Blueprint Institute

Between promise and pragmatism

Why renewables should lead and nuclear should wait



Executive Summary

Australia faces an urgent need to decarbonise its energy grid as 90% of the coal-fired power fleet retires by 2035. Delaying coal's exit risks severe economic, environmental, and reliability consequences, including billions more emissions and potential blackouts. Accelerating renewable energy deployment is critical, yet a pragmatic, evidence-based approach must also consider all low-emission technologies, including nuclear, to ensure a resilient, affordable, and sustainable energy future.

Key recommendations

1. Establish clear, technology-neutral environmental and biodiversity standards

> Implement nationally harmonised biodiversity and environmental standards for all new energy projects, including renewables, storage, and any future technologies.

> Define no-go zones, pollution limits, and clarify requirements around Indigenous and community consent to prevent opposition and protect Australia's biodiversity, which is currently under severe threat.

> Reform the Environmental Protection and Biodiversity Conservation (EPBC) Act to align climate, energy, and biodiversity policies effectively.

2. Develop a comprehensive, costed energy transition master plan

> Refine national energy modelling approaches to take a robust total system cost modelling framework that accounts for all costs of delivering reliable electricity, including generation, storage, transmission, and maintenance.

> Use this model to identify the least-cost pathways to meet reliability and emissions targets transparently.

> Reflect and consider diverse characteristics and interactions of different technologies-such as rooftop solar, utility-scale solar, wind, and nuclear-to optimise the energy mix and infrastructure planning.

3. Urgently address energy shortfalls

> Recognise that approximately 21 GW of coal capacity will retire by 2035, creating a critical capacity gap that must be filled to avoid calamitous blackouts or costly coal extensions.

> Maintain bi-partisan policy commitment to investment in renewables, transmission and storage, to prevent expensive and inefficient policy whiplash.

> Address supply chain weaknesses, regulatory delays, and skills shortages that hinder renewable rollout, while acknowledging the ongoing competition for skilled labour globally.

> Avoid prolonging coal dependence by failing to act decisively on renewable capacity expansion.

4. Invest in domestic nuclear research and maintain an open, evidence-based approach

> Acknowledge that nuclear energy is not a timely or cost-effective solution for immediate energy needs due to long construction timelines and high costs.

> Recognise that small modular reactors (SMRs) remain commercially immature and current nuclear technologies have limitations and risks.

> Remain open to incorporating nuclear energy in the future if and when technological advancements reduce costs and address safety, waste, and proliferation concerns.

> Avoid polarising debates that frame renewables and nuclear as mutually exclusive, which risks policy paralysis.

Australia needs as pragmatic approach – building out renewable forms of energy balanced with prudent openness to emerging low-emission technologies, supported by clear environmental safeguards, comprehensive planning, and immediate action to close the looming energy capacity gap, securing Australia's energy future.



Context

The need for year-on-year emissions reduction

Any consideration of Australia's future energy mix benefits from reflecting on why the world's energy mix is in transition, and why it is critical that Australia, together with other countries, achieves meaningful reductions this year, and every year between now and 2050.

The prevalence in our atmosphere of carbon dioxide is easily measurable, and has increased by almost a third since we started tracking it in 1958. Reviews of historic concentrations show that even though the level of global carbon dioxide has fluctuated since the Industrial Revolution began, current levels are at their highest point in the last 600,000 years—which is mostly a function of a rapid increase in the burning of fossil fuels for energy compounded by clearing vegetation that stores carbon dioxide (see **Figure 1**).

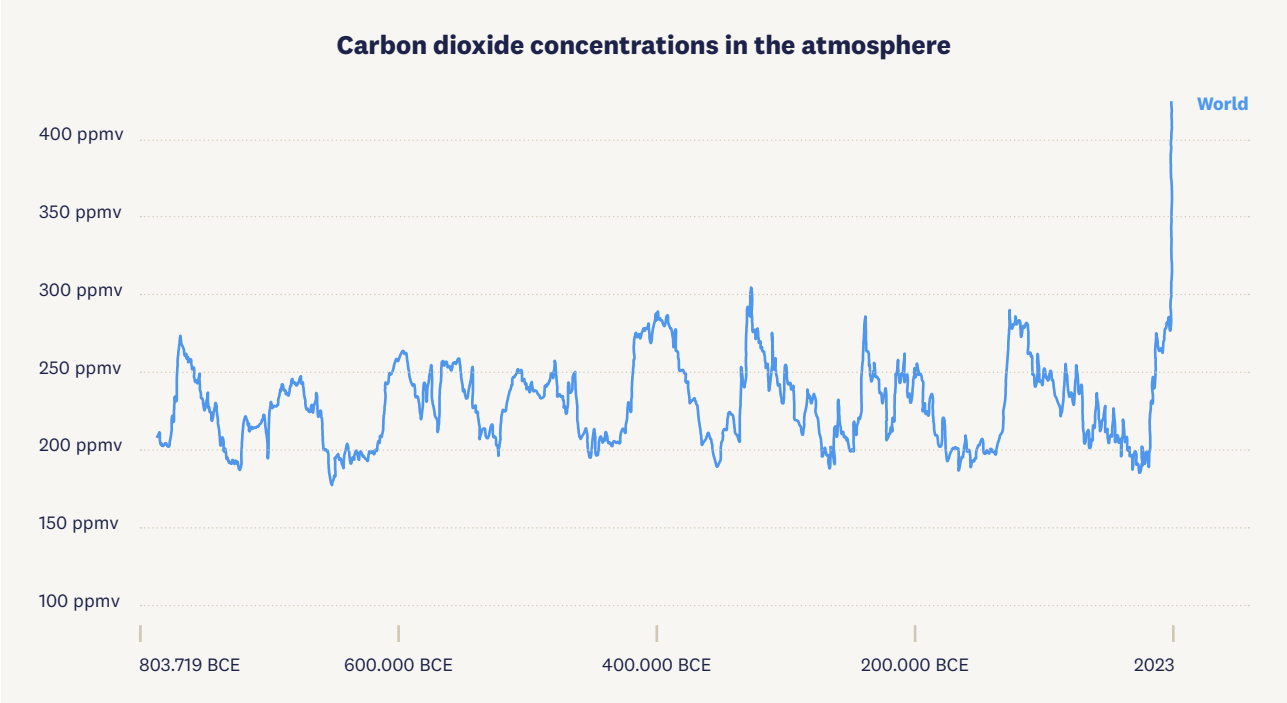


Figure 1: Carbon dioxide concentrations in the atmosphere, parts per million

Source: NOAA Global Monitoring Laboratory, EPA, Our World in Data

As we know, carbon dioxide, and other gases like methane and nitrous oxide act as a kind of blanket, increased concentrations of these compounds have led to significant changes in the climate—which is now on average, at least 1.1 degrees celsius warmer than pre-industrial levels. The majority of this warming has occurred since 1975. Australia has been getting even warmer than the rest of the world, because of our geography, with average temperatures increasing by 1.44 degrees celsius over the same time period. Since 1950 each decade has been consistently warmer than the last.

One consequence of this warming has been a fivefold increase in the frequency and cost of wild weather events since the 1970s. In 2023 natural disasters cost the global economy $US380 billion, exceeding the 21st century average of $312 billion (see **Figure 2**). In addition to getting warmer, our oceans have become 30% more acidic since the early 1800s, and have risen about 20 cm since 1920, resulting in bigger and more powerful hurricanes, the bleaching of the Great Barrier Reef, more rapidly melting ice sheets, and the dying off of many fish species.

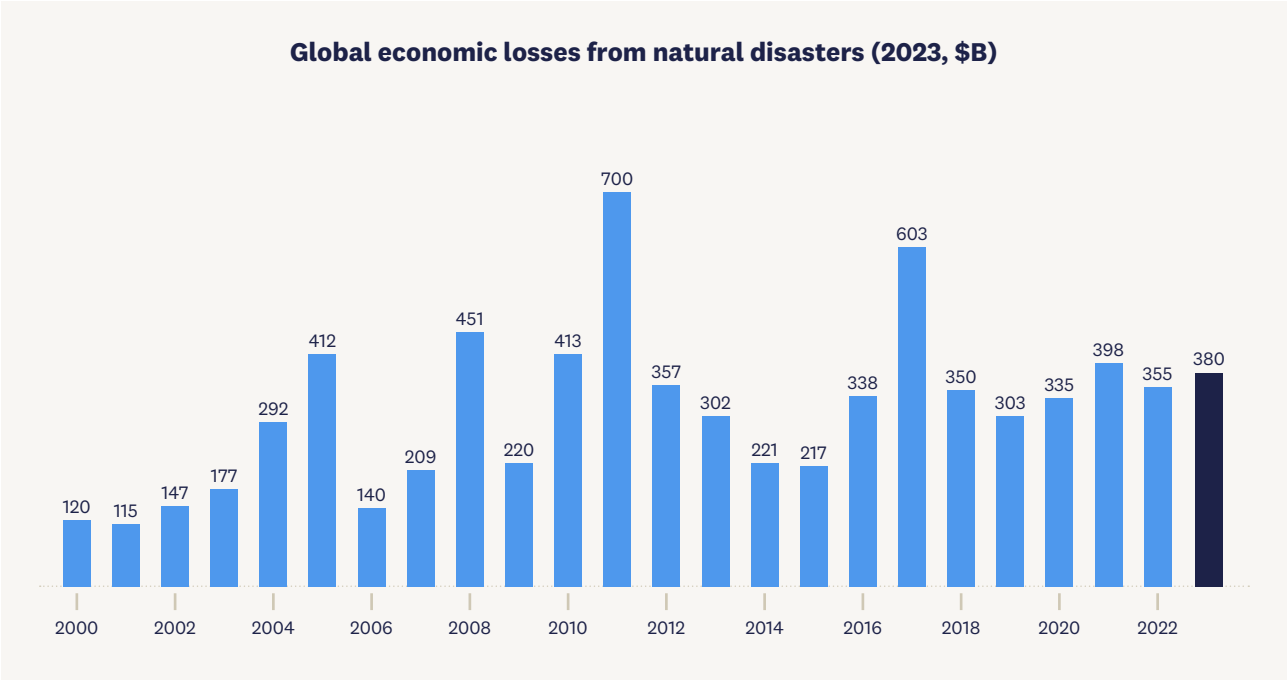


Figure 2: Global economic losses from natural disasters (2023, $B)
Source: Aon Catastrophe Insight

Increased rate of species decline and more frequent and devastating natural disasters are a reminder that the 2030 and 2050 emissions reduction targets are anything but arbitrary. The 2015 Paris Agreement set a goal to limit increases in global temperatures to 1.5 degrees above that of early industrialisation. This target was established through advanced climate modeling aimed at preventing catastrophic planetary tipping points. Exceeding this threshold risks triggering cascading effects.

For example, as big blankets of ice melt, we both lose the cooling effect they have (they work a bit like an ice pack at the moment), and when melted, they release more greenhouse gases into the atmosphere (that are currently stored in the permafrost), further speeding up the heating cycle. This is already happening—Antarctica is melting at an average rate of about 150 billion tons per year, and Greenland is losing about 270 billion tons of ice mass per year.

There is a lot at stake. This energy transition is a wicked problem—arguably the hardest problem we've ever faced or will face as humans. This is also happening at a time when Australians are facing financial squeezes, unprecedented mental health challenges for our kids, housing shortages, and a rapidly changing global world order. No wonder people are feeling anxious and stressed.

This reinforces the need for objective analysis, and real problem solving. We also need collective action. Climate change impacts us all and can only be addressed if we work together—both as Australians, and with the rest of the world.

Our recommendations speak to what needs to happen from here—how we can step forward, benefit from each other's knowledge and experience, and put a plan together that we can all feel confident about.



Recommendation 1:

Urgently establish technology-agnostic biodiversity and environmental standards

Clear biodiversity and environmental standards must be set for all new energy projects, including: identifying which fragile and biodiverse habitats are no-go zones; setting non-negotiable and technology-agnostic standards for waste and soil, water, air and greenhouse gas pollution; and identifying the levels of Indigenous and community buy-in required for approval. This must be the standard for all generation technologies.

It is incredibly inefficient for companies (and taxpayers alike) for standards to be set in place retrospectively. Indeed this should have already been done for renewables. The best time to set clear federal environmental standards would have been decades ago—the second best time is now.

We are facing a biodiversity crisis, with real implications for our future prosperity. We have 19 ecosystems under threat, and still have ongoing large-scale land clearing. An area greater than the size of Tasmania, with 7.7 million ha of threatened species habitat was destroyed between 2000 and 2017 (93% without Federal Government assessment or approval). Australia also holds the dubious world record for mammal extinctions, and ranks fourth globally in the rate of extinction of other species.

While our research has highlighted the need for retaining an open mind on emerging and changing energy technologies, as long as biodiversity and climate impacts are not priced in, the idea that the 'market' will drive long-term investment in ways that protect our environment or biodiversity is foolhardy. Technologies will come and go, and with them articulate lobbyists, promises of 'jobs for all', and the lure of revenue for state and federal coffers. However, citizens and future generations rely on the Government to set standards for protecting our natural environment. Clean water, a carbon-absorbing tree canopy, connected biodiversity corridors that allow inhabitants to thrive, and quality soil are all important—not just for our health and wellbeing, but for our long-term economic prosperity.

Labor's election commitment to overhaul the Environmental Protection and Biodiversity Conservation (EPBC) Act has yet to be met— the need for a strategic plan to improve cohesion between climate and biodiversity objectives remains a gap.

Australia's decarbonisation goals, particularly in the energy sector, need to be achieved in the context of protecting our natural environment. Clear standards developed independently from technology decisions are required to ensure that both our environmental and biodiversity goals remain paramount, but also so our renewable energy transition is not hampered with further green tape. Predictability and certainty is critical to driving innovation and investment, as well as slowing Australia's extinction rate.

Recommendation 2:

Update energy grid system design modelling and approach

The Government urgently needs a fully costed, flexible master plan for decarbonising the energy grid that ensures reliability and minimises consumer costs. While the Energy and Climate Change Ministerial Council (ECMC) may be addressing this, details remain unclear.

Without a better planning approach, we risk further paralysis. Unlike many other nations exiting coal, Australia's climate policy has been used as a political wedge due to reliance on fossil fuels. Business leaders, including those in fossil fuels, have long criticised inconsistent policies that delay investment, increase costs, and hinder emissions reductions.

The growing renewables versus nuclear divide risks further delay in reducing emissions, adding cost and creating economic harm for future generations. Delaying action is neither economically nor environmentally viable—we urgently need a plan we can agree on.

Include excluded system costs

The modelling for a decarbonised energy grid should take a total-system approach to costs (including iterated costs for generator assets, transmission, distribution, ancillary grid services, and storage), treat energy reliability as a constraint, and reflect a clear set of expectations and standards around biodiversity and waste management—at every life stage from development, production to end-of-life recycling. This approach would support a fair economic assessment of clean generating technologies and the optimal investment sequencing pathway for transmission, free of political or ideological bias.

The Integrated System Plan by the Australian Energy Market Operator (AEMO) is the closest thing we have to a plan, but it was arguably never designed to solve the question of how to decarbonise from first principles. As many others have noted, it covers only part of Australia's system, it assumes ongoing consumer uptake and funding of energy and storage resources and is constrained by the need to treat government commitments as a given.

Until very recently, the Australian Energy Market Commission (AEMO's counterpart) did not even have emissions reduction as a consideration for setting rules for the energy system—a major gap we identified in our untangling the NEM paper.

A robust plan for decarbonisation should objectively consider a wide range of technologies in addressing the question of energy mix. New infrastructure should be considered in the context of an appropriately nuanced understanding of the differences in technologies, and how they interact. For example, rooftop solar, utility-scale solar, and wind have different profiles, peak production periods, suit different kinds of locations, and if balanced appropriately can smooth out production. The same goes for nuclear— different types of technologies have different risks, benefits, costs and energy production capacities. The cost of different types of choices and designs for storage and transmission need to be modelled, with transmission planning explicitly included as a design variable.

The economics underpinning the current plan of 82% renewables must be revised and updated to include all costs. The merits of nuclear power cannot be considered seriously without clear standards as per recommendation 1, or without an established total system cost economic plan of the policy proposal.

The Coalition promised to provide total system cost modelling for their nuclear plan—well ahead of the 2025 Federal election. However the modelling put forth by Frontier Economics is hardly this. To start with, it does not actually model the Coalition's plan. The analysis includes 13 GW of nuclear capacity—way more than the 6.6 GW proposed by the Coalition. The model also does not consider the time nor full cost of building Australia's nuclear energy capacity. Specifically, it doesn't seem to include costs and time associated with regulatory approval (and in Australia's case—the time to actually develop sensible regulation for the industry that protects citizens). Concerningly absent from the model was an acknowledgement of site and transmission planning; risk mitigation; community engagement; biodiversity management and waste management. The costs and implications of extending coal fired power stations were also apparently unexamined.

The model also doesn't reflect a realistic costing of labour, materials, and supply paths. Instead cherry picking lowest delivery times and costs from systems with very different labour costs, experience paths and laws. Critically it also ignores the very substantial costs in delaying reductions in emissions, associated with overshooting carbon targets, and a resultant increase in the frequency and force of adverse weather events. For more details, see our short article on this topic.

Only once we have a total system cost planning model of all plausible decarbonisation pathways, including both renewables-dominant and nuclear-dominant scenarios, can we make informed, evidence-based assertions as to which pathway is most suitable to the National Energy Objectives.



Update transmission planning

There is room to improve our transmission planning, which currently risks being unnecessarily locked in an historic paradigm. An analogy is the introduction of telephones into emerging economies—a number of countries effectively went straight to mobile instead of adopting outdated landline systems (a practice known as leapfrogging technologies), thereby alleviating the need for rolling out a whole lot of poles and wires and dramatically reducing the cost of their telecommunication system as a result. In short, this strategy significantly reduced costs and infrastructure requirements.

The present transmission strategy appears to be an extension of the conventional model, focusing on large central projects interconnected by extensive transmission lines. However, just as telecommunications technology has evolved, so too has energy technology. Our grid design should reflect these advancements rather than simply expanding the existing infrastructure at great expense.

Solar, on-shore wind and even nuclear power plants can be installed close to energy needs, and in the case of roof-top solar, EVs and household batteries, within urban centres. Communities and facilities can operate microgrids (and are increasingly doing this, under their own steam), options that to date have been inadequately considered in our long-term transmission planning. More work needs to be done to ensure we have genuinely considered all the options, and stay flexible to what will continue to be a rapidly changing space.



Reflect the cost of delaying action

Delaying action costs real money. Although nuclear is a low-emissions technology, any plan that simultaneously steps back from renewables or creates further ambiguity about what is happening will cost taxpayers and hinder our economic growth in the short- and long-run.

Inaction will result in significant financial burdens stemming from both the costs of adapting to a higher heat environment and dealing with the impact of escalating extreme weather events. We are also missing out on potential savings (which translates to lost GDP) by further missing opportunities for energy efficiency improvements. We must ensure that our future energy planning is underscored by the need to act today—not in a decade or more.

As noted, adverse weather events are increasing in both cost and frequency, and the rate of these increases is expected to further escalate, with major economic consequences. Extreme weather currently costs the Australian economy $38 billion annually, a figure anticipated to climb to $94 billion per annum by 2050, representing a cumulative cost of $1.35 trillion dollars between now and 2050. The total economic costs of these events extend beyond damages—productivity losses, insurance, and energy insecurity also come with significant economic costs, ultimately borne by households.

It is important to note that reducing emissions does not imply an immediate reduction in natural disasters, but if we delay action, we are effectively stockpiling emissions, which risks a series of substantial consequences. In the absence of effective sequestration opportunities, stockpiling emissions creates a problem that will only get harder to solve over time.

The key to thinking about emissions is recognising that we can't wait until 2050, and then suddenly stop emitting. We actually have to reduce emissions each and every year at a steady rate, until we are at zero. Right now, we're piling up 430 million tonnes every year.

Imagine a rubbish bin that never gets collected– it can only fit in so much garbage. Now imagine it's your only bin—the only place you can put your garbage. Because we know that we generate a certain amount of rubbish every year, we know we're going to have to stop before it overflows. We know that one way to give us a bit more time before it overflows, is to gradually reduce how much rubbish we're putting in it each year. But if we don't stay on that path, or reduce it bit by bit, it's going to pile up faster, and soon be overflowing. So that means if we don't reduce our rubbish, or in this case our emissions, each and every year - we'll be out of time sooner. It will be full of rubbish with no where to go.

So thinking about greenhouse gas emissions, they too pile up. If we don't get and stay on a downward trajectory, if we keep producing 430 million tonnes of pollution each year, by 2050, we'll have more than 11,000 tonnes to deal with. That means a far higher concentration of CO2 in the atmosphere, a whole lot more adverse weather events, and that means costs. Costs that need to be reflected in our modelling and thinking.

Insurance and reinsurance companies (the companies who provide insurance to insurers) have been raising concerns about the risks of climate change for decades, because they have seen these impacts in their bottom line. For example, in a memo by global reinsurance company Swiss, their Board noted that "1988 was the warmest year ever recorded in the 130 years or so since worldwide meteorological monitoring first began. The mean global temperatures of five other years in this decade: also exceeded all previous readings, which is... strong evidence of a significant warming of the earth's atmosphere, i.e. that the man-made greenhouse effect is finally upon us".

The result is that insurance premiums are increasing, as these risks are reflected in price increases and also what insurance companies are willing to cover. Over the decade spanning 2012-22, the net ultimate insurance costs to households rose 71%, and net claim payments rose 103%[1].

These trends reflect the insurance (and reinsurance) industrys' response to the growing frequency and severity of extreme weather events. These changing weather patterns introduce a whole new array of challenges beyond merely damage inflicted by natural disasters, including coastal erosion, stranded asset risk, and looming fiscal decay as public balance sheets become more exposed by underwriting the insurance sector. It leaves the Government at a strategic impasse—as intervention to artificially suppress insurance premiums could distort market signals and could encourage development in high-risk areas. Nonetheless, these challenges for the insurance sector at large will worsen the longer we wait to take substantive action.

Missing energy efficiency opportunities costs us millions in lost revenue every year. This is particularly relevant when we have technical solutions available to us such as better insulation, smart-metres, and peak load management. Delaying the transition to a more energy-efficient economy will result in missed opportunities for cost savings and reduced emissions.

Last year modelling conducted by Frontier Economics evaluated a scenario that assumes a slower rollout of renewable energy and extended operation of coal fired power plants until nuclear energy enters the grid in 2036. Analysis of this pathway showed that it would result in an extra 1 billion tonnes more cumulative emissions by 2048-49 compared to AMEO's Step Change Scenario, which sees coal exit the grid earlier. As discussed, scientists warn that we would significantly increase the likelihood of exceeding the 2°C warming threshold with major costs and impacts across the economy.

This transformation will require real investment, especially as we have left our run so late. Investment and planning decisions must be based on rigorous and fair economic analysis. Making those decisions transparent will increase market clarity, boost investor confidence and help position Australia for long-term prosperity.

[1] According to APRA insurance data and Blueprint Institute analysis.



Recommendation 3:

Urgently address energy shortfalls

With approximately 21GW of coal coming offline by 2035, it is imperative that we focus on filling this critical gap in capacity to avoid calamitous blackouts or coal extensions. Failure to do this will see further increases in delayed action costs, such as those to service and maintain ageing coal stations for longer than expected.

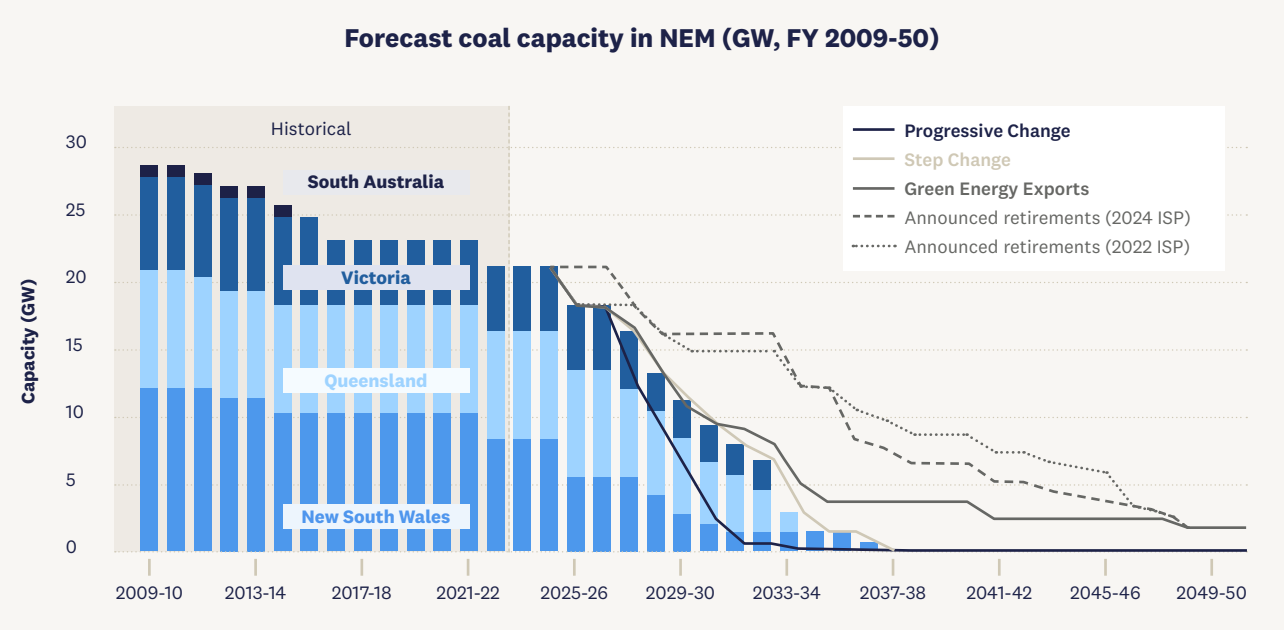


Figure 3: Forecast coal capacity in NEM (GW, FY 2009-50)
Source: AEMO

Australia saw a significant uptake in the level of renewable energy investment in 2024 with a record 7.5 gigawatts (GW) of renewable energy capacity added to the grid. It is essential that we continue on this trajectory if we are to reach the 2030 renewable energy target.

Whilst the recent surge in investment certainly gives ground for optimism, we must remain cognisant of the ongoing challenges of meeting our energy needs. Unlike China, which owns all parts of the supply chain (and are seeing their cost of renewables go down while the rest of the world goes up), we are price takers.

We own almost no elements of the renewable supply chain. We are also still trying to update our regulatory approval process to meet the needs of high volume rollouts. We have a massive skills deficit, and are competing for skilled labour at the same time as many other countries, who are also laggards now trying to do the same.

This—as well as the continued lure of fossil fuel dollars—is part of the reason why the Government continues to approve fossil fuel projects quietly in the background. Fumbling the renewable transition will prolong our dependence on coal.

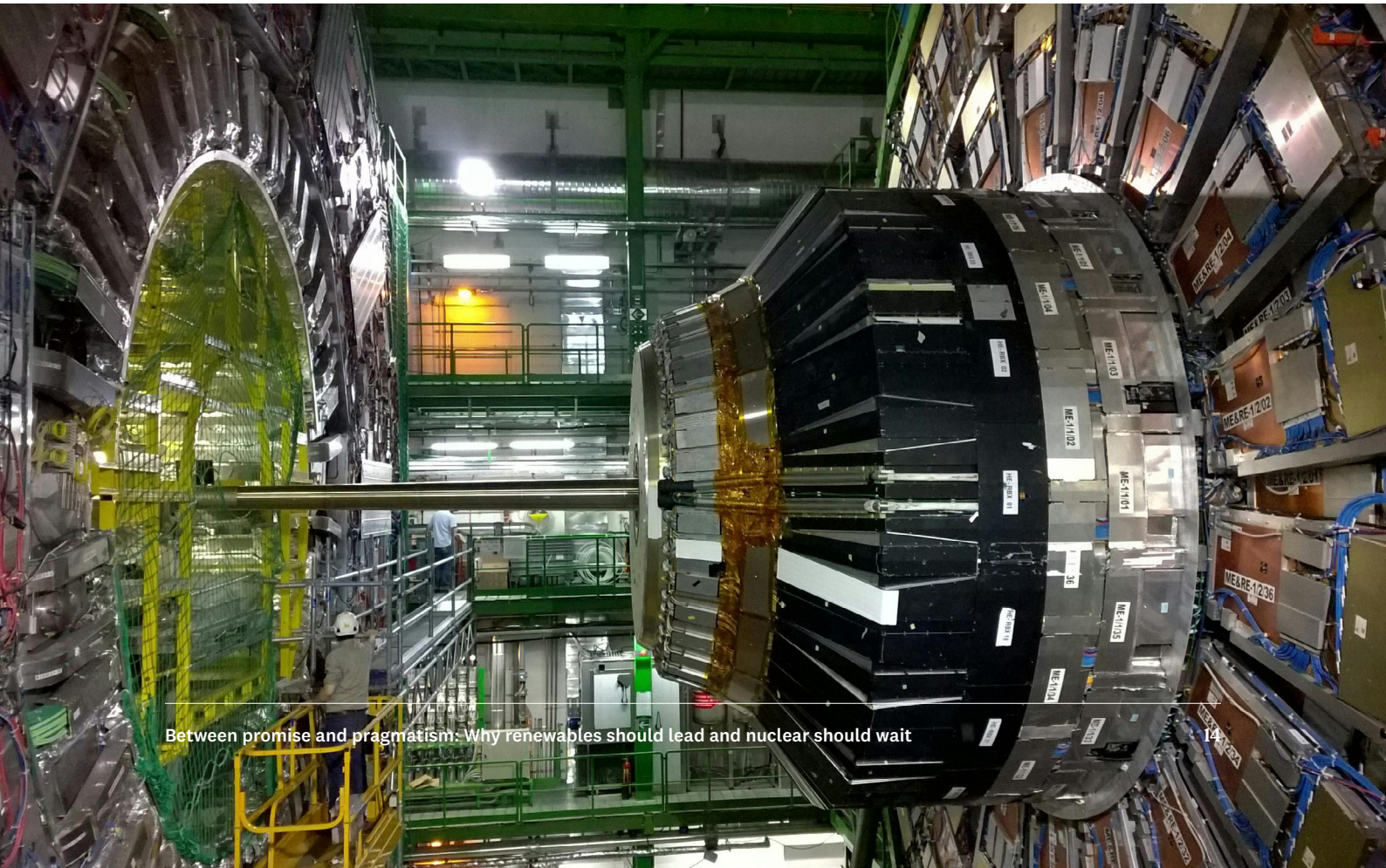
Recommendation 4:

Invest in nuclear research

Nuclear is a rapidly evolving field, with a range of different potential technologies purporting to address some of Australia's historic concerns about safety, nuclear waste and risks of weaponisation. To date, none of these alternative forms of nuclear technology, including small modular reactors (SMRS), are yet operating at scale or considered commercially viable. There is clearly a need for more objective and independent research that Australians can trust into what is and is not possible.

One of the challenges in the Australian debate is the lack of independent, Australia-specific knowledge in what is a rapidly developing field. And it's important to note that we don't need to lift the operational ban to do more research into nuclear technologies.

But we need to understand what we're dealing with. Our current lack of context-specific research arguably leaves the public and policy-makers alike vulnerable to 'pitches' from experts with commercial interests in accessing Australia's uranium reserves, as well as genuine concerns grounded in the risks and costs of current, rather than emerging, nuclear technology. We believe it limits the calibre and quality of informed discussion.



A critical analysis of nuclear energy

The following pages present some background and context for these recommendations, including an overview and history of traditional and emerging nuclear technologies, as well details on the range of costs, risks and global trends. These, together with modelling conducted in 2021 on the total system costs, have informed our recommendations.

Renewables versus nuclear – a false dichotomy?

The prevailing political debate in Australia often revolves around a binary choice between investment in renewables or nuclear power generation. However, this is inconsistent with the experience of other nations—where renewables and nuclear are seen as complementary components of a diversified energy mix.

Globally, renewables are prioritised as the most expedient and fiscally sound means to achieve decarbonisation. Renewables continue to be the fastest growing energy source around the world, with major investment from China, India and the European Union.

As shown in **Figure 4** renewables are massively outcompeting nuclear in both levels of total investment and subsequent electricity production. In 2023, total global investment in non-hydro renewable electricity capacity reached a record of US$623 billion. This is 27 times greater than the total investment decisions in nuclear, which remained largely consistent with previous years at US$23 billion in 2023. On a marginal cost basis, wind and solar are the cheapest forms of electricity in the world.

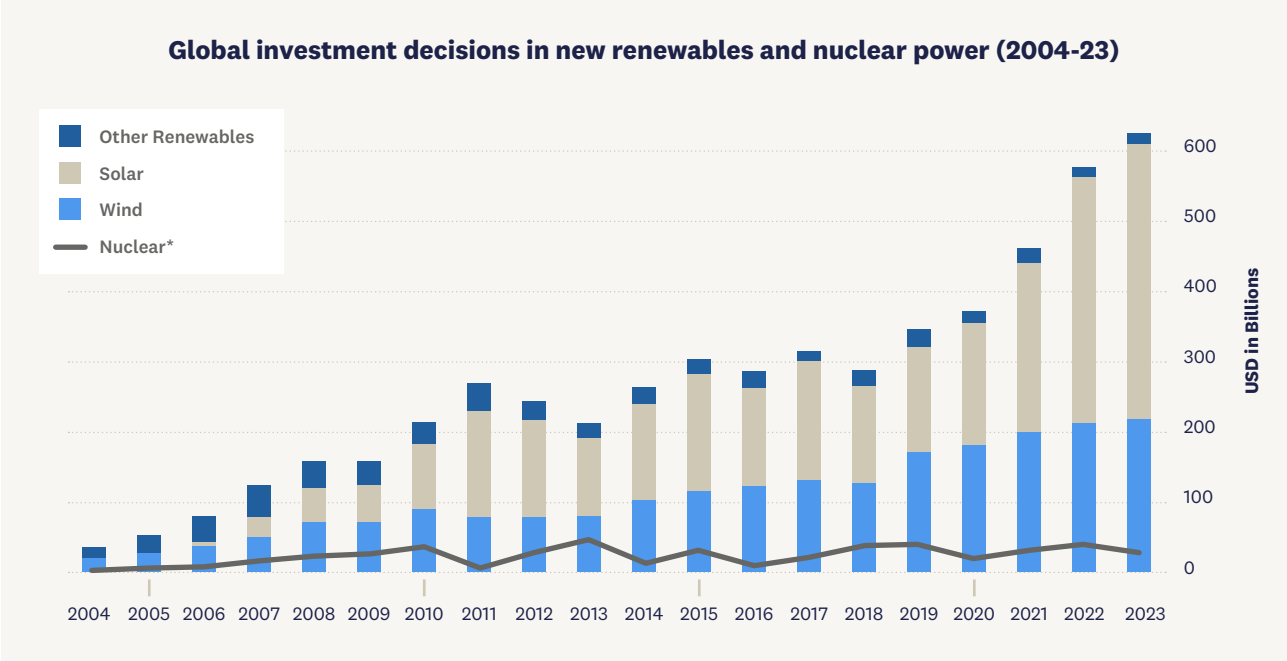


Figure 4: Global investment decisions in new renewables and nuclear power (2004-23)
Source: BNEF, World Nuclear Industry Status Report

From 2013 to 2023, non-hydro renewables added 3,508 TWh to the world's power generation, more than fourteen times the net increase of nuclear power, which grew by only 247TWh over the same period. In 2023, wind and solar facilities generated 50% more electricity than nuclear plants.

This underscores a clear global trend—even in regions where nuclear energy is part of the energy mix, the rapid expansion of renewable energy remains a top priority for meeting growing energy demands and achieving decarbonisation goals.

Whilst renewables are significantly easier, faster, and cheaper to build than nuclear—their intermittent nature and the difficulties associated with integrating them into a secure and reliable grid currently prompts reliance on fossil fuels for firming. The war in Ukraine has predictably compromised supply chains and sent many European Union states which depend on Russian gas exports into turmoil. As a result, several countries, including Germany, have been forced to turn to coal as a temporary measure to keep the lights on.

As a result, some countries have revisited plans to exit from nuclear energy. In the wake of the invasion, Belgium announced it would be delaying its planned phase out of its nuclear fleet by 10 years. The Finnish Green Party now supports nuclear power in conjunction with renewables, citing its role as firming capacity and making it a small but significant part of their energy system. South Korea also reversed their nuclear phase out policy in March 2022.



Conventional nuclear power

History and context

Nuclear energy first emerged from enthusiasm about the potential for civilian applications of military technologies. It was this Cold War desire to maintain dominance in the atomic field that saw the rapid uptake in nuclear reactors, particularly within the United States and Soviet Union.

The mid-1970s and 80s saw the largest waves of nuclear reactor startups. The Chernobyl accident in 1986 put an end to this golden age of nuclear expansion. Dramatically heightened concerns surrounding the safety of nuclear power, combined with increased competition from other energy sources—including the declining price of natural gas—led to a number of nuclear plant closures in the early 1990s.

A further collapse of public confidence in the safety of nuclear power followed the 2011 Fukushima nuclear disaster—the costs of which are expected to reach US$200 billion. As illustrated in **Figure 5**, governments around the world responded by shutting down their reactors at an unprecedented pace. Japan suspended nearly all operating nuclear power plants. Soon after, in a surprise decision made by the conservative leaning government, Germany announced it would also phase out nuclear power. Belgium, Spain, Taiwan, and Switzerland also announced plans to phase out their nuclear programs in the wake of the disaster.

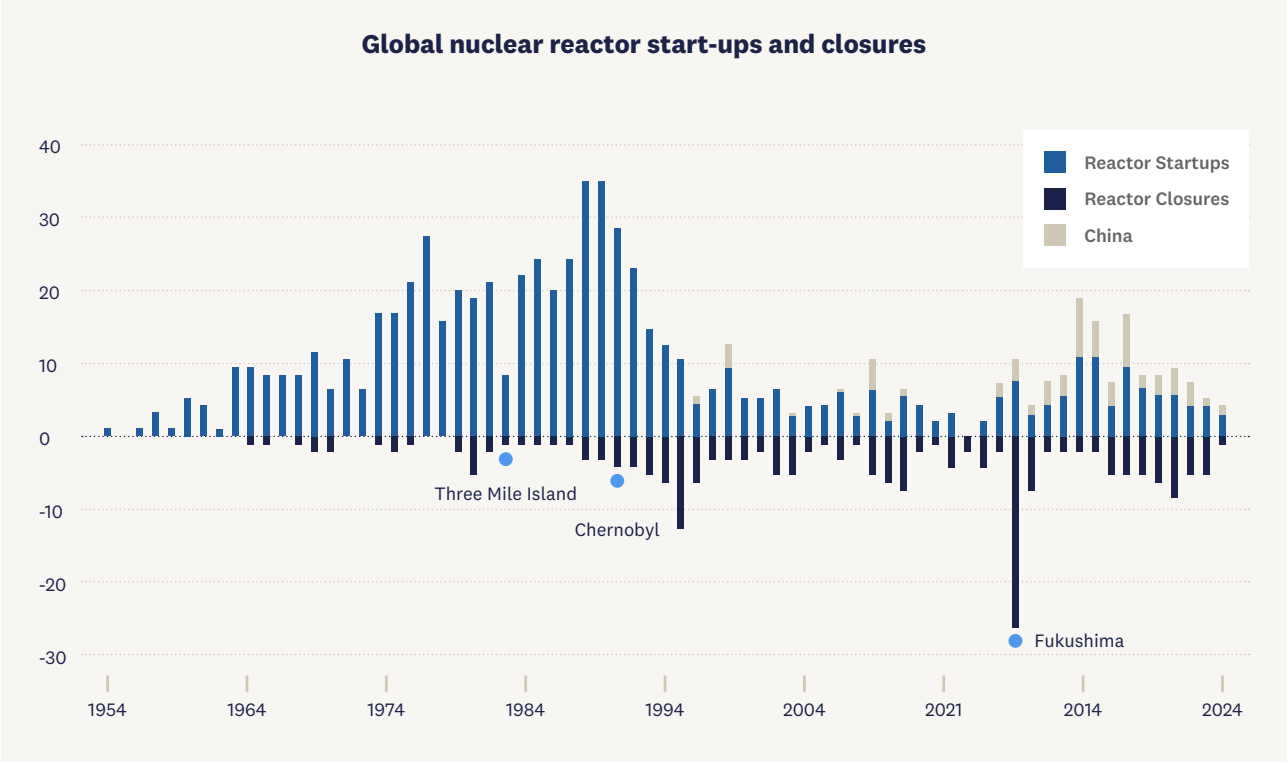


Figure 5: Global nuclear reactor start-ups and closures
Source: World Nuclear Report

Global dynamics

As of mid-2024, there are 408 nuclear reactors globally, operating in 32 countries, reaching a total capacity of 367GW. The vast majority of nuclear energy generation is concentrated in a handful of countries—these being the United States, China, France, Russia, and South Korea, which collectively generate over 70% of all nuclear electricity in the world (see **Figure 6**).

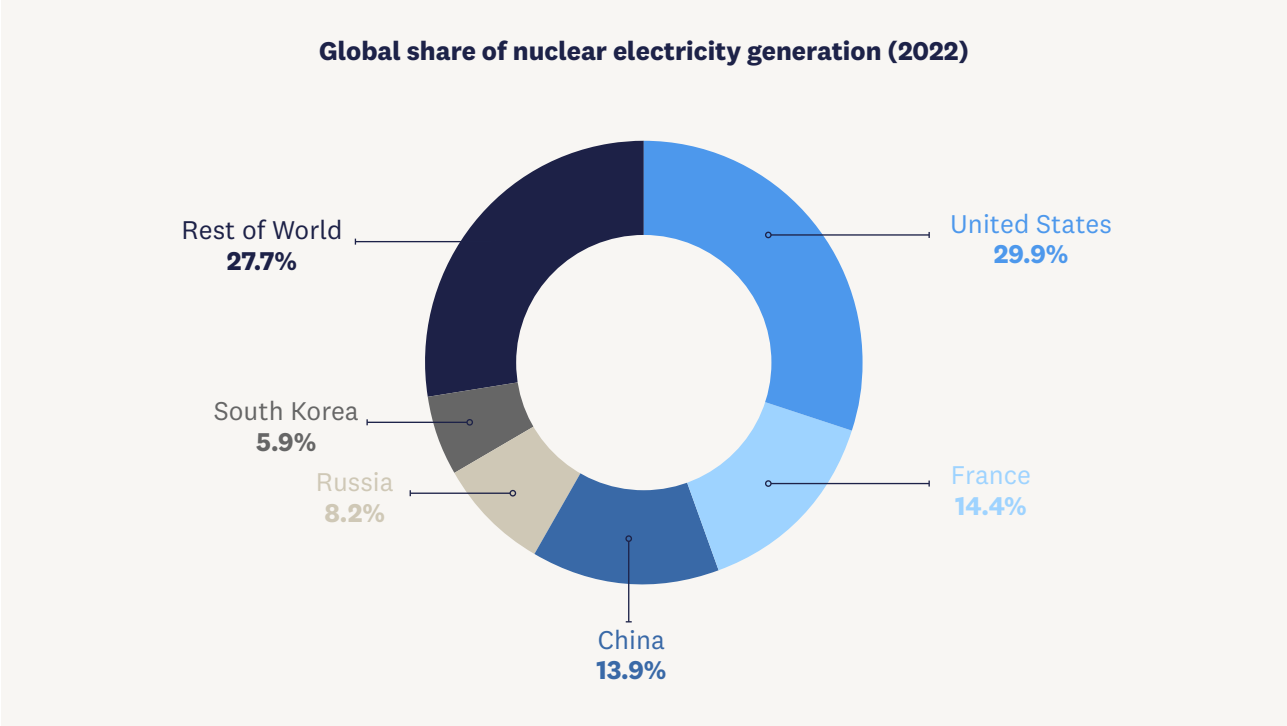


Figure 6: Global share of nuclear electricity generation (2022)
Source: US Energy Information Administration

While Western countries have historically held a significant share of global nuclear capacity, their grip on market leadership has weakened as new builds have become increasingly rare and expensive. In sharp contrast, Russia and China have been actively pursuing the expansion and exportation of their nuclear programs.

In addition to the most rapid build out of renewables in the world, China has also been expanding its nuclear energy production. As illustrated in **Figure 5**, during the past 20 years, China has been responsible for over half of the world's nuclear reactor startups. In addition, 40% of reactors currently under construction globally are in China. The average reactor in China is just nine years old, making it by far the youngest nuclear fleet in the world. China aims to double its share of nuclear electricity supply to almost 10% by 2035 (although according to recent projections, this target is unlikely to be met).

Russia has long viewed its nuclear program as a source of strategic influence and is the dominant supplier of nuclear technology to the international market. As of March 2024, Russia is currently constructing 26 units—20 of which are outside the country. All new reactor constructions within the last five years have been launched by Chinese and Russian government-controlled companies.

Of course, Russia and China are able to expedite the process with the backing of the state. The decision-making power within these states is also concentrated within a comparatively small group of institutional actors. Furthermore, the nature of their political systems means that the nuclear industry is largely insulated from public scrutiny and does not have to contend with widespread public opposition. The average construction time for a nuclear reactor in China is six years, compared to 10 in the West.

Proponents of conventional nuclear energy will often point to examples of successful and relatively timely deployment within authoritarian countries as evidence of its commercial viability, but this is misleading. A more worthy exercise would be to evaluate the experiences of countries with a political and economic system comparable to our own.

The early adopters of nuclear energy are now confronted with the challenges of maintaining an ageing nuclear fleet. In the United States, the world's leading nuclear power producer—the mean age of reactors is now over 42 years, making it amongst the oldest nuclear fleets in the world. Several reactors have closed prior to their licence expiration due to increasing competition from much cheaper energy sources. In mid-2024, nuclear power produced 18.6%, of commercial electricity generation in the United States compared to renewables share of 21.4% of electricity generation.

Similar trends are evident across the West. In 2022, France shut down nearly half of its reactors after evidence of cracks and corrosion were found. The prolonged shutdowns resulted in severe energy shortages in the middle of winter, with the French Government resorting to imported electricity from Germany.

Share of generation

Globally, nuclear energy's share of production peaked in 1996, at 17.5% of commercial gross electricity. A steady decline has followed. By 2023, nuclear reactors generated just 9.1% of global commercial gross electricity—a historic 40-year low. By comparison, solar and wind generated 50% more electricity than conventional nuclear plants.

The past two decades have seen a pronounced slump in conventional reactor installations. The decline has been particularly evident in the West, with this trend expected to continue in the near-term. A growing number of conventional nuclear reactors across the globe are facing decommission prior to the expiry of their operational licence. New builds are also rare, and subject to cost blowouts and long delays.

Costs

Global construction costs for different large scale reactors vary widely, from $15 billion to $28 billion per GW excluding financing (see **Figure 7**). Western jurisdictions tend to experience higher build costs and are more frequently prone to budget overruns. Several high-profile projects exemplify this trend, including Hinkley Point C, Vogtle 3 and 4, and Olkiluoto 3, all of which have experienced dramatic cost and build duration blowouts.

Large scale nuclear cost and completion time frames across the world

Name	Country	Year Announced	Year Completed	Capacity (MWe)	Capacity Factor (%)	Duration (Years)	Cost (AUD)	Cost Blowout (%)	Time Blowout (%)
Olkiluoto 3	Finland	2000	2023	1,600	~90	23	$18B	~269	~260
Hinkley Point C (Unit 1)	UK	2012	2029 (est.)	1,630 (3200 MW total)	~90	17 (est.)	$92.6B	~433	~70
Barakah 4	UAE	2009	2023	1,347	~96	14	$30B (total)	Minimal	On time
Sanmen 2	China	2009	2021	1,250	~92	12	$10B	Minor	Minor
Tianwan 6	China	2010	2021	1,000	~90	11	$7B	Minimal	Minimal
Flamanville 3	France	2007	2024	1,650	~85	17	$30B	~400	~300
Vogtle 3	USA	2009	2023	1,117	~90	14	$20B	~200	~150
Vogtle 4	USA	2009	2024	1,117	~90	15	$20B	~200	~150
Kashiwazaki-Kariwa 7	Japan	1992	2020 (restart)	1,356	~85	~30 (restart delay)	N/A	N/A	Restart delays
Rostov 4	Russia	2010	2017	1,000	~92	7	$6B	None	On time
Akkuyu 1	Turkey	2010	2023	1,200	~85	13	$25B (total)	N/A	On time
Kudankulam 2	India	2002	2017	1,000	~80	15	$4.5B	~50	Moderate
Hongyanhe 6	China	2010	2022	1,061	~92	12	$6.5B	Minimal	Minimal
Chashma 4	Pakistan	2007	2017	340	~80	10	$1B	Minimal	Minimal
Karachi 3	Pakistan	2013	2022	1,100	~88	9	$6.5B	None	On time

Figure 7: Large scale nuclear cost and completion time frames across the world
Source: World Nuclear Industry Status Report, IAEA, Blueprint Institute analysis

Unlike other technologies, the costs of nuclear construction in the US has increased in real terms, rather than decreased over time (see **Figure 8**).

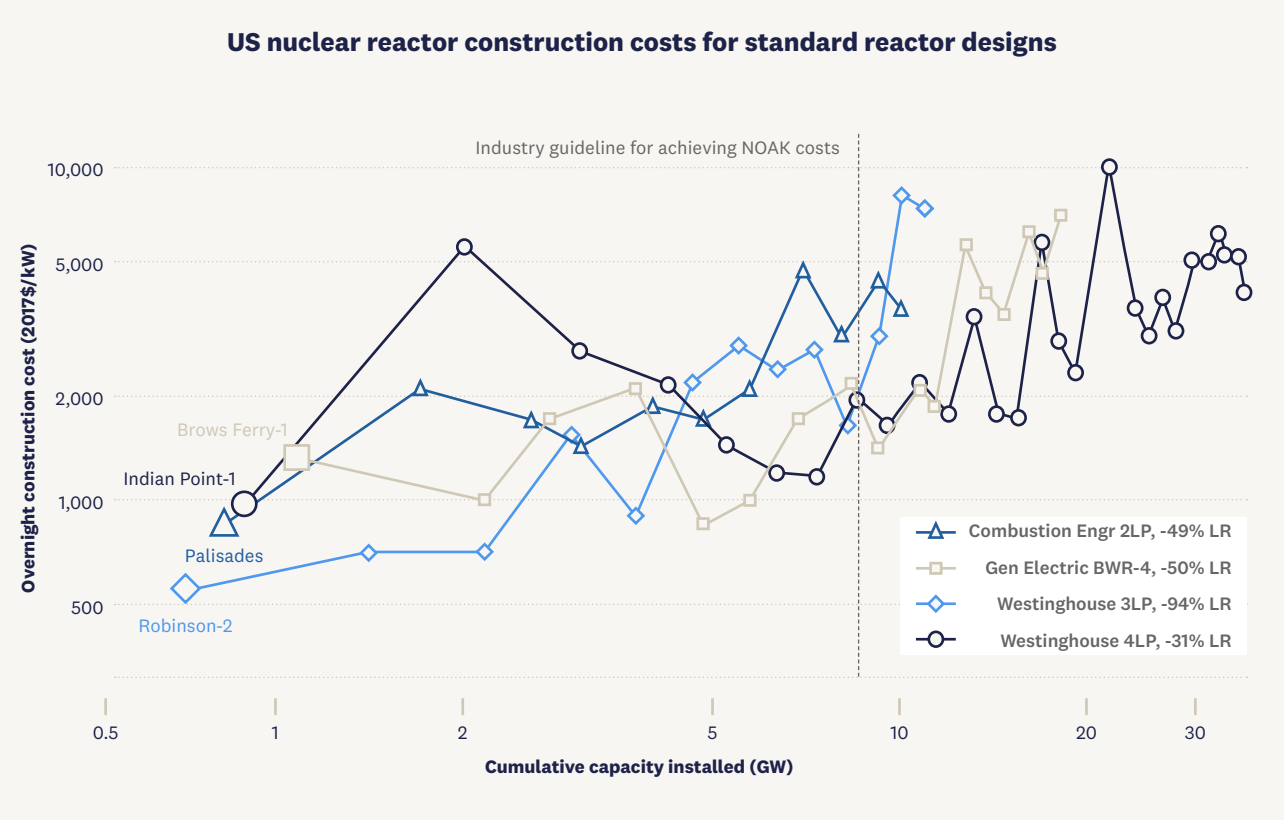


Figure 8: US nuclear reactor construction costs for standard reactor designs
Source: East-Gates et al, Joule[2]

Contributing factors for this cost increase include declines in labour productivity (which accounted for half of cost increases between 1976 to 1987); higher containment costs (which accounted for one third of costs increases between 1976 and 2017). The increases in containment costs were driven partially but not wholly by more stringent safety regulation requirements. There was a consistent gap observed between expected and actual construction costs, in part because the differences of site-specific builds, even with a repeated form of plant, were consistently more challenging than expected.

These issues are relevant for Australia—where we face a severe shortage of construction labour, highly site-specific challenges, and would expect the highest safety standards. It is hard to believe that Australia wouldn't also be vulnerable to these kinds of cost blowouts, particularly given that we are already seeing these in other more familiar infrastructure projects, like transport and housing.

[2] Sources of Cost Overrun in Nuclear Power Plant Construction Call for a New Approach to Engineering Design, Eash-Gates, Philip et al, Joule, Volume 4, Issue 11, 2348 - 2373.

Small modular reactors

Despite decades of investment and optimism, Small Modular Reactors (SMRs) are yet to deliver on their promise of safer, more affordable nuclear power.

Overview

SMRs are considered to be the next generation of nuclear fission reactors, addressing some of the constraints of traditional large-scale nuclear. They are defined both by their size, up to 300 MW of energy per module –around one-third of the power capacity of conventional reactors, and by the theoretical potential for modular production.

SMRs represent a broad class of reactor types. There are currently 68 different SMR designs across the globe in various stages of development, reflecting different technologies and coolants—the most popular being light water reactors, fast neutron reactors, and molten salt reactors.

While small modular reactors are sometimes proported as a breakthrough new technology, they have been around in various stages of development for decades. Across the world, governments and the private sector have invested in prototype projects. However, despite this interest, SMRs remain shy of genuine commercial viability.

The theoretical benefits of SMRs

There have been three main hopes for SMRs. First, that they may prove a less costly alternative to traditional nuclear reactors. Second, that they may provide a more flexible approach, increasing the range of potential uses. And finally, that they might produce less waste. Flexibility appears a valid claim, however the promises around cost and waste are yet to be proven.

Cost

SMRs are defined by their size. They are smaller than traditional nuclear reactors, and as a result, cheaper to build. However, on the basis of cost per unit of energy produced, SMRs remain more expensive than traditional nuclear power plants – approximately $387-641 per megawatt hour, more than double that of large-scale nuclear power at $155-252 per megawatt hour. Cost blowouts remain a challenge – Argentina has been constructing an SMR for over a decade, the most recent World Nuclear Report estimates the cost of the CAREM project to be US$32,000/kW.

However the theoretical advantage of SMRs lies in their potential modularity. Proponents envision that SMRs will be manufactured in portable segments en masse, leveraging streamlined factory-production processes and increasing affordability. However, to date, this idea remains strictly theoretical. There are only four SMRs in existence, all of which have been beset with significant operational challenges. The idea of mass factory production of SMRs is far from today's reality.

Flexibility

Expanding an electricity grid faces two key obstacles—a lack of transmission infrastructure, and the costs of grid connection. SMRs are designed to possess a distinct advantage over renewables due to their capability to run remotely off-grid, thereby enabling the production of clean energy in remote locations. This would allow for SMRs to be situated in regions with poor transmission infrastructure or limited capacity to plug into the grid. Microreactors, typically generating up to 10MW, would have a proportional advantage in these regions.

In an Australian context, this means that, like firmed renewables (wind or solar co-located with battery storage), SMRs could be used in relatively remote locations with high energy needs that are currently met by fossil fuels. Specifically, a potential use-case for SMRs outside the National Electricity Market is in the mining sector, which would benefit from a reliable, non-intermittent source of energy to electrify and decarbonise their operations.

Waste

SMR advocates claim they will produce less waste than traditional fission plants, but as yet, there's no definitive consensus on this claim. Most SMR designs will be fuelled by uranium, and are expected to use less fuel than conventional plants. However evidence to date suggests some SMRs may actually be more wasteful per unit of energy produced than their traditional counterparts—by factors of 2 to 30.

Another challenge is the complexity of waste—specifically, greater neutron leakage, which leads to higher levels of neutron-activated materials and more complex waste streams. Much more work needs to be done before Australians could be confident that this is a lower-waste solution.

An industry in its infancy

SMRs have long been heralded as the next giant leap forward in nuclear power technology, but despite more than two decades of investment and research, active commercialisation and proven benefits remain elusive.

There are currently 68 different SMR designs across the globe, spanning multiple design classes—the most popular being light water reactors, fast neutron reactors, and molten salt reactors, and are in various stages of development. None have emerged as a winner yet— all models remain early in the development curve, and costly as a result. Today only four SMRs are in operation—with a further four currently under construction. The vast majority of SMR projects globally remain in elementary, prototypical stages of design.

China and Russia are home to the four operational SMRs. The Russian modules were completed nine years later than originally scheduled, and their performance has been described in the World Nuclear Industry Status Report as 'mediocre.' China has two 100 MW reactors connected to a single turbine. The units began operating commercially in 2023. However, the capacity of the two units has since been downgraded significantly to a combined 150MW.

The general lack of transparency surrounding the Chinese nuclear program means that the reason for the 25% reduction in output is unclear but analysts believe it is almost certainly an indication of operational problems.

In 2021, China and Russia each began construction of another SMR, and the other two under construction are in Argentina and the US. The Argentine project has been underway for over a decade, and is not expected to be operational until or after 2028. The US project began in the middle of 2024 in Tennessee, and was the first Generation IV design to receive a construction license from the U.S. Nuclear Regulatory Commission. It marks the first non-light-water reactor approved in the United States in over 50 years.

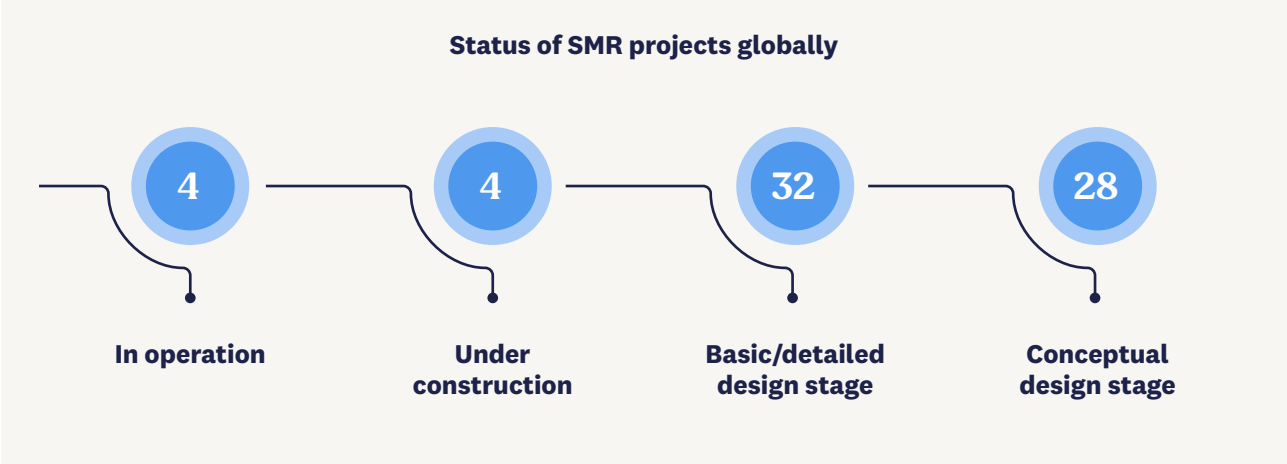


Figure 9: Status of SMR projects globally
Source: International Atomic Energy Agency

The economic reality

Macroeconomic and financial challenges facing SMRs

Today's macroeconomic climate poses significant challenges for large, high-risk infrastructure projects—SMRs included. These projects are particularly sensitive to interest rates and inflation. Most existing SMR prototypes were conceived under more favourable economic conditions, and if elevated interest rates persist, investors are likely to favour lower-risk assets over speculative ventures.

Unlike many technologies that become cheaper over time, nuclear construction costs in the US and France have trended upward. SMRs, despite their smaller scale, face similar issues. The Rolls-Royce SMR saw costs rise from £1.5 billion in 2019 to £4.37 billion by 2022. NuScale, once a leading US SMR project, was cancelled in 2023 after persistent cost overruns. Initially planned as a 12-reactor, 600MW plant costing US$3 billion and operational by 2023, its projected cost had risen to $9.3 billion before being abandoned.

Structural and market barriers

Cost management is only one piece of the puzzle. For SMRs to succeed, modularity must be paired with scale. That requires both factory capacity and customers ready to buy in volume—something only possible if the industry converges on a smaller number of viable designs.

Most leading SMR projects still need significant capital and rely on bespoke financing models to allocate risk. These ad-hoc structures, tailored to each project, risk fragmenting the industry and delaying the build-out of the manufacturing and deployment capabilities SMRs require.

Regulatory and infrastructure constraints

SMRs also face substantial regulatory hurdles. Licensing, safety approvals, and compliance costs are high across all jurisdictions. In Australia, like renewables, nuclear technologies will also face location-dependent transmission and distribution costs.

Moreover, industrial scaling assumes a viable product-market fit—which has yet to materialise. While several countries have expressed interest in SMRs, none have committed to integrating them at a meaningful scale in their energy grids.

The need for strategic coordination

This creates a feedback loop: high risk deters investment, which in turn weakens demand and delays progress. To break this cycle, coordination between SMR developers, institutional investors, and customers is critical. These partnerships are essential to produce a viable product at the right cost and unlock the capital required to scale.

Fusion technology

Overview

Another emerging nuclear technology that has garnered attention of both international governments and private enterprise is fusion. Nuclear fusion, the process powering the stars, involves combining lighter atomic nuclei, such as hydrogen isotopes, under extreme conditions to form heavier elements like helium—which releases vast amounts of energy in the process.

Achieving this on Earth requires temperatures exceeding those at the sun's core—tens of millions of degrees—forcing atoms to collide with enough energy to overcome their natural repulsion. Advanced lasers or magnetic fields create and sustain this superheated plasma, confining it long enough for the fusion reaction to occur. When successful, the reaction releases energy by converting a small amount of mass into power, as described by Einstein's most famous mass-energy equivalence equation ($E = mc^2$). This breakthrough promises the potential for a virtually limitless, clean energy source if scaled effectively.

Similarly to fission or conventional nuclear, fusion would be an abundant carbon free energy source. However, the marked advantage embodied by fusion power lies in its inherent safety—devoid of any long-term high-level nuclear waste—while capable of releasing four times more energy than fission does.

Unlike fossil fuel generation, or even traditional nuclear, fusion's fuel source—deuterium and tritium—are abundant and easily obtained. However, while igniting fuels like coal is straightforward, it is a much more complex task for hydrogen isotopes. In December 2023, the NIF achieved a net energy gain fusion ignition—meaning its energy outputs exceeded its inputs.

The laser used at the ignition facility exceeded the energy used in the entire US power grid, and the plasma reached temperatures ten times hotter than the centre of the sun. These are clearly parameters that breach extremities far beyond commercial scale capabilities.

Whilst the fusion reactions achieved a net energy gain, it was only for the fusion reaction itself, meaning the energy released by the reaction exceeded the energy directly delivered to the fuel target by the laser. However, when considering the total energy required to operate the lasers, including the inefficiencies of converting electrical power into laser energy (which can be less than 1% efficient), the overall process still resulted in a net energy loss.

A way to go

There is still a long road ahead before we can safely rely on fusion for energy generation. The spark ignited energy manifested as energetic particles, necessitating further advancements to sustain the reaction and transform the energetic particles into electricity. Another challenge to master is how to get the plasma—the matter in which fusion reactions occur—to endure the extreme temperatures needed to replicate the conditions of the sun. The plasma needs to reach temperatures exceeding 150 million degrees Celsius, meaning an equally ambitious engineering challenge lies in containing this plasma safely.

A commercial reactor would also require the structural integrity to withstand neutron bombardment—the process where free neutrons penetrate atomic nuclei, triggering reactions such as fission, fusion, or isotope formation by overcoming the electric repulsion that charged particles face. Achieving a full system-wide net energy gain remains a significant challenge for practical fusion energy production, and while the breakthrough ignition was a significant achievement, commercial viability could still be decades away.

Nonetheless, there has been significant private sector investment in fusion—which has nearly tripled (**Figure 10**)—with approximately 75% of all fusion investment occurring since 2021. Private funding for fusion has now reached US$5.9 billion, with a US$1.4 billion total increase in funding since 2022. It is difficult to reconcile with a commensurate acceleration in SMR investment if fusion is able to reach a projected US$40 trillion market valuation.

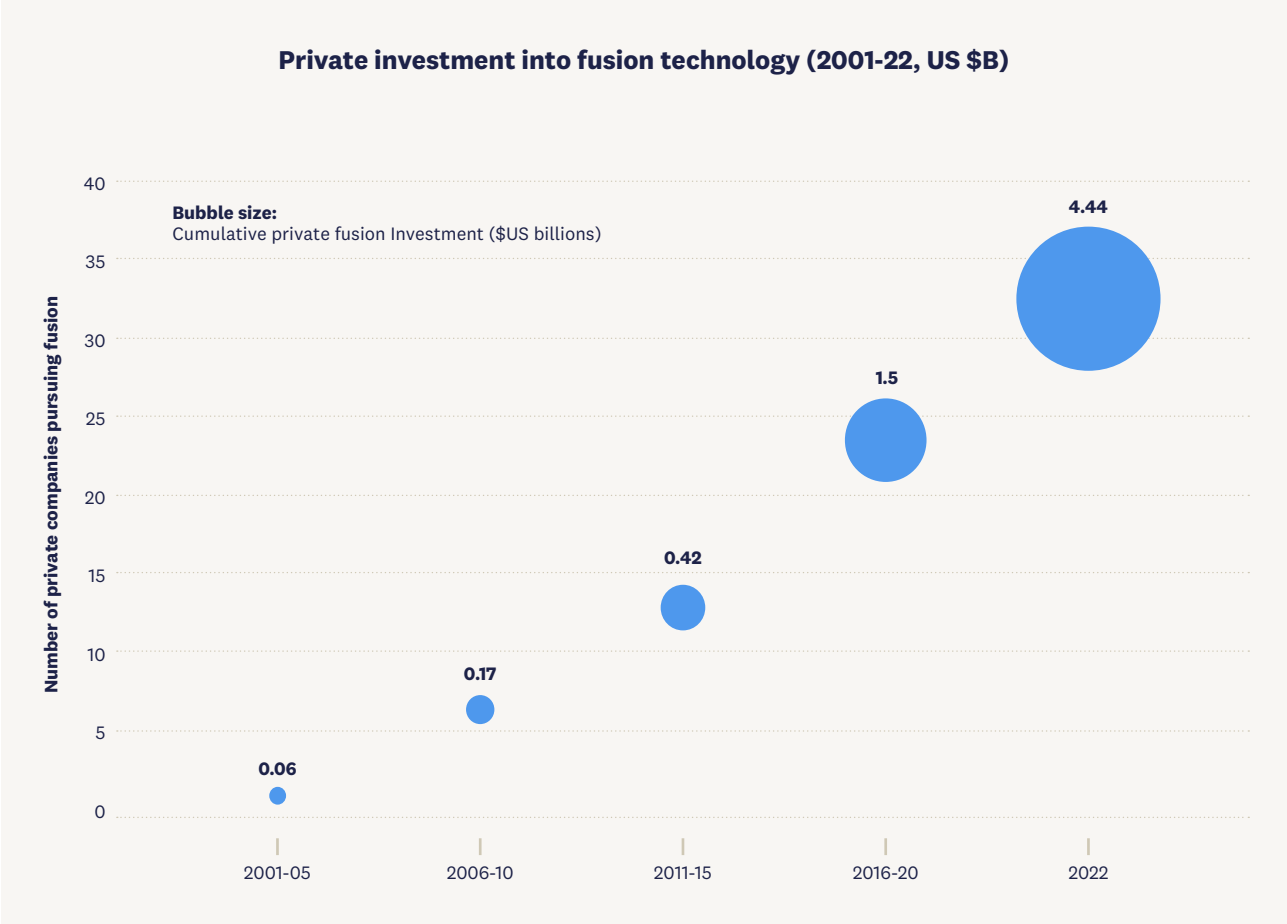


Figure 10: Private investment into fusion technology (2001-22, US $B)
Source: McKinsey & Company

One of the most promising demonstrations of fusion being used as a viable carbon-free energy source will be the International Thermonuclear Experimental Reactor (ITER). ITER members—the US, China, the European Union (through Euratom), India, Japan, Korea, and Russia, comprising 35 nations—are collaborating to build ITER, at a cost of around US$65 billion. Although such a display of international collaboration points to the promise of ITER, it is still a long way from being operational and has been subject to safety concerns, delays, and cost increases. ITER was originally expected to be operational by 2035, however, due to technical and safety setbacks, this timeframe is being revised.

Microsoft has recently bet on fusion's viability, making the first power purchase agreement to buy fusion electricity from fusion startup Helion Energy by 2028. Helion will be subject to financial penalty should they fail to produce 50 MW of fusion electricity after one year. This is without doubt an ambitious goal for Helion—but with many prominent investors backing fusion companies, it raises the question of whether SMRs might go to market as antiquated relics.

However, the claims that fusion power could be ready as early as 2030 are misguided. While the recent breakthroughs and growing investment alludes to the potential of fusion power, we are still decades away from a functional fusion reactor prototype that could be commercially scalable, and we do not have decades to waste in meeting our net-zero targets.

With strong cost-competitiveness from renewables generation, it would require an extraordinary advancement in fusion to warrant divesting in renewables. However, as with all technologies, it's smart to develop an informed watching brief.



Modelling the economic implications for Australia

GenCost modelling

The 2032-24 GenCost report now includes Levelised Cost of Energy (LCOE) estimates for large-scale nuclear plants, with ranges of $155 to $252 per MWh—implying almost double the LCOE estimates range for firmed renewables ($100 to $143 per MWh). In calculating LCOE, the GenCost model assumes lower utilisation levels for nuclear than theoretically possible, driven by market rules designed to minimise cost and ensure security that govern what sources of energy are used when, which means plants (including coal), typically operate below theoretical capacity levels. GenCost also considers the lifespan of a conventional nuclear plant as 30 years, however recent designs tend to have a lifespan closer to 60 years.

LCOE is a widely used measure for investors looking to compare the costs of building and operating different energy sources, it is not a measure designed to compare economy-wide operating costs. Indeed there is no simple measure that allows one to compare the economy-wide implications of one technology versus another one, because the costs will vary depending on how much you have of different types of technologies, where you situate them, and what infrastructure is already in place. Therefore, understanding economy-wide systems costs requires modelling different options for what types of energy are situated where, and what other infrastructure, like transmission or storage, are required to ensure stability and reliability in a redesigned net-zero grid.

Blueprint Institute/ RedVector – total system cost modelling

In 2023, Blueprint Institute analysis contracted RedVector to undertake large-scale system modelling of a range of different scenarios that included and excluded nuclear, leveraging their peer-reviewed Modelling Energy and Grid Services (MEGS) model. This analysis compared total system costs for different energy scenarios and reflected the costs of integrating different technologies, transmission costs and the cost of grid services including inertia, reserve and frequency response.

That analysis found that under any scenario: having a large base of renewables is the cheapest and economically rational approach to removing carbon from the energy system, underscoring clearly that even after including transmission costs, building out the base of renewables is an economic necessity.

It also found that in the cases of the most extreme weather events (a convergence of wind and solar droughts), achieving the final one percent of decarbonisation is approximately $2.8bn ($79 per person) cheaper if gas peaking with carbon capture and storage is included, and $1Bn cheaper which amounts to ($39 person) if some traditional nuclear capacity is included in the grid by 2040.

While this modelling considered a broader range of costs than many other models to date, like all models, it had its constraints. Specifically, the modelling:

> Used CSIRO's GenCost 2019 figures as baseline inputs to model the total system costs for a wide range of decarbonisation scenarios for the NEM;

> Considered only the NEM (excluding parts of the Australian grid that are not NEM connected;

> Excluded the possibility of demand reduction as a lever (over and above that reflected in GenCost modelling), and excluded concentrated solar power plants; and

> Excluded waste disposal and risk management associated costs with nuclear (though it is worth noting that including these don't materially shift the conclusions, also noting that analysis and costing of both of these considerations is a fairly well-established practice internationally).

Frontier Economics – modelling large scale nuclear deployment

Last year, Frontier Economics assessed the economic implications of rolling out large-scale nuclear power in Australia. The Coalition used this modelling as evidence of the merits of their own nuclear proposal. However the modelling conducted by Frontier Economics considers 13 GW of nuclear capacity--double the Coalition's official 6.6 GW commitment.

Unfortunately the analysis employs cost projections that are difficult to justify. Capital costs are modelled at approximately 20% below current US averages, and assumes cost reductions that have not been demonstrated in many major economies (as noted above, in the US costs involved in the construction of nuclear power plants have actually increased over time). Labour is a key component of nuclear power plant construction. Even without reflecting the current shortage of construction labour in Australia, the model has relied on data from the lowest cost geographies, such as the United Arab Emirates, where an average construction worker earns about 9-13 times less than in Australia.

The modelling similarly cherry picks aggressive assumptions around time to build. According to the model, Australia would see nuclear nuclear energy entering the grid by 2036. This 10-year timeframe is incredibly ambitious and defies recent historical precedent in the west. Moreover it does not include the time it would take to construct the necessary regulatory framework that would need to be put in place before construction could begin, not to mention the extensive legislative heavy lifting that would be involved in lifting the existing federal ban as well as several state bans. The cost estimates used by Frontier Economics also seem to exclude transmission connection times, a factor that has repeatedly delayed the rollout of domestic renewable energy projects.

Modeling implications for policy makers

The key conclusions from this modelling are thus:

> Maintaining the pace and scale of the renewables roll out is a must-do under any scenario, and the most economically rational approach to decarbonising the energy grid;

> Analysis to date suggests a marginal economic saving from including some nuclear 15 years down the track (from 2050); and

> Given the constraints around modelling done to date, and the rapidly declining battery storage costs, more fulsome modelling of ongoing total system costs is key (including energy efficiency mechanisms as an active lever).



Conclusion

Australia must urgently adopt a more comprehensive, technology-agnostic approach to its energy transition. While accelerating the roll-out of renewables is essential in the short term to address imminent supply gaps from coal plant closures, we must also establish robust biodiversity and environmental standards, update energy grid modelling to reflect total system costs and delayed action, and optimise transmission planning.

Staying objective and open-minded is critical as new technologies, including emerging nuclear options, continue to develop. Balancing urgency with long-term planning will ensure a reliable, cost-effective, and environmentally sustainable energy future.

