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What will it take?

NUCLEAR POWER IN AUSTRALIA'S ENERGY TRANSITION

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1. Introduction

Australia has a proud nuclear energy history. The lucky country, blessed with world class reserves of readily-won uranium, one of the world's most concentrated sources of natural energy, has achieved much of which it can indeed be very proud.

The 1950s Australian Atomic Energy Commission, led by Sir Philip Baxter and a selected team of distinguished scientist and engineers, deservedly took Australia to a well-respected 'seat at the table' in emerging nuclear power development. Working closely and cooperatively with eminent counterparts in Great Britain and the United States, Australia in its day led the world in centrifuge enrichment and the creation of Synroc, arguably the safest means of encapsulating high radiation wastes. Inspirationally too–Australia is now a world leader in the production of medical radioisotopes, critical for cancer treatment.

Australia's nuclear energy research and development, ably continued today by the Australian Nuclear Science and Technology Organisation (ANSTO), places our nation within the most highly credentialled such agencies worldwide. As well, Australia in the late 1960s committed–with responsibility, confidence and international support–to building two 500MWe nuclear power plants of proven design. Located in remote Jervis Bay in the ACT, they could have supplied Canberra and much of NSW with safe, reliable and affordable power for many years and certainly to the present day and minimising the many reliability issues now being experienced.

What though has Australia achieved in nuclear energy with its extraordinary legacy, beyond export of uranium oxide, namely yellowcake, to other advanced nations? Alas little: instead marked by a lack of willingness, indeed legal prohibition, of any national nuclear power deployment whatsoever. By contrast, as an example of what could have been, Arab nations have built advanced modern reactors within 10 years, while centrifuge enrichment, once within Australia's grasp, is now deployed by some of the world's leading industrialised nations – and not only them, but also by Russia, Iran and North Korea.

In the private sector, and in the main employing private capital, the dream of commercial nuclear fusion is promising. ANSTO has achieved much in radio medicines and radioactive waste disposal. But poor decisions, attributable to both sides of politics, have limited – at huge costs to taxpayers–so much of what could have been achieved in capturing the assured benefits offered by nuclear power generation. Australia has undoubtedly allowed itself to be overtaken by so many other industrialised nations.

In 2006 Prime Minister Howard, deeply concerned by Australia's fall from its early nuclear leadership role, yet supplying the world's nuclear enabled nations with processed yellowcake, asked the question of Australia's leading scientists, engineers and economists familiar with the challenges of complex electricity supply systems–what could Australia achieve given its relevant nuclear material and intellectual resources? Accordingly, on behalf of the Australian Government, he commissioned the Uranium Mining, Processing and Nuclear Energy Review (known as UMPNER), headed by distinguished physicist and industry leader Dr Ziggy Switkowski AO, to report back with answers to that question within six months.

The UMPNER team, following rigorous external peer review of its draft, delivered its final report in December 2006. Amongst its many findings – following visits and discussions at the highest levels to nuclear enabled nations – the report concluded that nuclear power generation could form part of Australia's generation technology mix, delivering up to one third of the nation's electricity by 2050. It suggested this could comprise say 25 reactors rated at around 1,000MWe, the first delivering electrical power to Australians by 2020. Concerns arising from well documented but long-past technological and operational failures, notably the USA's Three Mile Island in 1976 and Ukraine's Chernobyl in 1986, were fully evaluated by the team, and advances in reactor technologies and operational and safety procedures were carefully analysed in reaching these conclusions.

Following delivery of UMPNER, progress towards the adoption of nuclear power in Australia was keenly anticipated. The 2009 tsunami-induced Fukushima disaster, not itself a reactor failure, nevertheless served to trigger worldwide reassessments of all aspects of nuclear safety. As a consequence of these reassessments, nuclear power is today considered the safest of all forms of clean power generation.

However, since UMPNER, Australia has undertaken an ongoing succession of nuclear-related inquiries, both state and federal–both privately and publicly funded. All conclude with essentially positive albeit cautious findings. Yet, for this great nation, the debate on the technological and economic feasibility of nuclear power in the generation mix has unfortunately degenerated from being informed by science, technology, economics and power system experience to one of firmly held political divisions in Australian governments and the community at large.

This independent apolitical study, prepared voluntarily by some of today's most experienced scientists, engineers, economists, and lawyers, all with unquestioned relevant experience, seeks to present–yet again–to the Australian people the opportunity for nuclear energy to contribute to a safe, reliable, economically sustainable technology based upon Australian resources. It addresses fundamental questions of reactor technology, siting, and safety, economics and integration, legal reform, and waste management – the entire nuclear power cycle.

"What will it take to integrate nuclear power into Australia's energy transition?" is a crucial question–one that it is hoped this study will convincingly answer.

What indeed will it take? That is indeed the question.

2. Reactor technology and safety

The fundamental safety objective of any nuclear reactor is to protect people and the environment from the harmful effects of ionising radiation.[1] This is critical to obtaining a social licence to operate, with public reticence to embrace nuclear power technology partly linked to previous nuclear accidents and incidents such as Three-Mile Island, Chernobyl, and Fukushima.

Modern reactors are designed to be safe, avoiding Chernobyl or Fukushima type accidents. The basis of reactor safety is *Defence in Depth,* designed to prevent the release of radioactive material which may cause harm to people and the environment. There are a series of engineered physical barriers to prevent such a release: fuel type, reactor cladding, reactor vessel material, steel containment liner, and concrete containment building. To maintain the effectiveness of these barriers, there are five levels of *Defence in Depth* arrangements. The key elements of this approach are:

1. Conservative, proven design and high-quality construction and operation,
2. Comprehensive control and alarm system and regular testing,
3. Independent redundant and diverse engineered safety systems to avoid damage to the fuel,
4. Provisions to confine the effects of fuel damage to the plant itself, and
5. Attention to siting principles and off-site emergency plans and training

Rather than relying on back-up diesels, outside water supplies and operator action, all factors which contributed to the Chernobyl and Fukushima accidents, modern reactors have a range of *passive* safety systems engineered as part of reactor design to ensure safety. Such safety features include the use of gravity for control rods, natural convection, conduction via heat exchanges located in a heat sink to dissipate accumulated heat, and gas pressurised accumulators containing water to ensure the reactor is cooled without operator action. These passive safety systems are within the reactor containment, providing protection from

1 International Atomic Energy Agency, IAEA Safety Standard Fundamental Safety Principles SF-1 (2006) https://www-pub.iaea.org/MTCD/Publications/PDF/Pub1273_web.pdf.

external events, and the reactor containment itself is also cooled by natural air circulation, supplemented by gravity fed water as required. A modern reactor that incorporated such passive safety features would certainly survive a Fukushima-type accident.

Like Fukushima, in an accident situation hydrogen can be produced within the reactor, which may cause an explosion damaging plant and equipment. The hydrogen is produced by a chemical reaction between high temperature steam and the zirconium used as the cladding for the fuel rods. To combat unwanted hydrogen production, major nuclear fuel manufacturers have been developing *Accident Tolerant Fuel (ATF),* typically chromium-coated cladding and chromia doped fuel pellets which provide protection enhanced protection of fuel rods against debris fretting, and oxidation resistance and superior material behaviour in a range of conditions.[2] Full fuel assemblies have been successfully tested and are being deployed in reactor refuelling.

Australia is in the fortunate position of being able to choose from several types of nuclear reactors to implement nuclear power. Therefore, what follows below is an overview and assessment of suitable generation IV (Gen IV) reactors, and their present global status.

LARGE REACTORS

The average output capacity of nuclear power reactors under construction world-wide is ~ 1,100 MWe (electrical output). These would be suitable for Australia's larger grid systems in Queensland, NSW and Victoria. Examples of large reactors currently available include the Westinghouse AP-1000 (6 operating worldwide), the Korean APR1000 based on the OPR1000 (12 operating) and the Korean APR1400 (8 operating and two currently under construction – Saeul 3 & 4).

Westinghouse has over 60 years' experience of power reactors, specialising in Pressurised Water Reactors (PWR). The **AP-1000 (Advanced Passive)** is a two-loop PWR that utilises modular construction, thereby reducing component and construction materials and construction time. output from the AP-1000 includes 3400 megawatts thermal (MWt), 1250 megawatts electric (Mwe) of gross electrical power, an 18-month refuelling cycle, load-following capabilities enabling the reactor to regularly vary its output between 30-100% of its rated power.

The AP-1000 has multiple passive core cooling systems, including core make-up tanks filled with boronated water, water filled accumulators pressurised with nitrogen, and a large in-containment refuelling water storage tank (IRWST) that can flood water by gravity into the reactor vessel when required. Containment cooling is also passive , utilising air circulation supplemented by water from a large tank at the top of the containment as required. The APR1000 has full four train safety systems including direct vessel injection with a fluidic device to optimise flow. As a result of the multiple safety systems, the AP-1000 can survive extreme Fukushima-like events without operator action or AC/DC power.

Poland and Ukraine have contracted to build AP-1000s, and Bulgaria and India have selected AP-1000's for their nuclear programs. China continues to build more of this type with 6 under construction. South Korea started their nuclear power program in the 1980's and quickly standardised on the Westinghouse PWR design which they developed themselves into the OPR-1000, APR-1400 and now the APR1000.

SMALL MODULAR REACTORS (SMRS)

SMRs are typically up to 300 MWe and are designed to have a high degree of modular factory construction, reducing on-site construction time and delays. An example of an operating SMR is the Russian 70 MWe floating nuclear power plant (FNPP), the *Akademik Lomonosov,* which has been supplying electricity and heat to Russia's Chukotka energy hub and based in the town of Pevek since 2019. Although currently only

2 US Nuclear Regulatory Commission, *Accident tolerant fuel technologies* (2024) https://www.nrc.gov/reactors/power/atf/technologies.html

generating heat and electricity for a town of 5,000, the *Akademik Lomonosov* has the capacity to provide heat and electricity for a city of up to 100,000 residents.

SMRs are not confined to FNPPs. The UK is at an advanced stage of selecting one or more SMR designs for deployment as part of its Advanced Nuclear Technologies policy.[3] Leading contenders include the GE Hitachi BWRX-300, Rolls-Royce 470 MWe SMR, Westinghouse AP-300, and the Holtec 300 MWe SMR.

The GE Hitachi **BWRX-300** is an 870 MWt thermal power, 300 MWe electrical power boiling water reactor based on GE's licensed (since 2014) large economic simplified boiling water reactor (ESBWR) which has a rated power of 4,500 MWt. The BWRX-300's natural circulation reactor and its dry containment is located underground. Above the reactor are three 100% passive Isolation Cooling Systems for emergency core cooling. Emergency AC supply from diesels is not required, although the plant normally has two non-emergency diesels for plant investment protection. Fuel is standard GNF2 LEU, 1with 12-24 months refuelling cycle.

The BWRX-300 also undertook step 1 of the UK Office of Nuclear Regulation (ONR) Generic Design Assessment (GDA) process in January 2024. In this step the focus of the ONR was to ensure the necessary arrangements, processes, and submissions are established to commence Step 2 of the GDA, and the schedule for technical assessment of the BWRZ-300 are in place. In December 2025 the ONR indicated that it is satisfied that the scope and schedule for the assessment of the BWRX-300 are in place and are ready to progress to Step 2. During the Step 2 assessment the fundamental adequacy of the reactor for deployment in the UK will be assessed, with the ONR considering the suitability of the methodologies, approaches, codes, standards and philosophies identified by GE-Hitachi in the generic safety, security, safeguards and environment cases for securing future regulatory permissions and permits.

In December 2021 the BWRX-300 was selected for deployment at Canada's existing Darlington nuclear site, with the first commercial contract signed in Jan 2023 between OPG (licence holder), GEH (technology provider), SNC-Lavalin (architect Engineer), and AECON (constructor). The construction licence application was submitted in Oct 2022 and the Canadian Nuclear Safety Commission conducted hearings related to the construction licence for the Darlington. New nuclear project held in October 2024 and January 2025. The licence is expected to be granted in 2025, with construction to commence soon after. In July 2023 it was announced that 3 additional units would be built at the Darlington site.

The **Rolls-Royce (RR) SMR** is a 1358 MWt thermal power, 470 MWe net electrical power 3 loop pressurised water reactor (PWR). With an electrical output of 470 MWe, the RR SMR is technically bigger than the accepted 300 MWe maximum definition of an SMR. RR say that they chose 470 MWe because that is the largest size that can still be transported by rail/road as a factory-built module. RR has extensive experience in PWR design and construction as they have been responsible for all the PWR reactors fitted to the UK's nuclear-powered submarines. The RR SMR entered Step 1 of the UK nuclear regulator (ONR) Generic Design Assessment (GDA) process in April 2022, completed step 2 in July 2024, and is now in the final step.

The **Westinghouse AP-300**, based on their proven AP-1000 technology, is a 990 MWt thermal power, 330 MWe electrical power, 1 loop, 2 primary coolant pumps, PWR. It scales down the proven AP1000 passive safety systems, including the IRWST and containment cooling. It is yet to be assessed by the UK ONR GDA process or deployed.

The **Holtec International SMR-300** is a 1,050 MWt thermal power, 360 MWe electrical gross power, 2 loop PWR. Standard configuration is two x 300 MWe units combined into a single power station. It utilises passive safety features characteristic of SMRs.

3 UK Government, *Policy Paper: Advanced Nuclear Technologies* (2024) https://www.gov.uk/government/publications/advanced-nuclear-technologies/advanced-nuclear-technologies

The Holtec SMR-300 completed the UK ONR GDA step 1 in August 2024 and immediately entered step 2 with completion scheduled for October 2025. Holtec has confirmed to the ONR that it only intends to complete the GDA up to the end of step 2, which will provide an assessment of the fundamental adequacy of the design and safety and security cases.

ADVANCED REACTORS – POWER AND HEAT

Australia has been a full member of the Generation IV Forum (GIF) since 2017, established in 2001 to nurture cooperation in the developing research necessary to test the feasibility and performance of fourth generation nuclear systems (Gen-IV systems). The 14 country members of GIF all possess significant nuclear capabilities and together are progressing the R&D for the next generation of reactors which will excel in safety. The members of GIF wanted Australia, represented by ANSTO, to participate because of ANSTO's world-class nuclear research capabilities particularly in materials for advanced reactors.

Very High Temperature Reactors (VHTR) and Molten Salt Reactors (MSR) can produce process heat in addition to electricity generation. Accordingly they are of particular interest to Australia as a replacement for heat in industrial processes, an essential area to decarbonise in the transition to net zero emissions. Several companies are developing MSRs, including Canadian-based Terrestrial Energy (190 MWe). The US Nuclear Regulatory Commission (NRC) has just issued its first construction permit for a liquid fuelled advanced reactor (1 MWt research MSR) at Abilene Christian University. An example of a VHTR already in operation is the *Chinese Shandong HTR-PM* (211 MWe). X-Energy (USA) has a contract with Dow Chemicals to deploy a HTGR supplying heat and electricity (4 x 80 MWe) to a large chemical complex.

The **X-Energy Xe-100** is a High Temperature Gas-cooled Reactor (HTGR), fuelled by tristructural isotropic (TRISO) particles. It contains a graphite moderator, is helium cooled, with 200 MWt thermal power and 80 MWe electrical power. Standard configuration is 4 XE-100's configured as a 320 MWe 4-pack. The facility can produce process steam at 565°C.

The **Terrestrial Energy Integral Molten Salt Reactor (IMSR)** is 442 MWt thermal power, 190 MWe electrical power capable of supplying high-efficiency electricity and 585°C process heat. The IMSR has a graphite moderator and uses molten salt as coolant and fuel. Terrestrial has developed a two-unit configuration that can deliver 884 MWt/390 MWe. The design features a completely sealed reactor vessel with integral pumps, heat exchangers, all mounted in a single vessel which is replaced every 7 years.

The US company Terrapower (funded by Bill Gates) is deploying their Natrium Sodium Cooled Fast Reactor at the site of a retiring coal-fired power station in Wyoming The **GE Hitachi Terrapower Natrium Reactor Project**, which broke ground in June 2024, is a 345 MWe sodium-cooled fast reactor combined with a molten salt storage system, boosting output to 500 MWe when required. The reactor island is separate from the energy storage and electricity production island, simplifying licensing. The plant is being built through a public-private partnership with the US Department of Energy (DOE) Advanced Reactor Demonstration Program (ARDP). This program authorises a 50/50 cost share with up to $2 billion for the Natrium project. The new reactor plant, replacing the retiring Naughton 357 MWe coal-fired power plant, has strong local community support.

MICROREACTORS

Microreactors are typically <10 MWe and designed particularly to replace diesel generation in off-grid communities and mine sites. There are over 1,000 islanded electricity systems and microgrids across Australia. The small physical size of the microreactor enables transport to site in shipping containers with very short installation times. Leading contenders are Westinghouse eVinci, BWX Technologies BANR, Radiant Industries Kaleidos, and OKLO Aurora Powerhouse. These microreactors typically use advanced technologies and operate at higher temperatures and can supply process heat in addition to electricity.
In March 2020 the US DoD awarded contracts, under Project Pele, to three companies to begin design work on a microreactor prototype to supply mobile, transportable power for the US army.

The **Westinghouse eVinci Microreactor** is a nominal 15 MWt thermal power, 5 MWe electrical power micro-modular reactor particularly for off-grid remote applications. An eVinci can also supply 750°C process heat. It uses TRISO fuel and sodium filled heat pipes to passively transport heat from the fuel to the primary heat exchanger and requires no water for cooling or operation. The complete system is factory-assembled and transported to site in three shipping containers. Site installation is < 30 days with eight or more full-power years before refuelling. In late 2024 Westinghouse and Core Power formalised a cooperative agreement for the design and development of FNPPs utilising the eVinci Microreactor, with these vessels similar to the *Akademik Lomonosov* in their utility and deployability.

The **BWX Technologies (USA) BANR Microreactor** is a TRISO fuelled HTGR, graphite moderated, 50 MWt power scalable and is designed to be transported in five shipping containers. BANR is designed with inherent and passive safety features, refuelling is every +5 years. In 2021, BWXT received an award of $111M over 7 years from the US DOE under the Advanced Reactor Demonstration program (ARDP).
BWXT won the contract to supply a microreactor in 2024 for testing by the US Department of Defence under their "Project Pele" to supply mobile, transportable power for the US army.

The **Radiant Industries Kaleidos Microreactor** is a 1.2 MWe electrical power HTGR, TRISO fuelled, graphite moderated, and helium cooled. The power generator, reactor, cooling system and shielding are all packaged in one shipping container which can be transported back to the factory for refuelling every five years.

The **Oklo Aurora Powerhouse** is a 4 MWt thermal power, 1.5 MWe electrical power sodium-cooled fast reactor. The primary cooling system uses heat pipes to transport heat from the metal fuel in the reactor core to a supercritical carbon dioxide power conversion system to generate electricity.

3. Siting of nuclear power generation facilities

The siting of nuclear power plants (NPP) is a critical aspect of their deployment, influencing safety, environmental sustainability, and public acceptance. Proper siting ensures the long-term viability of the plant and mitigates potential risks. There are several key considerations and issues to consider in siting NPPs.

IMPORTANCE OF PROPER SITING

Siting decisions for nuclear power plants significantly affect operational safety, environmental impact, and especially community acceptance. A well-chosen site minimises the likelihood of catastrophic failures and ensures compliance with national and international safety standards. Moreover, appropriate siting supports the efficient integration of the plant into existing energy grids while reducing the logistic challenges of construction and operation. Siting is the first step in the staged licensing approach used internationally for nuclear installations.

Broadly speaking, key siting considerations are:

1. *Safety and Event Protection*: Safety is paramount, requiring rigorous assessment of geological and seismic stability. Sites must be located away from active fault lines and areas prone to natural disasters such as earthquakes, floods and tsunamis. For example, the Fukushima Daiichi disaster highlighted the risks of not putting in place adequate design provisions to compensate in areas vulnerable to natural hazards.[4]
2. *Environmental Impact*: Environmental considerations include impacts on local ecosystems, water resources, and biodiversity. Nuclear plants typically require water resources for cooling, making proximity to rivers, lakes or oceans a common requirement.[5]

4 World Nuclear Association, *Safety of Nuclear Power Reactors* (2023).

5 International Atomic Energy Agency (IAEA), *Nuclear Power and the Environment* (2022).

3. *Proximity to Population Centres*: NPPs should be located at a safe distance from densely populated areas to minimize risks in the event of an accident. At the same time, they should be close enough to electricity demand centres to reduce energy transmission losses.
4. *Regulatory and Political Factors*: Compliance with national and international regulations is essential (and considered in section 6 below). Political considerations also play a role, as public opposition or support can influence site selection and project timelines.
5. *Economic and Logistic Viability*: Sites should be accessible for construction and maintenance while minimising costs. Proximity to infrastructure such as roads, ports, and grid connections is also a key consideration.
6. *Long-Term Waste Management*: The siting process must provide for the safe storage and disposal of nuclear waste. Selecting locations that facilitate secure, long-term waste management is critical to ensuring environmental and public safety. Waste management is considered in section 7 below.

KEY CONSIDERATIONS

In the siting of NPPs, key considerations can be broken into two areas:

- Technical considerations
- Non-technical considerations

TECHNICAL CONSIDERATIONS

A standard approach to siting for nuclear power plants is outlined in the international best practice document produced by the IAEA's SSG-35 Site Survey and Site Selection or Nuclear Installations.[6] SSG-35 outlines a 5-stage approach to siting. This guide would be suitable for use in Australia to inform a screening and ranking process for the determination of the suitability of sites for nuclear power plants.

The screening potential of sites is carried out using two types of criteria, summarised broadly as:

- *Exclusionary criteria*: used to discard sites that are unacceptable due to events or hazards for which there are generally no practical engineering solutions to compensate for the event/hazard.
- *Discretionary criteria*: these are events/hazards for which protective engineering solutions are available. When a large number of potential sites are available, they are evaluated iteratively to eliminate those less favourable.

Two siting criteria that have been the subject of significant media discussion in recent times are earthquakes and cooling water.

Under SSG-35, the potential of a site to be subjected to surface rupture (faulting), which is likely to cause earthquakes, can be an exclusionary criterion. Ground vibration on the other hand is a discretionary criterion, meaning nuclear power plants can be (and are) designed to operate safely and securely during and following ground vibration. Ground vibration is but one criterion upon which potential sites can be compared and evaluated.

The availability of cooling water can be an exclusionary criterion. The amount and quality of cooling water required would depend on the reactor technology under consideration, hence cooling water availability and reactor technology would be considered together.

The number of sites in Australia that could be suitable for a nuclear power plant are considerable. For the sake of simplicity and a reduction in costs, countries including the USA are examining the suitability of their coal-fired generating sites for conversion to nuclear power plant sites. This approach has several advantages, including:

- the reuse of much existing infrastructure,

6 IAEA, *SSG-35 Site Survey and Site Selection or Nuclear Installations* (2015)

- a just transition for coal plant workers to stable, high paying and highly skilled jobs,
- an energy literate local community that well understands the benefits of the supply of constant reliable energy,
- direct replacement of fossil fuel intense energy generation, and
- reduction in the amount and complexity of new infrastructure needed for the clean energy transition.

Whilst existing coal fired generating sites are an attractive potential location for nuclear power plants, the versatile nature of NPPs means they can be sited alongside energy intensive industry, at mine sites or as a direct replacement for energy sources in remote communities.

NON-TECHNICAL CONSIDERATIONS

The technical solutions to siting are known and well regulated. The non-technical considerations take more time and effort, and there is still much to be learned on Australian best practice. These vary dependant on the location, nuclear literacy levels and the trust in the government within a community. Non-technical considerations include building a social licence. The IAEA refers to social licence as a situation where '*a project has ongoing approval within the local community and among other stakeholders, and also has political and public acceptance*'. There is no international best practice guide for social licence for nuclear installations as each individual town and community will vary in its acceptance and concerns regarding perceived risks with radiological and nuclear materials. Some of the considerations in non-technical siting include:

- Building transparency and trust,
- Working with traditional landowners,
- Working with community and environmental groups,
- Working with universities, TAFE and local industries,
- Access to a skilled workforce, and
- Security considerations

There are two recent examples at both ends of success in the non-technical siting of nuclear installations. The first is New Zealand's siting of its national radioactive waste facility, which had no community consultation and was built in secrecy on a military establishment, sparking community concern, even though the actual risk of harm is very low. At the other end of the spectrum is Canada's siting of their national radioactive waste facility, which included over a decade of community engagement and collaboration with traditional land owners to find a suitable site and build a skilled local workforce in support.

For social licence to be successful, education is essential. Education in nuclear and radioactive sciences, safety and risks allows for communities to be engaged and to want to become part of the nuclear workforce. Upfront investment in these communities over a long period allows for trust to be established and in turn allows for a local skilled workforce to be employed and value the contribution their community makes in the energy market. This cannot and should not be rushed.

Siting nuclear power plants involves a multifaceted evaluation of safety, environmental, and economic factors. Proper site selection minimises risks, ensures regulatory compliance, and facilitates public trust. Careful planning and adherence to best practices, as outlined by organisations such as the IAEA, are indispensable for the successful implementation of nuclear energy projects.

4. Integrating nuclear – economics and investment

Energy in the form of heat is the main output from a nuclear reactor.[7] In any system where nuclear fission is the primary energy source, the heat may be used directly (e.g. for district heating in cold climates, or for industrial processes), but is more commonly converted to other energy forms. At almost all commercial civilian nuclear plants around the world today, the heat is used to raise steam, to drive a turbine connected via a shaft to a generator for producing electrical power.

The same basic engineering process from fission-to-heat-to-steam-to-shaft-to-generator is used on FNPPs such as the *Akademik Lomonosov* currently deployed in the Russian Arctic, nuclear icebreakers, and in naval propulsion systems such as submarines and aircraft carriers. Propulsion for naval vessels — as also demonstrated by the United States, Germany and Japan in the 20th century for civilian maritime vessels — can be provided directly from the shaft power.[8]

The present scope of this section is focused on the application of nuclear energy to civilian electricity generation. This is not intended to rule out other future applications of nuclear energy in Australia, such as naval nuclear propulsion, for which economics and investment will also be important considerations.

To date 30 countries have nuclear power successfully integrated into their national electricity systems, and more are preparing to do so.[9] The economics of integration in power systems is more complex and nuanced than other applications, and therefore some explanation of the concepts may help.

Before discussing specifically the integration of nuclear energy, it is important for proper **context** to have a sense of the general topic of the integration of generation of any kind in any power system, and for situational awareness as to how that applies to the integration of wind and solar power systems which are part-time, low availability, low or zero marginal cost, zero rotational inertia intermittent forms of power generation. That technical, economic and investment issues related to integration are now belatedly receiving due attention follows 20 to 25 years of addition of wind and solar power, at accelerated rates in the last 10 to 15 years. The scale of those types of generation is now very large collectively on rooftops, and across utility-scale wind and solar 'farms', increasing at a very high rate of deployment measured in gigawatts per year.

Integration as a technical question is of paramount concern and a pivotal consideration for any form of generation in any power system: whether large or small. That includes Australia's National Electricity Market (NEM), the South-West Interconnected System (SWIS) in WA, and in other small utility, off-grid and island power systems. As a general comment, the principle applies to the integration of wind and solar power, as well as to gas, coal or nuclear power.

The importance of integration arises from the non-negotiable technical requirement to balance generation and load at all times, as well as from the mission-critical, economy-wide and whole-of-society reliance on electricity as an essential service and civilisational support system.

Integration *in general* here is first and foremost a technical engineering issue, for the simple reason that the system as a whole must work with the level of service quality and reliability required by customers. Thorough assessment of the economics must be based on the technical realities of power systems, and hence these are

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7 Reactors can also be used as a source of neutrons. Australia's Open Pool Australian Lightwater (OPAL) reactor owned and operated by ANSTO at Lucas Heights in Sydney is rated at 20 megawatts of thermal power, but it is design-optimised not for heat generation but for the production of neutrons for scientific experiments, production of medical isotopes, and production of specialised industrial products.

8 The USS Savannah was one of three nuclear-powered hybrid passenger-cargo demonstration vessels. The development of nuclear-powered civilian vessels is currently being pursued by several private companies, regulatory agencies and industry organisations as part of initiatives to decarbonise shipping. Civilian (and possibly military) vessels in the 21st century is likely to use electric drive propulsion.

9 International Atomic Energy Agency, 2023, *Country Nuclear Power Profiles*, Non-serial Publications, IAEA, Vienna. https://www.iaea.org/publications/15486/country-nuclear-power-profiles

very briefly summarised below. However, the economics of nuclear energy cannot be understood without a deep appreciation of systems, and a capacity for systems thinking, even if only at a basic level.

First, what's a system? A system is a whole, consisting of numerous interconnected parts, each of which is reliant upon and which can affect its behaviour or its properties. Humans, for example, are a biological system called an organism, and consist of parts: heart, lungs, stomach, pancreas and so on, each of which can affect the behaviour or viability of the whole.

The second requirement is that each part of the system, when it affects the system, is dependent for its effect upon some other part. In other words, the parts are *interdependent*. No part of a system, or collection of parts of a system, has an independent effect upon it. Therefore, the way the heart affects the whole human being depends on what the lungs, brain and all other interdependent parts is doing; they are all interconnected.[10]

Ignoring the system in its totality, together with a general lack of systems thinking and ill-informed substitution of *market thinking* in place of (or uninformed by) *systems thinking*, over-simplifies the debate about the cost of nuclear energy, tending to leads public energy policy in dangerous directions. Such a directions are characterised by short-term thinking, creating more problems than are resolved, while failing to meet *any* of the three universal and timeless goals of all national systems: namely high energy security and reliability, commercial and household affordability and business competitiveness, with minimal adverse impacts on local communities and the wider national environment.[11] It is notable that nuclear energy, when fully and properly understood, is the most effective means of resolving those three goals which are usually in tension, and therefore referred to as the energy policy trilemma. Common errors in thinking about energy costs, especially for electricity, include the following:

1. The use of the Levelised Cost of Energy (LCoE) metric to compare one generation technology with another in a vacuum, rather than as parts of a system.
2. The use of any other metric also based on the discounted cash flow (DCF) method, including Present Value (PV) or Net Present Value (NPV) as a simple decision tool.
3. Failure to consider the full value chain required for the delivery of electrical power to customers at specified quality and reliability levels the associated total system cost.
4. Failure to consider whole-of-life and national interest and security imperatives typical of long-dated infrastructure that are inherent in strategic and public policy decisions.

These four common errors are distinct but related and often found together. Most are usually present either explicitly or implicitly and interwoven in anti-nuclear arguments, or in arguments that often begin with... "I'm not anti-nuclear but...". Common such arguments are "nuclear energy costs too much" and "nuclear energy takes too long." Variants include: "the business case doesn't stack up", "companies aren't interested", and "nuclear energy is uninsurable."

The LCoE metric is an industry-specific instance of a discounted cash flow method. Moreover it is confined to the power generation sector of the electricity industry. The shortcomings of the LCoE metric have been

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10 Russ Ackoff, 'Beyond Continual Improvement' (original title) from a 1994 event hosted by Clare Crawford-Mason and Lloyd Dobyns to capture the Learning and Legacy of Dr W. Edwards Deming. Recording available online entitled 'If Russ Ackoff had given a TED Talk at: https://www.youtube.com/watch?v=OqEeIG8aPPk [**emphasis** added]

11 This category error is usually made by economists with little technical understanding who have fallen into the trap of treating free-market or other economic theory as universal truth, rather than a specific knowledge domain. The same problem sometimes applies to physicists with low awareness of their lack of engineering knowledge, and to software engineers with limited understanding of physical laws.

described by many authors. The CSIRO GenCost report provides readers with a warning about its use.[12] Nonetheless GenCost publishes LCoE estimates which are commonly cited in the public arena and the media as being authoritative for economic analysis, with no caveats as to their shortcomings.

The LCoE method role is but a very simple first-cut guide to indicative cost levels. The LCoE calculation itself is quite straightforward, with numerous variants, depending on how the details are implemented. More importantly, the assumptions and inputs to the calculation are such that answers spanning an enormous range can be obtained. An illustration is provided in a chapter on power system economics and nuclear energy with side-by-side worked examples for an illustrative nuclear power plant. One calculation shows LCoE using inputs from the GenCost 2019 report as $339.59/MWh (closely replicating CSIRO's result in that report). Another calculation alongside with reasonable changes to several input assumptions gives a result of $65.67/MWh.[13]

The LCoE metric is neither an investment-grade tool, nor is it a policy-grade metric. Using LCoE as the primary basis for investments or for policy will lead to poor investments in the long run and counter-productive policy settings. Private sector and government sources that rely on the LCoE metric as final and authoritative either do not understand the issues or, it has to be said, at times are trying deliberately to mislead their audience.

Strictly speaking, the LCoE metric provides a mathematical answer to a simple question:

'If I was to charge one constant price (usually expressed in dollars per megawatt-hour ($/MWh) or cents per kilowatt-hour, (c/kWh) for every unit of output from this power plant, for every year over the life of the plant, such that I would exactly recover all of my up-front capital costs, including interest during construction, and my other fixed costs, as well as my variable operating and maintenance costs, what would that price be?'

The flaws of discounted cash flow methods, as applied to equities and physical assets *in general*, have been clearly and succinctly laid out in a paper published in 2016 and available on the Columbia University Business school website.[14] As with the comments above on the LCoE metric, discounted cash flow methods have a role to play in commercial and policy decision-making. However, excessive or exclusive reliance on any discounted cash flow method for strategic, economic, or policy formulation can undoubtedly lead to poor decisions.

The underlying reason for this situation, as evident in Cifuentes,[15] is the inappropriate treatment of risk and uncertainty. An analytical failure here is the implicit assumption that reliable, affordable electricity will no longer be needed after 25 or 30 years from now. Perhaps that is the case, but it seems about as sensible as assuming that food, water, clothing, shelter, medical care, education, commodities, and manufactured goods will not be needed in that same time frame.

Another major shortcoming of discounted cash flow methods, also explained by Cifuentes, is the non-recognition of upside value. One of the many inherent and interesting characteristics of electricity is that its value (which can be appreciated through the opportunity cost) exceeds its cost by many orders of magnitude. This is recognised in the market design, where the price in the short-term is allowed to exceed the typical market price level by 100 to 200 times (the five-minute market price cap is currently $17,500/MWh). It

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12 See section 5.1 'Purpose and limitations of LCOE' in several editions of the GenCost report series, including: Graham, P., Hayward, J. and Foster J. 2024, *GenCost 2023-24: Final report*, CSIRO, Australia. This should not be taken as a definitive nor an authoritative statement on LCoE, but it does note the some dangers of relying on the metric.

13 Frame (Ed), 2020, *An Australian Nuclear Industry Starting with Submarines?* Connor Court, UNSW Press, Canberra. Wilson, Chapter 8: Too cheap to meter or too expensive to matter? Tables 8.2 a and b, p.124-5.

14 Cifuentes, Arturo, *The Discounted Cash Flow (DCF) Method Applied to Valuation: Too Many Uncomfortable Truths* (September 29, 2016). Available at SSRN: https://ssrn.com/abstract=2845341 or http://dx.doi.org/10.2139/ssrn.2845341

15 Cifuentes, Ibid.

is also recognised that persistence of very high market prices is value destructive, and so there is a lower cumulative price cap that is triggered if the market price level remains high.

That highlights another important issue that cannot be avoided in the discussion of costs and the integration of nuclear energy: even after assets are privatised and the principles of free-market competition are introduced, as happened in Australia and various other places around the world from the 1990s, electricity nonetheless continues to have strong collective attributes and public good characteristics. Electricity is certainly NOT ‘Just Another Market’ (JAM).

The collective characteristics arise from the physical laws and the nature of the engineering system in which generation and load (‘supply and demand’ to economists) must continuously be balanced very precisely or the entire system can rapidly collapse. This, combined with other characteristics make electricity markets vulnerable to economic issues of excessive market power on the supply side. One of the key characteristics of electricity systems on which (supposedly free) markets have been overlaid is barriers to entry, or lack of ease of entry.

This leads on to questions of investment, which are strongly connected with the question of time horizons in the discussion above. It also returns full circle to the question of integration. It was stated above that integration *in general* is first and foremost a technical engineering issue. While this is certainly true, the main impetus of this technical fact bears on the *comparative* question of the integration of various generation technologies in a power system as a whole, and the effect of technical realities on power system economics.

Power systems that include nuclear energy tend to have lower total system costs than power systems that exclude nuclear energy. Exceptions include systems where either coal or gas are available in abundance at low cost. When deep reductions or complete elimination of carbon dioxide (CO_2) emissions are applied as a policy constraint, it is found that systems with a cost-optimised share of nuclear energy capacity and generation are markedly lower in total system cost than systems relying on solar and wind power and round-trip storage technologies.

This finding was already evident in the academic literature prior to 2020, where most such studies focused on Europe, and on low to medium wind and solar energy shares of 50% or less. The finding is now stronger, evident in several PhD theses and journal papers since 2020.[16]

Integration of nuclear energy is technically and economically favourable. The key issue is to align the public policy and the approach to financial integration with the need for the technology.

The economic issues in integrating nuclear energy into Australia’s energy system can therefore be summarised thus:

1. How government, business, and academia think about the questions of cost and time is the key to the central aspect of the debate.
2. One important aspect of the public discourse and the sustainable embrace of nuclear energy by wider Australian society is the manner in which the cost debate is conducted.

16 Tómasson, Egill, 2020, Impact of High Levels of Variable Renewable Energy on Power System Generation Adequacy: Methods for analyzing and ensuring the generation adequacy of modern, multi-area power systems, Doctoral Thesis, KTH, Stockholm, Sweden; Rioseco, Gabriel, 2022, Understanding the opportunities and costs of planning and operating electricity systems with high shares of variable renewable energy sources, doctoral thesis, University of Queensland; Robert, 2022, *Electricity Markets with Renewables and Storage*, PhD dissertation, Rice University, Houston, Texas; Idel, Robert, *Levelized Full System Costs of Electricity*. Available at SSRN: https://ssrn.com/abstract=4028640 or http://dx.doi.org/10.2139/ssrn.4028640

3. The central recommendation of the report of the study published by the University of Queensland in December 2020 stands: Australia should create real options to be able to deploy nuclear energy if it is decided it is needed.[17]
4. Discounted cash flow methods (including NPV and LCoE) must be used with great care and are neither investment-grade nor policy-level single-metric decision tools.
5. Integrating nuclear energy in Australian electricity systems requires a properly considered, programmatic, fleet-level approach with a long-term horizon.
6. Systems thinking is required. A whole-of-system with analysis using a total cost perspective is called for.
7. Nuclear energy integrates favourably into power systems from a technical point of view, a finding that is based on long empirical and international experience, consistent with sound modelling.
8. Technical integration naturally forms the basis for the economics of nuclear energy and is a key aspect of design and vendor selection, which requires a properly resourced authority.
9. Integration must be looked at for each power system, as the 'fit' of each potential nuclear power plant reactor type and plant design will vary throughout a system as large as the NEM, and from a system on the scale of the NEM to smaller systems.
10. Every decision involves trade-offs. An example of this is the selection of the appropriate reactor unit size for Australia, trading off unit economies of scale and learning effects.

5. Integrating nuclear energy into the National Electricity Market (NEM)

Nuclear generation offers the opportunity to provide low cost, low emissions base load generation for Australian electricity customers in both the NEM and the SWIS (Southwest Interconnected System of Western Australia). Modelling shows that nuclear generation works best as part of a balanced technology mix including wind, solar PV, gas and energy storage, and that low emissions nuclear generation is a highly effective effective longer term means of displacing retiring coal generation.

Nuclear can directly provide 24/7 base load generation without the need for complex combinations of wind, solar renewable energy generation in combination with pumped storage, grid batteries and home batteries. It also provides essential power system services necessary to stabilise the national grid by providing system strength, inertia and frequency control services (FCAS) that are difficult and expensive to deliver under renewables-only energy schemes.

If needed, nuclear generation can also be designed to provide load-following capabilities. Compared to renewable only power systems, systems including a portion of nuclear base load generation require considerably less High Voltage (HV) transmission and less Medium and Low Voltage (MV and LV) distribution network capacity, thus providing major cost savings for electricity customers.

High initial capital costs of nuclear generation are more than offset over time by low operating costs and very long operating lives–in the order of 60-80 years. Total system cost of electricity to customers is the inclusive metric that should guide the development of Australian power systems. Failure to observe this principle is a major weakness of the reasoning in the Australian Energy Market Operator's (AEMO) Integrated System Plan (ISP).

Australia needs to develop a strategic nuclear power system development plan from the present to 2050 and beyond. Such a plan should work towards:

17 Wilson et al, 2021, on *What would be required for nuclear energy plants to be operating in Australia from the 2030s*, UQ, https://www.eait.uq.edu.au/research/energy/nuclear-energy

- The fast tracking of new nuclear power generation facilities;
- The development of a more cost effective, cut down low cost HV transmission system;
- The avoidance of large-scale distribution (MV) and (LV) network expansions;
- Life extension of existing coal and gas generation capacity until new nuclear generation plants are commissioned and available on line;
- Reducing customer gas prices through increased supply and domestic gas reservation;
- The progressive removal of subsidies in all their forms;
- Reform of electricity markets to provide essential logical price signals for investors, generators and customers, including signals covering the marginal cost of electricity (MWh) and the value of firm supply capacity (MW);
- Regulatory reform aimed at simplifying the business of electricity generation, transmission, distribution and end use;
- Restoring international energy costs competitiveness; and
- Placing the needs of residential, business and industrial electricity customers and centre of all energy planning.

Increasing natural gas supply and reducing gas costs is a crucial aspect of current Australian energy planning. A strategic gas plan will be needed to work in tandem with electricity supply plans.

Regarding the AEMO ISP (Integrated System Plan), before delivering its 2026 ISP, AEMO needs to deliver upon its 2024 ISP by considering and reporting upon total system costs including:

- Roof top solar PV;
- Behind the meter batteries; and
- Extra Medium Voltage (MV) and Low Voltage (LV) distribution costs.

Recent whole of system modelling by Electric Power Consulting shows that development of the NEM in accordance with the Step Change Scenario of the Integrated System Plan will lead to further electricity costs increase for all consumers–reference 2024 EPC ISP Submission. If implemented in its present form, electricity cost increases will inevitably contribute to accelerated de-industrialisation of the Australian economy.

System security requirements dictate the existing coal generation must not be decommissioned until adequate replacement capacity is provided. Hence new nuclear generation is now required with some urgency. Delivering affordable net zero electricity to Australian electricity customers is practically impossible without introducing nuclear power into the generation mix.

6. Regulatory reform for adopting nuclear power in Australia

Implementing the Coalition’s policy on nuclear energy requires minimal regulatory reform in Australia. While some targeted changes to nuclear law are necessary, they are relatively straightforward. Internationally, nuclear law is divided into four pillars: nuclear safety, nuclear safeguards, nuclear security and nuclear liability. Australia already has a strong foundation in each area due to its long-standing experience with nuclear medicine reactors, which have been operational since 1958, and its robust uranium mining industry, which has been active since the 1950s.

NUCLEAR SAFETY

Australia’s nuclear safety framework operates under a dual regulatory structure reflecting its constitutional division of powers. Federally, the Australian Radiation Protection and Nuclear Safety Agency (**ARPANSA**) regulates nuclear safety for government-related activities under the *Australian Radiation Protection and Nuclear Safety Act 1998* (Cth) (**ARPANS Act**). For state and territory-regulated activities, such as uranium mining and medical radiation, safety is managed by state and territory regulators in accordance with their respective laws. ARPANSA ensures compliance with international agreements, including the Convention on Nuclear Safety and the Joint Convention on the Safety of Spent Fuel Management and Radioactive Waste Management. The 2024 establishment of the Australian Naval Nuclear Power Safety Regulator (**ANNPSR**) further highlights Australia’s ability to implement specialised regulatory frameworks.

Extending ARPANSA’s remit to license and regulate civilian nuclear power plants would require minor amendments to the ARPANS Act. These changes would lift existing prohibitions on nuclear energy and empower ARPANSA with broader authority and resources to oversee safety in nuclear power generation. With ARPANSA’s decades of experience regulating facilities like the OPAL reactor, this transition would be seamless, leveraging existing processes for assessments, public consultations, and compliance monitoring.

NUCLEAR SECURITY

Nuclear security in Australia is managed through a robust framework led by the Australian Safeguards and Non-Proliferation Office (**ASNO**) and ARPANSA. ASNO enforces obligations under the Nuclear Non-Proliferation Treaty (**NPT**) and the Convention on the Physical Protection of Nuclear Material (**CPPNM**), as implemented in the *Australian Safeguards and Non-Proliferation Act 1987* (Cth) (**Safeguards Act**). These measures ensure the protection of nuclear materials against theft, sabotage, and other criminal acts.

Minimal changes are needed to adapt Australia’s nuclear security framework for civilian nuclear power. ASNO’s established expertise in managing security for nuclear materials provides a strong foundation for incorporating nuclear power into the regulatory system. Existing structures can be seamlessly extended to address the specific requirements of nuclear power plants, ensuring secure operations while aligning with international norms.

NUCLEAR SAFEGUARDS

Australia’s nuclear safeguards laws, governed by the Safeguards Act, enforce commitments under the NPT and the IAEA’s safeguards framework. These laws ensure that nuclear materials are used exclusively for peaceful purposes through mandatory reporting, inspections and verification. Australia’s safeguards regime is enhanced by the Additional Protocol, which expands IAEA oversight.

No significant changes are required to extend these safeguards to nuclear power. ASNO’s flexibility and operational capacity allow for the integration of nuclear energy within the existing regulatory framework. With a strong track record in compliance and international collaboration, Australia is well-positioned to adopt nuclear power while maintaining its non-proliferation commitments.

NUCLEAR LIABILITY

Australia’s nuclear liability law is currently limited, reflecting the country’s focus on research reactors, uranium mining, and radioactive waste management rather than nuclear power generation. Australia is not a party to major international nuclear liability conventions like the Vienna Convention or the Convention on Supplementary Compensation for Nuclear Damage (**CSC**), though it is a signatory to the CSC. Domestically, liability for nuclear incidents is governed by sector-specific arrangements. For instance, the ANSTO OPAL reactor has liability coverage through Comcover, the government’s self-insurance fund, along with a Deed of Indemnity for liabilities not covered by insurance. Private facilities like the Tellus Sandy Ridge repository rely on comprehensive insurance packages and financial assurance mechanisms.

To adopt nuclear power, Australia needs to determine the most suitable nuclear liability regime for its proposed installations. If nuclear power plants are government-owned and operated, liability could follow a model similar to that of the OPAL reactor, with risks underwritten by the government. Alternatively, for private entities, establishing a clear regulatory framework that ensures sufficient financial protection is essential. Ratifying the CSC could provide an internationally recognised framework, promoting investment and collaboration by clarifying cross-border liability and compensation mechanisms. Domestically, new legislation could codify liability principles, including exclusive operator liability and financial assurances for compensation in the event of nuclear accidents. By establishing these structures, Australia would build confidence among stakeholders and the public, ensuring accountability and preparedness for the transition to nuclear energy.

BUILDING ON AUKUS FOUNDATIONS

Australia's work under the AUKUS partnership has laid a solid foundation for advancing nuclear law and regulation. Regulating complex defence systems, such as nuclear-powered submarines with portable reactors using highly enriched uranium, involves significant legal, technical, and regulatory complexity. In contrast, adopting nuclear power involves established reactor designs using low-enriched uranium and straightforward regulatory requirements. This existing work simplifies the transition to nuclear power by leveraging expertise, frameworks, and international collaborations developed through AUKUS. Compared to the complexities of defence applications, civilian nuclear power regulation is simpler and more standardised, allowing Australia to build on its progress with greater efficiency and less regulatory strain.

Australia's existing nuclear legal and regulatory framework, shaped by decades of experience, is well-suited to support the adoption of nuclear power. Minor amendments to existing laws, particularly the ARPANS Act and nuclear liability provisions, would streamline this transition. With robust expertise in safety, security, safeguards, and liability, nuclear law is not a barrier to adopting nuclear power in Australia. Instead, it provides a solid foundation for integrating nuclear energy into Australia's energy mix, offering a practical, efficient, and achievable pathway to zero-emissions power.

7. Radioactive waste in Australia and the path to adopting nuclear power

Australia has a longstanding history of effectively managing radioactive waste, primarily generated from its nuclear medicine reactors, industrial activities, and naturally occurring radioactive materials (**NORMs**) associated with mining and petroleum industries. The country has demonstrated that it can handle radioactive waste safely, adhering to international best practices and regulatory standards. As Australia considers integrating nuclear power into its energy mix, effective radioactive waste management is a critical component—one that Australia is well-prepared to address.

Unlike waste from other energy sources, the management of nuclear waste is well-understood, globally managed, and regulated. This mature technology ensures a comprehensive plan from energy production to waste disposal, providing clarity and safety throughout the entire lifecycle of nuclear energy projects. The Coalition's "Our Plan for Zero-Emissions Nuclear" policy proposes leveraging existing waste management frameworks developed for the AUKUS partnership, thereby streamlining the process, minimising legislative hurdles, and capitalising on work already underway. This approach makes the adoption of nuclear power a practical and achievable goal for Australia.

CURRENT LANDSCAPE OF RADIOACTIVE WASTE MANAGEMENT

Australia's radioactive waste is currently stored securely at approximately 100 sites nationwide, including facilities managed by the Australian Nuclear Science and Technology Organisation (**ANSTO**), hospitals, industrial operations, and mining sites. According to the 2021 Australian National Inventory of Radioactive Waste, the country possesses approximately 2,490–4,146 cubic meters of low-level waste (LLW) and about 1,611–2,061 cubic meters of intermediate-level waste (ILW). Waste from spent nuclear fuel, such as that from ANSTO's OPAL reactor, is sent overseas for reprocessing, with the resulting ILW returned to Australia for safe storage.

The governance of radioactive waste is well-established, divided between federal and state authorities:

- Federal Authority: The Australian Radiation Protection and Nuclear Safety Agency (ARPANSA) oversees waste on Commonwealth land.

- State and Territory Regulators: Manage waste from other categories, including industrial and medical sources.

This framework demonstrates Australia's capability and readiness to manage radioactive waste effectively and safely.

GLOBAL EXPERTISE IN NUCLEAR WASTE MANAGEMENT

Globally, the management of nuclear waste is a well-understood and mature field. Countries with nuclear power programs have developed robust methods for handling, storing, and disposing of radioactive waste safely. These methods are regulated and standardised, ensuring environmental protection and public safety. This global expertise provides Australia with a wealth of knowledge and proven practices to adopt, ensuring that the management of nuclear waste is not an impediment but a manageable aspect of adopting nuclear energy.

LEVERAGING EXISTING FRAMEWORKS AND AUKUS

Australia is already undertaking significant work in radioactive waste management through the AUKUS partnership, which involves acquiring nuclear-powered submarines. This initiative necessitates the development of solutions for managing waste, including spent nuclear fuel and reactor components. Since Australia must address the management of AUKUS-related waste, it is practical and efficient to extend these solutions to encompass waste from civilian nuclear power plants as well.

The Coalition's policy proposes an integrated waste management strategy by co-mingling defence and civilian nuclear waste, utilising the same permanent repository for both. By building on the waste management frameworks developed for AUKUS, Australia can capitalise on existing groundwork, streamline processes, and avoid duplicating efforts. This approach mirrors practices in countries like the United Kingdom, where waste from both military and civilian nuclear activities is managed under a unified framework.

Advantages of the Integrated Approach

Integrating waste management strategies for defence and civilian nuclear activities offers several significant advantages:

1. Australia's Proven Capability: Australia has already demonstrated its ability to manage radioactive waste effectively. Extending this capability to include nuclear power waste is a logical and manageable step.
2. Resource Consolidation: Sharing infrastructure and expertise leads to more efficient and cost-effective outcomes, avoiding duplication of facilities and regulatory processes.
3. Regulatory Efficiency: A unified framework simplifies compliance under a single, comprehensive legal system, reducing potential conflicts and streamlining oversight.
4. International Best Practices: By adopting globally recognised methods, Australia ensures the safe and responsible handling of radioactive waste, aligning with international standards.
5. Alignment with Existing Efforts: Work is already underway for AUKUS-related waste management. Extending these efforts to include nuclear power means Australia is not starting from scratch, making the process more efficient.
6. Public Confidence: Transparent handling of both defence and civilian waste can enhance public trust, demonstrating proactive management and commitment to safety.

Legislative Amendments required:

- **Amend the National Radioactive Waste Management Act 2012 (NRWM Act)** to explicitly include high-level waste (HLW) and spent nuclear fuel from civilian nuclear power plants. These changes are practical extensions of existing laws, building upon the legislative groundwork already in place.

IN CONCLUSION

Managing radioactive waste is a challenge that Australia is fully capable of meeting. The management of nuclear waste is a well-understood, regulated practice worldwide, with established methods ensuring safety and environmental protection. By leveraging the existing work underway for the AUKUS partnership, Australia can efficiently extend its waste management strategies to include civilian nuclear power, without the need to develop entirely new plans.

The necessary legislative amendments are practical steps that build upon Australia's current legal framework. An integrated approach not only enhances regulatory efficiency but also demonstrates Australia's commitment to responsible nuclear stewardship. This strategy ensures that waste management supports, rather than impedes, the introduction of nuclear energy into Australia's energy portfolio.

Ultimately, adopting nuclear power while effectively managing radioactive waste aligns with Australia's commitment to safety, environmental sustainability, and a low-carbon future. By building upon established expertise, infrastructure, and ongoing efforts, Australia can confidently embrace nuclear energy as a viable and practical component of its energy strategy, contributing to a sustainable future while maintaining high standards of environmental and public safety.Bottom of Form

8. Conclusion

This report was written by a multidisciplinary research team assembled by Professor Tina Soliman-Hunter of Macquarie University's *Transforming Energy Markets Research Centre (TEMRC).* The research team drew on the views of a broad mix of professional managers, economists, geologists, scientists, engineers, lawyers, regulators and academics.

In setting the context for this research, a little history may be helpful. In post-World War 2 Australia, federal and state governments actively sought to develop the most readily-available and affordable energy resources. They were able to call on vast reserves of coal in the Hunter and Latrobe Valleys, but with limited public acceptance of the need to regulate the environmental effects of mining and energy production.

Australia also had, and continues to have, access to vast uranium resources. Around 1980, the Whitlam Government effectively nationalised the huge Ranger uranium project that had been discovered in the Northern Territory by Australian mining companies Peko-Wallsend and EZ Industries. A company was established by the British government to search for additional resources in Australia.

In 1998 the Australian government banned the development of nuclear energy, except for medical and research purposes. The repeal of this prohibition is now long overdue. Nuclear power is used for electricity generation in 32 countries, providing over 9% of the world's supply of clean electricity, while over 30 newcomer countries are now considering it. A significant number of nuclear power plants are under construction worldwide, with many more in the advanced planning stage. Nuclear power is today a well proven and increasingly widely accepted clean generation technology.

From the time of the Rio Climate Conference in 1992, Australian governments sought to control climate change by legislation or regulation. By 2023, many participants at the Dubai Climate Conference (COP 28), reaffirmed their nation's commitments to control climate change by legislating to achieve 'net zero' greenhouse gas emissions by 2050. Australia's Climate and Energy Minister the Hon Christopher Bowen MP, with no mandate from the Australian population, told COP 28 that Australia would promote renewable energy to the exclusion of fossil fuels and nuclear energy. Meanwhile an unofficial side-event pushed for longer-term strategies of accelerating the global development of nuclear power.

The aim of this independent study is to review, with knowledge and authority, the question of increasing importance to Australians: namely whether and how Australia can use modern nuclear technology to accelerate its economic, environmental and social development while focussing on the long-term challenge of decarbonising the Australian economy. The question is largely hypothetical: Australia still has a statutory ban on nuclear energy. This needs to be lifted as a matter of the utmost priority. Importantly the tripartite AUKUS initiative involving Australia, the UK and the USA has effectively guaranteed that Australia will one day use nuclear power for energy generation, possibly in the first instance for submarine propulsion. In agreeing to purchase nuclear-powered submarines, Australia will become a nuclear-powered nation.

The question posed to the study team was whether it is now practicable for Australia, presently a nuclear power-free country, to repeal its nuclear ban and adopt a modern nuclear regulatory regime in its pursuit of long term affordable, reliable and environmentally acceptable electricity supplies. The response of the study team is an emphatic yes; being of the view that these objectives, along with the task of eventually decarbonising Australia's economy, is well within Australia's capabilities and professional expertise.

The study team did not seek to resolve all of the detailed issues surrounding the introduction of nuclear power to Australia that clearly require, but believes it has highlighted most of the essential matters needing to be addressed. Importantly the team has emphasised that now is the time for Australia to refocus its research to include all, not a selected few, viable energy technologies. For nuclear energy this would be facilitated by bolstering ANSTO's resources and expanding its scope of work at the same time as bolstering related private sector commercial activities.

Of course renewables make sense in sunny Australia, but they are by no means the only energy source that does so. As well, wherever renewables are used, they inevitably have to be supported by storage technologies and extended transport to often distant demand centres. Such transport, storage and conversion of all forms of energy must impose additional costs.

The study team is of the view that nuclear energy can certainly be considered for civil nuclear generation in Australia under appropriate regulation. Because this will take time to achieve, an immediate start must be made on development strategies. Australia should also be evaluating small mobile nuclear reactors for future use across Australia's vast mining and agricultural landscape.

The study team considers that a diverse technology mix is key to bridging the gap between climate problems and their solution, underpinning the success of Australia's energy transition. The team also strongly believes that the selection of energy technologies is best left for investors, not governments, to decide, provided appropriate regulation is put in place.

The team also believes the public, if fully and properly informed, is likely to support all reliable, secure sources of power generation. Lay people are principally concerned about rising energy costs and keeping their jobs – far more concerned than whether Australia should or could become a 'renewable energy super-power'.

The overriding conclusion of the Macquarie study team is; *It is overdue for Australia to accelerate the implementation of all clean and reliable power generation technologies, including nuclear power, and for Australia to decarbonise its economy by drawing on the full resources of both public and private sectors.*

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