Submission No 42

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

Organisation: Down Under Nuclear Energy

Date Received: 13 October 2019

DOWN UNDER NUCLEAR ENERGY

Level 1, 55 St Georges Terrace, PERTH,
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To the Inquiry considering the *Uranium Mining and Nuclear Facilities (Prohibitions) Repeal Bill 2019*

I am pleased to offer this submission on behalf of DUNE – Down Under Nuclear Energy. It is the same document we provided to the ongoing standing Federal Inquiry and I hope you find it informative.

We submit that the new generation of nuclear technology, specifically SMRs, can and must play an important role in our nation's energy mix. Once deployed, the technology will satisfy the three imperatives of affordability, reliability and zero-emissions more comprehensively than any alternative.

Acknowledging the doubt that policy makers may have regarding the cost competitiveness of this new technology, a zero-cost first step would be to remove the NSW prohibition on nuclear energy and request the federal government to do the same.

The second low-cost step would be for the NSW government to request proposals from the private sector, requiring them to provide an outline to the investment hurdles that may require a market change or government assistance to reduce financing or regulatory costs.

If nuclear energy is not viable in NSW from an investment or an economic perspective, it won't be built. However, whilst the option is excluded from consideration, our nation cannot properly assess if nuclear technology is right for us. Our assessment is that NSW must, and most likely will, be the first state in Australia to build a nuclear power plant – it is uniquely well positioned to do so.

We are highly encouraged that the inquiry is leading this important conversation.

Thank you for your time and consideration. Do not hesitate to contact me if further information is required.

Kind regards

James Fleay

Chief Executive Officer - DUNE

DUNE

DOWN UNDER NUCLEAR ENERGY

SUBMISSION
INQUIRY INTO THE PREREQUISITES FOR NUCLEAR ENERGY IN AUSTRALIA

'In Australia we have options. One is to continue to maintain legislation that restricts our future choices to nothing but weak and possibly ineffective technologies. The other is to allow all technologies to be considered on their merits.'

Authors

This submission was prepared to inform the "Inquiry into the prerequisites for nuclear energy in Australia" requested by Minister Angus Taylor.

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Professor Alex Coram has had professorships at the University of Western Australia, University of Massachusetts and Robert Gordon University in Scotland. He is a partner in Lateral Economics. His main area of academic research is mathematical social science and economics. He has published over seventy papers and reports. He has also worked on a range of problems for industry and government.

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James has practised engineering and project management in the power and oil and gas sectors throughout Australia for 15 yrs including working for some of the world's biggest companies on the design, construction, start-up and operation of some of Australia's biggest and most complex energy projects. He founded DUNE in 2018 after extensively studying the difficulties within, and prospective options for the NEM. James also has extensive small business experience in the solar energy industry.

Executive Summary

Societies across the world are trying to deal with the problem of providing inexpensive and reliable energy while at the same time reducing emissions. There is an increasingly strong feeling that this cannot be done without nuclear energy. In Australia we have options. One is to continue to maintain legislation that restricts our future choices to nothing but weak and possibly ineffective technologies. The other is to allow all technologies to be considered on their merits.

This submission supports the position that the legislation should be amended to allow the development of nuclear energy.

Amending the legislation is not equivalent to mandating nuclear. It simply means that is will become possible for energy providers to consider nuclear as part of our energy mix. Without a change in legislation we cannot have an informed set of choices about our future and decisions cannot be made on either social benefit or commercial grounds. **It is a basic principle in mathematics that decision making under constraints can never be better than unconstrained choice.**

In brief we argue that removing the prohibition on nuclear energy offers substantial social, economic and strategic benefits. We also argue that the usual objections to this are at best misguided and often based on a poor understanding of economics and risk.

If the prohibition is lifted there is enormous potential for gain.
Those who wish to retain the prohibition will claim that nuclear is too costly. This is incorrect. It also doesn't make sense. If it were true nuclear would never get commercial support and the prohibition is illogical.

It will also be argued by those wishing to keep the prohibition that nuclear is too slow. Relative to what? Emissions? This is simply wrong. All the evidence shows nuclear energy has reduced emissions faster than any alternative by a large margin.

By keeping the prohibition, we are betting our economic future on the proposition that anti-nuclear crusaders are right, and the rest of the world is wrong. This seems a bad bet.

In more detail the structure of this submission and the arguments are set out as follows.

1. Australia would gain large scale national benefits from acquiring domestic nuclear capacity. This is a strong argument and is independent of energy production considered in a narrow accounting sense. It is based on national interest, economic modernization and development, regional influence and strategic considerations. These have weight independent of other considerations in the terms of reference.

2. The specific responses to the terms of references are:

    a. Waste management is not a difficult problem. It is simply a management issue and can be dealt with using straightforward engineering techniques. It is a lesser problem than dealing with waste from solar panels. In addition, modern reactor technologies dramatically reduce the scope of the problem.
    b. Health and safety. This is again a management issue. Nuclear has a better safety record than all other energy production technologies. For example, hydro and rooftop solar kill more people per GWhr of electricity than nuclear.
    c. Environmental impact. Nuclear does less environmental damage in terms of emissions avoided and material resources required than all other energy production technologies.
    d. Energy affordability and reliability. If total systems costs are taken into account nuclear is no more expensive than, and on many projections less expensive than alternatives. If modern developments in nuclear technology are taken into account, it seems less expensive.
    e. Economic feasibility is interpreted in commercial or market terms. We argue that all government needs to do is to remove the legislative barriers to nuclear energy and to not treat it in a less favourable way than other low emissions sources.
    f. Community engagement is an important issue and is not seen as a barrier. In addition, new generation small modular reactors have less of a community concern potential and are easier to explain than single large units.
    g. We reject the idea that our workforce is somehow inferior and cannot develop the required skills. Workforce capacity can be built by starting with small reactors and skilling the workforce over a period of years. The fact that this would increase skill levels through all sectors from the universities to engineering and machine workshops is a strong argument in favour of nuclear energy.
    h. Security in energy supply would be increased in several ways. Domestically, intermittency problems would be solved. In terms of security more generally a nuclear programme would reduce reliance on imported oil and the vulnerabilities this brings. Involvement in nuclear energy programmes in the region would also reduce risks of poor management.
    i. National consensus should not present a barrier. There is already significant concern with our emissions and policies to reduce them and polls show that a majority of the population is not opposed to nuclear energy. A modern energy sector is critical to Australia's future and the public could easily be led to support a move into a higher technology economy that increases their security and the countries international and regional standing.
    j. Apart from the general considerations above, we also include under this heading a discussion of anti-nuclear arguments.

Much of the objection to nuclear is based on ideas about risk, costs and time that are either ill thought out, outdated, or a straightforward misunderstanding of technology and economics. They also depend on an extremely selective use of data.

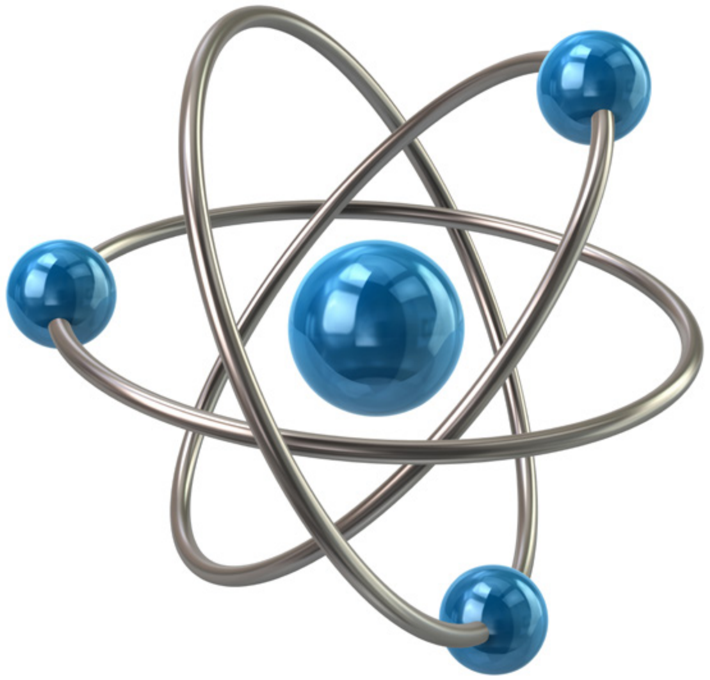
3. An obvious question implicit in the inquiry is, are there technologies that can currently be used and satisfy Australia's requirements? To answer this, we outline recent developments in small modular reactors. This section makes specific reference to technology developed by Nu-Scale.

4. We understand that talk is cheap. Can it be done? In order to answer this question and expand on Section 3 in the context of a real proposal we outline a business case prepared by DUNE for a small modular reactor installation. This is ready to deploy in a timeframe that will provide dispatchable power and cover the loss of coal fired stations.

It has been assumed that part of the reason for evaluating nuclear is to consider low emissions technologies. For this reason, cost comparisons are mostly made with reference to solar and wind. This restricts our discussion to scalable low emissions technologies.

We do not discuss coal or combined cycle gas. Both have high levels of emissions. Combined cycle gas is less than coal but still too high to solve emissions problems.

It is possible that carbon capture and storage may develop some time in the future. It is not currently commercially feasible and consideration



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DUNE
DOWN UNDER NUCLEAR ENERGY

1. Nuclear Energy: Some General Considerations on Australia's Development and Security

1.1. Introduction to the issues

Societies across the world are facing the problem of determining the generation mix that will provide acceptable levels of emissions while satisfying the imperatives of affordability and reliability. There is a high level of uncertainty about technologies and targets.

The one thing that is clear is that nuclear energy is increasingly seen as an essential part of the solution to these problems with recent endorsements by the IPCC, the UK Science and Technology Committee and the International Energy Agency. On the other hand, programmes that rely heavily on solar and wind, even in jurisdictions with large scale back up, such as Germany and California, are performing badly. **This raises the question. Is most of the world wrong, or should Australia remove its current prohibitions on considering nuclear?**
A serious consideration of this question had two components.

i. The first of these concerns' specific issues around energy generation in the narrow sense. These are set out in the Terms of Reference. They will be addressed in detail in the subsequent sections.
ii. The second is more general. The trajectories chosen at this stage will have long term consequences that go well beyond short term profit and loss figures. These trajectories will impact on the modernization of the energy sector, economic development and our role in the region.

The second goes to the general context in which we think about the energy sector and how it fits into longer term economic development and the type of economy we want to see emerge. Do we want to see a modern economy with capacity to engage in a region in which nuclear energy becomes increasingly important or do we want to remain a lower technology economy with limited capacity?

These issues go well beyond narrow accounting figures and short-term fixes for energy problems. They capture large scale external benefits that don't turn up on balance sheets.

In many cases figures on costs and risks don't make sense when taken in isolation. Energy problems have to be solved with some technology. The only sensible question is, does technology A cost less than B or is A riskier or does it produce less waste than B when all factors are taken into consideration?

If energy systems are considered without bearing in mind long range consequences and total social costs we will end up with a partial perspective. This ignores basic principles of economic analysis. It is almost guaranteed to produce sub-optimal solutions.

In the next section we try to put the discussion of nuclear energy into the broader context by elaborating on some of these points. We then address the specific terms of reference.

1.2. Modernization and options

Australia has a large and growing demand for energy and a number of power stations that provide dispatchable generation are nearing the end of their economic life. This provides almost textbook conditions for modernizing the energy sector and bringing new technologies online.

The problem is that Australia is almost alone amongst first world countries in having no nuclear capacity and current legislation makes it impossible to acquire it. This means it is committing itself to long term decisions under the handicap of artificial restrictions.

This violates almost every principle of mathematical optimization, systems engineering and policy choice. It will almost certainly produce poor results. To restrict decisions on ideological grounds may put our economy on a trajectory of second-rate and outdated technological solutions and high-power prices.

There is a great deal of uncertainty about future developments in technology. One way to bet is that the most probable large-scale technological developments will be in new generation nuclear. America, Canada, Japan, Europe, Russia, China and elsewhere are all actively pursuing new designs and high-tech companies such as Bill Gates's Terra Power and Rolls Royce are investing heavily. There is also a major international consortium working on Generation IV reactors.

In 10-20 years from now, a new generation of nuclear reactors will reach economic commercialisation that consume spent fuel. Thorium reactors will have wider applications than just electrical power and desalination thanks to their very high operating temperatures and will offer much greater flexibility and potentially lower cost.

Until and unless Australia develops capacity it will be locked out of these developments. Is that a risk worth taking with our national future?

If we continue along the present trajectory, we are assuming that the only advances will be in the weaker solar and wind technologies and that these are not exhausted. This seems a risky way to bet our future development. At the least there is a non-negligible probability that we will be stranded with an out of date and expensive energy sector.

To put it bluntly, to rule out what has proven to be the most effective scalable technology for producing low emissions energy and hope for the best is not good policy. This would be true even at lower levels of uncertainty. In the current environment it is wilfully irresponsible.

It is also necessary to consider the even greater energy needs that go beyond our existing electricity supply/demand. Hydrogen is emerging as an important store of energy for transport and industrial uses. Nuclear can produce this easily and cheaply as a by-product of its energy output and some reactor designs are specifically intended to do this. As weather patterns shift, desalination will become more necessary. Much of the energy needed to produce this can be extracted as a joint product from nuclear power.

Even under the most pessimistic assessment of nuclear energy all this creates a strong case for keeping our options open. In a world of uncertainty, we should be developing capacity across a range of possibilities.

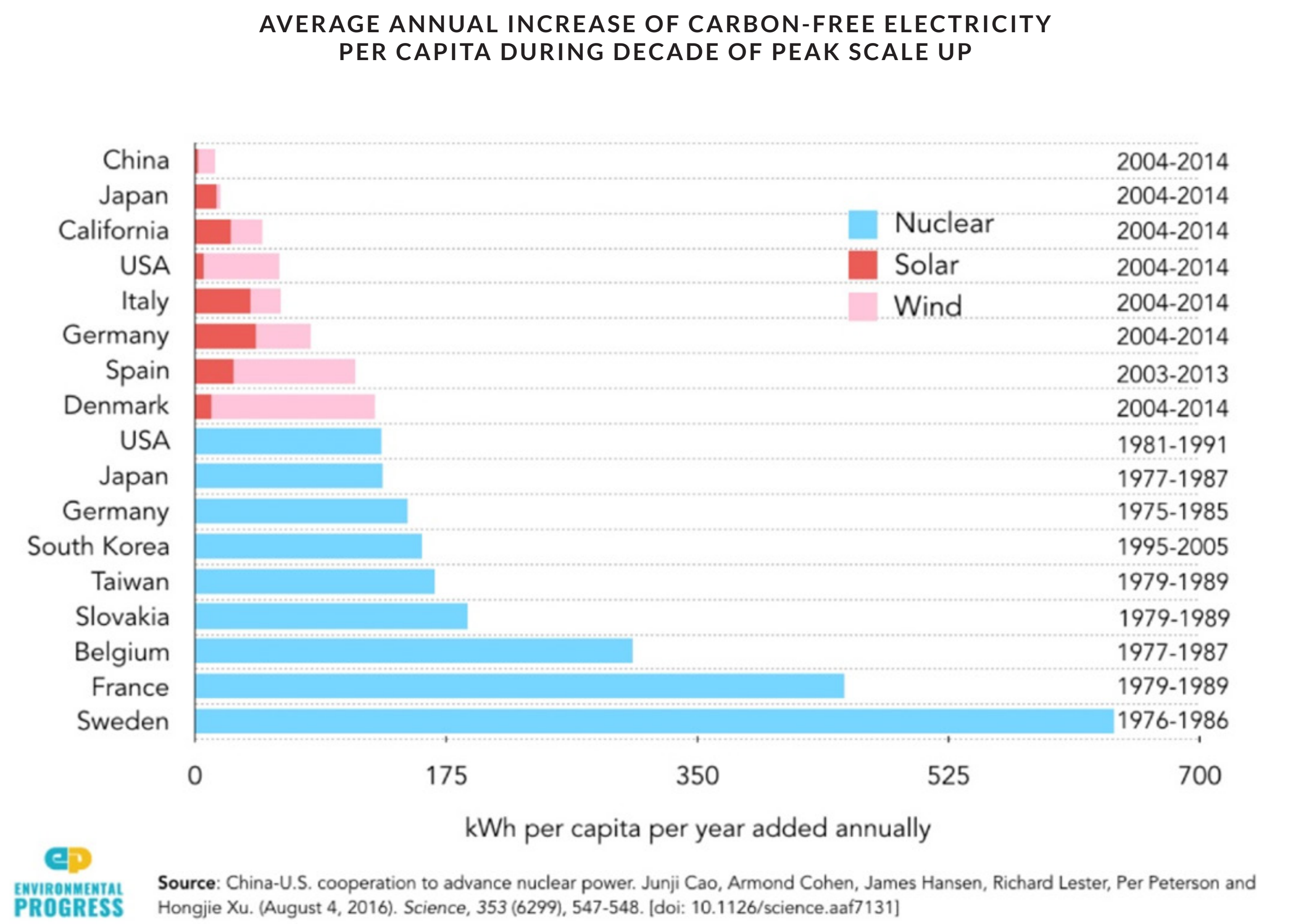


Figure 1. Scale-up rates for carbon-free electricity
Ref: https://environmentalprogress.org/the-complete-case-for-nuclear

It is by no means clear that solar and wind will be able to provide all, or even a large percentage of, electricity for a modern economy. Programmes that rely heavily on solar and wind, even in jurisdictions with large scale back up, such as Germany and California, are stagnating and have not shown any success in reducing emissions. Among the programmes which have managed to produce cheap energy and de-carbonize their electricity supply are France and Sweden. Both rely on nuclear energy.

Anti-nuclear groups in Australia are essentially claiming that most of the rest of the world and scientific bodies like the International Energy Agency, the IPCC and major scientific institutions like MIT are wrong. This seems a very bad bet.

1.3. Emissions control

The government's responsibility as a steward for the environment is to consider the impact of energy production in the larger sense of emissions, land use, end-of-life disposal and conservation of resources which do not have ready substitutes such as oil and gas. It is true that emissions reductions cannot be the sole parameter informing policy and reductions must be achieved in an economically responsible and, where possible, beneficial manner. It is also true that emissions must be reduced in order to reduce the risk of catastrophic climate change. We do not need to consider details here. What is certain is that there will be strong domestic and international pressures for Australia to dramatically reduce emissions over the next several decades.

From this perspective the argument for removing the prohibition on nuclear is clear. Even using what is now very outdated nuclear technology the only programmes that have succeeded in making rapid reductions in emissions are those that have relied heavily on nuclear energy.

This might be compared with the German experiment under the Energiewnde to replace nuclear with wind and solar. (see Figure 2)

It is estimated that Germany will spend about $580 billion by 2025 to get less than fifty percent of its electricity from low emissions sources.* Its programme has so far not produced any meaningful reduction in emissions.

If the same amount had been spent of nuclear it would have bought about between 70 - 100 ++ high cost old style reactors. Consumption of electricity is about 600 TWh per year. It follows that all this would have been produced by the reactors and a substantial proportion of fossil fuel used for transport could instead be electric vehicles.
Ref:https://www.thegwpf.com/german-energiewende-to-cost-staggering-e520-billion-by-2025-first-full-cost-study-finds/

We deal with emissions in detail under item j of the Terms of Reference.

FRENCH AND GERMAN ELECTRICITY PRODUCTION IN 2018 - HOW DIRTY WAS IT?
A COMPARISON OF HOURLY SPECIFIC CARBON INTENSITY

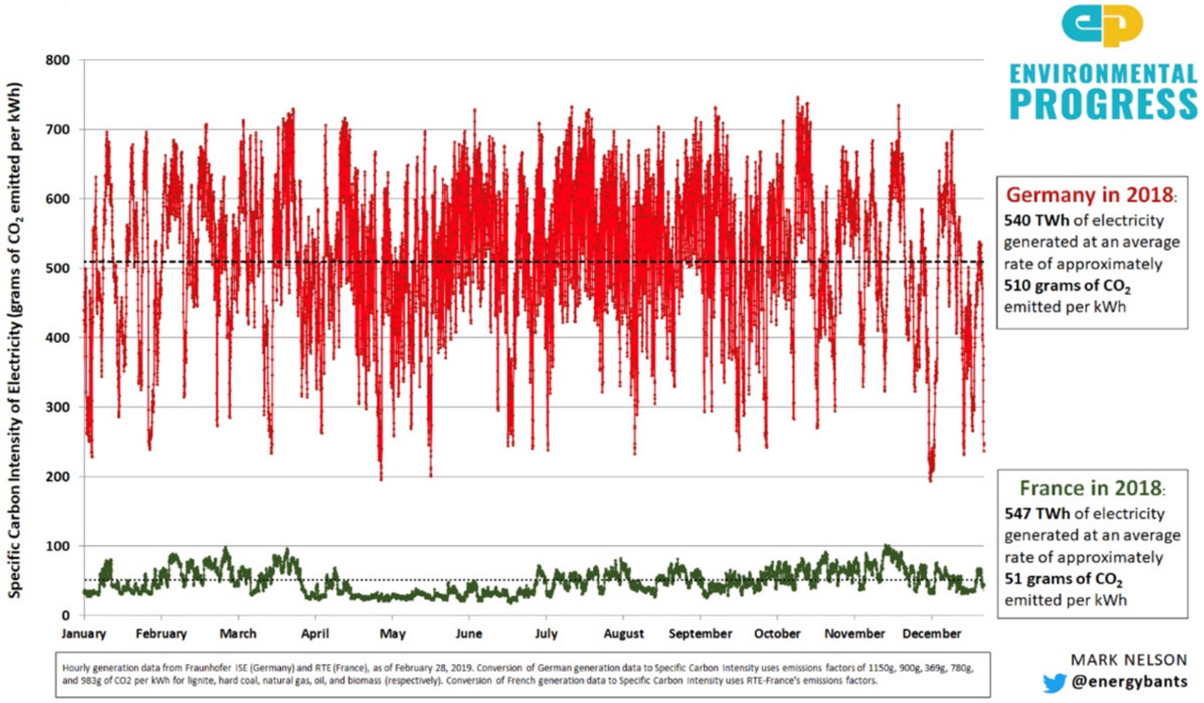


Figure 2. Emissions intensity of German and French Power Sector
Ref: https://environmentalprogress.org/the-complete-case-for-nuclear

1.4. Regional standing and economic opportunity

The countries in our region will increase their consumption of energy by about thirty to forty percent in the next few decades on most estimates*. On the other hand, they have high population densities and are poorly suited to solar and wind. This leaves them little option but to consider nuclear energy. Indonesia, Vietnam, Malaysia, Singapore and the Philippines are considering or planning to acquire nuclear technology, South Korea is a major producer and exporter and Japan continues its programme and export industry. China is marketing its own capabilities in a vigorous manner.

Ref:https://www.iaea.org/newscenter/statements/nuclear-power-and-global-challenges-energy-security

If Australia wants to be part of the region's development, it would benefit from having the capacity to help our neighbours build and manage modern low emission energy sources and grids. This would enhance our standing and economic integration. On the other hand, if we do not modernise we will be left as a relative technological backwater and be seen as such.

Developing these capacities would also bring significant economic opportunities. Australia could leverage its comparative advantage in intellectual and technological capacity to develop a sophisticated export market in the region. This might include installation, facility management, fuel provision, managing spent fuel, grid design and management, risk and safety management, financial and legal services.

It is difficult to assess the extent of the economic opportunities that would be created by engagement in the region. To give a ballpark, the British government is heavily supporting development of a small modular reactor by Rolls Royce. It is estimated that this will add about $UK 100 billion or $A 180 billion to the economy and create an export market worth about $UK 250 billion or $A 450 billion*.

Ref: http://world-nuclear-news.org/Articles/UK-commits-funding-to-Rolls-Royce-SMR

Although it is clear that South East Asia will need to develop its nuclear capabilities, the timing and extent will depend on political and economic considerations. These cannot be fully predicted. What can be predicted is that maintaining legislation that prevents firms making decisions on commercial grounds guarantees that none of these opportunities will become available.

1.5. Strategic considerations

Looking further ahead Australia is now confronted with an uncertain international environment in which power balances may shift and demands for scarce resources may increase. These will bring new challenges and may require greater self-reliance.

Currently our capacity to respond is severely limited by our lack of technology. We currently have no option but to refit nuclear submarines with diesel engines. Although nuclear propelled vessels are not part of Australia's strategic vision in the foreseeable future, the decision not to develop a modern fleet should be a military choice. It should not be imposed by lack of capacity.

1.6. Errors in analysing broader considerations

In many cases the broader considerations outlined above are undervalued because of the techniques used. This raises several complicated issues in economic theory that will be ignored here. For the present we make the point with three examples.

i. Much of the analysis of energy costs is short term and marginal. A standard analytical technique is to hold everything else constant and look at marginal changes, say adding a small additional capacity. If we are considering long term development, however, the entire trajectory needs to be assessed. What might make economic sense as a small increment might not make sense as part of a longer-term trajectory.

ii. Comparisons of technologies frequently ignores full systems cost and the problem to be solved by treating incommensurate technologies on the same footing. For example, dispatchable and non-dispatchable technologies are treated as if their output had the same value. A bicycle may have a smaller capital outlay than a truck. On the other hand, if the problem is to haul rocks this doesn't mean it is cheaper per ton transported.

iii. Most of the techniques used to analyse costs and policy options do not deal with uncertainty. By uncertainty is meant non-quantifiable outcomes as contrasted with probability. With uncertainty the standard rules of optimization place an economic value on flexibility and penalize irreversible decisions. To simply preclude a particular technological trajectory violates this.

1.7. Remarks on what follows

In what follows we set out the details of our response to the Terms of Reference. Some of the general points made above will be mentioned again where appropriate. They should be thought of in the context of the more general discussion in this section.

2. Terms of Reference

This section addresses the specific terms of reference of the 2019 federal inquiry in the context of general nuclear energy technology.

2.a. Waste Management, Transport and Storage

The first thing to note is that what is called nuclear waste is spent nuclear fuel and it has a great deal of value. Management and storage of this is often seen as a major impediment to nuclear energy. This is wrong.

a1. Management

Management goes to the heart of this. Spent nuclear fuel requires careful handling but this is simply a management issue in the same way that keeping a 400-ton airliner in the sky is a management issue. The spent fuel from reactors has been safely dealt with for nearly sixty years on the site of nuclear power stations with no accidents. This is done with the relatively simple expedients of using dry casks. It has been demonstrated that these casks can withstand a direct hit from a jet plane with no discernible damage. In other words, they can be transported with almost zero risk. Although the fuel can be reused, at a worst-case scenario this method of storage can continue indefinitely.

Ref: [https://www.nap.edu/download/11263, pg 108 of 127]

a2 Minimal danger

Spent fuel is not as dangerous as public perception has it and containment is relatively easy. For example you could swim in a cooling pool for spent nuclear fuel without harm, provided you stayed a metre from the top of the fuel assemblies.

a3. Small volume

The volume of spent fuel is several orders of magnitude smaller than people imagine and much less than the toxic waste from some alternative sources. It is about 300 times less than the toxic waste produced by solar for the same amount of energy*.

Ref:https://wattsupwiththat.com/2018/12/23/solar-panel-waste-a-disposal-problem/

The total amount of spent fuel produced in the US in the last sixty years would fit onto an American football field at a depth of less than 10 metres. This makes it easy to contain and transport. Since 1970, the global nuclear industry has conducted over 7000 transport operations of spent nuclear fuel without a single incident resulting in radiation leakage or personnel injury/sickness.

Ref: (https://www.nei.org/fundamentals/nuclear-waste)

It is estimated that the amount of waste from solar panels in Australia by 2050 will be one and a half million tons*. This contains toxic materials like lead and cadmium. It is about six times the total nuclear waste from fifty years of producing over ten percent of the world's electricity. If approximately twenty five percent of Australia's electricity were produced using current nuclear technology between now and 2050, the spent fuel would be about 375 tons.

Ref: https://theconversation.com/theres-a-looming-waste-crisis-from-australias-solar-energy-boom-117421

If we compare nuclear waste with current energy systems, we get this. An average Australian will produce about 1, 500 tons of carbon dioxide in a lifetime, or about 300 average elephants. If all the energy required were produced by a slow neutron reactor, it would produce about 17 kg or about the amount that would fit into one or two soft drink cans. If a fast neutron reactor would use it would be a few grams. It would fit into an espresso cup.

a4. Value of spent fuel

It often isn't understood that spent fuel is a valuable source of energy for the future. A typical once through slow neutron reactor burns out about three percent of the available energy. This could be reprocessed to fuel all existing and currently planned reactors for several hundred years without any mining. If fast neutron and liquid fuelled reactors are built the spent fuel can be consumed with no re-processing. This would leave a tiny residue of radioactive material requiring storage for no longer than 300 yrs.

a5. Economic opportunity from spent fuel

Instead of being treated as a problem spent fuel is an economic opportunity. There is significant potential for Australia to manage spent fuel storage and retrieval for the region. If this capacity were acquired through experience with a domestic nuclear facility it would provide a pathway to building a large-scale high technology industrial sector.

a6. Terrorists

It is sometimes claimed that terrorists can steal spent fuel and do something with it, such as build a bomb. Facilities for holding spent fuel are heavily guarded and moving or breaking into a dry cask or storage facility would require maybe weeks of industrial level activity. Even if waste were acquired it is almost impossible to use it to construct a weapon without industrial capacity on a country wide scale.

a7. Illogical time horizons

Time horizons are often treated illogically. It is often claimed that spent fuel must be stored for thousands of years. This is simply wrong as explained in a4. On even a fraction of those time horizons it will be needed as a source of energy.

a8. Long term sequestration

If it is thought that long term sequestration is required there are techniques to provide long term security readily available. Sweden and Finland have successfully engaged their citizens to build consensus and acceptance that have allowed those nations to develop geological repositories. In addition, as more countries consider expanding the use of nuclear to deal with energy problems new methods are being developed.
One method that is particularly interesting has been developed by the Californian company Deep Isolation™. This uses directional drilling and wireline technology developed by and used daily in the oil industry. This would be a cost effective, highly secure and reversible storage method for spent nuclear fuel.

2.b. Health and Safety

The health and safety effects that are of most concern are those of health in the usual sense of sickness and accidents and in the more severe sense of some sort of nuclear accident.

b1. Health.

Nuclear is the safest of all forms of energy production in terms of deaths per unit of energy. Figure 3 is a standard mortality table which is illustrative but fails to account for deaths from dozens of natural gas explosions in North America since 2007 when natural gas began its dizzying climb to become the ubiquitous fuel in the US, thanks to hydraulic fracturing technology.

It is also estimated that nuclear has saved almost two million lives by displacing fossil fuel and reducing air-borne emissions known to attack the respiratory system.
Ref: [https://pubs.acs.org/doi/abs/10.1021/es3051197]

b2. Accident.

The risk of accident probably looms larger in perceptions than health. Nothing is without some risk, as the previous table shows. The only question is, what does the comparative risk look like?

If we are serious, we need to discuss risk of accidents with current generation reactors or what is known as Gen III and Gen IV. These include small modular reactors. It is as silly to look at risk in terms of problems with second generation reactors designed in the 1960's as it is to look at airline safety with reference to the Hindenburg zeppelin disaster.

In essence, current and coming reactors are completely contained and have passive safety systems. This means that in case of an accident such as an earthquake or monster tsunami the reactors cooling system functions without any external intervention or the need for external power.

In the case of more advanced designs and small modular reactors a meltdown is virtually impossible. Most of these achieve the nuclear triple crown – no power, no additional water and no operator action required to achieve indefinite cooling.

Consider the only three accidents that have occurred.

i. Three-mile Island. Poor training and instrumentation led to overheating. Safety systems worked to shut down the reactor. There was no loss of life and a very small, intentional leak of radioactive gas. There were no adverse health effects of any kind*.
Ref: (https://www.world-nuclear.org/information-library/safety-and-security/safety-of-plants/three-mile-island-accident.aspx)

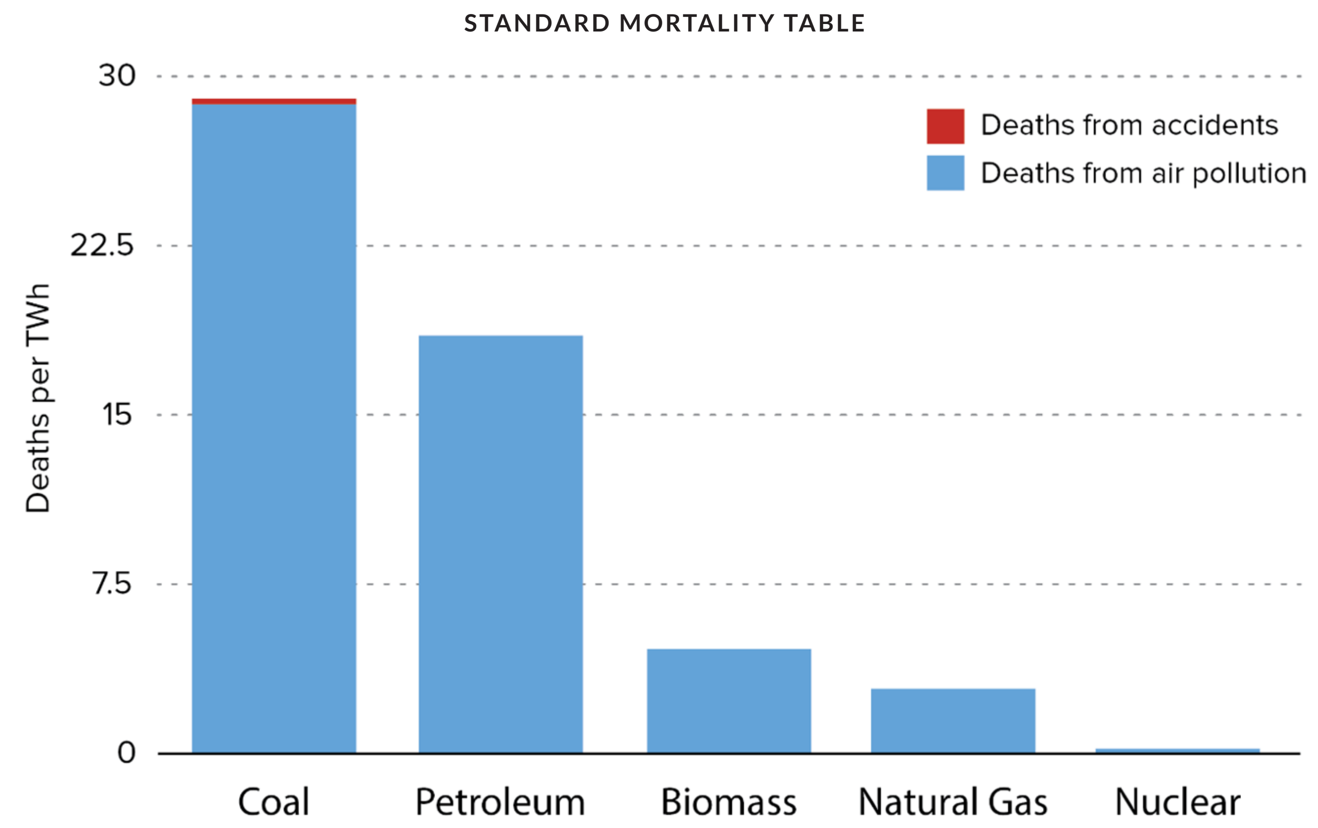
ii. Chernobyl. This is an old RBMK reactor. It was built under the peculiar conditions that applied to the USSR in the 1970's. It had no containment or commercial safety features and several inherent risk factors that do not exist in any other commercial reactor. It is important to point out the graphite-moderated technology of the Chernobyl reactor has never been allowed in western nations due to its inherent lack of safety. It is reasonable to assume that Australia would have sufficient competence to follow US, UK and Canada and to not adopt the cavalier attitude to nuclear safety of the Chernobyl plant managers.

The World Health Organisation and UNSCEAR (UN Scientific Committee on the Effects of Atomic Radiation) found that beyond the 28 emergency workers who died of acute radiation sickness the mobilisation of iodine-113 led to approx. 6500 extra occurrences of thyroid cancer. Of these 15 were fatal. Many of the emergency worker deaths would have been prevented if adequate protection had been available at the plant.

These organisations also estimate that, in the worst case, a further 4,000 cancer deaths may occur in the coming decades amongst the 626,000 emergency workers and those in the most highly contaminated areas. This figure is highly speculative. To get a perspective it is estimated that coal fired power stations in NSW will kill about 3, 400 people and cause about 4, 400 cases of diabetes during the remainder of their operations.
Ref : Sydney Morning Herald Peter Hannam November 21, 2018 'Scandal': NSW coal power plants will kill thousands before they close https://www.smh.com.au/environment/sustainability/scandal-nsw-coal-power-plants-will-kill-thousands-before-they-close-20181120-p50h66.html

There are no recorded instances of mutations or birth defects resulting from the Chernobyl disaster.

It has been found that the main public health problem emerging from Chernobyl is large scale effects on the mental health of the population.



ENVIRONMENTAL PROGRESS Source: Markandya, A., & Wilkinson, P. 2007. Electricity generation and health. The Lancet, 370(9591), 979-990.

Figure 3. Mortality table for various fuel types

This is due to misinformation and exaggerated fears about radiation.
Ref: https://www.who.int/ionizing_radiation/chernobyl/backgrounder/en/ https://www.thelancet.com/journals/lancet/article/PIIS0140-6736(05)67346-1/fulltext

iii. Fukushima. A 1960's reactor that relied on external power sources. Overheating and core meltdown due to poor placement of diesel back-up generators. According to international reports the loss of life is zero. The current and estimated future cases of cancer are statistically undetectable.

The loss of life from panic and unnecessary evacuation was approximately 2,000.
Ref: [https://www-pub.iaea.org/MTCD/publications/PDF/Pub1710-ReportbytheDG-web.pdf]

For comparison, consider risk factors inherent in other systems that cannot produce dispatchable and reliable energy. One possible indicator would be risks associated with severe weather conditions such as those that produce extreme heat in the absence of power for sustained high demand for cooling. To get some orders of magnitude on this consider the 2003 heatwave in Europe. This killed 70, 000 people. In 2010, a 44-day heat wave in Russia is estimated to have killed 56,000 people.
Ref: [https://www.who.int/globalchange/publications/heat-and-health/en/]
Like the airline industry, the nuclear industry has investigatory bodies and programmes in place to share information between operators. It also reviews designs and practises on a routine basis in response to experience and insights gained at other facilities. After Three Mile Island and then Fukushima, western nuclear regulators and operating companies comprehensively reviewed their own practises, designs and vulnerabilities to similar events.

We have confidence in Australia's intellectual and technical capital and abilities. Our industry has an excellent safety record and world class regulators in radiation and other complex, high energy sectors such as refining, LNG and offshore O&G production.

There is no reason to doubt that a properly resourced ARPANSA can effectively regulate a nuclear industry and ensure its safe operation.

2.c. Environmental Impacts

The very strong argument for nuclear is that it has the smallest environmental impact of any scaleable energy source. We consider emissions, material, land use, burden of mining and extracting, water use.

c1. Emissions.

The figures on emissions are undisputed and we will not elaborate. The table in Figure 4 (next page) is typical.

In many cases these figures understate the relative emissions of solar and wind. This is primarily because, in the absence of nuclear, solar and wind need to be backed up either by batteries, fossil fuels or pumped hydro. For example, a massive expenditure on solar and wind in Germany has not managed to reduce their emissions by any meaningful level.

LIFE CYCLE EMISSIONS

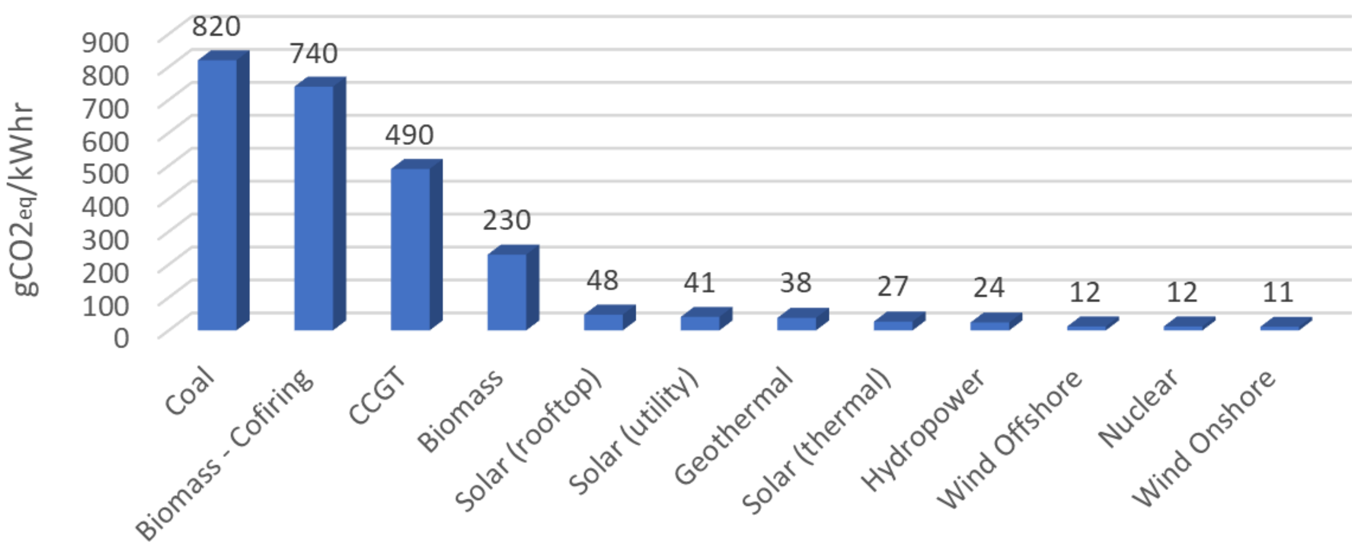


Figure 4. Lifecycle emissions (grams of CO2 equivalent / kWhr). Source: IPCC 2014

c2. Material

The graph in figure 5 shows the raw material inputs required to produce a TWhr of energy for various technologies. Like its negligible operating emissions, nuclear has a vanishingly small impact on our planet's finite resources.

c3. Land and visual amenity.

The only figures that make sense here are rough estimates given large variations in sunshine, average wind speeds and topology. Using solar, wind and nuclear in a single geographical area and within a single energy market, figures from California demonstrate the most efficient, single-axis tracking utility scale solar power stations require 450 times more land than nuclear energy to produce the same amount of electricity whilst wind installations require 400 times more land.

In addition to large areas of land there are also issues around the visual amenity and material embodied in the many new transmission lines that renewable energy requires to connect to the grid. In contrast to the nuclear power which can and does make ready use of existing transmission infrastructure.

MATERIAL CONSUMPTION FOR VARIOUS ENERGY TECHNOLOGIES

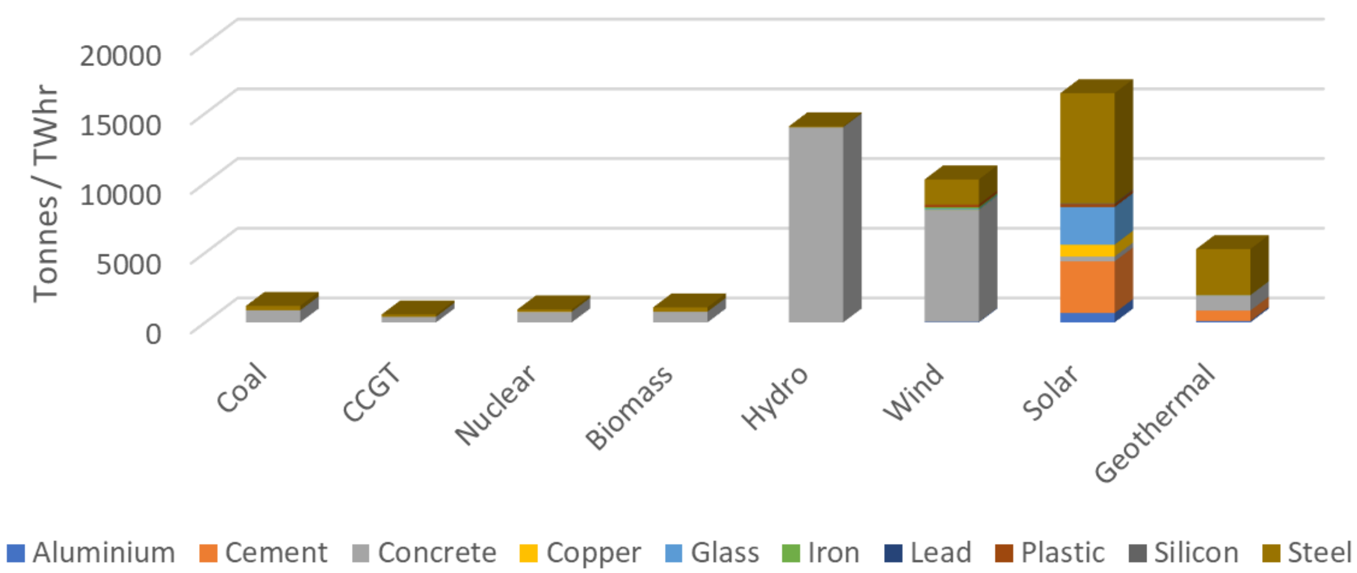


Figure 5. Material utilisation for plant construction for one TWhr energy. Source: US DOE "Quadrenniel Technology Review 2015", Table 10.4, pg 402

c4. Extraction.

The world production of uranium is about 65 thousand tons and this is enriched to produce about 10 thousand tons of fuel. Roughly 7,300 million tons of coal are mined to produce about four times as much electricity or a ratio of about 110: 1. This only gives a burn out of about three percent of available energy. If all this were used the ration would be 3,600:1.

It is estimated that the oceans contain four to five billion tons of uranium. This can be dissolved out using polymer mats or fibre yarn with essentially zero environmental impact.

c5. Energy return on investment

An important indicator of total environmental impact is energy return on energy invested. This is the amount of energy a system produces for each unit of energy used. The higher the return the easier and less expensive it is to meet energy needs. To maintain a modern economy an energy return on investment of about seven is required to allow the energy to be processed, transported, managed and so on. See figure 6 below, of typical figures.

c6. Water.

The amount of water used by a nuclear power plant is not as significant as often thought. It is about the same as that used by any other thermal plant such as a coal or gas fired plant. It is used to dump heat in order to provide efficiency in the transfer of energy between the turbines and the source of heat. It is not used in the reactor itself.

It follows that if all our electricity were produced by coal or gas, the water used would be about the same as if it were produced by nuclear energy.

If all our electricity were produced by solar and wind water use would be essentially zero.

Back of the envelope calculations show that if all electricity were produced by nuclear the amount of water used would be about one tenth of that required to irrigate our cotton crop. This conservatively assumes a reactor uses about 2500 litres per MWh which can be reduced by depending on the cooling method selected.
It is not necessary that this is fresh water. The location of nuclear reactors is flexible, and they are typically located near the sea.

It is also possible to use dry cooling be circulating air across a heat exchanger or a mix of water and dry cooling. Depending on energy sales agreement, stand-alone dry cooling is possible for small modular reactors where less thermal energy is to be dumped. In this case water use goes to zero.

ENERGY RETURNED ON INVESTMENT
RELATIVE TO THE BREAKEVEN VALUE OF 1

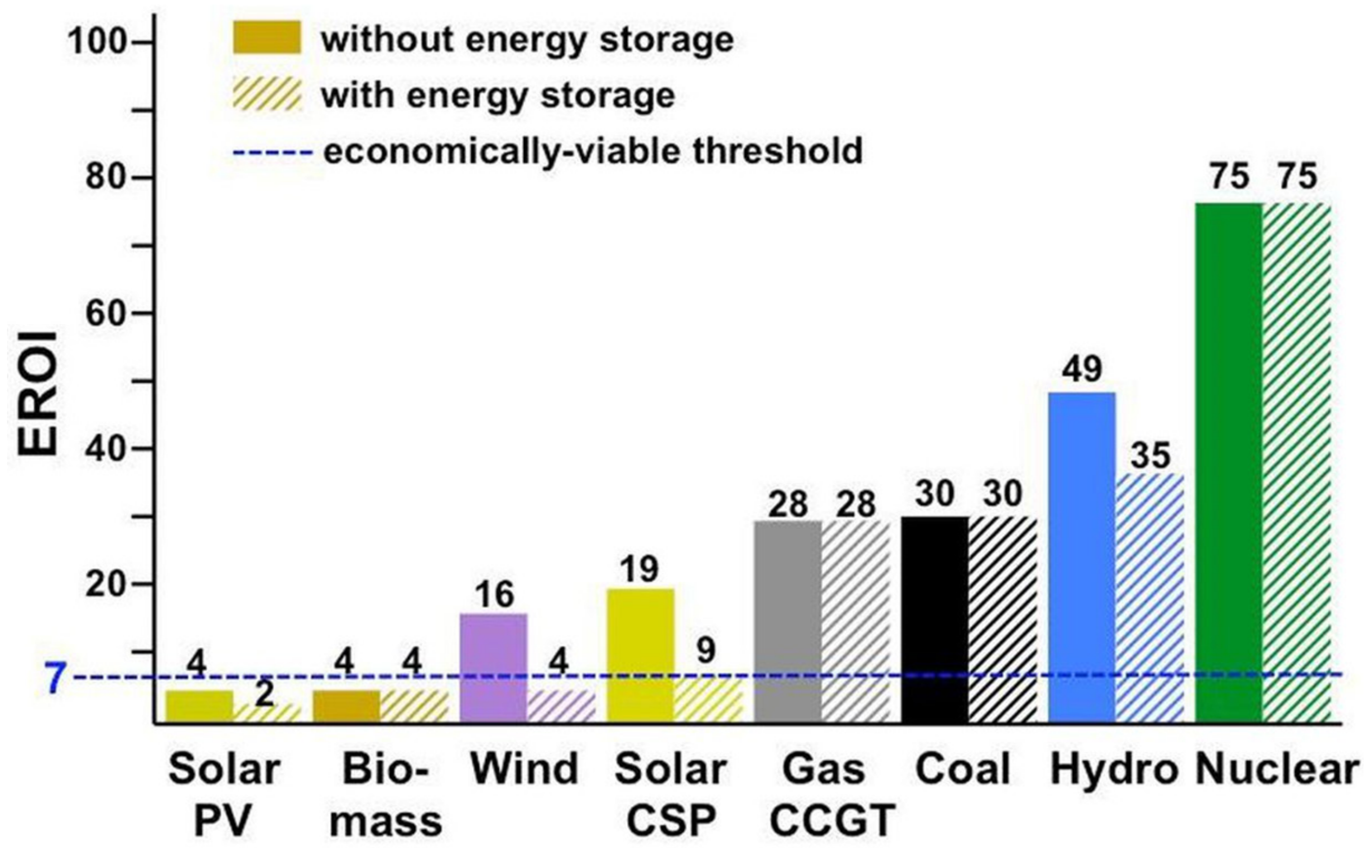


Figure 6. Energy return on Energy Invested

Ref: https://www.forbes.com/sites/jamesconca/2015/02/11/eroi-a-tool-to-predict-the-best-energy-mix/#4bed8060a027

c7. Waste.

The spent fuel from a nuclear plant is completely internalized. All other sources of electricity generation dump their primary waste into the environment. It has already been explained that the volume of waste is much less than that produces by other thermal sources and solar and wind which require large amounts of material that require replacement every twenty years or so. It is easily contained until it can be used as fuel.

2.d. Energy Affordability and Reliability

The terms affordability and reliability are interpreted in the broad sense of total costs across the economy of different energy sources. This is called total systems cost. It includes all cost factors such as the cost of extending the grid and building new infrastructure, buffering costs, the cost of back up etc. These may be of the same order of magnitude or more than the cost of the plant itself. It also includes other costs such as loss of land and cost of power outages. These are what are referred to as externalities in economics and policy analysis. They are a critical component in any analysis of costs and benefits.

Item e in the Terms of Reference 'economic feasibility' is interpreted in the narrower sense of commercial considerations and price for the consumer.

d1. General remarks on total systems costs

The figure of most interest to policy makers is total systems costs since these must ultimately be covered one way or another. This might happen through subsidies, or loss of growth or price to the consumer.

The overview is that the figures on total systems cost show a wide range of variation depending on assumptions and conditions. There is nothing in these figures to suggest nuclear is more expensive than other scaleable energy sources such as solar and wind. Under some figures it is a good deal cheaper. This is all that is needed to remove any objection to nuclear on cost ground.

We follow standard economic practice and treat costs in terms of opportunities foregone. In other words, cost has no meaning in isolation. The only relevant consideration is the relative cost of different technologies with the same capacity.

For the purpose of this submission we have not considered coal, gas and biofuels. These are all high emitting energy sources. One of the implicit aspects of the inquiry seems to be to consider nuclear in the context of emissions reduction.

It is possible that carbon capture and storage may develop on a commercial scale. It is currently not available. Most current figures seem to indicate that it would be at a significant cost disadvantage when compared to nuclear.

From the perspective of the energy system it depends how you do the figures, but to claim nuclear is significantly more expensive than other low emissions energy sources is a very selective reading. It requires that most items in systems cost are ignored.

Before proceeding to this and the next section two things must be stressed:

i. There is a great deal of uncertainty about emissions reduction and technologies and figures can only be a rough guide to long term optimality. Many of the figures currently in circulation make claims to certainty that are essentially meaningless from a mathematical perspective.
ii. Penetration level is particularly important in considering costs and is often overlooked in comparing technologies. A major reason for considering nuclear is that it allows us to reduce emissions. If the international community does what it says and moves towards zero emissions, the technologies chosen must at the least provide all our electricity and a considerable portion of other energy as well.

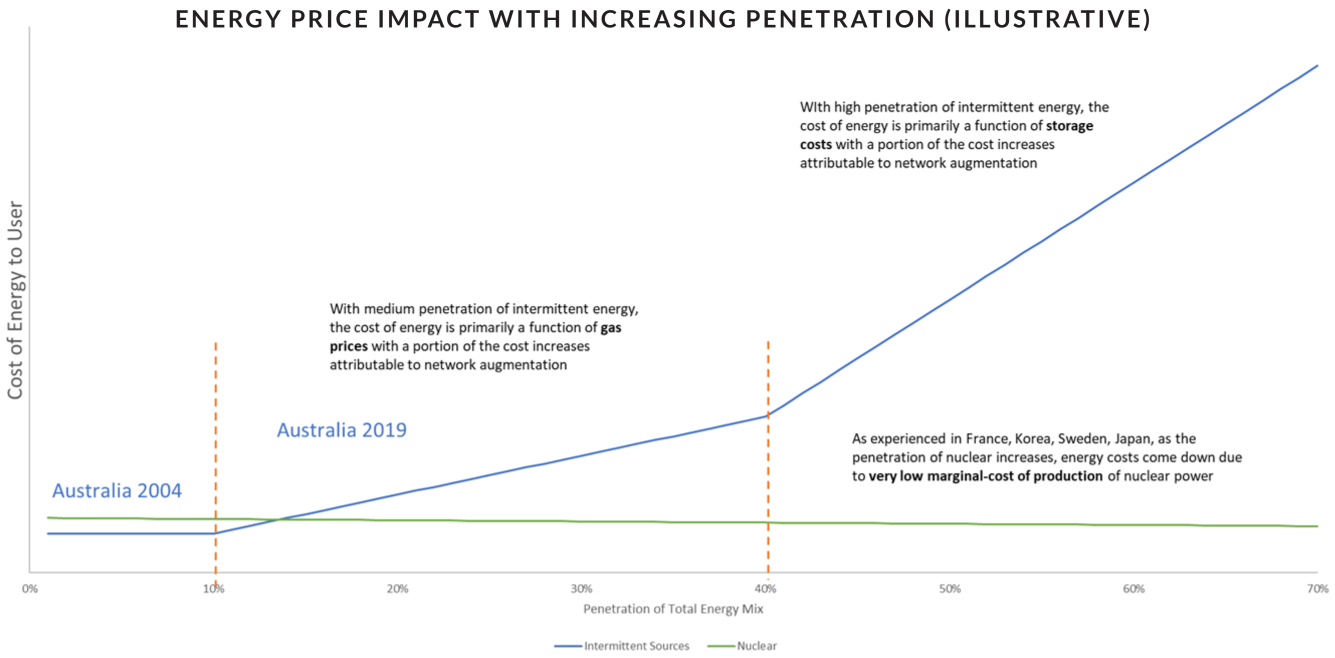


Figure 7. Cost profile with increasing penetration for renewable energy and nuclear. Synthesised from the following sources - "Taming the Sun" Varun Sivaram, "A Bright Future" Joshua S. Goldstein and Staffan A. Qvist, "Dumb Energy" Norman Rogers.

It must be noted that the higher the penetration by solar and wind the more expensive the grid level costs. This cost increases non-linearly. For example, doubling the penetration more than doubles the cost. In Australia issues are already emerging with solar and wind at about seven percent of electricity. What happens at seventy percent?

It will be also be noted that nuclear gradually lowers energy prices as its penetration increases.

We will return to the analysis of penetration throughout the submission since it has implications for costs, intermittency, security and back up.

d2. Total and marginal cost figures

The figures and estimates currently published on the cost of nuclear and other forms of energy are often based on a misunderstanding of the economics. In many cases they also fail to understand the possible range of figures that different assumptions will produce.

One of the most important mistakes is that marginal costs are confused with total economic cost. This creates serious distortions. A marginal cost is what happens if you add an extra small unit of generation to the existing grid without changing anything. This ignores systems cost or real costs from a policy perspective.

In order to provide some understanding of these issue we set out a range of figures. This starts with the marginal and working towards a proper set of real economic costs.

d2.i. Levelized cost of electricity. The figures that are most frequently used to claim nuclear is more expensive than other sources of electricity come from levelized costs. The problem here is that these are narrow accounting costs and not economic costs. They are usually constructed as a guide for short term investors rather than as a tool for policy analysis. A typical set of these figures is produced by Lazard in figure 8 on the following page.

The problem here is that these figures cannot be used to represent the total cost of energy sources. Like most levelized cost analyses they ignore most grid level costs and penetration levels since these do not concern short term investors. They also ignore external benefits such as emissions reduction, security of supply, health and back up costs avoided, and other items included in total systems cost.

These figures assume an eight percent discount rate. This basically means anything produced after about twenty years has almost no value. In this case the economic value of long-lived infrastructure like nuclear is discounted away. The cost of replacing short lived plants and disposing of the waste material is also discounted away.

In order to demonstrate the effect of interest rate compare Lazard's figures with levelized costs at a 3% discount rate. These range from

Korea $US 29 per MWh
UK $US 64 per MWh*

Ref: World Nuclear Association. Nuclear Power Economics. https://www.world-nuclear.org/information-library/economic-aspects/economics-of-nuclear-power.aspx

Another problem is that levelized costs assume every unit of energy produced has equal value. This is only correct if buyers are mandated to take it. If not, value depends on demand. If supply is intermittent, significant amounts of output may have no value.

d2.ii. Estimates for nth of a kind. The question of costs is essentially directed at current and future costs and not historical costs. This is often misunderstood. Many comparisons use very expensive one/first of a kind nuclear reactors to compare with the results of a heavily subsidised programme to produce solar and wind at scale.

The Energy Innovation Reform Project has tried to estimate costs if new generation nuclear reactors were developed at scale. Their findings are summarised below.

COST SUMMARY. $US PER MWH

	Average	Minimum	Maximum
Capital cost	$3742/kW	$2,053/kW	$5,855/kW
Operating Cost	$21/MWhr	$14/MWhr	$30/MWhr
Levelized cost	$60/MWhr	$36/MWhr	$90/MWhr

Ref: Energy Information Reform Project, 2018. What Will Advanced Nuclear Power Plants Cost? – A Standardized Cost Analysis of Advanced Nuclear Technologies in Commercial Development. [Online] Available at: https://www.innovationreform.org/wp-content/uploads/2018/01/Advanced-Nuclear-Reactors-Cost-Study.pdf

d2. iii. Levelized and grid level costs. The OECD has provided grid level costs for various technologies. In order to show the range of uncertainty around the figures and the importance of the discount rate the OECD levelized costs at a three percent interest have been integrated with grid level costs. This gives the following table.

OECD GRID LEVEL COSTS $US PER MWH

Average	Minimum	Maximum
Penetration level	10 %	30%
Nuclear	53	53
On-shore wind	85	96
Commercial solar PV	126	143

Ref: OECD The Full Cost of Electricity Provision. http://www.oecd.org/publications/the-full-costs-of-electricity-provision-9789264303119-en.htm

It is necessary to be cautious with these figures. Apart from using a different interest rate to Lazards, the OECD figures are an attempt to cover all economic costs at the plant level including externalities.

It is clear, however, that it is misleading to claim that levelized costs show nuclear more expensive than other technologies.

d2.iv. Emissions reduction. The best way to assess a technology is with reference to the problems it is trying to solve. One reason for considering nuclear is to help solve emissions reduction problems. Instead of asking how cheap a technology is we might ask what is the cost benefit analysis in terms of emissions reduction.

LAZARD'S LEVELIZED COST $US MWH

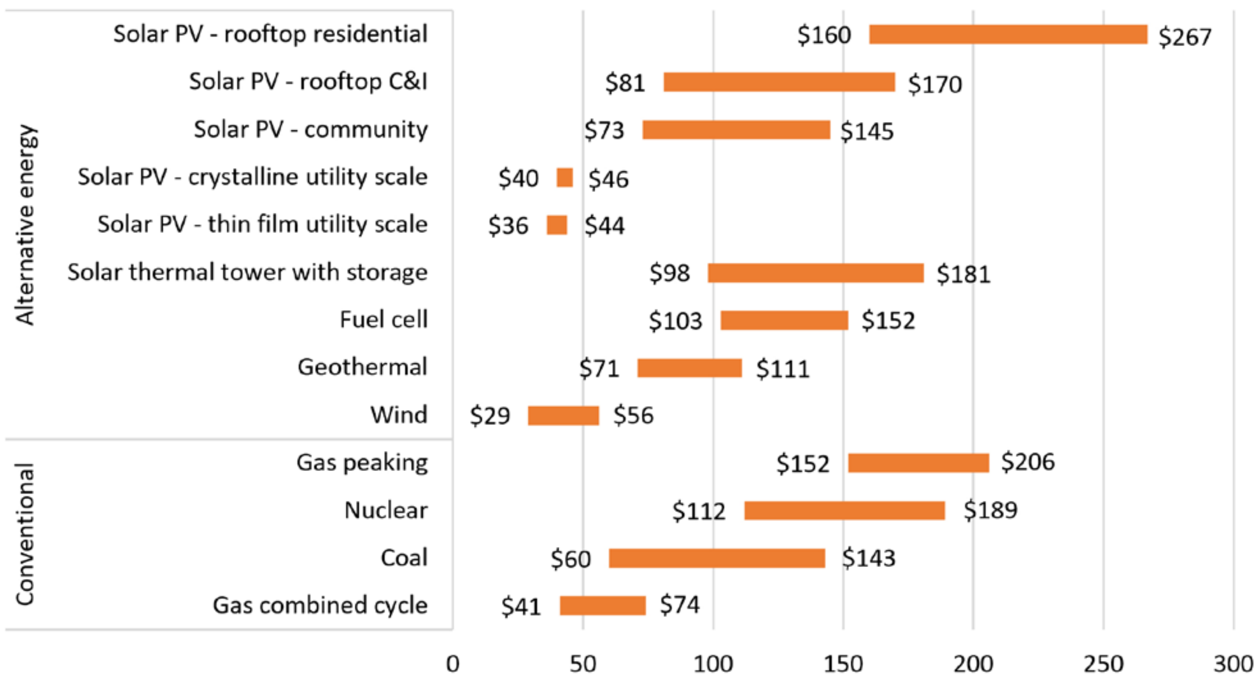


Figure 8. Lazards LCOE table

Ref: Lazard, 2018. Lazard's Levelised Cost of Energy Analysis – Version 12.0.
[Online] Available at: https://www.lazard.com/media/450784/lazards-levelized-cost-of-energy-version-120-vfinal.pdf

To get an estimate we use the figures produced by the Brookings Institute on total costs of and total benefits of different technologies. We have recalculated these under the assumption that the cost of emissions is $100 a ton and that each technology replaces a coal fired power station. This gives the following benefits for each MW of capacity installed.

Nuclear	$US484,084
Wind onshore	$US344,132
Solar PV	$US125,233

At $US 50 a ton wind gives greater benefits than nuclear and both are greater than solar. The difference is explained by the fact that nuclear has higher capacity and displaces more emissions than wind and solar.
Footnote: Carbon at $US100 a tonne is a reasonable figure. See Carr, M., 2018
Ref: Carr, M. October 2018. How High Does Carbon Need to Be? Somewhere From $20-$27,000. Bloomberg. [Online] Available at: https://www.bloomberg.com/news/articles/2018-10-10/how-much-does-carbon-need-to-cost-somewhere-from-20-to-27-000
Frank, C., 2016. New results on the net benefits of low carbon electricity technologies. Brookings. [Online] Available at: https://www.brookings.edu/blog/planetpolicy/2016/10/17/new-results-on-the-net-benefits-of-low-carbon-electricity-technologies/

What this says is that on straightforward cost benefit grounds with emissions as a metric, nuclear compares well with, or is better than, renewable alternatives.

d2.v. Back of the envelope calculations. The best way to get some idea of what figures actually mean is to do some crude back of the envelope calculations. These give a ballpark and allow us to at least guess whether some of the claims being made are sensible or whether they are distorted by hidden assumptions and cherry picking.

Here are two easy calculations.

i. The most expensive nuclear power station and the one that is often held up as proof that nuclear is not economically viable is the Olikolouto reactor in Finland. Its current cost is about $US 7 billion per GW capacity. Current figures for other reactors are roughly $US 3 billion per GW capacity for China and $US 5 billion per GW for reactors being built by Korea in the UAE.

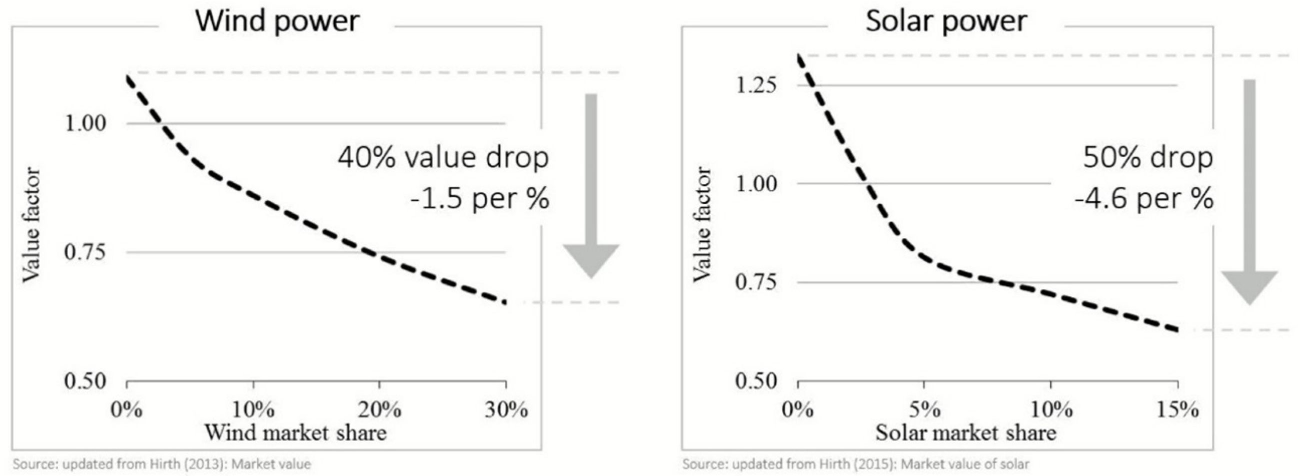
   By comparison the Topaz solar farm in California costs about $US 16 billion per GW output to produce the same amount of electricity for about 8 hours a day. Darling point in Australia has a projected construction cost of $US 4.4 billion per GW output without grid level costs.

   On these figures, expensive solar costs more than expensive nuclear and cheap solar about the same.

ii. Assume that all electricity was produced by solar and wind. Ignore short term buffering and grid costs and consider the back-up needed to ensure supply for one and a half days. This would require about 10 Snowy 2.0 schemes at a cost of more than $US 50 billion assuming viable sites were available, and they aren't. If batteries were used it would require about 7, 000 Tesla batteries at a cost of about $US 500 billion.

In terms of opportunity cost, back up would cost between 6 and more than 10 old style 1 GW nuclear reactors with pumped hydro. With batteries the cost would be between 60 and 100 reactors. It would take about 25, 1GW reactors to provide all our current electricity.

VALUE OF WIND & SOLAR DECLINE



Source: Lion Hirth, "Market Value of Variable Renewables," EUI Working Paper, 2013, http://cadmus.eui.eu/bitstream/handle/1814/27135/RSCAS_2013_36.pdf?sequence

Figure 9. Value decline of energy from wind and solar with increased penetration

Ref: Environmental Progress. https://environmentalprogress.org/the-complete-case-for-nuclear

iii. Reliability

Reactors produce continuous and dispatchable electricity under all conditions and are not subject to extreme weather damage. Down time for refuelling is short and predictable years in advance.

In terms of back up and short-term fluctuations Australia doesn't share an interconnection with an adjacent high reliability grid unlike, say California and Germany. This means that we either have nuclear or need fossil fuels or large back up systems to ensure reliability.

2.e. Economic Feasibility

The economic feasibility of nuclear is understood to mean supply cost to markets and commercial feasibility. We have already seen that there is no argument for nuclear being more expensive than other low emissions alternatives from a total cost perspective. Let us take a narrower view.

There are a great many problems in simply downloading figures since energy markets are badly distorted. Costs may only be stated in marginal terms, they frequently exclude externalities of the type discussed in the previous section, they are unclear about levels of subsidy and so on. For example, solar and wind are heavily subsidised when it is required that all output needs to be purchased and this also pushes up costs for all other technologies.

It is also necessary to bear in mind that because of uncertainties about grid configurations, technology and penetration all figures are extremely approximate. They probably only make sense at around the thirty percent figure at best.

In particular we need to be aware of the distortions involved in comparing the marginal cost of an extra unit of solar and wind with the total cost of nuclear. We also need to be aware of using figures based on current levels of penetration. Both practices are common.

Neither makes any economic sense.

For these reasons we avoid using the usual marginal cost figures and try to get more economically justifiable estimates.

e1. Overview of the current situation

The problem that is beginning to emerge with our current trajectory is illustrated by the fact that from the cheapest power prices in the world in the late 90's, Australia has now some of the most expensive. There are several contributing factors to this. One of the most important is the thoughtless subsidisation of intermittent renewable energy. As the level of penetration increases this can only get worse if solar and wind become our primary sources of generation. Above a certain level of penetration, intermittent generation externalises significant costs and so begins to drive energy prices in several ways. As penetration increases the following changes take place across the grid.

- The capacity of the dispatchable generation assets that must remain idle for extended periods increases. This is economically inefficient. It also shifts costs to the community by pushing up the price of dispatchable power, or reducing the economic viability of suppliers.
- Variability of supply increases. This requires more frequent use of the FCAS (Frequency Controlled Ancillary Service) market by AEMO to ensure grid stability
- Increases in the supply and demand balances are not only inefficient, it also results in high variability in prices which leads to greater financialization and gaming of energy markets. This also

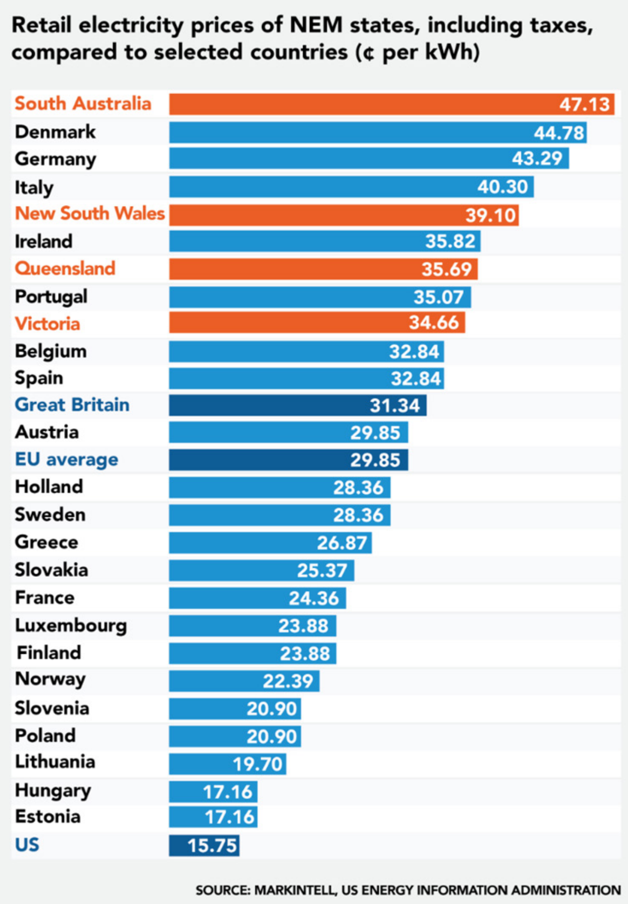


Figure 10. Energy prices in various economies
Ref: Australian Financial Review. https://www.afr.com/politics/australian-households-pay-highest-power-prices-in-world-20170804-gxp58a

- If grid penetration goes beyond some point the system, can no longer benefit from legacy thermal generators.

An important consequence of this last change is that electricity costs begin to increase in line with the cost of storage. This means that the short run marginal costs of solar and wind are irrelevant, as is the argument that the costs of providing electricity using solar and wind are falling.

Another way of presenting the problem is to look directly at the estimates of the energy produced by solar and wind. This was partly captured in figure 7. Here are some typical figures from a different perspective.

In terms of the levelized cost figures discussed in the previous sections this means that at levels of penetration well below a hundred percent of electricity the value of production from solar and wind will begin to fall towards about one half. In other words, if penetration is accounted for, levelized cost figures must double.

e2. International comparisons.

The nuclear industry not only provides reliable dispatchable electricity that is affordable in countries like France, Sweden, Switzerland, Japan and South Korea, but also provides those nations with an industrial and scientific capability that Australia lacks.

International comparison gives some idea even though it must be remembered that the figures are influenced by several variables and no definite conclusions can be drawn. On the other hand, there is nothing in them to suggest that nuclear is more expensive. It will be noted that countries like France with over seventy five percent nuclear and Sweden and Hungary with about fifty percent have lower energy prices than Denmark and Germany with high levels of solar and wind. (Figure 10)

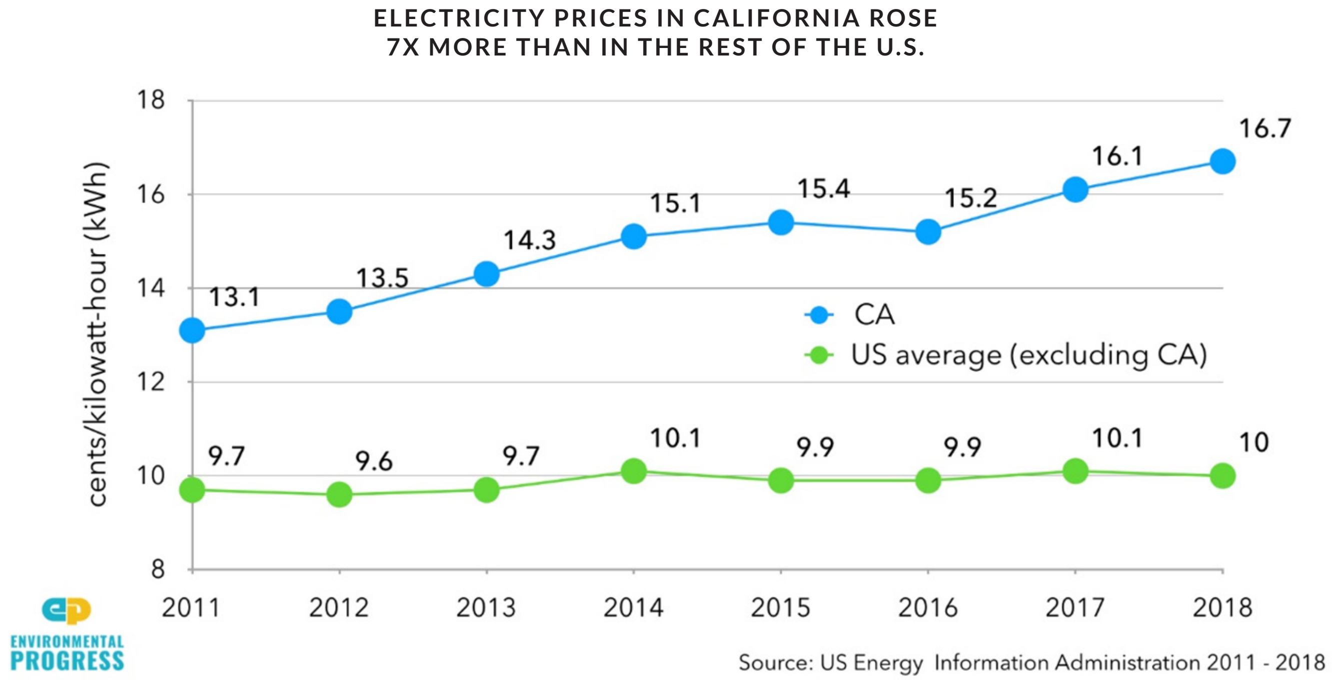


Figure 11. California vs Rest of the US Energy Prices
Ref: Environmental Progress. https://environmentalprogress.org/the-complete-case-for-nuclear

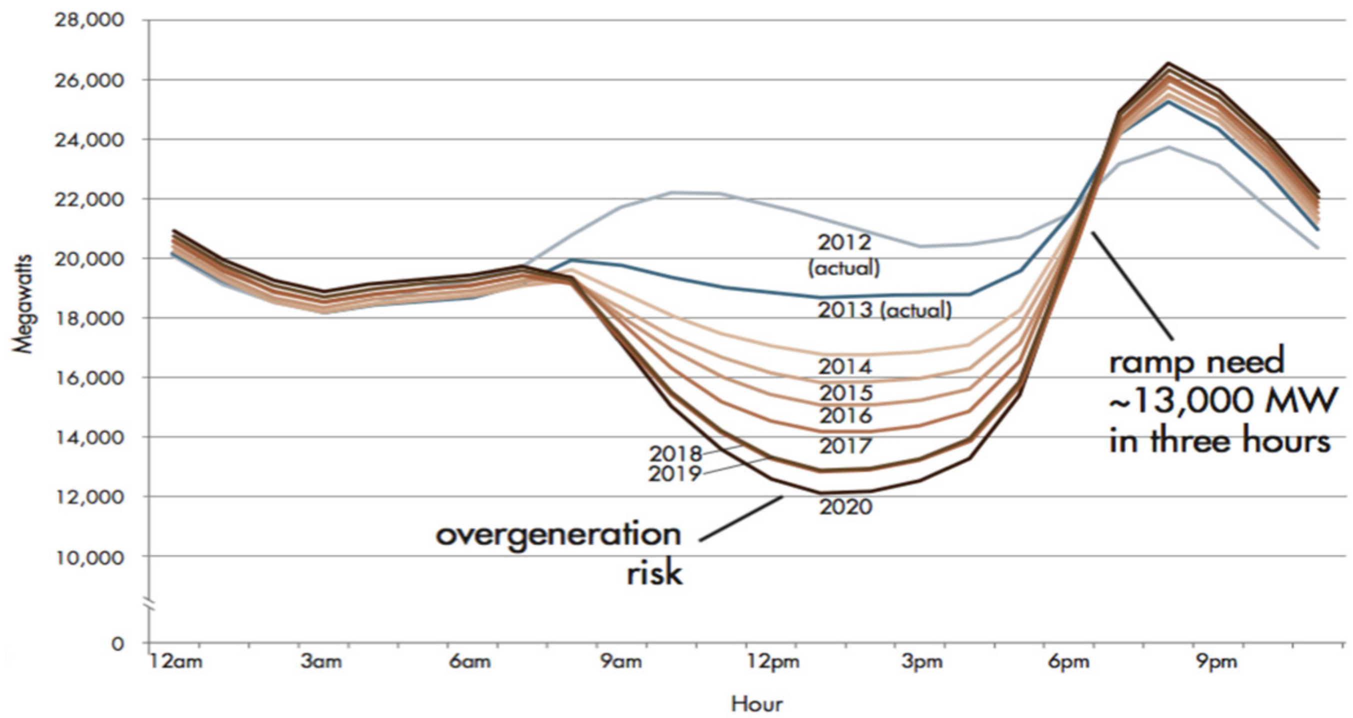


Figure 12. California duck curve, Mar 2018
Ref: https://www.vox.com/2018/5/9/17336330/duck-curve-solar-energy-supply-demand-problem-caiso-nrel

It is difficult to generalize from the US figures. Energy prices in California are more interesting because it has heavily subsidized solar and wind and phased out nuclear. Unlike Australia it has the advantage of being able to buttress its system by importing energy when domestic solar and wind production fails. It also imports roughly thirty percent of its energy from adjacent states with more reliable base load. (Figure 11)

Another example is the Hinkley Point C reactor currently under construction in the UK. This has a strike price of $ US 111 per MWh. This price has been criticized as excessive. On the other hand, note that this puts it at the bottom end of the Lazard cost figures and within the range of OECD figures for solar shown in section d2.iii.

It is often not appreciated that choice about financing is a significant issue. It has been estimated that financing Hinkley C at the borrowing rate available to the UK government instead of vendor financing would have approximately halved the project capital cost.

e3. Costs of regular gaps in energy avoided

The cost of nuclear is also significantly reduced compared with solar because it avoids the support needed to fill in regular gaps in solar production. These costs are in addition to routine buffering for highly variable wind, buffering for weather disturbances and back-up. They also increase with the penetration of solar. Like intermittency costs, they also increase volatility in the system and allow investors and speculators to game the market.

This is again a significant problem for Australia because unlike the US states or the EU, we don't have interconnections with adjacent, high reliability grids.

The problems created by the fact that solar comes in chunks can be illustrated with the duck curve. An example is set out in Figure 12. This summarizes electricity production in California over the period 2014 to 2019.

What the curve shows is that, even at low levels of penetration, significant amounts of additional energy must be provided on a regular basis. For approximately a third of each day solar can produce the majority of the electricity demand. For two thirds of each day the demand has to be met from other sources.

It will be seen that as the penetration of solar increase the amount of despatchable generation that is required to cover energy shortfalls also increases. This will essentially require that the system has to be built twice as something close to total capacity of the solar and wind systems will be required.

It will also be seen that a very rapid ramp up is required. This means that the system will require technologies such as expensive open cycle gas turbine sprint machines or batteries with a capacity of several hours to smooth the gradient.

e4. Estimated costs for Australia.

The best way to get figures for the cost of nuclear in Australia would be to take estimates based on commercial proposals since there are no historical figures. Obviously, costs will depend on such things as the type of reactor, the technology, the project and operating companies, market structure etc. They will also depend on the way in which the project is financed.

e4.i Purchase of a complete 1 GW plant

The option here is to contract to have a large plant built on site with

IN 2030 ONE OF GW OF INSTALLED CAPACITY WOULD GENERATE

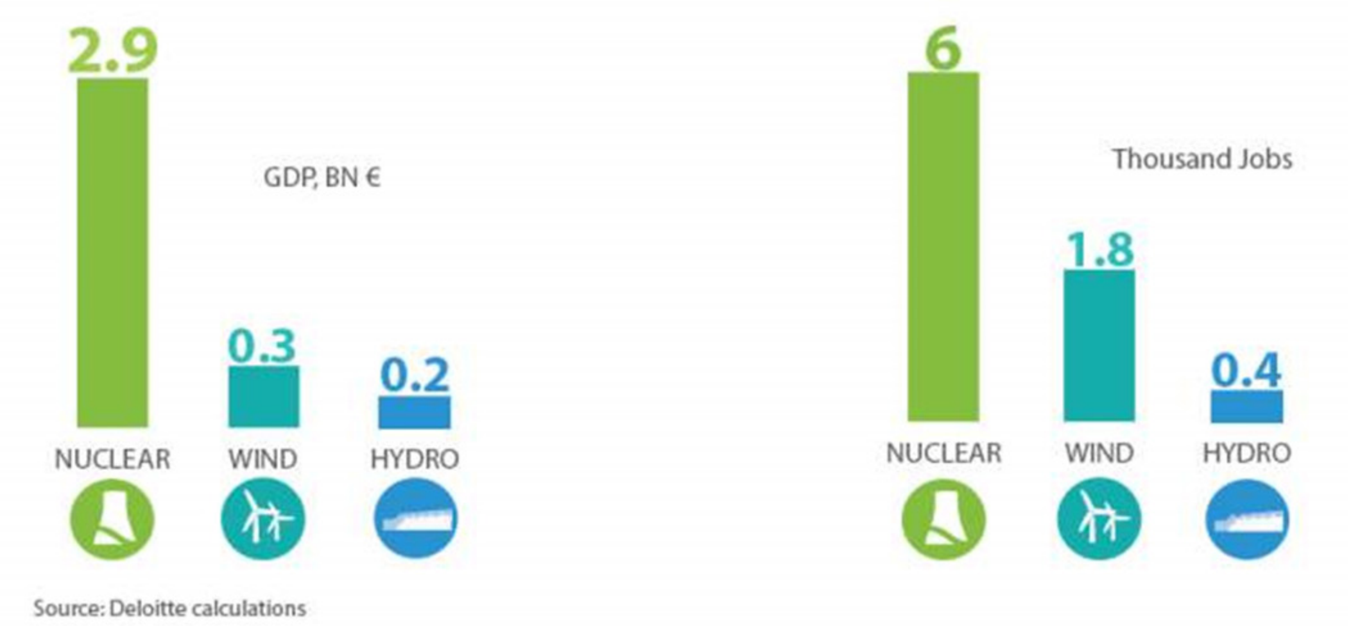


Figure 13. Economic benefits of nuclear vs solar and wind in EU28.

Ref: Deloitte Report April 2019 "Socio-Economic Impact Evaluation of Nuclear Energy for EU28" http://world-nuclear-news.org/Articles/Viewpoint-The-climate-and-economic-benefits-of-nuc

imported expertise. It is difficult to estimate costs because if factors such as labour supply and finance. Some examples are:

a. The French company EDF is building Hinkley point C for a cost of $US8 billion per GW although it is anticipated that subsequent builds would cost less. It is also estimated that under different financial arrangements the project would have cost approximately half.
b. The Korea Electric Power Corporation is building a four-unit plant in the United Arab Republic at Barakah. The cost is approximately $US 4.5 billion per GW. Construction started in 2012 and the first unit was completed in 2018.
c. The Russian company Rosatom is building four-unit plant in Turkey at Akkuyu at a cost of about $US 4 billion per GW. Construction started in 2018. Estimated completion date for the first unit is 2023.

e4.ii A commercial case for small modular reactors

The option here is to use small modular reactors. These have different build characteristics and different financial and cost features. These are discussed in further detail in section 3 and 4. We can get an idea of the cost by looking at a commercial proposal from DUNE.

DUNE proposal

The proposal to replace a significant portion of NSW and Victoria's coal fired power stations and deliver 50% of the NEM annual energy requirements using NuScale small modular technology. This compares the nuclear overnight cost with the cost of a system using an energy split of 25% solar, 25% wind and 50% combined cycle gas.

This uses the latest figures from wind, solar, storage and CCGT projects in Australia and cost estimates provided by NuScale.

It is important to note that if Australia's emissions targets were to be met the percentage of gas would have to decrease. This would make the non-nuclear option more expensive and may not even be technically achievable for energy availability reasons.

It is again pointed out that there is a range of uncertainty around the figures. Future gas prices are not known, land prices are not known and the cost of reconfiguring the grid for the non-nuclear option is not known with any reasonable degree of accuracy.

If we ignore all external costs the overnight costs are roughly

$A64 billion for the nuclear option
$A61 billion for the alternative option

This is roughly $US 4.5 billion per GW for the nuclear option and the very low operating/fuel costs of nuclear plants compared to gas plants would place nuclear at an advantage in Australia where gas prices are reasonably high and likely to stay that way.

To get this figure for the alternative option we need to ignore the cost of land acquisition, the cost of gas, the cost of replacing solar panels, wind turbines and batteries during the life of the project and network or grid level costs.

If network costs are added at the lowest estimate the figures are roughly:

$A64 billion for the nuclear option
$A78 billion for the alternative option

If land acquisition, replacement costs of solar, wind and battery systems

during the life of the project are considered, then nuclear becomes much less expensive.

Exact figures will depend on assumptions about factors such as interest rates. If it is assumed, for example, that the interest rate is 3 percent and batteries, solar and wind only need replacing once after twenty years and that the replacement cost is the discounted original cost, the figures are

$A64 billion for the nuclear option
$A105 billion for the alternative option

See section 4 and appendix A for further details.

2.f. Community Engagement

It would be possible to engage the community in a mature discussion of nuclear technology through the simple expedient of encouraging rational debate. Simply bringing the issue to public discussion should do a great deal to remove the irrational reactions to nuclear based on claims about Chernobyl killing millions, hospitals full of mutated babies and Fukushima polluting large areas of Japan and so on.

As well as growing concern about the environment, it is also clear that there is considerable concern about the reliability and the cost of electricity. It should be a simple matter to encouraging public and local involvement in decisions about electricity supply and cost factors and the environmental benefits.

It is our belief that given an opportunity to participate in matters that are simultaneously locally and nationally important, but at the same time do not cross entrenched financial interests, the public is capable of educating itself. We say more on this issue under the topic of national consensus.

2.g. Workforce Capability

The idea that the Australian workforce is somehow inferior and cannot develop the skills and capacity to manage nuclear technology seems to be in the background of some arguments for retaining the prohibition. We reject this. Our workforce not only has the capacity to develop the skills required but also the potential to develop a comparative advantage in nuclear management and technology that would drive exports in the region. For example, prior to 1989, Australia had no expertise in the design, construction, operation and regulation of LNG facilities. Thirty years later, Australia is home to some of the most advanced LNG operating and engineering capacity. This includes a world class workforce that has been a key factor in attracting steady investment in the sector.

Unlike the starting position of the LNG skills base, Australia already has some highly regarded nuclear expertise. It also has a deep skills base in engineering, finance, law and regulation and a world class university sector. It also has close allies in the US, Europe, Japan, Canada and Korea.

If small modular reactors were acquired, the skills we have could be expanded quickly and easily. Expertise transfer and secondment of experienced personnel would be part of the programme. It would be a simple matter to embed appropriate personnel in existing programmes to gain experience.

2.h. Security Implications

This has several possible meanings.

h1. Plant security.

Nuclear facilities are intrinsically secure from attack and interference. They are small and are easily and cheaply guarded, all but impossible to break into without a large, modern military force and easily monitored by satellite. It has been shown that they are impervious to a direct hit from a fully laden aircraft. If terrorism is seen as an issue, they are much less attractive as a target than other fossil fuel facilities or dams. If terrorists were to get waste what could they do with it? It is not feasible to build a bomb from either nuclear fuel or waste by any organization without the industrial capacity of a sizeable country. If you had this potential, using waste would be about the worst way to go about it.

h2. Energy security.

We have already discussed security of supply on a twenty-four-hour basis. If we compare with existing fossil fuel generators there are other elements. A nuclear plant is not susceptible to interruptions of fuel supplies in the short and medium term as it can carry enough fuel for one or more years of operation depending on the type of plant. It is also not susceptible to price spikes or large variations in fuel prices. This is because the amount of fuel used is small and only makes up less than 10% of running costs for a light water reactor.

h3. International and regional security.

In Section 1 we dealt with the way nuclear capacity would benefit our international security and how it would also contribute to our economic development and integration in the region.

It is almost certain that our neighbours will begin to deploy nuclear technology. In this, the least risky option for Australia is to have the capacity to be part of this process and to assist with the management, operation, risk assessment and the management of spent fuel.

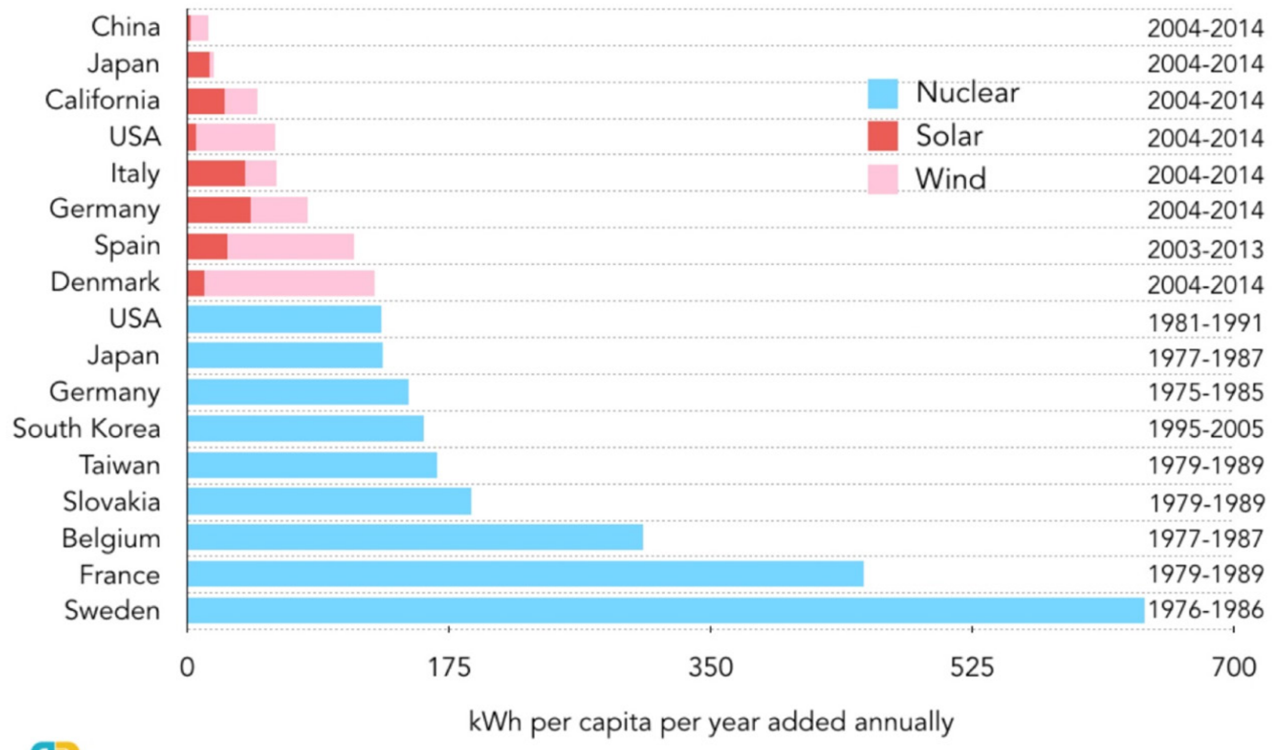
2.i. National Consensus

Recent figures show that about forty four percent of Australians support nuclear power and about forty percent oppose it. This is a remarkable high level in favour given that the general population knows very little about nuclear energy and that it has been subjected to decades of scare campaigns and misinformation.

From school children and university students, to the CEOs and directors of Australia's largest companies there is increasing concern about emissions and the risk of catastrophic climate instability.

The electricity sector produces about thirty five percent of our emissions and nuclear is an obvious solution for getting these close to zero. As a younger generation, unburdened by childhood fears of nuclear war weighs the available options, they will increasingly find that wilfully imposing a barrier to emissions cuts of this magnitude is unreasonable and short sighted.

AVERAGE ANNUAL INCREASE OF CARBON-FREE ELECTRICITY PER CAPITA DURING DECADE OF PEAK SCALE UP



Source: China-U.S. cooperation to advance nuclear power. Junji Cao, Armond Cohen, James Hansen, Richard Lester, Per Peterson and Hongjie Xu. (August 4, 2016). *Science, 353* (6299), 547-548. [doi: 10.1126/science.aaf7131]

Figure 14. Scale up rates for carbon-free electricity

It would be reasonable to assume that an honest attempt at education would be remarkably successful. To lack knowledge is not the same as being unable to understand the issues if they are properly discussed. It would only be necessary to make a sensible attempt to simply inform the public of the real dangers, or lack of dangers, and give the facts about Chernobyl and Fukushima. This would go a long way to removing the irrational and at times hysterical reactions to nuclear based on claims about Chernobyl killing millions, hospitals full of mutated babies and Fukushima polluting large areas of Japan.

There is no doubt that any attempt to present the facts about nuclear energy in a clear and rational manner would meet with some political opposition. It must be accepted that, in some quarters, opposition to nuclear is an article of faith.

It is doubtful, however, that this opposition could withstand the light of public debate. From a green perspective, there is a contradiction between opposing nuclear and concern for emissions and the risk of climate disequilibrium. In other words, there is a contradiction between being an environmentalist and opposing nuclear.

For example, it is undeniable that any programme of emissions reduction based on solar and wind will need significant back up. If not nuclear, what is plan B for the anti-nuclear argument?

It is not feasible to develop enough pumped hydro and the environmental damage it produces is significant. Batteries are absurdly expensive on the scale needed and produce enormous quantities of toxic waste in their manufacture and disposal. Gas and biomass are high emitting sources of energy.

It should also be noted that there are significant members of the environmental movement that are pro-nuclear. Examples are Lovelock, Shellenberger, Monboit, Hansen and others on the fringe like Bill Gates.

Another factor is the standout economic value that nuclear energy brings to a nation and to a hosting community. An April 2019 socio-economic impact evaluation by Deloitte clearly revealed that the nuclear industry brings far more benefits to national and local economies per GW of power installed than either wind or solar. (Figure 13) The graphic below is illustrative and should provide comfort to policy makers and project developers that nuclear energy can and does make a wonderful contribution.

It might also be possible to develop a sense of national pride in our workforce and our capacity to deal with advanced levels of technology as the French have done. It may be the case that by taking an initiative and showing leadership, the political system could do a great deal to restore some faith in the nation's abilities and maturity.

2.j. Other Considerations

j1. Remarks on the anti-nuclear argument

Many of the standard anti-nuclear arguments have been dealt with in the previous discussion. We bring them together here and expand on some aspects for ease of reference.

The overarching point in all this is that to justify retaining the existing legislation, the anti-nuclear argument must be correct beyond reasonable doubt, and the rest of the world must be wrong. If this cannot be guaranteed the existing legislation places our economy, development and position in the world at serious risk.

j1.i. Cost. This has been extensively dealt with. There is a great deal of uncertainty around figures but nothing justifies the claim that the total cost of nuclear is significantly more than other low emissions technologies.

j1.ii. Time. The time argument has been made for a decade or more by the anti-nuclear interests. Time relative to what? It doesn't make much sense. Here are two reasons.

a. There is a large reservoir of international expertise in management, security, regulation, siting and construction to draw on should Australia wish. The time required for legislation and establishing regulatory agencies is a choice variable. It is not a hard constraint and it is wrong to pretend otherwise. We have already seen that an initial build programme could be reduced to a matter of years.
b. Is time relative to emissions reduction? This assumes that there is an alternative technology that gives a faster or even the same rate of emissions reduction. France got all its electricity in about twenty years. Had we started with nuclear in 2000 our emissions would have fallen by over thirty percent. Instead twenty years of solar and wind have given us a fraction of our electricity and no appreciable reduction in emissions. Results in California and Germany haven't been markedly better. See Figure 14

What is the likely development time for an advanced, wealthy nation to acquire a nuclear energy capacity?

If a large reactor were built such as Olkiluoto in Finland it could be achieved in about ten years from commencement. A fast programme with small modular reactors would take less if no native technology is developed. Physical build times would be short since essentially, we would be acquiring factory built, off the shelf units. Reductions in preliminary and set up costs could be achieved with assistance from allies with nuclear programmes and the International Atomic Energy Agency. Regulatory requirements can be harmonised with leading nuclear nations and bodies like the NRC, ONR and CNRC. This would lead to faster design and site licensing.

Is 10 years too long? No. Not in the absence of a faster and equally good alternative. In fact, without an alternative time is irrelevant.

j1. iii. Waste. This has been dealt with previously. See appendix A for a detailed discussion on Deep Isolation™ technology.

j1. iv. Risk. This has been dealt with. It was pointed out that risk cannot be assessed in isolation. We cannot choose to not produce electricity. The only sensible question is; how risky is one option compared with others?

If all risks are accounted for, including the risk of being unable to meet emissions targets, nuclear seems the least risky option.

It is almost certain that our neighbours will begin to deploy nuclear technology. It could be argued that the least risky option for Australia is to have the capacity to be part of this process and to assist with the management, operation, risk assessment and the management of spent fuel.

j1. V. Terrorism. A favourite. One response is that, if it is so easy why hasn't anyone done it or even once tried to do it, ever? Nuclear facilities are easily guarded. Small modular reactors can be locked down and satellite monitored to prevent tampering and fuel removal. It is not at all clear what could be done with spent fuel even if it were procured.

j2. Renewable energy isn't a plan B - The problem is to produce electricity in a way that has low emissions and is cost effective. It is one thing to oppose using nuclear energy to do this. It is another to have a plan B.

j2. i. Cost. Much is made of the plummeting cost of renewable energy and advocates are at pains to point out its lower LCOE. This ignores systems costs. These are paid by the consumer one way or another. We have already seen that at modest levels of penetration, nuclear energy has lower end-user prices when compared to renewable energy. An obvious comparison is the German and French programmes.

j2. ii. Example. France and Germany. Through its Energiewende program, Germany has been rapidly scaling up renewable energy and scaling back nuclear energy for close to 15 years. France continues to rely on its nuclear programme of the 1980's and 1990's which produces over seventy percent of its electricity.

The consequences of these two programmes are clear. France has some of Europe's lowest power prices and emissions. Germany has some of the highest and emissions have not fallen in any meaningful sense.

This story is illustrated in figure 15. It shows that the main reason for the increase in German household energy prices is the renewables surcharge.

French household prices were on a slow decline till 2009 when they started adding solar and wind. This programme has now been wound back.

Had Germany spent the same amount on nuclear energy as it had on the Energiewende program the results would have been much different. At best it will achieve production of twenty percent of its electricity by 2030 with little reduction in emissions.

If the same amount had been spent on nuclear reactors it would have produced all its electricity and enough energy for most of its transport needs. This would have reduced total emissions by roughly forty to fifty percent.

j2. iii. Economic risk and a paradox in systems costs. Many commentators are not aware of the economic risks that the non-linear price characteristics of intermittent energy sources present as their penetration goes beyond some threshold.

BREAKDOWN OF GERMAN DOMESTIC ENERGY PRICES

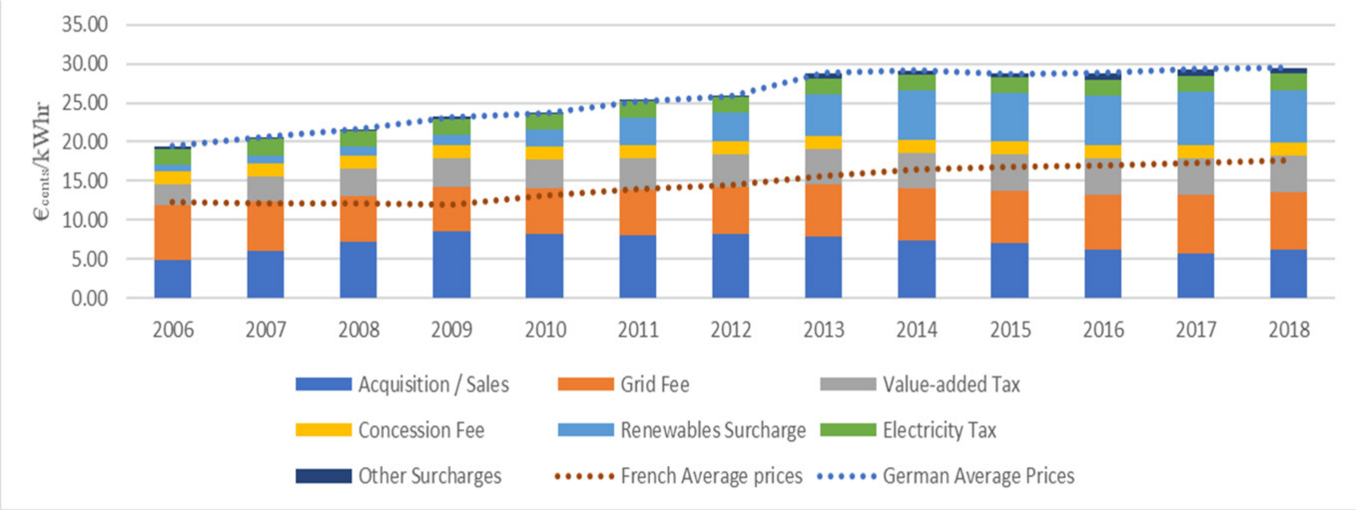


Figure 15. German and French Average Household Prices.
Ref: Eurostat(https://appsso.eurostat.ec.europa.eu/nui/submitViewTableAction.do)
and Clean Energy Wire (https://www.cleanenergywire.org/factsheets/what-german-households-pay-power)

At a low threshold of maybe less than twenty percent, the system level costs of intermittent energy increase approximately linearly with increases in supply. This threshold point is likely to be different for different grids. If gas back up is used and intermittent supply goes beyond the threshold price, increases are primarily a function of fuel prices and the cost of deploying the generation technology. It also becomes necessary to increasingly modify the entire grid. In addition, increasing amounts of the energy generated either have no value or have to be stored, the amount of standby capacity as a percentage of total generation capacity has to increase, short term buffering becomes more expensive and so on.

At a sufficiently high level of penetration total system costs increase disproportionately. At the same time the value of solar and wind energy begins to fall.

This could lead to the paradoxical situation where energy prices continue to escalate whilst owners of renewable energy make significant losses. In this case either subsidies increase, or investment and reliability of the system begins to decline. The economic efficiency of the energy system would be destroyed.

3. Options for Australia

3.1. Remarks on options

The case for removing the restriction on nuclear energy in Australia applies to all forms of reactors. The best choice of a nuclear energy system for Australia would depend on several factors including the supplier and financial arrangements.

In most countries successful programs are being run with slow neutron reactors of about 1 GW average capacity. Olkiluoto has a capacity of about 1.6 GW and Hinkley C is made up of two reactors with a total output about 3.2 GW . New builds in the United Arab Republic and Turkey are units of about 1.4 GW. One advantage Australia has is that it can gain from the experience of other nations and it can also benefit from access to the latest advances in technology.

Apart from new Generation III reactors of +1GW that are currently available and can be purchased commercially, there is a large range of different types of reactors under development, each with different build times, power ratings and characteristics. Among these are slow neutron, sodium fast neutron, breeder, molten salt, thorium fuelled, standing wave, pebble bed, small modular and so on. Many of these are being developed by the Generation IV International Forum, of which Australia is a member.

In order to establish some parameters, let us assume that for an initial purchase Australia would want a reactor that met the following characteristics.

a. currently available (or available very soon)
b. minimal build risk and complications
c. minimal up-front capital outlay
d. easy to manage
e. intrinsically safe especially while the industry is growing, and capability is being built.
f. flexible to meet back-up requirements for solar and wind
g. flexible enough to accommodate future policy directions

Despite the attractiveness of many of the new Generation IV designs, it is doubtful if they would be a good choice. This is partly because many are not operational and there may be significant development risks. First of a kind builds are typically expensive and may create problems for a country without a depth of experience and an already skilled work force and the related manufacturing and service industries. Finance and insurance also become major cost factors. Lack of experience in these may also prove difficult.

3.2. Generation III Large Reactors

The first possibility would be to buy a generation III established design that has been built more than once previously. Some options were discussed in the section on costs including the EPR reactor being built at Flamanville, Olkiluoto, Hinkley and already operational at Taishan in China. Other examples are the Korean APR 1400 being built in Turkey, Russia's gen III VVER 1200 and China's Hualong 1.

The advantage of buying an nth of a kind is that there are cost and time savings resulting from experience in all facets of project delivery. These savings may be in excess of fifty percent of the build cost*. They go from engineering to project management to financing to legal issues and so on across the board.

Ref: Lang, P. 2017 Nuclear Power Learning and Deployment Rates. https://crawford.anu.edu.au/publication/crawford-school-working-papers/10276/nuclear-power-learning-and-deployment-rates

It is difficult to cost this since any agreement with a vendor would depend on negotiation, timing, financing, available of support industries, risk spread and so on.
It is also difficult to fully evaluate the flow on benefits to the labour force and our industrial capacity.

On the downside, a programme based on large reactors would struggle to meet criteria b, c, d and perhaps e. There may also be difficulties with criterion f depending on the degree of penetration from solar and wind.

Although it should not be an issue there may also be questions of political acceptability. An up-front cost of several billion provides an easy target for critics of government and attempts to modernize our energy system.

3.3. Small Modular Reactors

The alternative to a programme based on large units would be to consider small modular reactors SMRs or a mixed programme perhaps starting with SMRs to build capacity. Either would be better than simply hoping for the best with solar and wind. Nonetheless, an SMR seems to offer some additional advantages. It would easily satisfy the criteria set out above. It would minimize build and financial risk and maximize flexibility. Specifically, an SMR that uses standard light water reactor (LWR) fuel and operating principles and so benefits from 60 yrs of operational experience for most of its technical characteristics.

An additional important advantage of small modular reactors for Australia is that there are off the shelf designs commercially available in the very near future. This would make a build within a ten-year time frame easily achievable and this may solve several problems.

If we look at the practicalities it goes like this. If the federal and NSW or VIC state governments were to lift the moratorium, the first commercial sale of nuclear energy could be achieved between 2028 and 2030. This may not be in time for the closure of the Liddell station. It would allow just-in-time deployment prior to the planned retirement of the Vales Point B power station around 2028. The life of these stations could be extended for a few years to usher in nuclear energy without a period of acute supply shortage. If this path were not followed there are two likely outcomes. One is that more fossil fuel generation would have to be built. This would be a wasted opportunity. It would set Australia on an energy trajectory that may not be long run optimal and leave the country with expensive stranded assets and little technological progress.

Another is to continue on the current trajectory of subsidizing more solar and wind. This will most likely create a shortage of dispatchable energy leading to astronomical prices and forced investment in diesel or gas fired generation. It would likely require either government ownership of emergency assets or binding, expensive, long-term contracts with private owners to justify their deployment.

3.3.i. Small modular reactors: an outline

The main characteristic of small modular reactors is they generally have a capacity of 300MW or less and a typical set of dimensions for a single unit would be about 20 metres in height and about 5 metres in diameter although there is a great deal of variation. Their size allows them to have significantly different features than large reactors. Among the advantages are:

a. Factory production and economies-of-many dramatically reduces build costs and time
b. Passive safety features and inherent barriers to accident
c. Easy to locate
d. Low running costs and more efficient fuel burn out.

a. Production. It is difficult to estimate the cost reductions that could be achieved by factory production of large numbers and the obvious parallels here are with the automobile and aircraft industries. OECD projections shown in section d2.iii indicate potential cost reductions could make output from small modular reactors much cheaper than all alternatives.

Complete units could be purchased from the supplier and shipped to Australia to place on a prepared site. Domestic participation in constructing the associated generation units would be an obvious starting point with later technological transfer and participation in engineering and construction of the reactor units.

b. Passive safety. Small size means that the designs can be made inherently safe in the sense that core meltdown is impossible in any contrived scenario short of a direct strike from a medium-large meteorite or projectile with equivalent energy. It is easier to engineer safety features that are passive in the sense that they operate according to the laws of physics. They do not depend on additional back-up systems or human intervention.

c. Location. It is easy to locate small modular reactors on existing thermal power station sites and other brownfield areas where access to the grid can be optimized.

d. Fuel burn. Many small modular designs under development burn out a greater proportion of the available energy in the fuel. This reduces the quantities of spent fuel to be managed. Their size also allows them to be designed to require less human oversight and intervention. In principle this makes then suitable for deployment in remote locations. Small modular reactors could be used as a standalone unit or a number could be grouped together to build larger capacity. This could be done by sequentially adding smaller units over time as required. This would avoid total up-front costs of a single unit with the same capacity and build delays.

Research and development in small modular reactors is currently being pursued across the world. There is heavy private investment in countries such as the US, UK, China, Canada, China as well as across the EU generally. In addition, there is also a high level of government support.

Approximately fifty small modular reactors are between the early design and imminent deployment stage. These include light water reactors, fast neutron reactors, graphite-moderated high temperature reactors and various kinds of molten salt reactors.

Light water reactors are the closest to commercialisation and have the lowest technological and financial risk at present. Molten salt reactors are still in development. They promise to be smaller and simpler again with much higher fuel burn out capabilities. On the other hand, they do not satisfy the criterion of currently being ready for deployment.

Several designs might be suitable for Australia including that by Terrestrial Energy, Rolls Royce and NuScale.

Rolls Royce is being heavily backed by the British Government though NuScale seems to be the closest to deployment.

3.3.ii. Example: NuScale SMR

The SMR developed by NuScale has some special features which make it of particular interest for Australia. These are listed below.

Safety. This has been the overriding design parameter from the reactor's conception which means expensive bolt on safety systems required for traditional reactors are not required for any postulated accident event.
Modularity. Modularity and factory construction techniques built-in from the start. A NuScale NPP built in Australia would essentially be a medium sized civil project with all complex equipment and machinery fabricated and assembled at the vendor's manufacturing facility before being transported to site as a "skid".

Minimum build risk. Build and installation is a completely different type of project than Hinkley Point C, Vogtle 3 &4, Olkiluoto and other large-scale conventional projects. In particular, the build costs and times are predictable. It minimizes the risk of cost escalation in construction and schedule overruns that have created significant increases in financial costs. Through DUNE's collaboration with NuScale, we have confirmed their deep knowledge of the causes for cost escalation at all recent nuclear projects and how they have developed their design to eliminate or reduce the probability and magnitude of similar issues with a NuScale build.

Size and flexibility. The small size (60MWe) is well suited to Australia's relatively small energy market. **It gives the flexibility of quickly deploying 60MW chunks of capacity within a pre-built facility to respond to market signals. This would allow the most efficient market operation possible.**

Finance. DUNE has studied traditional and non-traditional business models for deploying the NuScale design within the NEM. **The highly flexible and compartmentalised design combined with modest capital costs have allowed DUNE to develop a highly prospective, non-traditional business model that promises to substantially reduce barriers to entry for non-nuclear proponents as well as appreciably reducing financing costs.**

3.3. iii. NuScale technical characteristics

DUNE understands that NuScale will be making a submission to the inquiry and so there is no need to repeat in detail the technical operation of this ground-breaking technology. What may be of interest to the inquiry panel is some of the safety and operating characteristics of the NuScale design in comparison with traditional Gen II designs.

Combined with the characteristics outlined in the table above, the medium power output of the NuScale 12-pack means that the existing grid connection, cooling water and road access to a retired coal fired

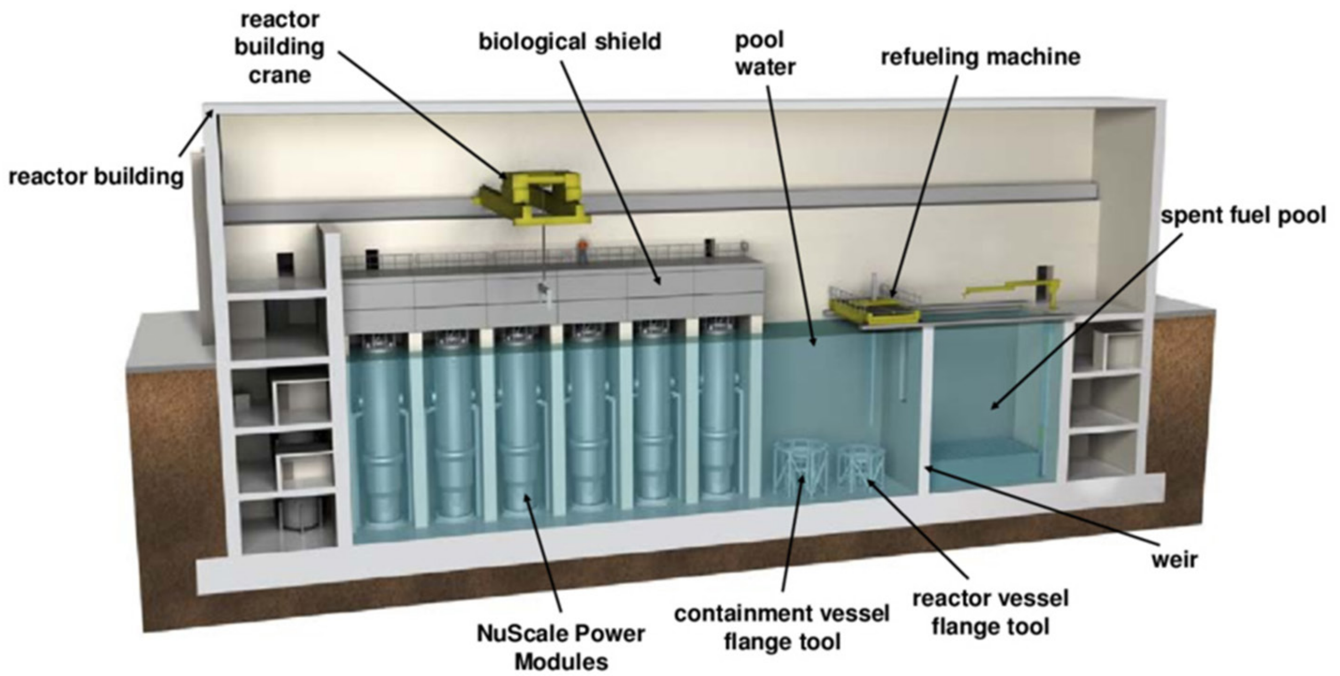


Figure 16. Cutaway of a NuScale "12-pack"™

THE NUSCALE POWER MODULE

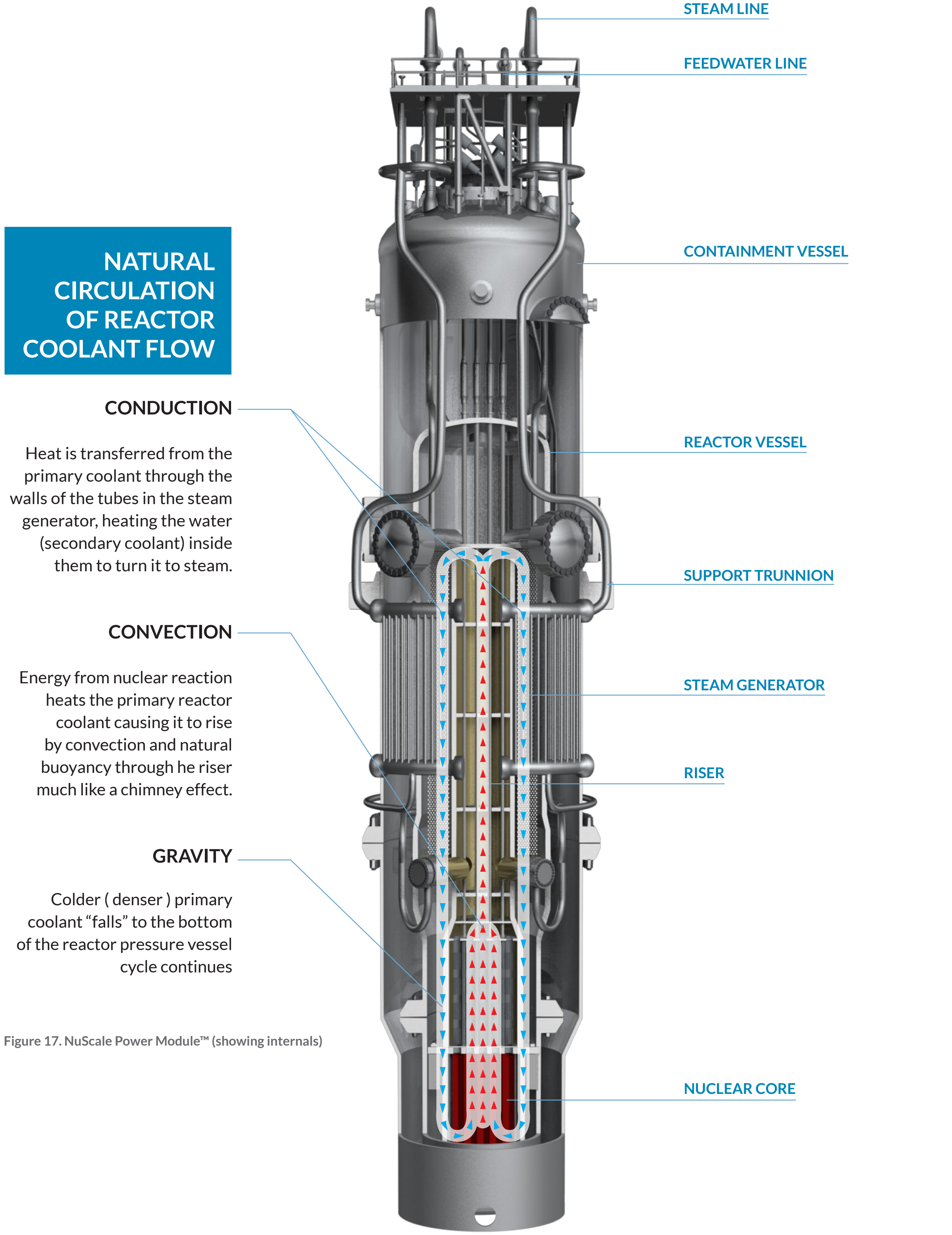


Figure 17. NuScale Power Module™ (showing internals)

power station are optimised for a NuScale deployment. The integrated reactor-steam generation – containment vessel is about 25 metres tall and about four metres wide and is transported to site in three, prefabricated sections.

The concrete pool and structure of the reactor building is built to the highest possible seismic category and can withstand a direct hit from a fully-laden commercial aircraft. The spent fuel storage area of the plant is designed to store the entire spent fuel load for 60 yrs in dry cask storage.

The reactor operates through convection. Water is heated as it passes over the core. As it heats up, the water rises through a riser within the interior of the vessel and the heat is drawn off by a steam circuit to run a turbine. The steam is then cooled in a condenser and pumped back to extract heat from the reactor primary coolant circuit.

In the event of an unplanned shutdown, the reactor can automatically cool itself without the need for any external power or cooling systems. Natural convection ensures continued circulation of primary coolant, transferring decay heat to the containment pool. This has sufficient volume to keep the temperature of the vessel within safe limits for an unlimited time.

A plant would consist of twelve small modular reactors submerged into a common pool of water. Each would drive its own turbine thus eliminating single-shaft-failure (Figure 16).

Plant operation is controlled by a central control unit. Reactors are fabricated and then installed sequentially within the completed reactor building and the developer benefits from early revenue and early retirement of construction loans for long term debt facilities.

The low power density of the NuScale core combined with other innovative features means the individual reactors are highly manoeuvrable and can be deployed on a network with a high penetration of intermittent energy sources.

3.4. The Role of Government

3.4.i Regulation.

The nuclear industry requires regulation and this needs to be done in a way that promotes public confidence and does not cause unnecessary delay. There is a large pool of experience to be drawn on here from the International Atomic Energy Agency and countries with hundreds of reactor-years of experience. If the prohibition were removed, this could be used to scale up ARPANSA as required and to create the regulatory pathway so that project developers could get line-of-sight on regulatory costs and timeframes.

It is also imperative that Australia has a single nuclear energy regulator at a federal level and that no state level nuclear regulatory function is attempted. A clear national framework must be created and enforced in order to avoid any uncertainty or clashes with state based regulatory functions that may overlap with national standards.

If the prohibition is removed it would also be necessary to consider the licensing process for reactor designs, site selection and operating licensing. The obvious way to avoid past mistakes and build on the expensive processes that others have undertaken is to initially accept designs that have previously been licensed in the US (NRC), the UK (ONR) and Canada (CNSC). This would avoid expensive review of designs that nuclear regulatory agencies in other English-speaking nations have already accepted. If this were made clear in advance there would be enough regulatory certainty for a project proponent to begin early development.

In time, designs licensed by other regulators such as Japan, South Korea and China may also be considered.

3.4.ii. Market structure

The current market structure does not provide adequate investment signals for large CAPEX, dispatchable baseload generation. It is essential to be able to provide reliable generation but until recently, it wasn't necessary to define this as a separate and valuable characteristic.

To remedy this situation there are numerous proposals for appropriately valuing reliability. These include capacity markets, capacity payments, PPA and reverse auctions for dispatchable supply, reliability guarantees etc. We do not seek to recommend one method over another.

What is important is that the market is structured to place a value on stewardship, affordability and reliability in order to properly price the output from clean, dispatchable, readily integrated technologies. Figure 19 visually depicts the parameters of such a market design.

3.4.iii Financing

The cost of building reactors can be divided into hard costs like concrete and steel which cannot be avoided and optional costs like methods of financing. Financial costs are to an extent optional. If policy makers wish to maximize long term gains it is important to pay attention to financial arrangements.

It was noted that bad financial decisions have almost doubled the cost of Hinkley Point C. Had better financial decisions been made; the strike price of the energy would have been within the range of solar and wind without considering systems costs. This is largely a self-inflicted wound. Failure to reduce financing costs to an acceptable level by reducing vendor risk was also the reason for GE-Hitachi's recent cancellation of the Wylfa-Neywd project. This seems a poor policy decision as it is now proving costly for UK energy policy and the economy more generally.

One of the main issues is that, although the long-term benefits of nuclear energy may be large, these are difficult for private suppliers to capture in the short term. They may be offset by sudden changes in the regulatory environment, alterations to markets structures that remove the value of dispatchable power and various forms of political risk.

This creates a situation in which low initial investment, short lived generation facilities that may be heavily subsidised and can shift the cost of externalities may prove more attractive for investors. This is despite their low long-term value in terms of emissions reduction or energy security.

From this perspective it is puzzling that environmental groups demand that nuclear energy be judged totally on its economic credentials in what they see as a free market. This simply ignores the externalities that are central to environmental arguments.

A consequence of undervalued externalities and inability to shield from uncertainty is that private vendors are forced to borrow at high rates. And, as we have seen, this substantially increases the costs of nuclear builds for reasons that have nothing to do with the physical cost of providing the infrastructure.

It is not suggested that government subsidize nuclear energy. It is important that government think carefully about the financial arrangements that are adopted, however, in order to produce energy with maximum efficiency and reduce the overall cost to the consumer.

In the case of the UK, for example, government has indicated that any new nuclear energy project will likely be developed under a regulated asset base framework. There are a range of other innovative financial arrangements that might be considered.

	Traditional Nuclear Plants	NuScale
Core Damage Frequency Event	1 in 100,000 reactor years	1 in 100,000,000 reactor years
EPZ (emergency planning zone, an exclusion zone around a nuclear reactor)	10 mile	Approx 250m
Necessary Safety Systems	22	8
Nuclear Fuel (radiation) barriers	3	7
Project Length (FID to commercial operation)	12 yrs (avg)	3-4 yrs
Ability to Load Follow	Good	Excellent
Ability to Integrate with Wind/Solar	Fair	Good
Re-fuelling duration	2 months with up to 800 temporary workers mobilised	2 weeks with in-house staff

Figure 18. Comparison table for NuScale vs Traditional Nuclear Plants

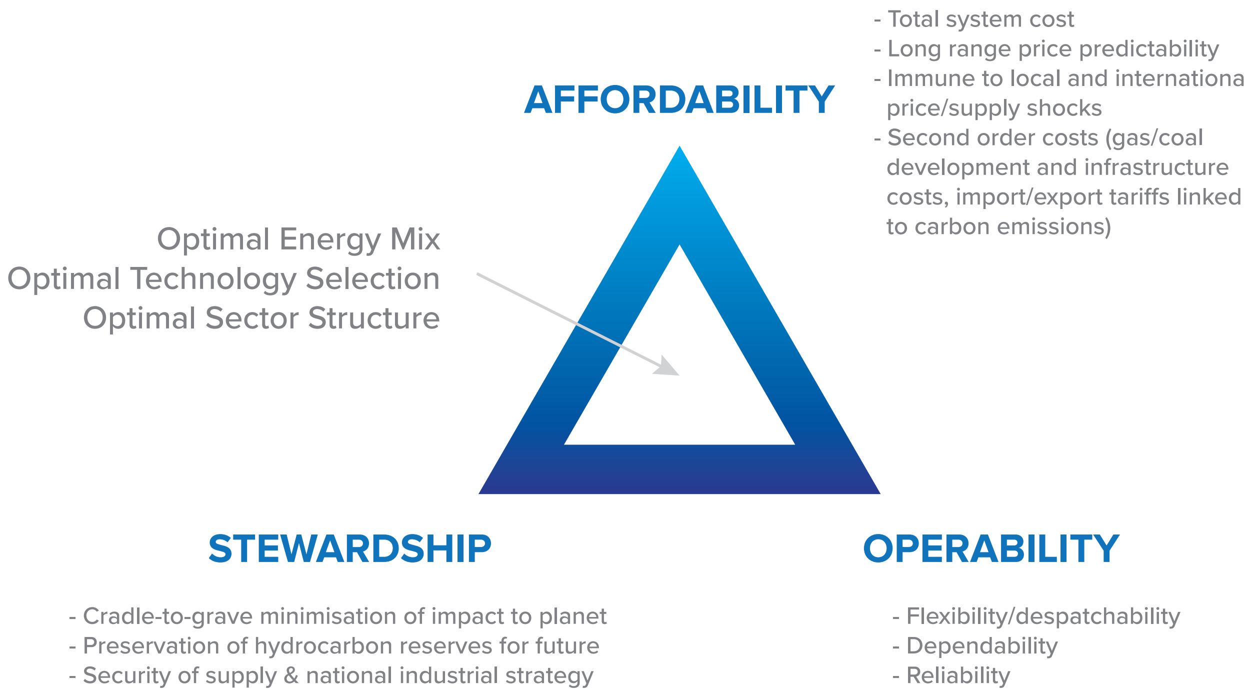


Figure 19. DUNE Vision 2050 - Optimum Market Parameters

4. DUNE: A Business Case

The cost section referred to a business case put together by DUNE for Australia. We now set this out in further detail. In DUNE's Jan 2019 EOI submission to the Underwriting New Generation Investment scheme, DUNE outlined the key numbers from an independently produced project financial model for an project in NSW that deployed SMR technology from NuScale. We have recently updated the cashflow model with firmer estimates and more conservative assumptions regarding labour productivity and owner's costs. **Project CAPEX is estimated at A$4.1B** whilst project financing costs are based on a traditional 50% equity, 50% debt split, with ½ of the debt coming from US Export/Import bank and the other ½ coming from Australian banks at standard commercial rates to give an all-in **WACC of 8%.**

DUNE found the project to be financially attractive, particularly for investors who value stable, long term cashflow businesses (insurance companies, pension funds etc.) with a 10.4% IRR (base case) when 70% of energy production was hedged whilst the remaining 30% was sold on the spot market. The early cashflow from placing reactor 1of12 in production and the retirement of construction debt for long-term debt at an earlier stage further improve the economics.

Due to the greatly shortened construction schedule, simpler construction methods and relatively modest capital cost when compared with traditional NPPs, the NuScale design will result in more manageable financing costs for the first deployment in Australia. Subsequent deployments of NuScale technology by DUNE will see further reductions in financing costs as our company's capacity to deploy and operate the technology is established and therefore warrants a smaller risk premium.

Our development timeline estimates that, with a motivated state and federal government, first commercial sale of nuclear power could realistically be between 2028 and 2030.

Much of the information in this model, including capital and operating costs, was supplied by NuScale (under NDA) or from the IAEA, NEI and other reputable sources with scaling for Australian conditions done by DUNE using acceptable early-phase estimating techniques. Allowance for spent fuel management, long-term fuel storage and de-commissioning were made according to WNA and IAEA best practise guidelines.

We are seeking investment to further detail the business case for this project which we plan to undertake as the first in a multi-build program between now and 2050.

DUNE's financial model and assessment of non-traditional business models will undergo independent review by US-based nuclear energy technical, economics and legal experts in the second half of 2019. NuScale has agreed to keep working with DUNE to further detail the costings for an Australian deployment of their technology.

Pending investment, DUNE will also engage NuScale and independent experts to validate our site selection process and detail the geotechnical, cooling water and transport considerations unique to that site.

Nameplate (gross)	720MWe
Nameplate (net)	684MWe
Number of Nuscale Power Modules (reactors)	12
Land usage (including EPZ required by the NRC)	60 acres
Capacity Factor	95%
Operational Workforce	360-400
Construction Workforce	1200-1600
Refuelling Cycle (per reactor)	24 months
Design Life	60 years
Build Time	3 years

"...a situation in which low initial investment, short lived generation facilities that may be heavily subsidised and can shift the cost of externalities may prove more attractive for investors.

Appendix A. Deep Isolation

The options for handling spent fuel are dry cask storage for later retrieval or if longer term sequestration and retrieval is required the technology developed by a Californian company, Deep Isolation™ could be used.

Deep Isolation™ is backed by engineering giant Bechtel, that has developed a novel solution using directional drilling and wireline technology developed by and used daily in the oil industry. This would be a cost effective, highly secure and reversible storage method for spent nuclear fuel.

To provide some context, if a NuScale 12 pack nuclear power plant were to operate for 80 yrs, the spent fuel requiring storage could be safely stored in 8 -> 16 Deep Isolation™ wells, depending on local geology. This is based on figures provided to DUNE by Deep Isolation for storage requirements for a Westinghouse AP1000 reactor. It could be safely and economically retrieved when required for use in fast neutron reactors or for fuel re-processing in LWRs.

The following material was provided to DUNE by Deep isolation.

DEEP ISOLATION DISPOSAL SOLUTION

Application of Deep Isolation's Radioactive Waste Management System for the proposed disposal of Highly Radioactive Wastes Resulting from use of Nuclear Power in Australia

Introduction and Executive Summary

Deep Isolation's proprietary technologies offer an inherently safe method for disposal of spent nuclear fuel and other highly radioactive wastes that would result from the use of nuclear power in Australia. The approach is superior to disposal in a mined repository in terms of cost and long-term radiological performance. It also avoids the design feature associated with deep vertical boreholes that requires the stacking of waste containers, thereby increasing the risk of a breach or release of radionuclides to the environment.

Deep Isolation believes it is of critical importance to conduct meaningful stakeholder engagement early on. Deep Isolation integrates comprehensive, in-depth stakeholder outreach and engagement into technical planning. This philosophy is founded on the understanding that nearly every failure in the last 40 years for siting nuclear waste facilities in democracies has stemmed from the absence of a working social contract.

Deep Isolation proposes work to manage the proposed Australian spent nuclear fuel. Deep Isolation's patented waste disposal system leverages mature drilling technology to place nuclear waste—including spent nuclear fuel and other types of radioactive waste—up to 5 km underground in a horizontal drillhole within deep, highly stable geologic formations.

To implement this repository system, well understood and existing technology is used to drill a vertical access hole to a depth of 0.5 to 4 km. At that "kick-off point" (an industry term) the borehole begins a gradual curve to become nearly horizontal, but with a slight upward tilt (1° to 4°). The drillhole then continues along this nearly horizontal path for 0.3 to 3 km. This nearly horizontal region is the waste disposal section. A schematic representation of a deep horizontal drillhole repository is shown on the next page.

Once the hole is drilled, casing is inserted into the length of the hole. The casing consists of long segments (typically made of carbon-steel, although other metals or alloys can be used) that are screwed together at the drill rig and lowered into the drillhole. The casing is typically several mm to 1 cm thick; the thickness will depend on the geochemistry found at depth. The curved path to reach a horizontal orientation typically so gradual (a few degrees per hundred feet) that the casing bends easily around as it is lowered to the disposal section. Once the casing is in place, the standard industry practice is to push cement down the casing and back up in the gap between the casing and the rock to make a sturdy support and provide an additional rock-casing seal.

Canisters containing the nuclear waste will then be lowered into the casing and pushed (using wireline and a tractor, drill pipe, or coiled tubing) so that they are placed end-to-end within the disposal section of the drillhole. The tilt in this section provides additional isolation from the vertical access borehole, because any mechanism that transports radioisotopes in an upward direction would move up and towards the dead end of the disposal section. Once waste canisters are in place, the borehole will be backfilled with bentonite and then sealed with rock and bentonite.

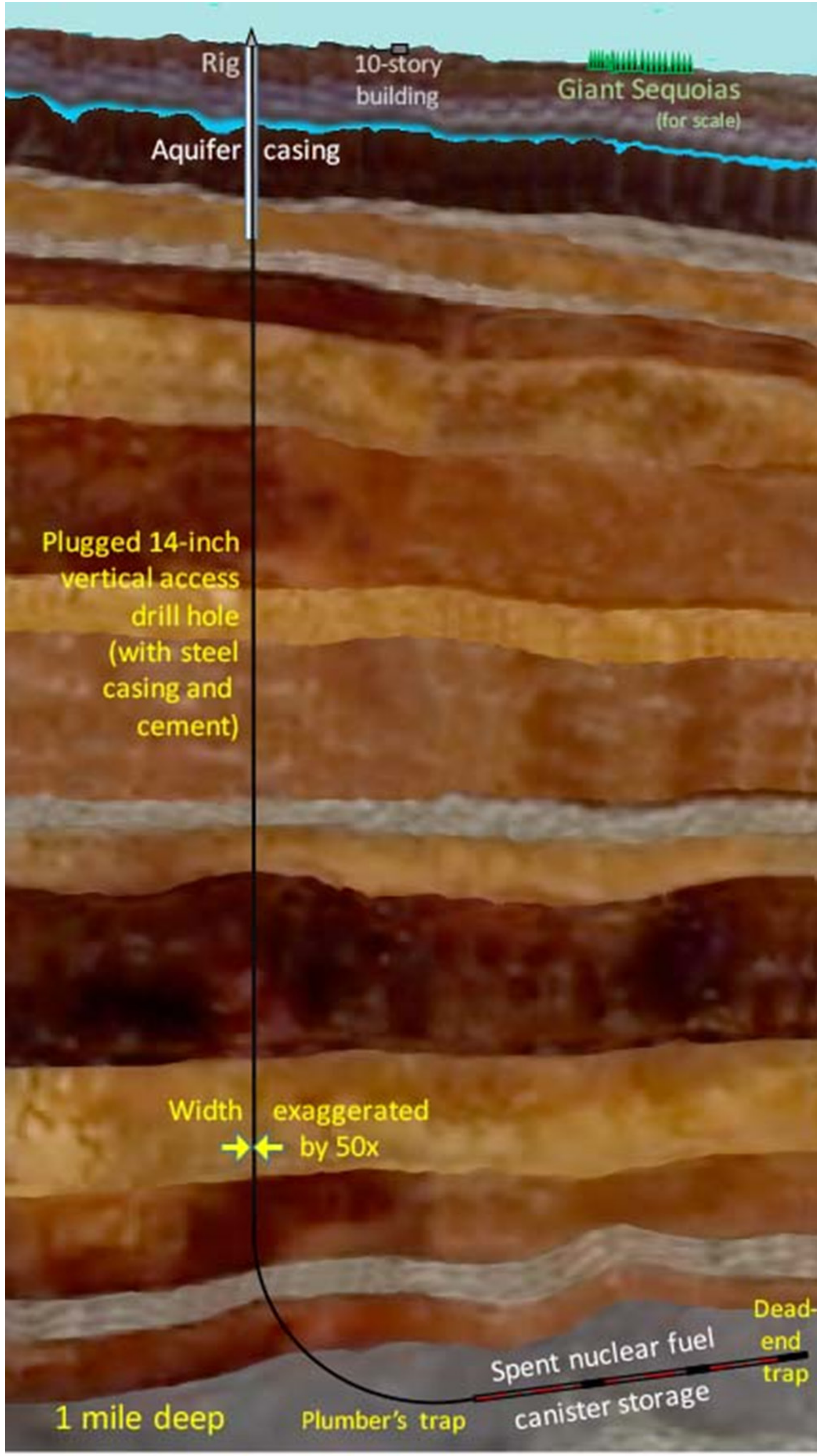
Advantages of the Deep Isolation Disposal System

In this section, the benefits and advantages of the Deep Isolation disposal system are presented and contrasted to other disposal approaches.

In general terms, there are three accepted approaches to disposal of long-lived radioactive wastes. These are emplacement in a mined repository, a vertical borehole, or the Deep Isolation drillhole where the wastes are placed in a horizontal setting; see Figure 2. Note: this is a replica of Figure 1, duplicated here for convenience.)

Disposing of the spent nuclear fuel in the Deep Isolation drillhole is less expensive than in a mined repository. More importantly, the long-term safety case for emplacing wastes into the Deep Isolation drillhole is dramatically simplified due to features inherent in its concept. Some contributing factors to this are:

1. Disturbed rock in a disposal setting can create a potential transport pathway. Broadly, rock disturbance is approximately the radius of the opening. Hence, for a mined deep geological repository with a 7-meters diameter tunnel, the disturbed zone reaches 3.5 meters into the host rock; for a borehole with a 50-centimeter diameter, this reaches only 25 centimetres into the host rock. Minimizing the extent of disturbed rock is obviously beneficial.
2. Disposal of spent nuclear fuel in the Deep Isolation drillhole enables the waste to be positioned below a layer of "tight," low-permeability cap rock with demonstrable barrier characteristics.



This can be in shales or basement rock (often granites).

3. The greater depth allows for placement well below aquifers, in deep geological formations where the presence and mobility of water is extremely low.
4. The drillhole environment at depth is chemically reducing, that is, very low in oxygen. A reducing environment adds additional level of safety, as corrosion of stainless steel and other engineered barriers are dramatically reduced.
5. Very often, the density of water increases significantly with depth due to the concentrations of salts and other dissolved minerals. This density gradient establishes a physical barrier to the vertical movement of radionuclides to the biosphere.
6. The sealing is easier than a mined repository since there is only one access drillhole and it has a very large length to diameter ratio.
7. The approach using horizontal emplacement of canisters eliminates the stress that results from "stacking" waste containers in vertical emplacement. Waste canisters rest on the bottom of the horizontal disposal section of the drillhole in our system.
8. The long linear array of the canisters in the disposal section results in substantially lower temperatures than would occur if the canisters were stored more compactly. Deep Isolation drillhole avoids this safety issue because the heat is dissipated radially along the axis of the horizontal drillhole with very limited conductance horizontally to the vertical portion of the drillhole. Moreover, emplacing the waste horizontally, well separated from the vertical access hole, means that there is no direct pathway to the surface through the disturbed zone; any driving force (such as buoyancy) that drives flow upwards will direct to the dead end of the slightly tilted disposal sector.
9. Disposal of spent nuclear fuel in the Deep Isolation drillhole will significantly reduce the cost and time for site characterisation and completion of the long-term safety case when compared to the development of a mined repository. This is because the safety case is formed around the characteristics noted above that can be rapidly verified with a limited number of exploration or pilot holes. Dating methods which require little time and cost can be used to determine the stagnancy history of the brines in the proposed emplacement zone. If measurements indicate that they have had no mixing with surface waters for thousands to millions of years, then that result indicates a safe location for disposal. The isotopes used to determine such isolation include C-14, Cl-36, and I-129.

Key differences between a mined repository and the Deep Isolation drillhole concept are listed in Table 1 hereafter.

Best Practice and International Disposal Guidance

In this section, comments are provided on how the Deep Isolation disposal system meets and exceeds international best practice standards.

Deep geologic disposal has traditionally meant having a large mined repository that is ~500 meters below surface. This requires extensive excavation as well as workers to be underground.

Over the past few years, an alternative deep geologic disposal solution using boreholes drilled thousands of meters deep has received extensive research. This approach does not require extensive excavation nor are workers underground.

Feature	Mined Repository	Deep Isolation Drillhole Repository
Depth	0.3-0.9 km	1-5 km
Access Borehole Diameter	3-8 m	0.5-0.7 m
Emplacement Borehole Diameter	1.5-5.0 m	0.5-0.7 m
Excavation Volume	Large	Small
Ground Support	Shotcrete, rock bolts, wire mesh	Casing, liner
Drainage and Depressurisation	Yes	No
Ventilation	Pre- and post-emplacement	None
Workers Underground	Yes	None
Local Waste and Heat Density	High	Low
Temperature Limit	~100 C (bentonite)	In situ boiling temperature
Implementation	Later	Earlier
Repository Closure	**50 years**	**Immediate**
Retrievability	**Yes**	**Yes**
Costs	**High**	**Low**

Table 1 Comparison between a mined repository and the proposed deep horizontal drillhole repository

Initial thinking was that boreholes had to be vertical and deep enough to allow waste to be 'stacked' from the bottom up. This vertical approach presents problems – particularly related to stacking nuclear waste containers on top of one another and the presence of a thermal gradient that can become the driving mechanism to move radionuclides from their emplacement location to the biosphere.

Disposal of spent nuclear fuel in a Deep Isolation horizontal drillhole addresses the problems associated with vertical boreholes by creating a horizontal emplacement site at a depth that is geologically isolated from the surface.

All waste is disposed in the horizontal portion – safely away from the vertical hole. Use of a vertical borehole for disposal results in a potential direct vertical path to the surface through the filled hole itself and the surrounding disturbed zone. With a horizontal disposal section, particularly with a slight upward tilt towards the dead end, the isolation of the waste is significantly increased.

The International Atomic Energy Agency (IAEA) has published a Specific Safety Guide for Borehole Disposal Facilities for Radioactive Waste (SSG-1). (IAEA SSG-1 is focused on sealed sources, but it has application for long-lived ILW and HLW waste streams.)

Host Rock Conditions

In this section, comments are provided about the compatibility of the Deep Isolation system with Australian geology.
Deep Isolation has developed a unique approach for determining the suitability of a host formation for the disposal of radioactive waste. The method involves measurements of Cl-36, Kr-81 and I-129. By measuring these isotopes at various locations in a vertical profile, Deep Isolation is able to confirm the age of water in the formation. This, in turn, informs the safety assessment by inferring the speed of travel of water from the emplacement depth. While other methods of characterisation will be employed (e.g., geophysical, geochemical and hydrogeological testing), the isotopic measurements are fundamental to Deep Isolation's determination of suitability of a host rock formation. There are few if any other limitations to the selection of a host geology. A Deep Isolation drillhole can be developed in sedimentary, metamorphic or igneous rock. The drilling industry has vast experience at developing boreholes in all three rock types. The oil and gas sector have developed over 50,000 horizontal boreholes that serve as the template for a Deep Isolation drillhole. Deep Isolation has relationships with global oil and gas drilling companies that can be used for the development of drillhole repositories in Australia.

Drilling horizontally through a basement rock such as granite is more challenging but based on discussions with oil and gas drilling company experts, this is achievable and cost-effective compared to a mined repository.

Disposal of Australian spent nuclear fuel in a Deep Isolation drillhole can be accomplished in any geology in Australia that meets Deep Isolation's stringent technical criteria for disposing of radioactive wastes.

Based on fuel load and standard refuelling of an AP1000 nuclear reactor over a 10-year period, approximately 4.78 km of the horizontal section will be needed for disposal. Depending on geology, disposal of 10 years of spent nuclear fuel could be accomplished in one to three drillholes.

Community and Stakeholder Acceptance

In this section, Deep Isolation's approach to gaining community and stakeholder acceptance is discussed.

Deep Isolation recognizes that the successful disposal of spent nuclear fuel may only be accomplished through a collaborative, productive and lasting partnership with the host community and other stakeholders. In this context, the term "partnership" is worthy of special attention as it provides the guiding theme for all our projects and is the defining concept for meeting community and stakeholder expectations. In particular, Deep Isolation's partnership strategy is comprised of three components: cultural competency, process transparency and legitimacy, and the creation of shared outcomes.

I. Cultural Competency

Understanding the context and culture of a community is the fundamental prerequisite to meaningfully engage in partnership. To that end, Deep Isolation has put together a team of professionals with decades of proven experience in working effectively with the complexities of community dynamics. With this experience and our appreciation of the ways in which host communities respond to the challenges and opportunities associated with hosting a waste management facility, we have become experts in crafting productive stakeholder engagement programs. More importantly, this institutional understanding provides the critical platform for ongoing and productive dialogue with the goal of creating mutually crafted community partnerships.

II. Process Transparency and Legitimacy

It is widely recognized that a solid understanding and appreciation of community and cultural dynamics is a fundamental prerequisite to any radioactive waste disposal solution. That knowledge, however, is only useful if it may be purposefully applied to engagement processes that create lasting and productive stakeholder partnerships. Deep Isolation's experience in building these productive partnerships is rooted in the elements of transparency and legitimacy.

From a transparency perspective, Deep Isolation creates engagement platforms and mutually reinforcing communication programs that attract and sustain stakeholder participation because they are accessible, easily internalized and resonate with target audiences. Deep Isolation's engagement processes are designed in a collaborative manner in order to realize the level of trust and "buy-in" that any agreement and partnership will require. Deep Isolation also tailors a two-way dialogue to incorporate the cultural nuances that are inherent in every host community. This initial investment in process transparency, with an equal commitment to collaboration, creates the opportunity for the community to make the informed decisions that will be needed for a durable agreement.

In parallel, and building from this commitment to transparency and collaboration, Deep Isolation establishes the essential framework of process legitimacy. Due to the fact that stakeholders have had a clear and deliberative role in designing the engagement process, they are increasingly likely to view both the process and ensuing outcomes as legitimate and worthy of their trust. This added level of legitimacy gets to the root of a successful facility siting effort by creating the foundation for mutual trust and the development of shared outcomes: the hallmark of any successful waste facility siting effort.

Deep Isolation also recognises that a part of the effort to be transparent and gain legitimacy is to engage with the academic community in a very open way. Within the Deep Isolation team, for example, lies significant experience in establishing open, public dialogue with the academic community in national and international conferences. Deep Isolation and concerned parties could explore facilitating a regular conference in Australia to explore the academic developments and uncertainties related to the use of drillholes for HLW disposal. Such events could

be organised by the Australian Institute of Nuclear Science and Engineering (AINSE) thereby directly engaging its member universities. The international flavour of such an initiative would be realistic given the number of countries around the world exploring the use of borehole disposal. The broader stakeholder engagement process is enhanced with open, academic discussions.

III. Shared Outcomes

Through the combination of cultural competency with expertise in process transparency and trust- building, the foundation for creating shared outcomes from a siting and hosting process becomes possible. These outcomes are at the core of any working relationship with a host community as they set the overall goals and objectives for an ensuing disposal project.

It is, however, important to recognize that these outcomes are not the same as the technical goals of a disposal effort. Shared outcomes define the macro, community-based objectives that may be supported by a disposal program and are defined in metrics that are created by, and resonate with, a particular host community. The disposal project is simply the means by which these outcomes may be achieved.

Shared outcomes are generally defined in terms of Community Well Being (CWB) metrics and divided into the following general categories: economic, social, cultural and political. The combination of these four dimensions helps define the overall well-being of a particular community and its ability to sustain itself and meet the needs of its residents.

Deep Isolation finds that CWB is often useful to assess the effects of a proposed HLW disposal facility on a community. To that end, the first step in the shared outcomes process is to build upon the process and relationship legitimacy discussed previously and to work with community stakeholders to define a baseline CWB definition. With this sense of the present established (through the CWB process), Deep Isolation's stakeholder engagement team then works to define and establish a host community's CWB aspirations: essentially giving voice to, and quantifying through CWB metrics, its plan for the future.

After having worked collaboratively to create a clear definition of the present and a desired future scenario, Deep Isolation would then work to incorporate the ways in which a disposal facility may help or hinder the desired options for achieving CWB goals. In particular, Deep Isolation would work with community leaders and stakeholders to explore how economic, social, cultural and political decisions about a disposal facility may advance overall CWB objectives. In doing so, Deep Isolation would place the presence of the spent nuclear fuel facility at the heart of the larger discussion about collaboratively achieving a community's CWB aspirations.

By developing trusted partnerships, formed through collaboration and transparency and informed by cultural competency, Deep Isolation builds a model for the pursuit of Community Well Being. This design increases additional incentive for successful project siting and hosting by aligning waste management goals with those of the host community. The results of such an approach may be summarized in the following quote from a local elected official who spoke as part of a recent Deep Isolation community engagement process:

"We are very fortunate to have this facility here in our county. We appreciate Deep Isolation and welcome them any time."[3]

- [3] Richard Watkins, Milam County Commissioner, 2019.

Appendix B. Cost Comparison: Renewables, Storage and CCGT vs SMR at System Level

	TECHNOLOGY	ENERGY SPLIT	NAMEPLATE CAPACITY	LAND USAGE	OPERATING LIFE	OVERNIGHT COST OF GENERATION	ONGOING COSTS (EXCLUDING NORMAL O&M)	NETWORK COSTS	ADDITIONAL COSTS
Option 1	Solar	25%	16.5 GW[1]	210,000 ha	25 yrs	A$16.5 B[2] Note: This cost will be incurred every 25 yrs to replace facilities at the end of their life	Additional capacity to be added as performance decays by 20% till end of life	Between 50% and 300% of the cost of generation[3]	Land costs up to $270 M @ $1282/ha[4] Disposal
	Wind	25%	12.5 GW	164,000 ha	25 yrs	A$18.3 B Note: This cost will be incurred every 25 yrs to replace facilities at the end of their life	-		Land costs up to $211 M @ $1282/ha[4] Disposal
	Storage	-	65 GWhrs (1 days storage for solar and wind production)[5]	Minimal	15 yrs (or less)	A$20 B[6,9]	Additional capacity to be added continuously as performance decays by 20% after 10 yrs	Minimal	Disposal cost of batteries including toxic
	Combined cycle gas	50%	6 GW @90% capacity factor	Minimal	40-50 yrs	A$6 B	An additional 300PJ/yr would be required in the NEM gas market equating to approx. A$1.27B capital investment every year assuming the gas can be economically developed[7]	Gas network additions and upgrades to accommodate 43% more gas flows[8] OR Network costs increase to allow power stations to be sited adjacent to gas fields	
Option 2	NuScale by DUNE	100%	11.6 GW	Minimal	+ 60 yrs	$64 B	-	Nil or very low, makes use of existing infra-structure	Decommissioning and spent fuel storage are fully costed at project sanction and money allocated to a 3rd party administered fund throughout the operating life

Note: Option 1 still can't guarantee that supply and demand will be kept in balance and it is likely that 1 day of storage will be woefully inadequate at certain periods throughout the year.

1 Based on capacity factor of 25% with overbuild factor of 1.5x to account for extended cloudy periods

2 Costs based on the non-network cost of latest large-scale utility project, Nyngan Solar in NSW (102MW, $440m)

3 The limits of this range could be more extreme, but these figures are based on the Nyngan Solar farm and Macarthur Wind Farm in Vic (420MW, $790m)

4 Land usage based on power density of Nyngan and Macarthur which are respectively the most recent deployments of solar and wind in Australia. Land prices come from Lucas Group, agricultural consultants.

5 Extrapolated calculation based on quoted figures from "A Bright Future: how some countries have solved climate change and the rest can follow". Engineering opinions on adequate system sizing for properly firmed renewable systems are still widely debated so DUNE decided to use the lowest storage quoted in most literature – 1 day. Much sound engineering assessment requires a 7-day storage capacity at normal loads which would increase the upfront capital cost to $140b with batteries or less with pumped hydro. 65 GWhrs is equivalent to 504 installations like Tesla's South Australian battery.

6 Lazards Energy Report 2018, assuming an Aus-US exchange rate of $0.75

7 Based on the cost of the recently sanctioned Western Barracouta project in the Bass Strait which has the benefit of leveraging existing infrastructure. Greenfields projects can expect to be more expensive. Capital expenditure quoted doesn't include backfill for declining gas reserves for current demand.

8 Based on McKinsey "Meeting Australia's Gas Supply Challenge" 2017. 690PJ domestic market, needs to expand to over 1000PJ to accommodate 50% of energy for NSW and Vic coal replacement

9 The precipitous decline in solar technology is highly unlikely to be replicated in batteries, a technology already approaching 150 yrs of maturity. A Wood Mackenzie report "Pulling the handbrake on the electric vehicles revolution" 2018 highlighted the enormous supply side issues related to raw material inputs of rare and expensive metals. In their book, "A Bright Future…" Josh Goldstein and Staffan A. Qvist point out that in order to support 100% renewables, a new Tesla gigafactory (which takes 5 years to build) would have to be built every year for 60 years to make enough batteries to store the worlds energy use for a single day.

Appendix C. Ingredient vs Energy: The Opportunity Cost of Gas

The most advanced and productive economies are those whose industries add the most value to raw material inputs. Unfortunately, Australia is on track to exploit its domestic gas reserves for their least-value purpose; energy.

Natural gas is a very useful resource that has literally hundreds of unique applications in petrochemicals and manufacturing for which there is no substitute. Conversely, DUNE is unaware of any application for U-235 (and in the future, U-238 and Th-232) outside its use as a fuel.

To continue to consume and export finite gas reserves for energy when there is a cleaner alternative available in enormous quantities seems extremely wasteful. Because of its unique properties and versatility, we can be certain that future generations will require natural gas for manufacturing plastics, fertilisers, synthetic hydrocarbons, explosives and countless other essential products. We must take action to conserve these resources for more valuable usage or be harshly judged by future generations when gas supplies that can be economically developed begin to run low.

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