regulation, general opposition and greatly increased cost of construction, resulting in abandonment of many new projects. This situation certainly impeded the growth in nuclear power in many countries in recent times, particularly in the USA and some European countries, although other countries including South Korea and China successfully maintained their programs at substantially lower cost and construction times. The Fukushima accident in 2011 accentuated the problems and caused some countries such as Germany and indeed Japan to consider abandonment of nuclear power. Figure 1 indicates the number of nuclear power reactors commencing operation and the total capacity by year up to 2016.



Source: CarbonBrief – "The World Nuclear Power Plants".

Figure 1 World Nuclear Capacity

The new reactors that have been built in recent years up to 2020 have generally replaced older reactors which have been shut down. However, there is now a rebound in response to carbon emission reductions with renewed interest in European countries such as Sweden, Belgium and the UK, and significant activity in Asian countries such as China with 24 now under construction, India and South Korea. There are also a number of countries which have recently introduced nuclear for the first time – Turkey, Egypt, Bangladesh, Romania, Poland, and Slovakia. There are 59 reactors under construction in 18 countries, with 40 more in the planning stage, and with over 300 more proposed. The International Atomic Energy Agency expects world nuclear capacity to double to 792 GW by 2050 from the present level of 393 GW.

An argument against the adoption of nuclear power technology in Australia has been the absence of a nuclear power industry in the country and the time that would be required to build the expertise needed to install and operate nuclear power stations. This is unfounded since the Australian Nuclear Science and Technology Organisation (ANSTO) and its predecessor the Australian Atomic Energy Commission (AAEC) have been in place for more than 70 years conducting research into all aspects of nuclear science and have operated a nuclear reactor at Lucas Heights for most of that time. The present reactor (OPAL or Open Pool Australian Light water reactor) was opened in 2007 and is now primarily for the purpose of producing radioactive isotopes for nuclear medicine. Many other countries throughout the world with a far lower level of general technical expertise have successfully embraced nuclear power as indicated above, and the planned acquisition of nuclear submarines for the Australian Navy will in any event require capabilities to be significantly upgraded.

Construction times.

It is also a popular theme that nuclear reactors take too long to build – well in excess of 15 years. An analysis of construction times since 1950 has indicated a median construction time of 6.3 years with the spread of times illustrated in Figure 2.

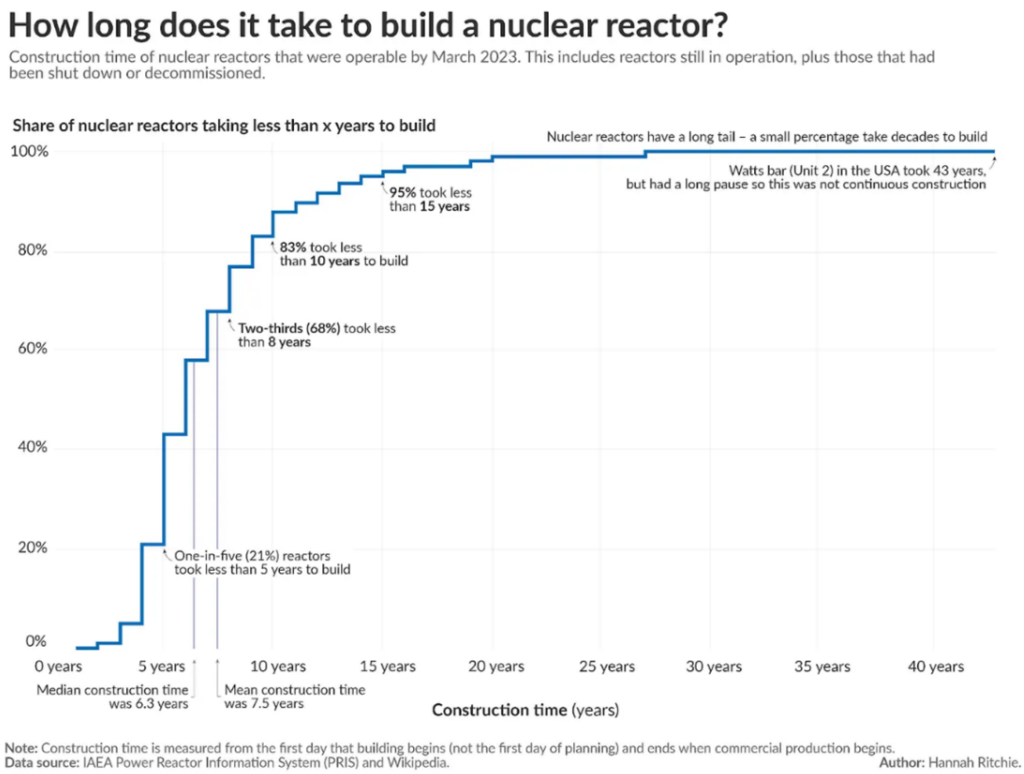


Figure 2

Few reactors are built in less than 5 years and most within 10 years. This pattern is not dependent on reactors size and has not changed over time, except for the long tail of delayed projects. There was some increase in construction times in the 1970s and 1980s only, but with reversion to the above pattern thereafter.

In terms of where the reactors are built, construction has been much faster in Japan, South Korea and China with median times of 52 to 68 months, whereas in European countries it is around 80 months. In the USA, of the 93 reactors constructed to date, the median construction time is 9 years with a range of one reactor at 4 years to one reactor at 19 years- despite the Minister for Energy claiming the average time was 19 years. For South Korea the median construction time is 6 years with a range of 5 to 10 years.

Except for South Korea and France there is no evidence of learning as evidenced by a decrease in construction times (and cost) with experience. This may be the result of disruption of many nuclear programs, with few new units being constructed in recent years. Another contributor will be increased regulation and the various hurdles the construction teams have to manage. This situation can be significantly improved by using standardised reactor designs as in France and South Korea rather than one-off unique designs for each new project which is inevitable if they are few and far between.

Small Modular Reactors constructed in a factory present a much greater opportunity for learning and for construction efficiency to reduce both time and cost. Having multiple units on site can also mean that commissioning can be sequential and progressive, and first power output can be much earlier than for a single large reactor.

Cost of Construction.

There have been significant problems in recent times with construction cost blowouts and extended construction times, particularly in the USA, UK and some other western nations. The reasons are well 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, and recently material supply problems. The perceived high risk due to these factors has led to high financing costs exacerbated by extended construction times which can greatly escalate estimated cost. Means of reducing financial risk will be an important part of the funding of any investment in nuclear power generation.

An explanation of the high construction costs is the delays, changes in regulations, the high interest rates arising with private investment which have been 12.5% in the USA and 10% generally, but 3% in Japan and South Korea. The effects of financing costs during construction are illustrated in the following Table for an initial "same day cost" or base cost of 100 units.

Interest rate	3%	7%	12.5%
5 year construction	105.6	114	125.6
10 year construction	114.0	138	172.8
15 year construction	122.0	170	273
20 year construction	131.0	207	373.9

For USA plants which average 9 years construction time the cost will increase to around 170% of the base cost just due to interest alone, and in the extreme more than 2.5 times the base cost. Inflation will add further to the costs and if taken as 3% pa the costs will be as follows:

Interest rate	3%	7%	12.5%
5 year construction	112.6	121	133.2
10 year construction	130.5	156	195.2
15 year construction	153.0	215	303.4
20 year construction	175.4	267	411.6

With a reasonable inflation rate of 3% this indicates that construction costs will nearly double for an average US plant and in the extreme case over 3 to 4 times. Whereas for South Korea with low interest costs and low construction times the costs will only increase by 15 to 20%. **This emphasises the importance of interest rates and construction times. It indicates that government funding or guarantee can provide low interest finance to keep final construction costs as low as possible with ultimate benefit to the power consumers.**

Nuclear power plants are unique among other utilities in the regulatory and permitting rules which are applied. This is a result of the extreme consequences of catastrophic failure even though the risk of that failure is quite low with only three major failures in 19,000 reactor years of experience over a period of 60 years. This risk has been dramatically reduced with modern reactor designs which include passive safety involving a reduction in heat generation as the temperature rises, avoiding the possibility of meltdown due to loss of cooling. Nevertheless, regulations remain cumbersome and excessive with the US Nuclear Regulatory Commission having 32 steps in the licensing procedure which can take up to 80 months to obtain approval, and reforms and updating are necessary. Regulatory changes have often occurred during construction, requiring completed work to be modified or replaced, interfering with construction schedules, and reducing labour productivity and construction efficiency. Design change during construction is a certain recipe for major cost escalation in any project particularly one as complex as a nuclear power station.

Given the experience in the USA and other countries where changing requirements and permitting issues have caused major escalation in construction costs, it is clear that a well-defined and stable regime for permitting and for regulatory clarity is necessary for a viable nuclear power industry.

Construction costs for a nuclear power station are usually expressed as "overnight construction costs", which includes the cost of engineering, procurement and construction, as well as indirect owner's costs such as land, site preparation, project management, training, and commissioning. It excludes inflation, financing costs, and interest during construction, and represents the cost as though the plant was built overnight.

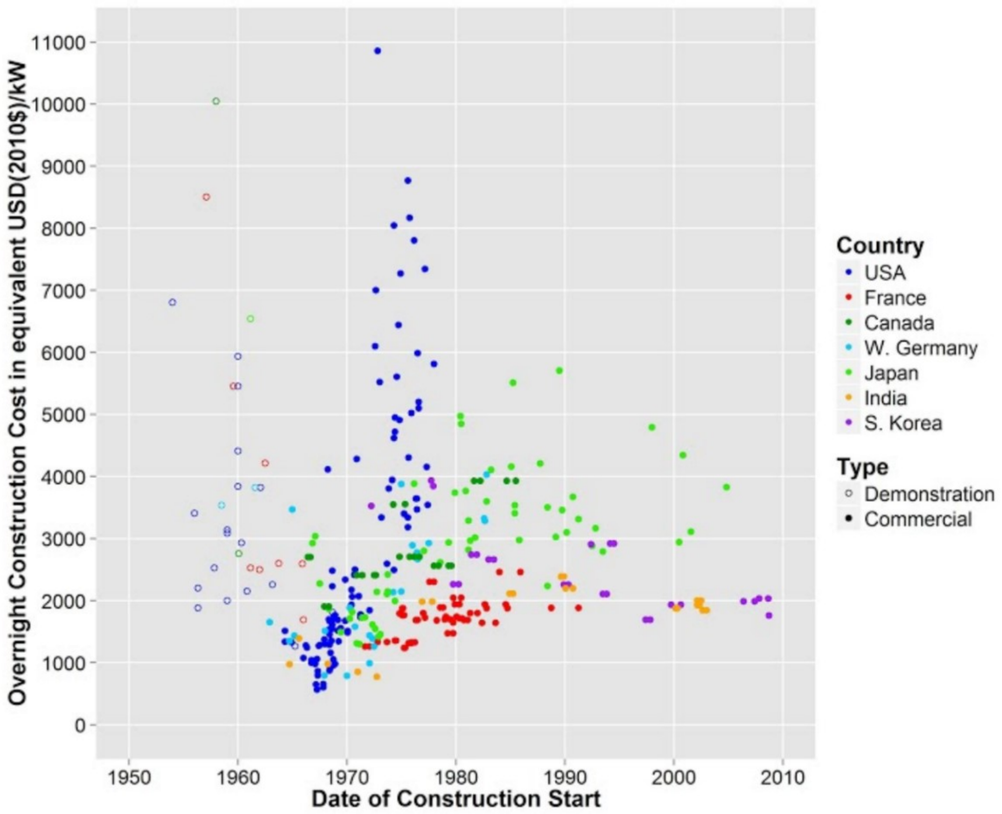
Available data on such costs has been analysed in a paper by Lovering et al in 2016, for 153 reactors built between 1954 and 2015 in 7 countries and covering 58% of all reactors built in that time. As a result of increasing regulation and disruption most have exhibited heavy escalation in costs, well beyond inflation. This data is illustrated in Figure 2 with all costs adjusted by inflation in the various countries concerned and expressed in 2010 US dollars.

Clearly from Figure 2 the cost of nuclear installations in the USA has shown exceptional increases in some instances and most of these are attributed to regulatory changes required during construction and delays following the Three Mile Island incident (ie reactors which commenced construction during the 1970s). This cost increase in the USA has made it difficult for nuclear to compete with other means of power generation, and only five reactors have been completed in the USA in the past 20 years (Watts Bar 2 in Tennessee, and Vogtle 1, 2,3 and 4 reactors in Georgia).

The latest USA plant is the Vogtle Plant in Georgia containing 4 units of 1150 MW each. Unit 1 took 11 years, unit 2 took 13 years and was completed in 1989. The first two units cost $18.3 billion (in 2023 dollars) or $7,530/kW. The last two units used a novel Westinghouse AP1000 design and commenced construction in 2009 but were extensively delayed following the Fukushima accident in 2011 with significant delays and changes in regulations and design requirements. Unit 3 was completed in July 2023 and Unit 4 in April 2024, taking 15 years in total and resulting in costs escalating to $35 billion representing $15,220/kW.

Hinckley Point C in the UK is in a similar situation to Vogtle 3 and 4 and is a litany of disasters. It commenced construction in 2017 for a plant capacity of 3,260 MW, but due to delays and changes the cost is now expected to have blown out from $31billion to $62 billion representing around $19,000/ kW.

These recent cases have coloured the widely held view that nuclear power is too expensive, but they are exceptions due to serious delays and problems and this is not generally the case for the bulk of previous nuclear projects.



Source: "Historical construction costs of global nuclear power reactors" J.A.Lovering, A.Yip, T.Nordhaus. Energy Policy Vol 19, April 2016, pp 371-382.

Figure 2 Nuclear plant construction costs

Apart from excessive cost in the USA, the general range of costs shown in Figure 2 are between US$2,000 and US$5,000 per kW of installed capacity in 2010 dollars. Inflation to 2024 dollars would raise these costs by a factor of 1.40 and would raise the general range of construction costs to US$2,900 to US$7,300 /kW. (or A$4,400 to A$11,200 per kW, with an average of close to A$6,500/kW).

Presently the Korea Electric Power Corporation – KEPCO is in the business of building nuclear power stations globally and has contracts in the UAE, Kenya and Brazil. KEPCO is presently constructing the Barakah power station in the UAE located in Abu Dhabi (5.6 GW with 4 units). The first unit commenced construction in July 2012 and first delivered power in Aug 2020 with 8 years construction. Subsequent units started 12 months later and unit 3 commenced in Feb 2023, also after 9 years construction. The fourth unit was completed in March 2024.

The final cost of Barakah is given as $32 billion or US$5,700/ kW. (A$8,600/ kW).

OECD figures for the cost of nuclear power plants (as overnight costs – from 2020 edition of the "Projected Cost of Generating Electricity") range from US$2,157/kW in South Korea to US$6,920 in Slovakia. Costs in China are given as US$2,500/kW.

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

Nuclear plant overnight construction costs US$/kW

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/kW with an average of US$5,300/kW (A$8,150/ kW).

Since fuel and annual operating costs are relatively low, the ultimate cost of nuclear energy is largely determined by the initial construction cost. It is therefore important to ensure that conditions are conducive to a high level of construction efficiency. This reflects on the approach taken to design, project management, construction financing and most importantly to regulation. The avoidance of one-off unique designs and use of standardised designs and construction procedures can keep costs low and reduce them in time.

South Korea is an example of a disciplined approach along these lines. It has 26 operating nuclear reactors; the median construction time has been 6 years, the shortest 5 years and the longest 10 years. It is one of the few countries where construction costs have actually fallen over time in real terms. The initial construction costs were $5,000/kW and have reduced for the latest plants to $2,200/kW.

The above data suggests that the construction cost for large scale nuclear in Australia based on well established design should average around US$5,500/kW or A$8,500/kW. As the industry develops this figure is likely to decline.

The typical figures for the cost of nuclear energy are far removed from the assumptions made in the first draft CSIRO GenCost 24 Report which essentially assessed the cost of the nuclear option in Australia at $31,000/KW. This was 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. Following wide concerns about this analysis the figures were revised downwards to a minimum of $8,600/ kW but potentially up to $17,100/ kW, although there was minimal justification of these figures or any in depth analysis. It is difficult to understand why expert advice from ANSTO has not been sought or information from the International Atomic Energy Agency (IAEA), the Nuclear Energy Agency (NEA), the International Energy Agency (IEA), the OECD and other expert sources has not been cited and critically assessed. Unfortunately, this report has been accepted as a basis for decision making by the Australian Government and generally by the press.

Annual operating costs and the cost of energy.

It needs to be recognised that nuclear presently provides the world's lowest cost electricity supply at around $30 to $35/MWh in the USA and $40/MWh in Europe from many plants built 30 to 40 years ago.

The main components of annual operating costs are:-

- Amortisation costs or return on invested capital over the life of the facility. The life of a nuclear power station is at least 50 years, and the common commercial discount rate used may be 7%. This indicates an annual amortisation or capital recovery charge of 7.25% of invested capital.
- Operating and maintenance costs, covering all personnel, management, supplies and maintenance. This is typically taken as 3% of the basic construction cost.
- Fuel costs which represent the cost of fuel rods containing enriched uranium oxide. This is taken as US$5.20 per MWh.
- A sinking fund to provide for eventual decommissioning. The final cost is taken as 15% of the construction cost and assuming inflation is covered by the earning rate of the fund this will require an input of around 0.375% of the capital cost per year.

For a 1,000 MW power station costing A$8,500/ kW or $8.5 billion, operating at 95% of capacity and producing 7,524 GWh per year, the costs of operation are:-

Amortisation	$616 million per year
Operating and maintenance	$255 million per year
Nuclear Fuel	$39 million per year
Decommissioning fund*	$32 million per year
Total annual costs	**$942 million per year or $125 per MWh.**

* Note: Decommissioning costs are not normally included in the comparable operating costs for most renewables.

This represents the cost of steady output of power. Any variation in load will reduce the utilisation of the power station and for typical demand profiles may be around 75%. In that case the energy produced would reduce from 7,524 GWh to 5,643 GWh and the cost of fuel will drop to $29 million per year. Other costs are fixed, and the total will reduce only to $932 million per year or a power cost of A$165/MWh. **Because of the capital intensity of nuclear power, it is best operated for the maximum time possible – that is it should primarily be used for base load power supply with renewables and storage supplying the variable demand.**

Comparative system costs.

The cost of electrical energy generated by different methods is often compared using the Levelized Cost of Electricity (LCOE) which is simply the annual cost of owning and operating the facility divided by the annual energy produced. This is typically estimated at $60/ MWh for solar PV, $69/ MWh for wind, and $121/ MWh for nuclear. Unfortunately, these figures are highly misleading as they do not compare the cost of supply to meet a given electricity demand.

For any mix of generation methods such as solar PV, wind and nuclear base load to meet a given demand, it is necessary to include the cost of energy storage (both short-term battery storage and long-term storage such as pumped hydro), any back-up emergency generating plant, and grid connections. This will entail modelling the effect of expected climatic conditions on variable renewable output on an annual basis to ensure that both the capacity of variable renewable generation and energy storage capacity is sufficient to avoid any failure to meet demand. It is suggested that storage capacity has been generally and substantially underestimated for a system with renewables only but can be greatly reduced by oversizing the renewable generating facilities, by the inclusion of emergency gas turbine generation, and by the inclusion of a significant level of base load nuclear supply.

As an example of such a total system analysis, two cases with and without nuclear are summarised as follows:

> Case1. Wind and solar with equal energy outputs, supported by gas generation for 5% of total energy supply and both battery and pumped hydro energy storage. Solar and wind are assumed to have 10% excess capacity to reduce the energy storage required.
>
> Case 2. As for Case1 but with nuclear base load supply added to supply 30% of the total energy output.

Details of the two cases are given in Appendix 1 and the following comparative figures are highlighted below and the component costs are illustrated in Figure 3.

	Case 1	Case 2
Capital for generating 1,000 GWh pa	$1,346 million	$1,244 million
Cost of system energy supply	$133.5/ MWh	$124.8/ MWh

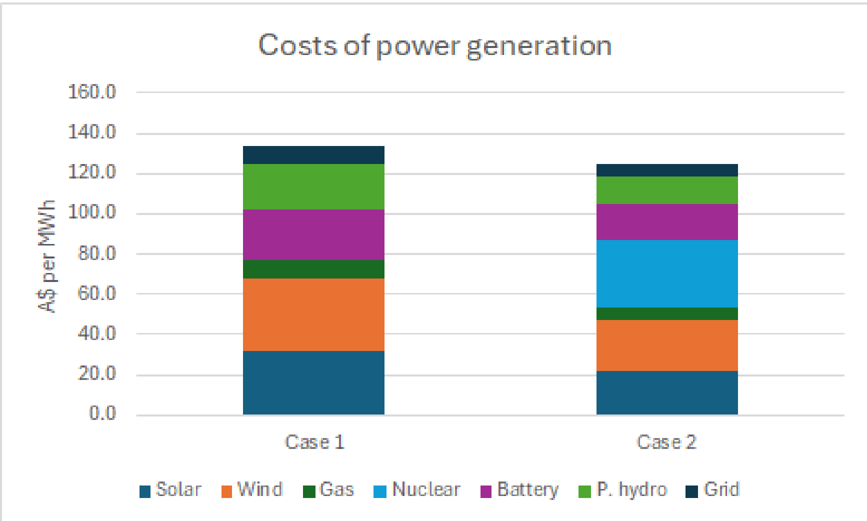


Figure 3.

The capital cost of nuclear used in the above estimates is $8,500/ kW which gives a lower system supply cost than a fully renewable system. The break-even capital cost at which supply costs are the same is $10,800/ kW indicating that base load nuclear is clearly a cost competitive option since the cost of well-established large scale technology should be well within this figure.

This analysis demonstrates that comparison of generating methods must be based on total supply system costs and comparing the Levelized Cost of Electricity (LCOE) is meaningless. Unfortunately, LCOE has been the basis of comparison commonly used and promoted by Government Ministers which is totally misleading.

It is strongly recommended that future decision making is based on total system cost analysis to optimise the mix of generating and energy storage facilities using those with the expertise and capability to undertake such analysis.

Installation in Australia

Presently Section 140A of the Commonwealth Environment Protection and Biodiversity Conservation Act 1999 specifically prohibits nuclear power generation and this Act needs to be rescinded before installation can be considered.

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. Also as indicated above there is ample scope for nuclear generation to be included well into the future to meet the expanded electricity demand as well as the future replacement of end of life solar and wind capacity.

Small modular reactors.

The construction of large reactor units on site, often as specific one-off or bespoke designs to meet local regulations, can be very expensive. In addition, there have been strict requirements for the deconstruction of the plant at the end of its life. This is now being addressed by using standardised designs and the concept of Small Modular Reactors (SMRs) which can be constructed in a factory to uniform design standards and manufacturing processes, and then transported to the construction site, similar to the other power station equipment such as turbines, generators, electrical equipment and transformers, etc.
There are other advantages such as faster construction times, greater flexibility in plant operation, and the ability to easily retrofit at sites of retired fossil fuel plants. Inherent safety is another major benefit in the design of SMRs.

The technology has been well established over more than 60 years 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 with the new designs and there is a great deal of uncertainty in the capital cost. The initial prototype units will necessarily cost more and this needs to be recognised. There is considerable promise to reduce the cost of nuclear energy; however, the base line is the cost of conventional reactors as assessed above and SMRs are unlikely to be adopted unless they can reduce costs below this base line.

Safety concerns.

Safety concerns are very real for the public and need to be addressed by an information program using the appropriate expertise. It is largely an issue of the perception of involuntary risk based on past experience and reported incidents, and consequently on resulting cognitive biases. However, technology has changed in a major way since the first generation of reactors involved in those incidents and the improvements in reactor stability and safety with recent designs need to be highlighted.

It is also stressed that Australia is in a fortunate position having major world class resources of both uranium and thorium and has ideal geology for the safe long-term disposal of high-level nuclear waste, the quantities of which are really very low; many orders of magnitude lower than the amount of waste generated by coal fired power stations.

R. J Sinclair
28 October 2024

APPENDIX 1 Cost Estimate Details

Case 1 Renewables only.

Installed solar capacity	1,000 MW	Energy generated	1,735,000 MWh
Installed wind capacity	629 MW		1,735,000 MWh
Installed gas capacity	208 MW		183,000 MWh
		Total energy	**3,652,000 MWh**

Short term battery storage	2,500 MWh
Long term pumped hydro	5,835 MWh

Capital costs

Solar @ $1,200/ kW	$1,200 m	Annual capital charge	$103.2 m/a
Wind @ $2,200/ kW	$1,383 m		$112.0 m/a
Gas @ $1,250/ kW	$261 m		$19.5 m/a
Batteries @ $300/kWh	$750 m		$82.5 m/a
Pumped hydro @$150/kWh	$900 m		$64.8 m/a
Grid connections	$422 m		$31.6 m/a
Total capital	**$4,916 m**	Total capital charge	$413.8 m/a

Total capital cost per MWh generated per year **$1,346**

Annual operating and maintenance costs	$67.2 m/a
Fuel cost for gas back-up	$6.6 m/a
Total annual costs	**$487.6 m/a**
As an energy cost	**$133.5/ MWh**

Note: Annual capital charges have been based on the life of the various generating facilities and an interest rate of 7%. Respective lives are taken as 25 years for solar, 30 years for wind, 40 years for gas turbines, 15 years for batteries and 50 years for pumped hydro facilities.

Case 2 Renewables plus base load nuclear

Installed solar capacity	1,000 MW	Energy generated	1,735,000 MWh
Installed wind capacity	629 MW		1,735,000 MWh
Installed gas capacity	208 MW		183,000 MWh
Installed nuclear capacity	200 MW		1,565,000 MWh
		Total energy	**5,216,000 MWh**

Short term battery storage	2,500 MWh
Long term pumped hydro	5,000 MWh

Capital costs

Solar @ $1,200/ kW	$1,200 m	Annual capital charge	$103.2 m/a
Wind @ $2,200/ kW	$1,383 m		$112.0 m/a
Gas @ $1,250/ kW	$261 m		$19.5 m/a
Nuclear @ $8,500/ kW	$1,687 m		$119.8 m/a
Batteries @ $300/kWh	$750 m		$82.5 m/a
Pumped hydro @$150/kWh	$772 m		$55.6 m/a
Grid connections	$436 m		$32.7 m/a
Total capital	**$6,488 m**	Total capital charge	$525.3 m/a

Total capital cost per MWh generated per year **$1,244**

Annual operating and maintenance costs	$106.8 m/a
Fuel cost for gas back-up	$6.6 m/a
Fuel cost for nuclear	$12.5 m/a

Total annual costs **$651.3 m/a**

As an energy cost **$124.8/ MWh**

Note: Annual capital charges have been based on the life of the various generating facilities and an interest rate of 7%. Respective lives are taken as 25 years for solar, 30 years for wind, 40 years for gas turbines, 60 years for nuclear, 15 years for batteries and 50 years for pumped hydro facilities.