

The State and Outlook for Nuclear Generation

Power Session Webinar

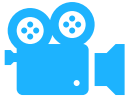
September 23, 2025



Agenda and Housekeeping

Agenda

- Housekeeping and Introductions
- Nuclear Policy
- Key Technologies and Performance Indicators
- Competitiveness
- Review Power Session Webinars

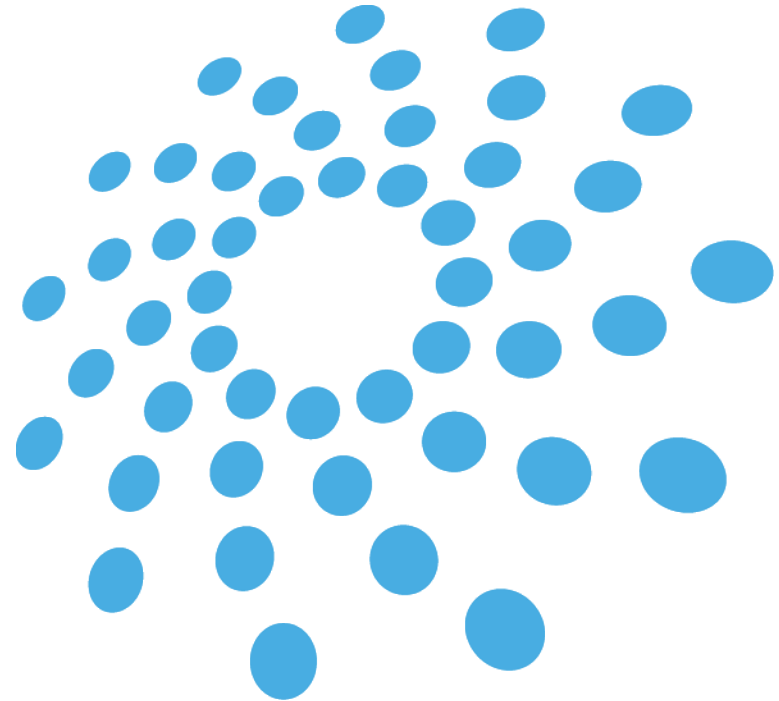


Housekeeping

This webinar is being recorded and distributed to all registrants along with this presentation



Add your questions to the chat. My colleague, Sara Gonzales, is monitoring the chat for the Q&A session



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Ezra Beeman

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Nuclear Policy

Australia

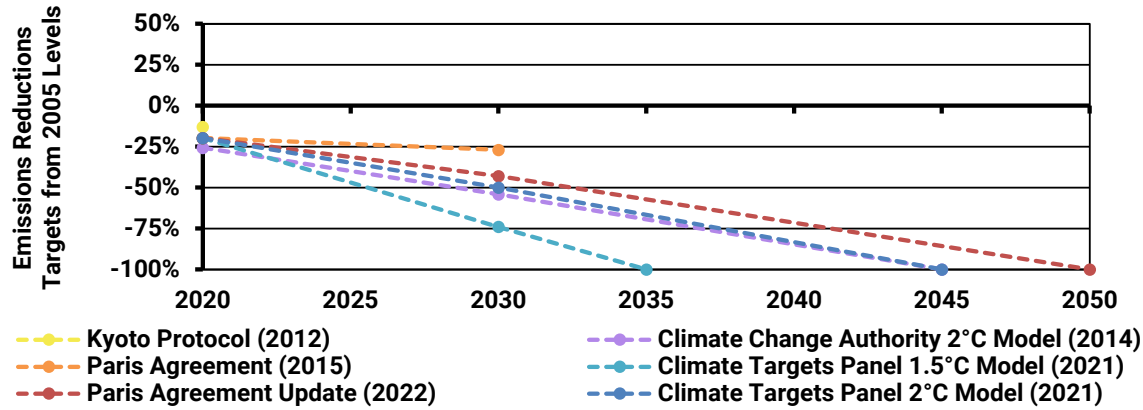
Targets

Incentives



Australian Policy

Australia's Net Zero Targets



Source: DCCEEW (2021), Climate Targets Panel (2021), Climate Change Authority (2014), Energeia, Note: 2020 datapoint is historical (excluding the Kyoto Protocol and Climate Council Authority targets)

ARPANSA (1998) Section 10

10 Prohibition on certain nuclear installations

(1) Nothing in this Act is to be taken to authorise the construction or operation of any of the following nuclear installations:

- a nuclear fuel fabrication plant;
- a nuclear power plant;
- an enrichment plant;
- a reprocessing facility.

(1A) Paragraph (1)(b) does not apply to a naval nuclear propulsion plant related to use in a conventionally-armed, nuclear-powered submarine.

(2) The CEO must not issue a licence under section 32 in respect of any of the facilities to which subsection (1) applies.

Source: Federal Register of Legislation

- Historically, Australia has not taken up nuclear energy, despite having advantages that support the uptake and development of nuclear energy, such as the world's largest supply of Uranium
 - Despite this, Australia does have significant infrastructure and experience with nuclear, through the 20MWt Open Pool Australian Lightwater (OPAL) research reactor, owned and operated by the Australian Nuclear Science & Technology Organisation (ANSTO)
- The Australian Radiation Protection and Nuclear Safety Agency (ARPANSA) contains prohibitions on developing a nuclear energy industry in Australia
- In recent years, there has been a push to develop a nuclear energy industry in Australia to address:
 - Climate Change,
 - Rising Energy Costs
 - Ageing of the Coal-Fired Power Plant Fleet
 - Baseload power for an increasingly Renewable Energy Grid
- Though the push for nuclear development in Australia has been met with strong resistance, the conversation has been started

Global Nuclear Policy – Targets

Summary of Worldwide Nuclear Targets

| Target Type | Australia | USA | EU | UK | France | Russia | China | Japan | South Korea | India | Canada | Finland |
|---------------------------------|-----------|-----------------|----------------|----------------|----------------|------------------------|-----------------------|-------|----------------------------------|-------------------|--------|----------------|
| Total Target Installed Capacity | None | 400 GW by 2050 | 109 GW by 2050 | 24 GW by 2050 | | | 200 GW by 2035 | | | 100 GW by 2047 | | |
| New Capacity | None | ~300 GW by 2050 | ~10 GW by 2050 | ~18 GW by 2050 | 6 New Reactors | | ~145 GW by 2035 | | | ~90-95 GW by 2047 | | 2 New Reactors |
| Share of Generation | None | | | | | 23.5% by 2042 | 15% by 2050 | | 34.6% by 2036 | | | |
| Exports | None | | | | | | Targeting BRI Nations | | Export 10 Nuclear Plants by 2030 | | | |
| Other | None | | | | | Full Recycling of Fuel | | | | | | |

Source: Energeia Research

- Though Australia is not expected to pursue nuclear in the near future, other nations have recently announced support for nuclear energy development
- A notable exception to this is Japan, who are expected to reduce their overall dependence on nuclear going into the future
- France has reversed their 2014 policy to lower nuclear penetration from 70% to 50% and, since 2022, plans to install 6 new reactors
- Canada is also a current world leader in nuclear energy, but notably has no explicit targets

Global Nuclear Policy – Incentives

Summary of Worldwide Nuclear Incentives

| Funding Type | Australia | USA | EU | UK | France | Russia | China | Japan | South Korea | India | Canada | Finland |
|---------------|-----------|---|----|---|--|--------|---|-------|--|--|---|---------|
| Loans | | Federal loans and loan guarantees prioritising projects that support nuclear energy | | | Government subsidised loan for half the construction costs | | State-backed loans cover around 70% of the cost of Chinese reactors | | Low-interest loans up to \$7.5 million (\$USD) | | Financing available under the Green Bond Framework | |
| Subsidies | | | | Use a CfD and RAB model to ensure nuclear investors secure a return on investment | Use a CfD model to ensure nuclear investors a guaranteed energy sell price | | Government providing financing and subsidies, including feed-in tariffs | | | \$3 billion (\$USD) budget for the Department of Atomic Energy | \$55 million (\$CAD) grant for three small modular reactor projects | |
| Tax Incentive | | Tax credit of 0.3c/kWh (\$USD) for gross nuclear power generation | | | | | | | | | 30% tax credit for small modular reactors | |

- Countries are commonly funding the nuclear energy development through federal subsidies and loans
- South Korea incentive is almost zero

Source: Energeia Research

Key Nuclear Technologies – Definitions

Nuclear Reactor Technologies

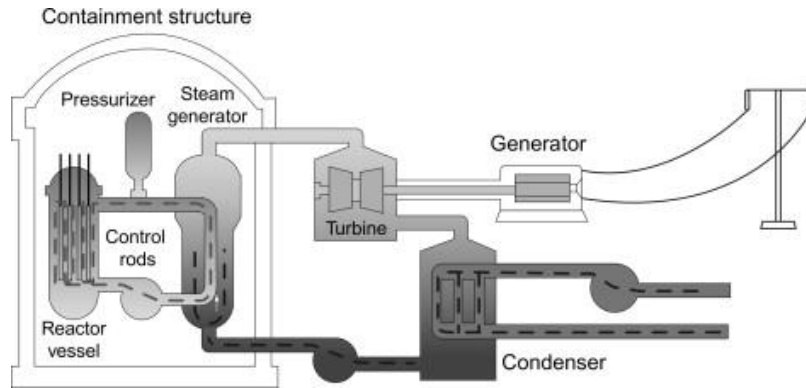
| Type | Definition |
|--|--|
| Pressurised Water Reactor | Pressurised Water Reactors (PWR) are the most common type of nuclear reactor present today and uses either pressurised light or heavy water to both moderate and cool the reactor core. The heat is transferring from the reactor core into a secondary steam circuit to drive turbines |
| Boiling Water Reactor | Boiling Water Reactors (BWR) are the next most common type of nuclear reactor present today, where light water that's used to cool and moderate the reactor core is directly boiled in the reactor vessel into steam. This steam is then sent straight from the reactor to the generator turbines to produce electricity |
| Small Modular Reactor | Small Modular Reactor (SMR) is an umbrella term for compact nuclear reactors designed to be mass-produced in factories and transported to site, typically producing 30-300 MWe of electricity |
| Molten Salt Reactor* | Molten Salt Reactors (MSR) use molten fluoride or chloride salts as the reactor coolant and in some designs, the fuel carrier. The fission energy that is absorbed by the molten salt is transferred to a secondary fluid circuit which is used to drive turbine generators |
| Fast Neutron/Breeder Reactor* Sodium Fast Reactor* Lead Fast Reactor* Gas Fast Reactor* | Fast Neutron/Breeder Reactors (FNR/FBR) use fast neutrons, no neutron moderator, to sustain the reaction. Sodium, Lead, and Gas Fast Reactors (SFR, LFR, GFR) use liquid Sodium, Lead, or Helium Gas as the coolant, transferring fission energy into a secondary fluid circuit to generate electricity |
| High Temperature Gas Reactor* | High Temperature Gas Reactors (HTGR) use Helium gas as a coolant, with the reactor running at very high temperatures (1,000°C), and relatively low pressure. HTGR's can be used for process heat generation as well as electricity generation |
| Supercritical Water Reactor* | Supercritical Water Reactors (SCWR) operate similar to BWR's, except rather than allowing the coolant to boil into steam, the coolant is kept supercritical and transferred directly to the generating turbines. SCWR's are designed to operate in a very similar manner to traditional fossil-fuel plants |

Source: Energeia Research, Note: Reactors marked with an asterisk (*) are considered Generation IV nuclear reactor technologies

- Generation IV nuclear reactors indicated by an * aim to be the next step in reactor designs, promising improvements to nuclear sustainability, economics, safety and reliability, and proliferation resistance
- They are still novel, with limited to-date grid deployment
- However, with nuclear becoming increasingly relevant for generating flat (data centre), clean electricity, as well as the slated installation of Gen IV nuclear reactors, they're expected to capture a greater worldwide generation market share
- Small modular reactors are indicated in light blue, as this approach can be applied to the other reactor technologies
 - It is mainly a design philosophy around standardisation, modularity, etc.

Conventional Technology - Installations by Type

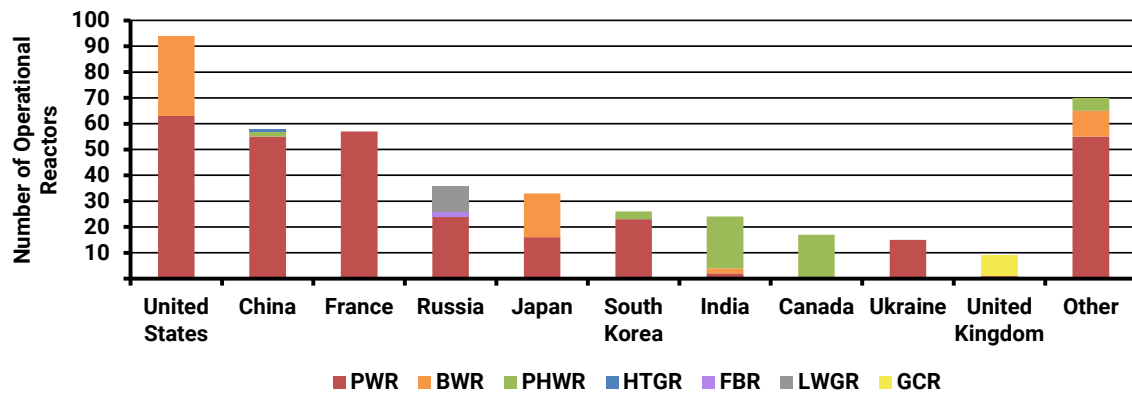
Pressurised Water Reactor



Source: United States Nuclear Regulatory Commission

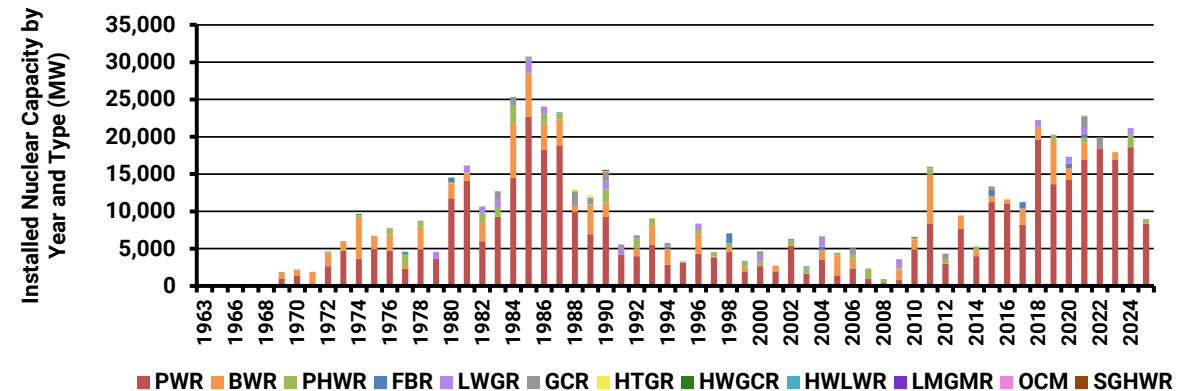
- The most common nuclear reactor technology that is used today is the Light Water Reactor (LWR)
 - The two most common types of LWR's are the PWR and the BWR, which have a global market share of 71% and 14% respectively
 - Their operation mechanism is similar, except that a PWR transfers heat through two fluid circuits, compared to a BWR, that only uses a single fluid circuit
- There are variants of these designs that use Heavy Water (D₂O) in the reactor vessel, such as the Pressurised Heavy Water Reactor (PHWR - 11% of market share), but the method of operation is still the same

Nuclear Reactor Counts by Country and Type



Source: World Nuclear Association. Note: PHWR – Pressurised Heavy Water Reactor, HTGR – High Temperature Gas Reactor, FBR – Fast Breeder Reactor, LWGR – Light Water Graphite Reactor, GCR – Gas Cooled Reactor

Historical and Future Installed Nuclear MW by Year and Type



Source: World Nuclear Association, Note: PHWR – Pressurised Heavy Water Reactor, FBR – Fast Breeder Reactor, LWGR – Light Water Graphite Reactor, GCR – Gas Cooled Reactor, HTGR – High Temperature Gas Reactor, HWGCR – Heavy Water Gas Cooled Reactor, HWLWR – Heavy Water Light Water Reactor, LMGMR – Liquid Metal Graphite Moderated Reactor, OCM – Organically Cooled and Moderated Reactor, SGHWR – Steam Generating Heavy Water Reactor

Conventional vs. Small Modular Reactors

Conventional vs Small Modular Reactors (PWR)

| Parameter | Conventional Nuclear Reactors | Small Modular Reactors |
|----------------------------|---------------------------------------|---|
| Levelised Cost (\$AUD/MWh) | \$141-\$233 (CSIRO) | \$179 ¹ |
| Build Cost (\$AUD/MW) | \$8.6m (CSIRO, 1,000 MW reactor) | \$31m ¹ (NuScale, 6x 77MW modules) |
| Construction Time (Years) | 7 | 3-5 |
| Minimum Sizing (MW) | 1,000 | 30-300 |
| Safety / Leaks | Significant Measures in Place | Significant Measures in Place |
| Ramp Rate (/min) | 5% | Control Rods: 3.3% down, 0.8% up ¹ Turbine Bypass: 10% down, 3.0% up ¹ |
| Minimum Run (%) | 20%-50% | 20% ¹ |
| Planned Outages | 1 Month every 18-24 Months | 10 days every 18-20 months ¹ |
| Waste Management | Significant waste management required | Significant waste management required |
| Water Requirements (L/MWh) | 1,500-2,700 | 950-1,500 ¹ |

Source: Energeia Research. ¹based on current NuScale SMR estimates. For the cost assumptions, this includes no subsidy and is converted to AUD

- The table compares conventional nuclear reactors to a PWR small modular reactor
- Small Modular Reactor (SMR) is an umbrella term for reactors with the following features determined by the International Atomic Energy Agency (IAEA) and World Nuclear Association (WNA)
 - Reactors and other major components are designed to be standardised
 - Smaller physical footprint
 - Designed with inherent passive cooling, in the case of a power failure
 - Minimum capacity 30-300 MWe, which can be daisy-chained
- Estimates for the SMR are based on NuScale, which is not yet fully commercialised, but is the only SMR to be certified by the US nuclear regulatory commission
- CSIRO (Commonwealth Scientific and Industrial Research Organisation) notes that, as Australia has no existing nuclear, a first-of-a-kind multiplier of 2x could apply to capital costs in Australia

Small Modular Reactors – Current Projects

Grid-Connected Small Reactors Operating

| Country | SMR Name | Completion Year | Build Years | Capacity (MWe) | Budget (\$AUD/MW) | Technology |
|---------|----------|-----------------|-------------|----------------|-------------------|------------------------------|
| Russia | KLT-40S | 2020 | 11.5 | 70 | \$16 Million | Pressurised Water Reactor |
| China | HTR-PM | 2023 | 9 | 210 | \$7.6 Million | High Temperature Gas Reactor |

Source: World Nuclear Association, Energeia Research

Small Modular Reactors Under Construction

| Country | SMR Name | Completion Year | Build Years | Capacity (MW) | Budget (\$AUD/MW) | Technology |
|-----------|--------------|-----------------|-------------|---------------|-------------------|---------------------------|
| China | ACP100 | 2026 | 5.4 | 125 | \$9.5 Million | Pressurised Water Reactor |
| Russia | BREST-OD-300 | 2026 | 5 | 300 | \$9 Million | Sodium Fast Reactor |
| Russia | RITM-200S | 2027 | 5 | 300 | \$9 Million | Pressurised Water Reactor |
| Argentina | CAREM-25 | 2027 | 3 | 32 | \$5.4 Million | Pressurised Water Reactor |
| USA | Hermes | 2027 | 2.5 | 70 | \$9.2 Million | Molten Salt Reactor |
| Canada | BWRX-300 | 2030 | 5 | 300 | \$28 Million | Boiling Water Reactor |

Source: World Nuclear Association, Energeia Research

- SMRs have seen limited grid-connection deployment worldwide to date, with Russia and China leading SMR deployment
- SMR deployments are not limited to conventional PWR designs, there are reactors in operation and being constructed that use advanced reactor technologies, such as:
 - High Temperature Reactors
 - Fast Breeder Reactors, and
 - Molten Salt Reactors
- SMR pilots are seeing as delivering
 - ~3-5 year deployment times
 - ~\$5-10m (\$/M) unit rates
- However, actual delivery times and costs for the planned projects is TBC

Summary of Key Nuclear Reactor Technologies

Comparison of Key Nuclear Reactor Technologies

| Name | Cost (\$AU/MW) | Lead Time (Years) | Sizing (Min MWs) | Ramping (% MW / Min) | Maintain Time (%/Year) | Min Load (%) | Water (kL/MWh) | Restart Costs (\$/MW) | Maturity (Total MWs) | Availability (Years) |
|---|----------------|-------------------|------------------|----------------------|------------------------|--------------|----------------|-----------------------|----------------------|----------------------|
| Conventional Nuclear Reactor Technologies | | | | | | | | | | |
| Light Water | \$5.8 Million | 7.5 | 1,000 | 5% | 5% | 20-50% | 2 | - | 511,807 | 80 Years |
| Small Modular – Pressurised Water | \$20.1 Million | 2.5 | 10 | 10% | 2% | 20% | 1.2 | - | 70 | 60 Years |
| Generation IV Nuclear Reactor Technologies | | | | | | | | | | |
| Molten Salt Reactor | \$10.6 Million | 2.3 | 10 | 12% | - | - | - | - | 0 | 12 Years |
| Sodium Fast Reactor | \$6.6 Million | 4.5 | 50 | 8% | 18% | 30% | - | - | 5,001 | 60 Years |
| Lead Fast Reactor | \$20.3 Million | 3.0 | 50 | - | 12% | - | - | - | 300 | 60 Years |
| Gas Fast Reactor | - | 3.5 | 40 | 20% | - | - | - | - | 0 | 60 Years |
| High Temperature Gas Reactor | \$10.3 Million | 8.5 | 24 | - | - | 25% | - | - | 296 | 60 Years |
| Supercritical Water Reactor | \$5.8 Million | - | - | - | - | - | - | - | 0 | 60 Years |

- Nuclear technology has long-served as a key baseload generator in the US, Europe and Asia
- Countries with the most nuclear capacity as a percentage of total include the US, France, China, Japan, and Russia
- The most recent nuclear plants to come online have done so in March 2025 in India, and in December 2024, in France
- Key issues with the technology in the past has included cost overruns, minimum sizing, flexibility, leaks and waste disposal
- A new generation of technology is promising to address these concerns, the question is, will they be competitive?

Source: Energeia Research

Cost Competitiveness

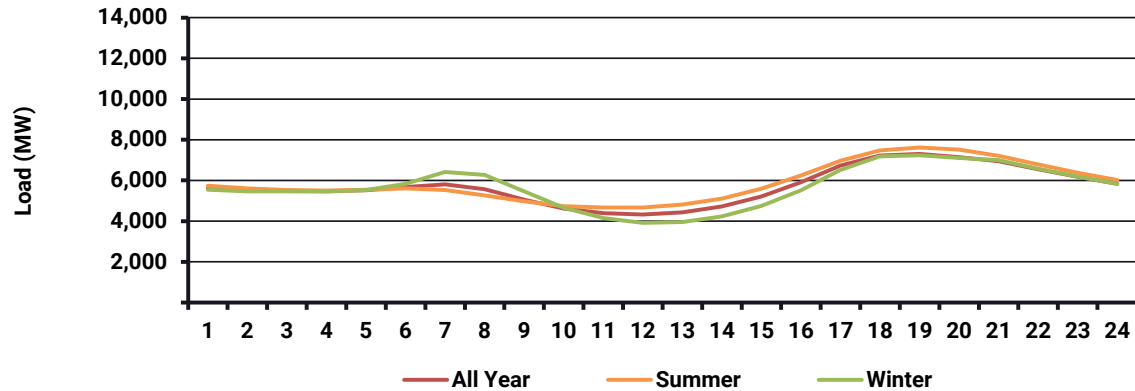
Queensland Case Study

Data Centre Case Study



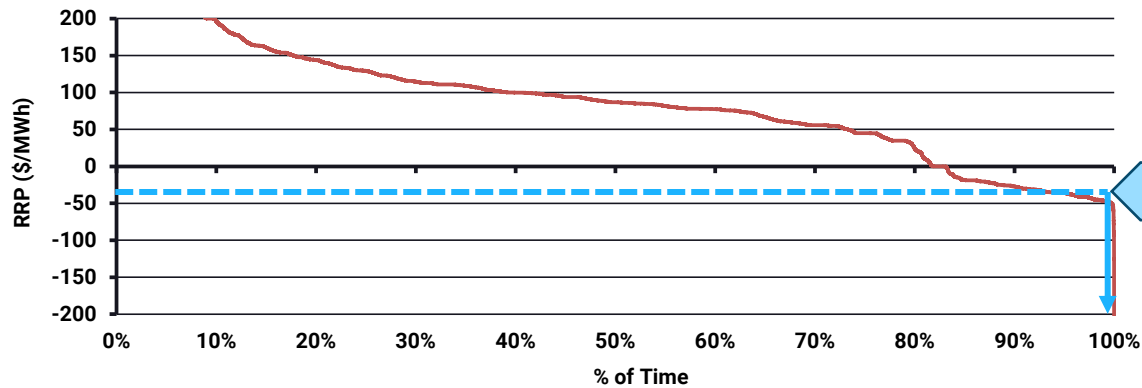
Bulk System Load and Price Duration in QLD in FY25

QLD Average All, Summer and Winter Days (FY25)



Source: AEMO ISP (2024)

QLD Price Duration Curve (FY25)

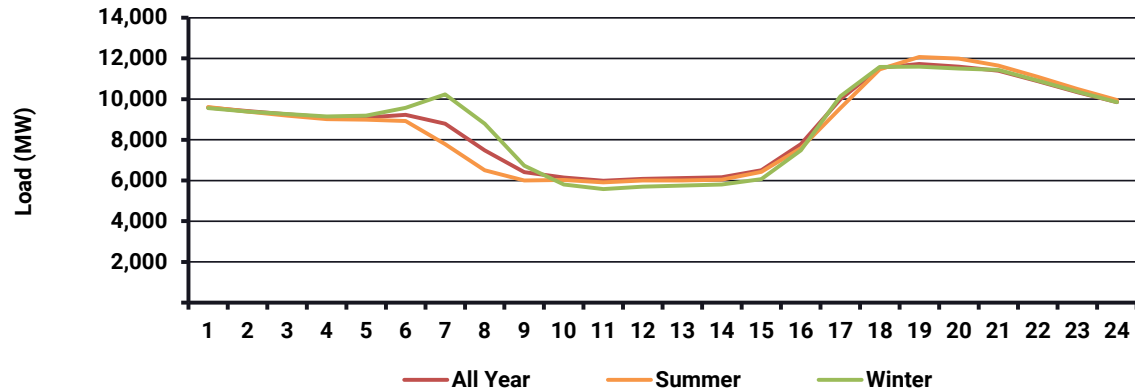


Source: AEMO (FY25)

- Energeia has analysed the Queensland (QLD) electricity energy market for insight into potential strengths and weaknesses of nuclear technology
- We found that at current prices in FY25, a baseload operating nuclear plant would expect to receive \$109/MWh on average, assuming ~100% dispatch, including negative prices
- This is much lower than the best CSIRO pricing of \$141/MWh
- The plant could avoid negative prices, but that would incur additional restart costs, and increase the investment and fixed O&M costs per MWh delivered

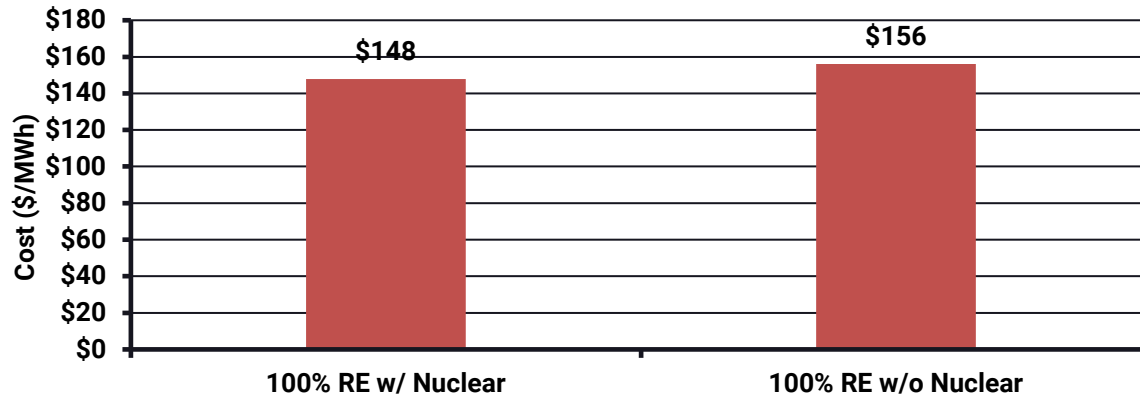
Bulk System Load in QLD in FY45

QLD Average All, Summer and Winter Days (FY45)



Source: AEMO ISP (2024)

QLD Cost in 2045 - With and Without Nuclear

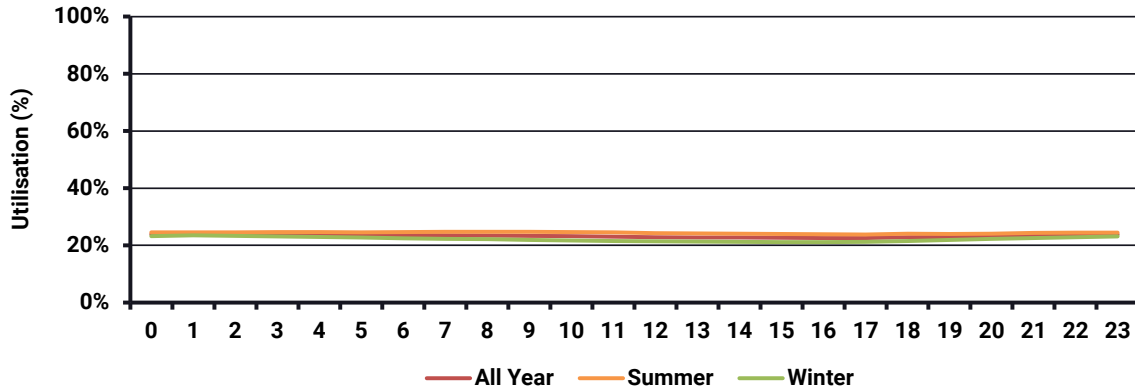


Source: Energeia Analysis

- In FY45, load is expected to evolve due to electrification and behind the meter resources
- Our indicative analysis of the cost to serve these load is reported below left
- Analysis assumed a 30 MW SMR for the nuclear scenario

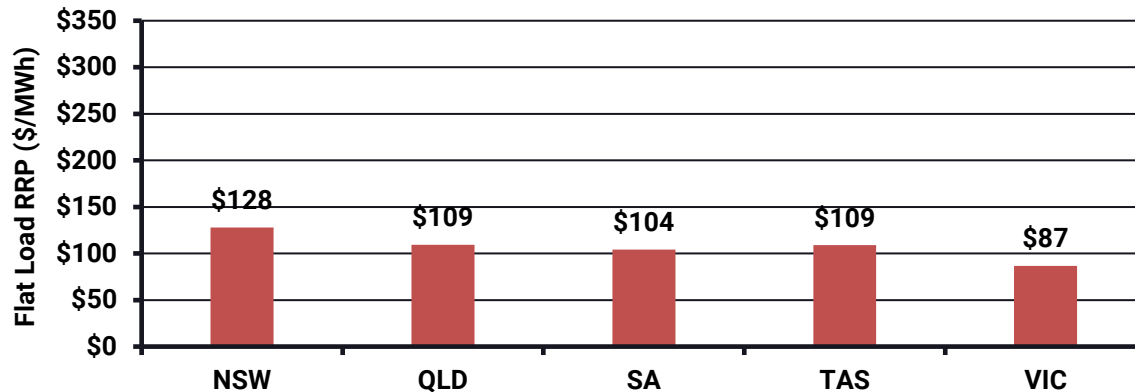
Data Centre Load and Price to Beat (\$/MWh)

Estimated Data Centre Load (FY25 UK Data Centre Example)



Source: UK Power Networks Data Centre Demand Profile (FY25)

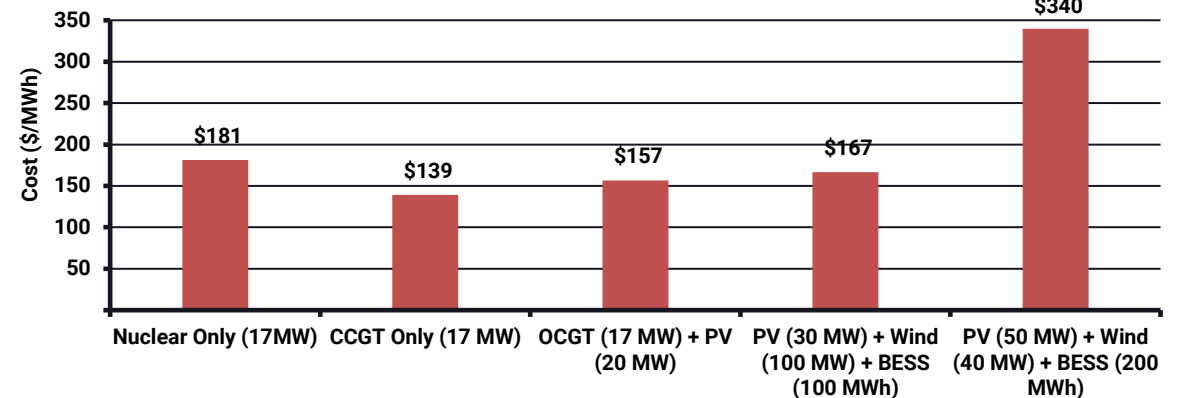
Data Centre (\$/MWh) by NEM State in FY25



Source: AEMO (FY25), Note: NEM – National Electricity Market

- Data centres typically run a flat load because the majority of their power consumption comes from non-time dependent processing, which are overlay on synchronous business use
- Most states see an average wholesale Regional Reference Price (RRP) of ~\$107/MWh
- The analysis shows that a data centre would pay less than the best priced nuclear station in FY25
- A key consideration, however, is which stand alone electricity solution delivers the lowest cost, as a connection workaround

Data Centre Cost of Service by Solution (FY25, \$/MWh)



Source: Energeia Analysis

Takeaways and Recommendations



Takeaways and Recommendations

- **Takeaways**

- Australian law prohibits nuclear installations for power generation
- There is a great deal of nuclear capacity around the world, which will need to be replaced at some point
- Most countries with nuclear capabilities are aiming to invest in next generation technology, or at least keep their options open
- Small modular reactors promise smaller form factors, faster construction times, without too much of a cost impact from the smaller scale
- There are very few small modular reactor designs in the world that have been certified
- Key limitations of the technology still include nuclear waste management, water consumption, ramping rates, and restart costs
- A surprising number of pilot projects are currently underway, with significant results expected in the next 3 years or so
- The high utilisation / baseload nature of the technology may find it hard to integrate into a high renewables system
- Data centres, with their flat loads, could be a key future customer, especially where there are connection limitations, but access to water will be key
- Our analysis shows that the flat load profile makes a modular reactor competitive with a solar + wind + BESS solution, economically speaking

- **Recommendations**

- Monitor the outcomes of small modular reactor pilots around the world to see if they deliver on timelines and cost targets
- For data centres, and other major industrial loads, consider the value of flexibility to maximise grid connection capacity and minimise stand alone costs
- It will also be important to monitor the cost of alternative technologies, esp. long-duration storage

Power Session

Q & A

Next Power Session Topic



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Thank You!

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