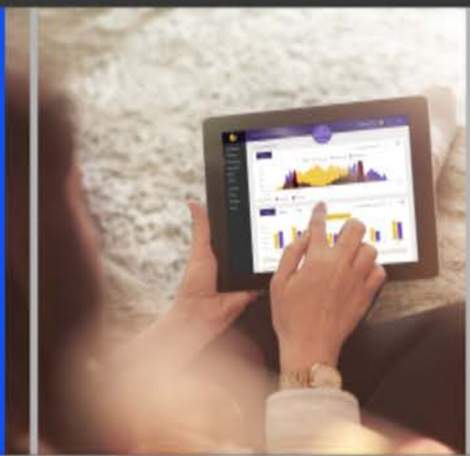
Institute for
Sustainable Futures

Beyond Coal:
Alternatives to Extending the Life of Liddell Power Station


Beyond Coal: Alternatives to Extending the Life of Liddell Power Station

Prepared for:

AUSTRALIAN CONSERVATION FOUNDATION

AUSTRALIAN CONSERVATION FOUNDATION INCORPORATED

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Responsibility for the report resides with ISF.

Liddell Cover Photo Credit: Zephyr L'Green.

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About ISF

The Institute for Sustainable Futures (ISF) was established by the University of Technology Sydney in 1996 to work with industry, government and the community to develop sustainable futures through research and consultancy. Our mission is to create change toward sustainable futures that protect and enhance the environment, human wellbeing and social equity. We seek to adopt an inter-disciplinary approach to our work and engage our partner organisations in a collaborative process that emphasises strategic decision-making.

For further information visit: www.isf.uts.edu.au

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List of abbreviations

ACEEE	American Council for an Energy-Efficient Economy
AEMO	Australian Energy Market Operator
AER	Australian Energy Regulator
EAAP	Energy Adequacy Assessment Projection (published by AEMO)
ESOO	Electricity Statement of Opportunities (published by AEMO)
kW/ kWh	kilowatt/ kilowatt hours
MW/ MWh	megawatt/ megawatt hours
NEG	National Energy Guarantee
NEM	National Electricity Market
NSW	New South Wales
OFGEM	Office of Gas and Electricity Markets (Great Britain)
RET	Renewable Energy Target
SA	South Australia
Vic	Victoria

List of key terms

Capacity factor	The output of generating units or systems, averaged over time, expressed as a percentage of rated or maximum output.
Demand Response	Demand Response is customer load that can be voluntarily reduced in response to incentives at critical times, such as at times of peak demand, high pool prices or low reserve conditions on the power system.
Dispatchable generation	Dispatchable generation refers to generators that can be scheduled to run and increase or decrease their output to meet changing demand or the changing needs of the power system. Some dispatchable sources can do this quickly and effectively, such as hydro-electricity, gas power plants and battery storage. Other dispatchable sources, such as coal-fired generators, can be scheduled to run, but cannot change output as quickly or flexibly.
Flexible demand	Flexible demand refers to customers' loads that can be relatively easily reduced or shifted in response to variable prices or other incentives. It can include loads such as pumping, water heating, crushing and grinding, aluminium smelting, battery and electric vehicle charging, some refrigeration, etc.
Firm capacity	Firm capacity is the amount of energy available for production or transmission which can be relied upon to be available at any given time, for example during peak demand periods.
Low Reserve Condition (LRC) notice	A Low Reserve Condition (LRC) notice is issued when, for the nominated period, AEMO considers there are insufficient short-term capacity reserves available. This capacity must be sufficient to provide complete replacement of the contingency capacity reserve when a critical single credible contingency event occurs in the nominated period.
Load shedding	Involuntary disconnection of customers or their load from the power system ("blackouts").
Medium Term Projected Assessment of System Adequacy (MTPASA)	Medium Term Projected Assessment of System Adequacy is the primary tool used to assess the expected supply and demand of electricity for a period of 24 months from the coming Sunday.
Peak demand	Peak demand describes the period of highest customer requirement for electrical power. Major spikes in demand occur during heat waves and cold winter days when we turn on appliances to cool or warm our homes, workplaces and other spaces.
Peaking generator ("peaker")	A generating system that typically runs only when demand (and spot market price) is high. These systems usually have relatively lower capital costs, but usually higher operating costs, and very fast start up and shutdown times compared with base load and intermediate systems.
Power system security	The safe scheduling, operation, and control of the power system on a continuous basis in accordance with the principles set out in clause 4.2.6 (of the National Energy Regulator).

Reliability	The probability that plant, equipment, a system, or a device, will perform adequately for the period of time intended, under the operating conditions encountered. Also, the expression of a recognised degree of confidence that an event or action will occur when expected.
Reliability Standard	The power system reliability benchmark set by the Reliability Panel. The maximum permissible unserved energy (USE), or the maximum allowable level of electricity at risk of not being supplied to consumers, due to insufficient generation, bulk transmission or flexible demand, is 0.002% of the annual energy consumption for the associated region, or regions, per financial year.
Reliability and Emergency Reserve Trader (RERT)	The actions taken by AEMO in accordance with clause 3.20 (of the NER) to ensure reliability of supply by negotiating and entering into contracts to secure the availability of reserves under reserve contracts. These actions may be taken when: • reserve margins are forecast to fall below minimum reserve levels (MRLs), • a market response appears unlikely.
Unserved energy (USE)	The amount of energy required by customers that cannot be supplied because demand exceeds supply. Under the provisions of the Reliability Standard, each region's annual USE can be no more than 0.002% of its annual energy consumption. Compliance is assessed by comparing the 10-year moving average annual USE for each region with the Reliability Standard.

Executive summary

The electricity sector in transition

The electricity sector, in Australia and around the world, is experiencing its most fundamental transition since the mass provision of electricity more than half a century ago. This transition involves the rise of renewable energy and in particular, variable output solar and wind power, a shift from centralised to decentralised supply of electricity and a much greater role for smarter, more controllable and more efficient consumption. A key driver of this transition is the need to reduce the sector's greenhouse gas emissions in order to reduce the risks of climate change.

Two critical questions in this transition are:

- How do we best manage the retirement of existing coal-fired power stations as they reach the ends of their economic lives?
- What are the best options to replace the *capacity* that coal-fired power stations provide at times of peak demand, and to replace the *energy* that they provide throughout the year?

Wind and solar power have very low operating costs and this tends to depress wholesale electricity prices. While such downward pressure is generally welcome, it makes it harder for older, less efficient and more costly coal-fired power stations to compete. This has contributed to the closure of ten power stations with about 5,000 MW of generating capacity, between 2012 and 2017. This retirement of capacity has disrupted the electricity market, increased electricity prices and raised questions about the reliability of supply. Furthermore, these retirements have largely occurred with short notice, in the absence of a coordinated plan or related policy. In this context, Australian Energy Market Operator (AEMO) has raised the prospect of a shortfall in supply in the summer of 2017/18, following the closure of Hazelwood power station in Victoria earlier this year, and also in 2023/24 following the scheduled closure of the Liddell Power Station in NSW in 2022.

The lessons of recent experience and the long advance notice period mean that the forthcoming closure of Liddell Power Station creates an unprecedented opportunity to effect a smoother transition, while minimising adverse impacts on electricity consumers, the environment and the local community.

The Commonwealth Government has suggested that the preferred way to minimise the impact of the scheduled closure of Liddell is to defer the closure for at least five years. On the other hand, AGL, the owner of Liddell Power Station, has flagged a potential alternative strategy to manage the transition through a mix of new generation, batteries and demand response. AGL requested that the Government allow their board 90 days to consider the options of keeping Liddell open for five years, selling the station, or maintaining AGL's current strategy of scheduled closure of Liddell in 2022.

The Australian Conservation Foundation commissioned the Institute for Sustainable Futures (ISF) at UTS to undertake this study ***Beyond Coal: Alternatives to Extending the Life of Liddell Power Station*** in order to inform this debate by investigating alternatives to the Commonwealth Government and AGL proposals. To this end, the study illustrates and compares three different primary scenarios: the extension of Liddell's operations; AGL's proposal and a "clean energy package" including renewable energy, energy efficiency, energy storage, demand response and flexible pricing. These choices are not only relevant for the case of Liddell, but also as an important precedent for the expected closure of the majority of Australia's existing coal-fired power stations within the next two decades.

Understanding the problem

The first step in developing viable solutions is to describe the problem clearly. There are a number of elements to the challenge associated with the scheduled closure of Liddell, as summarised below:

1. Reliability: We need sufficient electricity supply capacity to meet expected demand. AEMO has identified that there could be shortfalls in electricity supply in the order of 1000 MW by the summer of 2022/23 when Liddell closes. AEMO indicates that there could be one or more such shortfalls lasting up to six hours at a time. (Note however that AEMO does not forecast a breach of the Reliability Standard.)
2. Prices and bills: In the wake of the closure of Hazelwood and nine other power stations since 2012 and the lack of planning to ensure appropriate replacements, the gap between demand and supply has tightened, contributing to, amongst other things, a rise in electricity prices. Simply providing additional capacity for a few hours of peak demand per year is unlikely to reduce electricity prices significantly. For this reason, it is critical that any strategy to replace Liddell provides equivalent peak capacity (about 1,000 MW) and energy output (about 8,000 GWh per year).
3. Longer term transition: Ten coal power stations have closed in the past five years. Liddell is the first of a further nine large power stations, representing as much as 60 per cent of Australia's coal generating capacity, that are expected to reach the end of their economic lives within 15 years. Therefore, in responding to the impending closure of Liddell, it is crucial that we consider solutions that could provide a useful precedent for the much bigger transition that is soon to come.
4. Climate action: Australia is a signatory to the Paris Agreement and has committed to take action on climate change to support global efforts to limit global warming to well below 2 degrees, aiming for 1.5 degrees. The electricity sector is responsible for about 33 per cent of our emissions, while Australia produces more greenhouse gas emissions per unit of electricity than almost any other developed country. Cutting emissions from coal-fired power stations is crucial to achieving deep cuts in carbon emissions.

A range of solutions

There are many potential options to provide additional electricity capacity and energy in 2023. For simplicity, we have focussed on ten technology options, including extending the life of Liddell Power Station and a range of generation (supply side) and energy management (demand-side) options. These options include a range of the most prominent and practical options.

These options were then aggregated into the following three primary scenarios:

- **Extend Liddell** (refurbishing Liddell Power station to provide 1,000 MW of coal-fired electricity)
- **AGL Proposal**, as outlined by AGL at their 2017 Annual General Meeting (comprising a 100 MW of capacity upgrade at the Bayswater coal power station, 750 MW of gas power, 50 MW of wind, 100 MW of demand response and 50 MW of batteries)
- **Clean Energy package** (comprising a mix of 1000 MW of energy efficiency, 600 MW of new wind energy generation, 250 MW of demand response and 200 MW of flexible pricing).

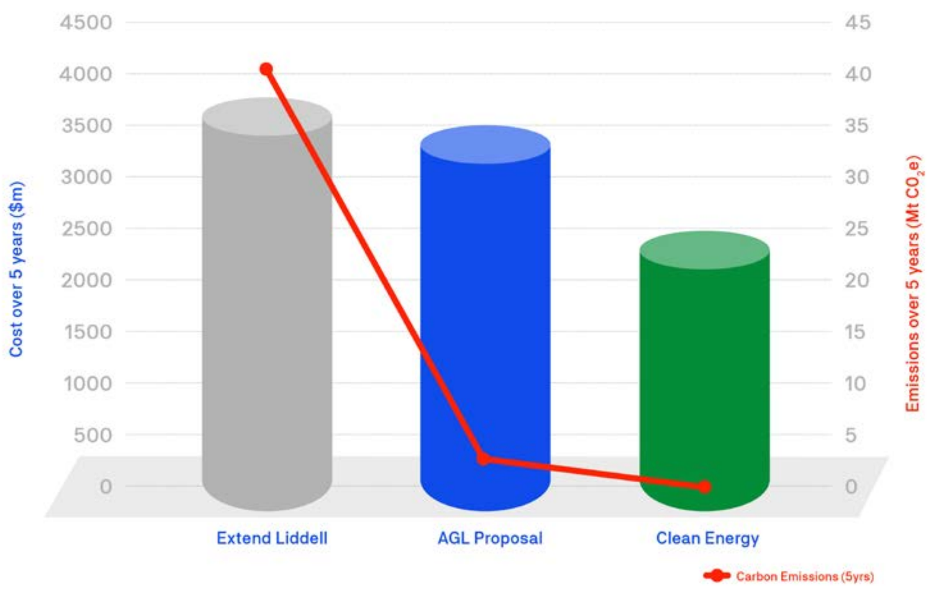
The modelling considered the cost and carbon emissions over five years (2022-2027), in two cases:

- a ***capacity-only*** case, which only sought to replace 1,000 MW of firm capacity of Liddell for six-hour peak demand events, up to four times per year
- a ***capacity and energy*** case, which sought to replace both Liddell's 1,000 MW of firm peak capacity, and its 8,000 GWh per annum of energy output.

The capacity-only case addresses only the reliability challenge, while the capacity and energy case addresses all four challenges: reliability, prices and bills, longer-term transition and climate action. The capacity and energy case is therefore the more relevant case.

The results of the capacity and energy case are summarised in Figure1.

Figure 1: Cost and carbon emissions comparisons across scenarios



Source: ISF Modelling

As illustrated in Figure 1, our modelling found that the Clean Energy Package would save more than $1.3 billion compared to the Extend Liddell scenario and more than $1 billion compared to the AGL Proposal. The total cost (including capital and operating costs) for five years is estimated at $2.2 billion for the Clean Energy Package, compared to $3.6 billion for the Extend Liddell proposal and $3.3 billion for the AGL Proposal. Furthermore, the Clean Energy package would have zero carbon emissions compared to 40 million tonnes of carbon dioxide over five years in the case of the Extend Liddell proposal and 2.5 million tonnes of carbon dioxide for the AGL scenario. The above costs do not include any value for carbon pollution. Including the cost of carbon emissions would further add to the cost of the Extend Liddell and the AGL Proposal scenarios, as shown in Figure 2.

The above three primary scenarios were complemented by two additional scenarios:

- **Expanded Clean Energy package** (This includes all of the Clean Energy Package plus an additional 100 MW of solar thermal, 100 MW of batteries and 50 MW of bioenergy)
- **Energy Efficiency Only** (This comprises 1,200 MW of end use energy efficiency improvement only.)

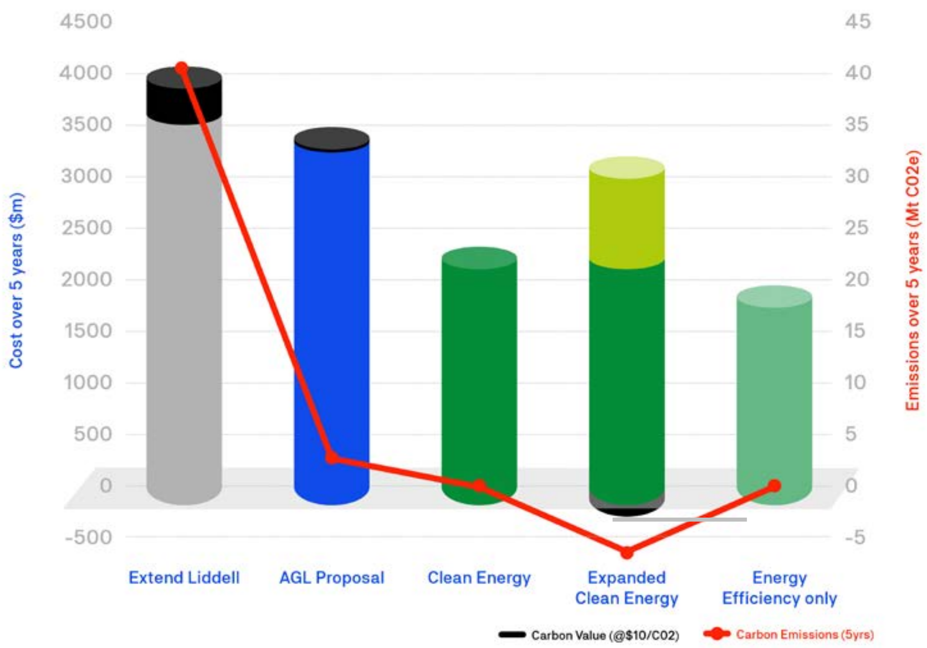
In the Expanded Clean Energy package, some of the cost savings from the primary Clean Energy Package (relative to the Extend Liddell scenario) are redirected to support local and regional economic transition and renewal in the form of employment and investment support. In addition to the Clean Energy technology options, this scenario includes providing 100 MW of batteries to customers in the Hunter region, 50 MW of bioenergy generation based at the Liddell site and 100 MW solar thermal with storage (although this last option is unlikely to be located at the Liddell site). Even with this substantial additional cost over five years of about $880 million, this Expanded Clean Energy package is estimated to be about $400 million less expensive than the Liddell Extension scenario.

The Energy Efficiency Only scenario replaces the wind energy, demand response and time varying pricing of the Clean Energy scenario with a further 300 MW firm capacity of energy efficiency improvement. This scenario is about $347 million or 15% cheaper than the primary Clean Energy scenario.

These two additional scenarios for the capacity and energy case are shown in Figure 2, alongside the primary scenarios. Figure 2 also illustrates the cost impact of associated carbon emissions, based on a modest carbon price of $10/tonne of carbon dioxide equivalent. Note that the carbon value does not impact on the cost of the clean energy or energy efficiency scenarios as they have zero emission. This carbon value is a “carbon price” applied to reflect the environmental cost of carbon dioxide and other greenhouse gases emitted into the atmosphere.

However, the Expanded Clean Energy scenario also contributes by offsetting an extra 6.2 million tonnes of carbon dioxide over five years due to an *additional* 1,200 GWh per annum of energy generation over and above the 8,000 GWh per annum required to replace the output of Liddell Power Station.

Figure 2: Cost and emissions comparisons – primary and additional scenarios



Source: ISF Modelling

Conclusions

There are a number of key implications that can be drawn from this study.

1. Liddell Power Station was commissioned in the early 1970s and is nearing its end of design life. Despite significant maintenance and refurbishment, the reliability of the plant has significantly reduced over recent years with major unplanned outages during the February 2017 peak.
2. In the context of other recent coal power station closures and future expected closures, there are legitimate concerns about the closure of Liddell Power Station, particularly relating to maintaining overall supply-demand balance and system security. These concerns demand a considered strategic response, as the proportion of coal-fired generation declines and the proportion of variable output renewable energy rises.
3. The response to the proposed closure of Liddell Power Station should be linked to clear policy objectives around reliability, affordability, sustainability and minimising economic shocks for the local community and the nation.
4. Based on these policy objectives, extending the life of Liddell Power Station would represent a poor outcome for energy consumers and the community. Choosing this option would be relatively expensive, potentially risky and much more polluting and it would do little to smooth the economic transition.
5. As Liddell Power Station and its owner, AGL, are operating in a competitive electricity market, the Commonwealth government should adopt competitively neutral policies that

treat all market participants fairly. Singling out one company to respond would not provide an effective government policy and framework to transition the whole electricity sector.

6. The existing AGL Proposal is likely to provide a lower cost, cleaner and more reliable outcome that extending the life of Liddell.
7. The Clean Energy Package is likely to be much cheaper and cleaner and no less reliable than either the Extend Liddell or AGL Proposal.
8. Some of the lowest cost options for replacing the capacity and energy of Liddell Power Station are beyond the control of AGL and require government policy setting. For example, energy efficiency, demand response and time varying pricing all require effective government policy to ensure they have a fair opportunity to compete, and provide least-cost outcomes.
9. There are viable technologies and policies available to facilitate a smooth, low cost and reliable transition that supports the local economy and community and helps to reduce carbon emissions. If such technologies and policies are adopted in the case of the Liddell Power Station closure, this would provide an invaluable precedent for successfully managing the longer-term energy transition.
10. Drawing on this study, further detailed analysis and consultation is urgently required to develop practical clean energy alternatives to extending the life of Liddell Power Station. This analysis and consultation should include:
    - Thorough and balanced assessment of the potential and cost of all available options to provide both peak capacity and energy. This should include all relevant supply-side and demand-side options.
    - Developing detailed policies and programs to drive energy efficiency and time varying pricing in the context of the future energy market. (These options were largely neglected in the recent Finkel Review.)
    - Developing detailed policies and programs to support local economic transition for communities around those coal-fired power stations that are expected to close over the next 15 years.

1 Introduction

In order to contribute to the national debate on energy security, affordability and the need for emission reduction, the Australian Conservation Foundation asked the Institute for Sustainable Futures to examine alternatives to extending the life of a 'to-be-closed' coal-fired power station. The aim of this study is to investigate the costs and availability of clean energy options that could substitute the capacity and output of Liddell Power Station after 2022. To this purpose, the study illustrates and compares different scenarios: the five-year extension of Liddell Power Station, AGL's proposal, and a clean energy package including renewables, energy efficiency, demand response and flexible pricing. The modelling covers the cost and carbon emissions over a five-year period in two scenarios: a capacity-only scenario and a capacity and energy scenario. The key consideration in the capacity-only case is reliability of the system for meeting peak demand, as this capacity could be constrained after the closure of Liddell Power Station. Hence, this scenario addresses a potential shortfall of about 1,000 MW capacity and offers a comparison of costs and emissions for three alternative scenarios.

The focus of the capacity and energy case is, in addition to the above, the affordability of the transition in the medium to longer term. The recent closure of Hazelwood, Northern and other coal-fired power stations has led to a "tightening" between overall supply capacity and demand in the national electricity market. This has in turn led to significant recent rises in electricity prices. Simply providing short-term capacity would do little to relieve these price pressures. Moreover, if the output of more coal-fired power stations is removed over the next decade or two and not replaced, then electricity shortfalls will occur not just during peak periods, but throughout the year. Therefore, to address both the reliability challenge and affordability challenge, we took into account replacing both Liddell's 1000 MW of capacity and its 8,000 GWh per annum of energy output.

This report starts with an outline of the challenge described by the Australian Energy Market Operator (AEMO) in their Electricity Statement of Opportunities in September 2017, which includes the general profile of, and background to, the closure of Liddell Power Station. It then discusses possible scenarios, firstly by presenting an overview of ten technology options, secondly by introducing the three scenarios, and thirdly by comparing the different options. The last chapter provides insights into implications and opportunities for workers and the local community in the Hunter region. It also reflects on the future development of electricity prices in the light of the three scenarios and offers broad policy recommendations. The report concludes with recommendations for further research.

2 What is the problem?

Liddell Power Station is located in the Hunter region, a hub of various industries, including black coal mining, electricity generation, manufacturing, agriculture and viticulture. In April 2015, AGL announced that the power plant would be closed in 2022 and tabled a proposal to replace Liddell's capacity with a combination of gas, wind and solar power. In the context of AEMO's recent 10-year forecast on the electricity supply in NSW, this announcement has been called into question by the Prime Minister Malcolm Turnbull and Minister for the Environment and Energy Josh Frydenberg (MacDonald-Smith and Potter, 2017). The Prime Minister announced that the Commonwealth Government is trying to delay the closure of Liddell for at least five years (Yaxley and Lowery, 2017) .

Figure 3: The Hunter Region in context of the state of New South Wales

Source: State Records, NSW Government.

Yet, simply extending the life of Liddell Power Station will not solve the problem. In fact, there are four dimensions associated with scheduled closure of Liddell that need to be addressed:

1. Reliability: We need sufficient electricity supply capacity to meet expected demand. AEMO has identified that there could be shortfalls in electricity supply of the order of 1000 MW by the summer of 2022/23 when Liddell closes. AEMO indicates that there could be one or more of these shortfalls lasting up to six hours at a time.
2. Prices and bills – affordability: In the wake of the closure of Hazelwood and nine other power plants since 2012, coupled with the lack of appropriate planning, the gap between demand and supply has tightened and it this has been a contributing factor to electricity prices rises (ACCC, 2017). Simply providing additional capacity for a few hours of peak demand per year is unlikely to significantly reduce electricity prices. For this reason, it is critical that any strategy to replace Liddell provides equivalent peak capacity (about 1,000 MW) and energy output (about 8,000 GWh per year).
3. The longer-term transition for replacing aging coal power stations: Ten coal power stations have closed in the past five years. Liddell is the first of a further nine large power stations, representing as much as 60 per cent of Australia's coal generating capacity, that are expected to reach the end of their economic lives within 15 years. Therefore, in developing solutions to address Liddell, it is crucial that we consider solutions that could provide a useful precedent for the much bigger transition that is soon to come.
4. Climate action: Australia is a signatory to the Paris Agreement and has committed to take action on climate change to support global efforts to limit global warming to well

below 2 degrees, aiming for 1.5 degrees. The electricity sector is responsible for about 33 per cent of our emissions, while Australia produces more greenhouse gas emissions per unit of electricity than almost any other developed country. Cutting emissions from coal-fired power stations is crucial to achieving deep cuts in carbon emissions. Further, the Paris Agreement requires that emission reduction commitments to be reviewed every five years with the expectation that they will be increased.

2.1 AEMO's reliability challenge

On 5 September 2017, AEMO published the Electricity Statement of Opportunities (ESOO) which provides a 10-year outlook for the supply-demand balance of the NEM. Their analysis indicates that the potential for unserved energy (USE) in NSW and Victoria remains within the current Australian Reliability Standard until 2027.[1] This means, that their modelling confirms adequate supply in both states even after Liddell Power Station closes (AEMO, 2017a).

However, AEMO identifies two big threats. Firstly, there is a medium- to longer-term risk associated with the retirement of the coal-fired power station in NSW. The likelihood of any unserved energy in 2024/25 ranges between 29 per cent and 46 per cent in NSW, and such an event could last from two to six hours. Since demand is expected to increase in 2024 as the net effect of solar PV plateaus[2], AEMO indicates that 1,010MW of additional dispatchable resources would be required in 2024-25 in NSW and Victoria to reduce the risk of any unserved energy to a one in 10-year probability after the closure of Liddell. Secondly, their modelling indicates that in the event of another large coal-fired power station[3] retiring in 2022-23 '*there is a significant risk of a low reserve condition (LRC)*' (AEMO, 2017e). Hence, the likelihood of a need for load shedding across the state could increase if no additional firm capacity or demand response measures are established. AEMO emphasises that the likelihood of additional thermal capacity exiting the market earlier becomes more likely will increase due to an increase in competition, which could reduce generator profitability. These competitive influences come from declining demand due to an increase in the use of rooftop solar PV and energy efficiency with more low cost renewables, and will be compounded by the aging generation fleet, higher temperatures and complex challenges faced by generators in managing their fuel supplies due to tighter gas markets, coal quality issues and water management strategies. In addition, there is a risk associated with the unavailability of large thermal units during the hot summer months, as was experienced in February 2017. A number of factors, including the tripping of Liddell and Vales Point in NSW, made load shedding of the Tomago smelter necessary to maintain overall supply-demand balance and system security (Australian Energy Regulator, 2017) .

In AEMO's ESOO modelling, the projected unserved energy would exceed the reliability standard in South Australia (SA) and Victoria under a high demand scenario for summer 2017/18 (see Figure 4). This is backed up by the mid-term projected assessment of system adequacy (MTPASA)[4] which indicated there was a risk of low reserve conditions. AEMO and the SA government have taken action to secure a reserve via the Reliability and Emergency

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[1] According to AEMO, unserved energy is the amount of energy that cannot be supplied to consumers, resulting in involuntary load shedding (loss of customer supply), because there is insufficient generation capacity, demand site participation, or network capability, to meet demand. The NEM Reliability Standard requires that projected unserved energy should not exceed 0.002**%** in any region.

[2] AEMO predicts operational demand will remain flat until 2023/24 as rooftop PV offsets projected increases in appliances, cooling and population growth. AEMO predicts demand will then increase, with the time of maximum demand delayed until after sunset. NSW is expected to shift from a summer to a winter peak around 2026/27 as rooftop PV has a bigger offset during summer.

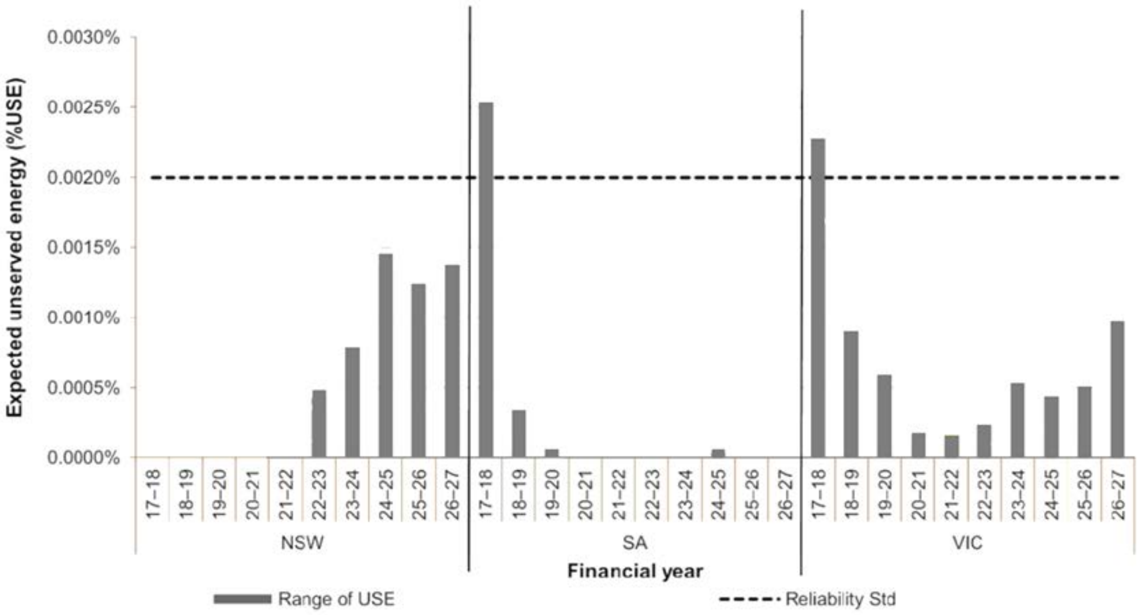
[3] Another candidate for closure is Vales Point Power Station (1,320 MW), which was built in 1978 and will be 44 years old in 2022.

[4] AEMO uses the MTPASA as a deterministic model to identify potential low reserve conditions (LRC) for each region in the National Electricity Market.

Reserve Trader (RERT),[5] a demand response program and the SA Energy Plan (AEMO, 2017b).

The range of USE outcomes over the period is linked to supply and demand and is summarised in Figure 4:

Figure 4: Range of unserved energy outcomes



Source: AEMO ESOO 2017, page 2.

Consequently, AEMO warns that '*we face an increasing and unacceptable risk that there will be insufficient capability in the system to meet NEM reliability standards*'. They conclude that, with the increase in variable renewable resources, the current market design does not provide adequate and sustained signals to the market to incentivise the development of new flexible dispatchable resources at the level required to maintain system reliability over the medium to long term (AEMO, 2017b). In fact, AEMO highlights the opportunities of dispatchable resources to provide reliable supply which can include generation on the grid, storage, demand resources behind the meter, flexible demand, or flexible network capability(AEMO, 2017e).

2.2 The Energy trilemma: reliability, affordability & sustainability

In reference to AEMO's Electricity Statement of Opportunities in September 2017, the prime minister raised his concerns about security and affordability of supply in the summer of 2017/18 and the subsequent challenges in 2022. He stated to that: "The report also warns that, on top of the immediate risk, there will be more pressure in 2022, when the Liddell Power Station is due to close. The energy minister and I are already in discussions with the owner of Liddell, AGL, about how we can ensure that that power station stays in operation for at least another five years after 2022." (House of Representatives, 2017)

[5] The Reliability and Emergency Reserve Trader (RERT) is a function conferred on AEMO to maintain power system reliability and system security using reserve contract. AEMO is seeking offers of additional reserves for summer 2017–18 through the RERT provisions. The RERT allows AEMO to procure additional generation or DSP capacity not normally available to the market, to maintain the reliability or security of the power system.

However, AEMO does **not** indicate that there is a specific need to extend the life of existing coal-fired power stations, or to build new ones beyond 2022. Indeed, AEMO state that the biggest risk for USE is projected for this summer of 2017/18.

Despite an expectation that the reliability standard will be met in the NEM over the forecast period, risk assessments demonstrate the continued risk of supply shortfalls if generator availability is lower than expected, or if extreme summer conditions prevail in this period (up until 2027) (AEMO, 2017f). This expectation that the reliability standard will be met in the short term is also backed by declining future energy prices out to 2021 (see Figure 5). Reliability is still challenged during peak demand events, and the risk of unserved energy increases if wind and photovoltaic (PV) generation drops to low levels, other generation stops unexpectedly, or electricity flow between regions is constrained. Additionally, we still face a reliability challenge for capacity and energy in the long term if adequate measures are not taken in the next few years.

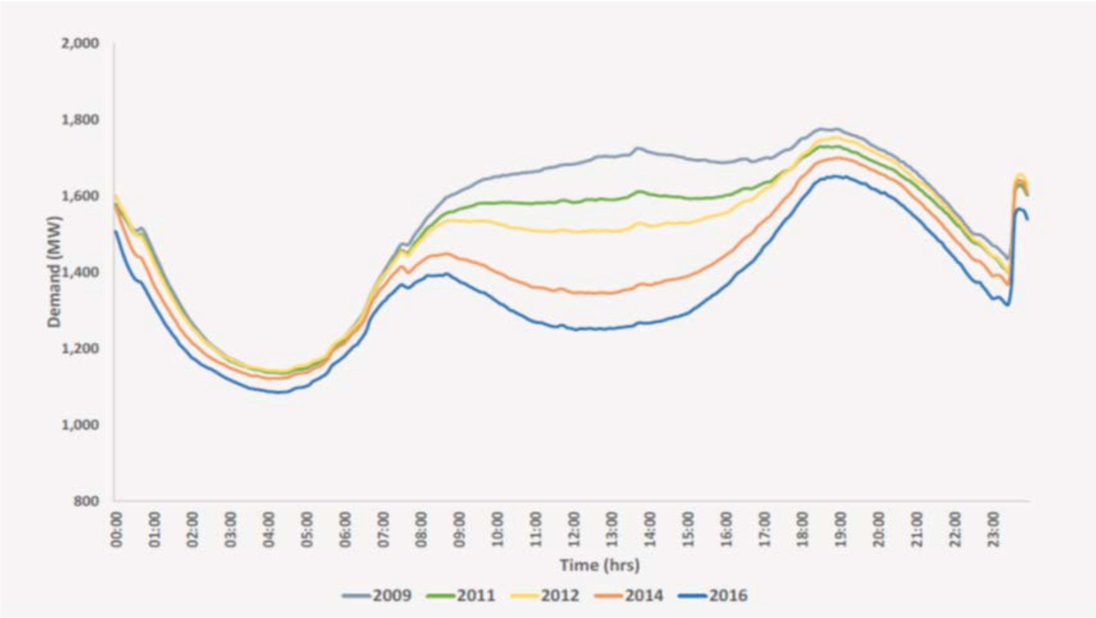
Figure 5: NEM quarterly base futures prices

Source: AER, 2017

Since wind and solar have very low operating costs, these technologies tend to depress wholesale electricity prices. This can make it harder for older, less efficient and more costly power stations to compete. Because solar has variable output, it gives rise to challenging "ramping" issues for conventional generation as illustrated in the now famous 'duck curve' (see Figure 6). Due to the strong growth in rooftop solar installations, AEMO expects that demand on the grid in the middle of the day will fall further, resulting in a rapid increase in demand in the lead-up to the evening peak as the sun sets (AEMO, 2017h). This highlights the need for substantial load shifting, demand response, energy storage and/or flexible generation to ramp up and down output in a short amount of time. As older coal fired power stations close, the gap between supply and demand tightens and wholesale prices rise.

Thus, the affordability challenge has both capacity and energy concerns in the short, medium and long term.

Figure 6: The "Duck Curve" in South Australia[6]



Source: AEMO. (2017). Visibility of Distributed Energy Resources. page 12.

The impacts been evident in the last five years when ten coal fired power stations closed in Australia (see Table 1). Hence, as coal fired power stations are pushed out of the market we need affordable alternatives that help to manage peak demand times during hot summer or cold winter months and to provide flexibility to complement variable output solar and wind power

Table 1: Australia's decommissioned coal-fired power stations

State	Power Station	Primary fuel type	Year of commission	Year of closure	Age	Capacity in MW	Notice period
NSW	Munmorah	Black coal	1969	2012	43	600	None
NSW	Redbank	Black coal	2001	2014	13	144	None
NSW	Wallerawang C	Black coal	1976-80	2014	38	1,000	4 months
VIC	Morwell	Black coal	1958-62	2014	52-56	189	n/a
VIC	Hazelwood	Brown coal	1964	2017	53	1,600	5 months
VIC	Anglesea	Black coal	1969	2015	46	160	3 ½ months
QLD	Collinsville	Black coal	1998	2012	14	180	6 months
QLD	Swanbank B	Black coal	1970-73	2012	42	500	n/a
SA	Northern	Brown coal	1985	2016	31	546	11 months
SA	Playford	Brown coal	1960	2016	56	240	4 months

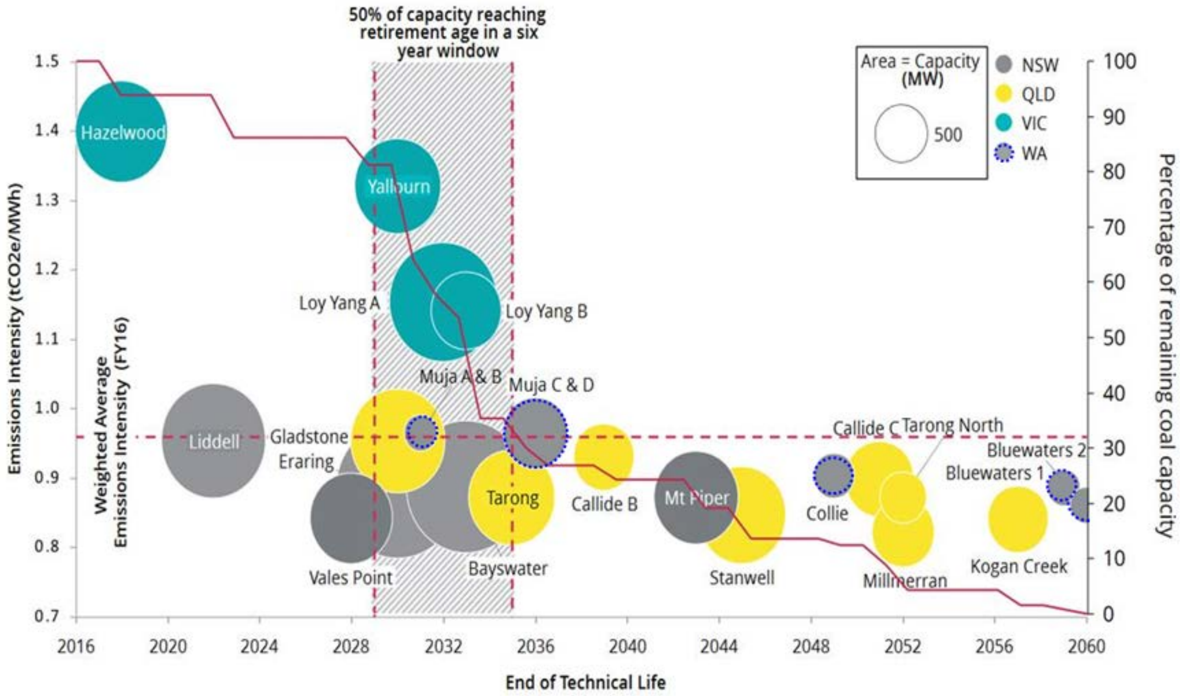
Source: Australian Energy Council 2017.

[6] Daily demand for grid electricity in South Australia.

Another factor that is widely regarded as contributing to the capacity problem was the investment uncertainty caused by the reviews of the RET which resulted in deferred investment in new renewable energy projects.

Furthermore, delaying Liddell's termination will compound the problem of other coal-fired power stations closures. This effect is illustrated in Figure 7, which highlights that suspending Liddell's termination would result in up to nine coal-fired power stations reaching retirement age in a seven-year window starting in 2028. It should be also noted that the closures are based on the economic and technical design life of the power plants. However, national climate change commitments could also impact the schedule for closing coal-fired power stations before 2030.

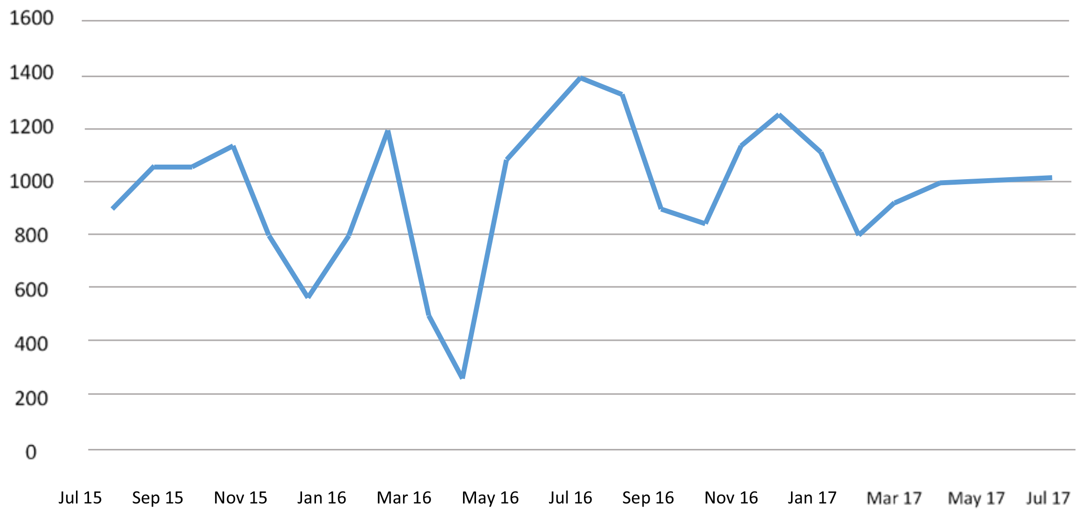
Figure 7: Potential future coal-fired capacity losses



Source: Investor Group on Climate Change, 2017, p. 9.

Another issue is the reliability of coal-fired power stations. AGL emphasises that Liddell's reliability has decreased over the last few years and Liddell is expected to experience more unanticipated outages as it approaches its end of life (AGL Energy Limited, 2017a). In fact, Parkinson (2017a) reported that Liddell's capacity factor was just 38.2 per cent in September 2017 while the plant operated at about 50 per cent through 2016/17 (see also Figure 8). While the age of the plant is a crucial factor for its reliability, it was found that heat waves can trigger outages of coal and gas-fired power plants. The events in February 2017 are evidence of this. At this time, NSW experienced forced outages of thermal generation of more than 1,000 MW capacity, including losses from Liddell and Vales Point Power Station (AEMO, 2017i).

Figure 8: Liddell median output July 2015 to July 2017



Source: NEM review 2017

Currently committed and proposed wind and solar projects are sufficient to replace the energy output of the coal power stations that are expected to close over the next decade (see Table 2). There is also potential for much more wind and solar energy to be developed over this period.

Table 2: Proposed renewable energy generation in the NEM

Status	NSW		NEM		
	Wind	Solar*	Wind	Solar*	Total
Existing (MW)	665	254	4,070	274	4,344
Committed (MW)	173	145	690	692	1,082
Proposed (MW)	4,466	837	11,938	6,975	19.995
Total (MW)	**5,303**	**1,236**	**16,698**	**7,941**	**24,682**
Potential output of proposed & committed (GWh/y)**	**13,408**	**1,377**	**36,505**	**10,746**	**47,251**

*Excluding Rooftop solar

** Calculated based on assumptions: 33% capacity factor for wind; 16% capacity factor for solar

Source: (AEMO, 2017d)

However, this energy output must be complemented with adequate firm peak capacity on the supply side and demand side in order to maintain reliability and affordability. By combining new renewable capacity with demand response, time varying prices, storage firming capacity and energy efficiency, Australia can have more than adequate energy resources to cope with the closure of multiple coal-fired power stations, while ensuring low cost, reliable, low carbon energy.

3 Technology options

This section describes the technology options that we have analysed, and outlines the assumptions that have been made in estimating their cost, and their contribution to firm capacity and energy supply. Section 4 then describes the scenarios, or packages of technology options, that have been developed to meet the specified needs for capacity and for capacity plus energy. Finally, the results of the analysis for the two outcomes (capacity, and capacity plus energy) for each of the scenarios are presented and compared.

A range of technology options, from 3.1 to 3.11 are described below, including the background, description and key assumptions for each one.

3.1 Extending Liddell (coal)

The Liddell Power Station is located in the upper Hunter Valley and was commissioned in 1972. After the closure of Hazelwood Power Station in March 2017, it became Australia's oldest operating large coal-fired power station. AGL acquired the assets of Liddell from the NSW Government in 2014, at an effective price of zero dollars (AGL Energy Limited, 2014).

As part of AGL's Greenhouse Gas Policy, the company announced at its Annual General Meeting in 2015 its intention to close Liddell Power Station at the end of its expected operating life in 2022 (AGL Energy Limited, 2017b). However, in September 2017 the Commonwealth Government announced that it had started to negotiate with AGL about extending the life of the power station in order to maintain what they believe is critical baseload power during the transition to a low carbon economy (AFR, 2017). Prime Minister Malcolm Turnbull and the Minister for the Environment and Energy Josh Frydenberg have expressed their desire for the power station to stay in operation for at least another five years after 2022 (House of Representatives, 2017).

Several estimates of the necessary costs for refurbishment needed to extend the life Liddell are circulating in the media. The capital costs used in this report are based on the desktop research commissioned by Liddell's then owner, the NSW Government's Macquarie Generation, in 2013. WorleyParsons Consulting assessed that the cost of extending its life by ten years would amount to $980 million (WorleyParsons Consulting, 2013).

Other sources such as the Finkel Review (2017) estimated that the cost of the refurbishment needed to extend the generator's life for another 10 years would be between $600 million and $700 million. However, experience with other aging coal power plants such as the Muja Power Station in Western Australia has shown that the refurbishment can be more difficult than anticipated. The costs and timeframe for the Muja plant 200km south of Perth ultimately doubled from the initial estimate of $150 million to beyond $300 million, and the project was subject to numerous operational problems. Since its refurbishment the plant was running for only 20 per cent of the time and its closure has been announced for next year (Morton, 2017).

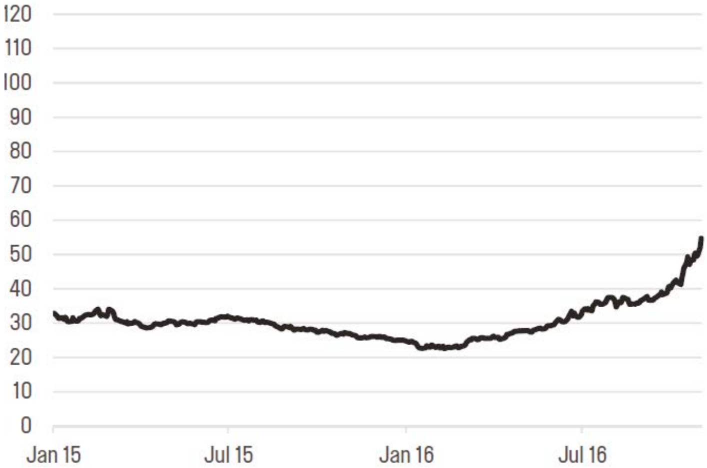
The cost of finance to extend the life of Liddell is also likely to be higher. The weighted average cost of capital[7] for coal is projected to be 14.9%, compared to 7.1% for renewables (Gerardi and Galanis, 2017) .

[7] The weighted average cost of capital (WACC) is the rate that a company is expected to pay on average to all its security holders to finance its assets. The WACC is commonly referred to as the firm's cost of capital.

Liddell operated in 2016 at an equivalent availability factor[8] of 53 per cent (AGL Energy Limited, 2016b). This figure has also been used in this modelling, however estimates and statements by AGL representatives suggest a much lower percentage of energy available (Parkinson, 2017b).

The fuel costs in our scenario are based on data from AGL (2016a) which indicate $60/MWh as the NEM-wide costs of coal in 2016 (Figure 9). These costs are conservative and are expected to rise in the following years.

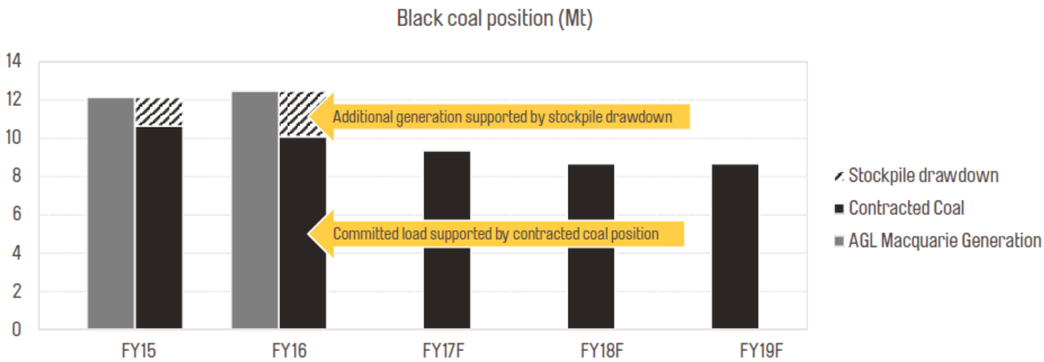
Figure 9: Black coal costs in the NEM (AUD/ MWh sent out)



Source: AGL Investor Day 2016, slide 8.

Furthermore, AGL's contracted coal stockpiles have declined since 2015 and are expected to further decrease until 2019. In 2015 and 2016 the contracted coal volumes were less than requirements, suggesting that spot market buying was necessary (see Figure 10). This trend suggests that AGL's coal under a purchase contract (at the old price) will further drop and hence Liddell will be exposed to increasing fuel prices. The developments in the coal market suggest that in 2022 the costs for contracted coal could be 10 to 20 per cent higher than today (Leitch, 2017).

Figure 10: AGL's black coal under a purchase contract 2015 to 2019



Source: AGL Investor Day 2016, slide 7.

[8] The equivalent availability factor is a standard industry performance indicator. It measure the proportion of a given operating period in which a generating unit is available without any outages.

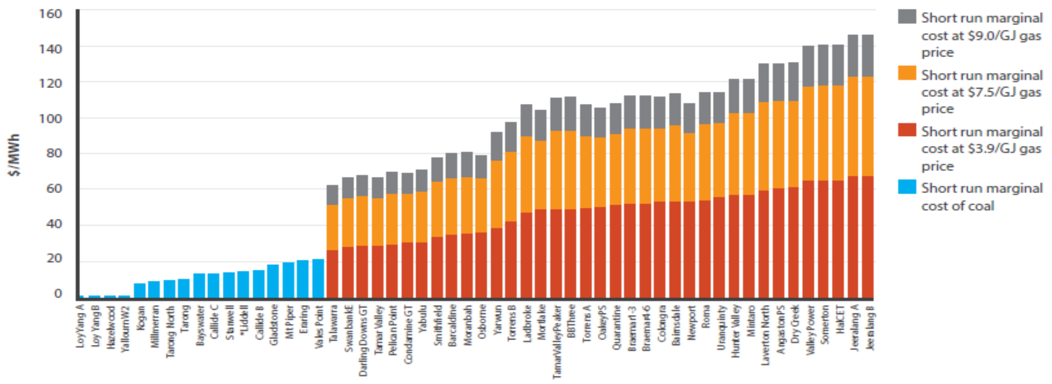
Beyond the costs for refurbishment and operation, keeping the plant running longer will result in additional emissions, both in carbon dioxide and local air pollutants. Coal-fired power plants are the major contributor to the energy sector's carbon emissions. We have used the figure from AGL's 2016 Sustainability Report, which stated that the carbon intensity of Liddell is 1.01 tCO2e/MWh (AGL Energy Limited, 2016a). The plant emitted around 7.7 million tonnes of carbon dioxide in FY 2016 (AGL Energy Limited, 2016c). The local air pollution can be a serious problem. Pollution from mines such as Bulga in the Hunter Valley has increased 32 per cent in the past year. Air quality studies indicate that power station sulphur dioxide emissions cause between 10 and 40 per cent of annual average particulate air pollution in the Sydney, Lower Hunter and Upper Hunter regions. For the area in and around the cities of Sydney, Wollongong and Newcastle, coal-fired power plants contributed 87 per cent of the area's 187,000 tonnes of sulphur dioxide pollution and more than a third of the 724 kilograms of mercury registered over 2016 (Hannam, 2017).

3.2 Gas-fired peaking plant

AGL proposes to replace Liddell's capacity by focusing on gas technology. According to AGL, its gas project would use reciprocating engine technology similar to that used in its Barker Inlet Power Station in South Australia (AGL Energy Limited, 2017b). Our modelling is based on the investment estimate for Barker Inlet of $295 million for 210 MW, which would amount to $1,404 per kW. While reciprocating engines have lower capital and operating costs than combined cycle power plants (CCGT)[9] or Open Cycle Gas Turbine (OCGT)[10] technologies, the efficiency is lower and the emission intensity is higher, and the economic lifetime of the systems is less. The lifetime of the engine is 15 years, based on the GE report for 10 MW reciprocating engines (General Electric Company, 2016). We note that the lifespan of the engines depends on the number of cycles of use. Hence, if the gas plant were only to be used as peaker replacement, it could run for a longer time. Based on this we have used 20 years as the lifetime.

For our emissions intensity estimate we used the figures provided by AEMO in their 2016 Planning Study. The emission rate for OCGT technologies in northern New South Wales ranges between 0.465 and 0.520 tCO_2 e/MWh. In our calculation, we used the average of 0.48 tCO_2e/MWh. We note that new gas power plants are less polluting than coal, but when one considers the entire supply chain, gas is not significantly less polluting (Climate Council, 2017).

Figure 11: Indicative relative gas price impacts on generation fuel costs



Source: Finkel et al. 2017, p. 111.

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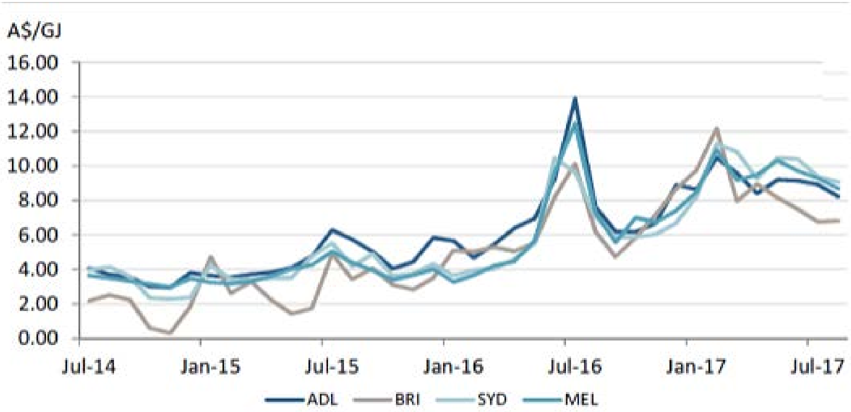
[9] Combined Cycle Gas Turbines (CCGT) are a form of efficient energy generation technology that combines a gas-fired turbine with a steam turbine.

[10] An open cycle gas turbine (OCGT) is a combustion turbine plant fired by liquid fuel to turn a generator rotor that produces electricity.

A major cost driver for gas technologies is the fuel cost. In recent years, gas prices have increased significantly and contributed to a decline in gas-fired electricity generation (see Figure 11). These higher gas prices have been attributed to a number of factors: increased exports, linkage to international oil prices, diversion of gas reserves to meet export contracts, market responses to shortages and reliance on gas power to meet demand. In addition, gentailers[11] have used their market power to push up the gas price on the spot market, particularly in South Australia in June 2016 (Climate Council, 2017). We note that domestic gas prices will likely be higher in the future compared with historical levels (Finkel et al., 2017). It is estimated that the fuel cost of generating electricity at a gas price of $9/GJ is in the range of $60/MWh to $140/MWh (Figure 11 and Figure 12) depending on the efficiency of the plant. We used the average value of $100/ MWh since no change for medium-term gas prices is expected due to the abovementioned factors.

Figure 12: Domestic gas market price



Source: AEMO 2017.

3.3 Pumped hydro (Snowy 2.0 upgrade)

The current energy storage markets, both domestically and internationally, are dominated not by batteries but by pumped hydro, which is a mature technology (IRENA, 2012). Pumped hydro currently constitutes 97 per cent of worldwide electricity storage, but is neglected in many analyses (Blakers, Lu and Stocks, 2017). Australia has three large-scale pumped hydro facilities operating which contribute 1,340 MW to the NEM. They are: Tumut 3 in the Snowy Mountains with 600 MW, Shoalhaven in southern NSW with 240 MW, and Wivenhoe in southern QLD with 500 MW.

In combination with renewable energy generation, pumped hydro storage is considered beneficial for storing surplus energy when energy production exceeds demand and then providing power back to the market at times of peak demand or capacity constraint. It has to be noted that approximately 80% of Australia's grid electricity is generated using fossil fuels, and that most pumped hydro facilities in Australia still use grid electricity to transport their water from the bottom to the top of the hill. Hence, pumped hydro capacities cannot be considered to be clean energy as long as they are powered by a fossil fuel-based grid.

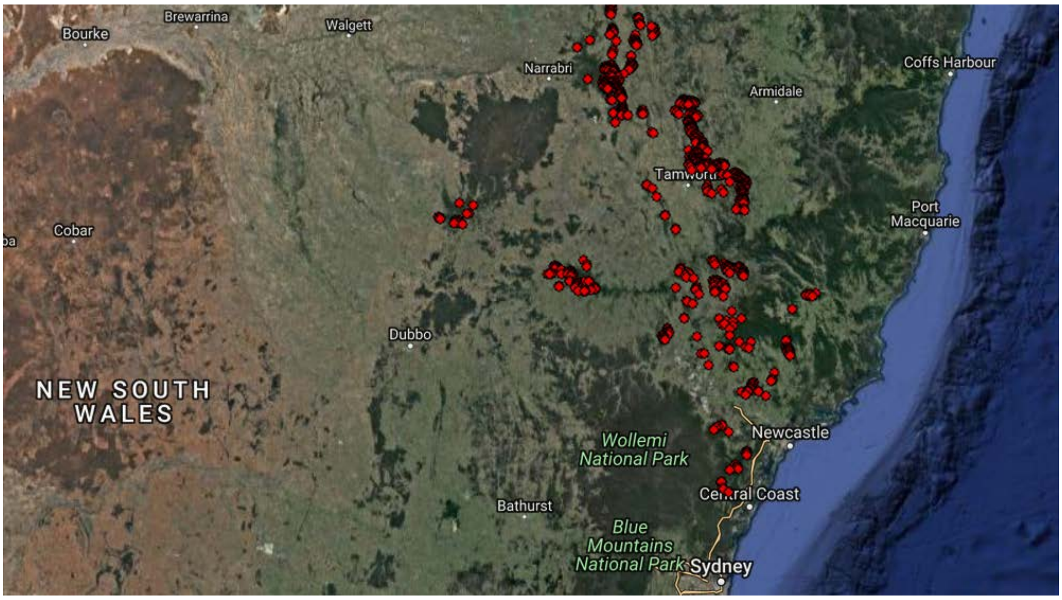
The Commonwealth Government is proposing the Snowy 2.0 upgrade as the '*solution to the national energy crisis*' (Ludlow, 2017). The project, announced in March 2017, would be expected to add another 2,000 MW of electricity, or about 350,000 megawatt hours (350 GWh) of energy storage, to the existing pumped hydro scheme. It could run non-stop for seven days.

[11] Gentailer is a portmanteau word combining generator and retailer, i.e. **gen**erator-re**tailer**. It refers to the vertical integration of companies operating in the NEM, where generators own a retail arm.

The plan involves creating generation and pumping capacity, and connecting two reservoirs with an underground tunnel. It is expected that only a small amount of net additional water will be used (Snowy Hydro Limited, 2017a). The capital costs of the project are estimated at $2 billion, plus an additional estimated $2 billion to be spent on upgrading transmission lines (Ludlow, 2017). Our model is based on these cost estimates, including network costs, which translates to $2,136 per kW of firm capacity (considering a capacity firmness of 93.6 per cent). However, we note that a feasibility study for Snowy 2.0 is still underway and no detailed data have been disclosed yet (Snowy Hydro Limited, 2017b).

Although some critics have stated that the planned extension would be ‘diabolically difficult to deliver’ and might take longer than anticipated (Gribbin, 2017), the potential for pumped hydro in Australia has been recognised recently. A study by ANU investigated off-river reservoirs located at the top of hills and identified more than 22,000 suitable sites for pumped hydro across the country (Blakers *et al.*, 2017). The ARENA co-funded study found that New South Wales has 200 times more pumped hydro resources than that required to decarbonise the electricity supply, and many of the potential sites in NSW have good co-location with infrastructure, such as transmission lines, and are also located within renewable energy hubs. Some 8,600 sites with a total capacity of 29,000 GWh were identified across NSW (ANU, 2017) (see Figure 13).

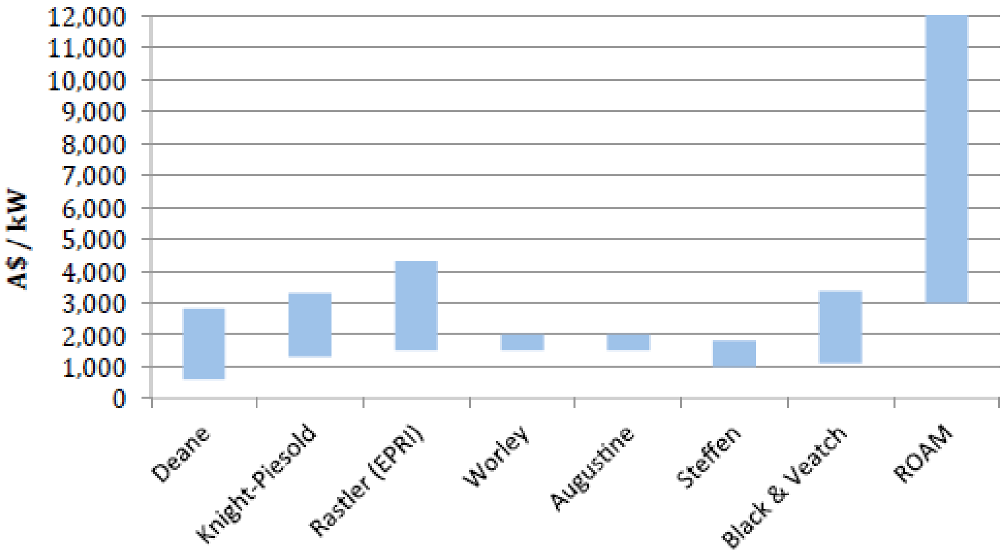
Figure 13: Potential of pumped hydro in the north-west NSW



Source: ANU. New South Wales PHES atlas. 2017

Indeed, beyond Snowy 2.0, a number of other projects were announced recently. These include the Oven Mountain Pumped Storage between Armidale and Kempsey in NSW, Kidston in North Queensland, the expansion of Hydro Tasmania and the Cultana Pumped Hydro Project in South Australia. However, the estimated costs of these projects vary significantly depending on the location and works required (Hearps, Dargaville and Mcconnell, 2014). The Melbourne Energy Institute found that internationally, the costs for pumped hydro can be as low as $600/kW (see Figure 14).

Figure 14: Comparison of estimated capital costs per unit of electricity capacity ($/kW)



Source: Hearps et al. (2016) from Melbourne Energy Institute

Capital cost estimates for specific Australian examples range from the lower end of $1,100/kW (Blakers, 2015) and $1200/kW (Genex Power Limited, 2017), to the middle range of $1,600/kW (Oven Mountain Pumped Storage, 2017) up to the higher end with $2,100/kW for Cultana's SeaWater pumped hydro (EnergyAustralia, Arup and Melbourne Energy Institute, 2017).

Advantages of pumped hydro in combination with renewable energy generation are: delivering electricity as a highly dispatchable and renewable energy source that can deliver firm capacity much cheaper than wind energy alone. However, we need to ensure that all relevant options are considered in order to procure the most cost effective flexible capacity such as demand response, battery storage and time varying prices.

While pumped hydro does not generate emissions directly, it is not necessarily emissions free, when emissions associated with pumping water uphill are considered. The efficiency losses are estimated at 42 per cent based on experience with existing plants (ACIL Allen Consulting, 2014). As this energy is an additional consumption, it is likely to be driven by coal and gas-fired generation. On this basis, the emissions are estimated at 0.29 tCO_2/ MWh.

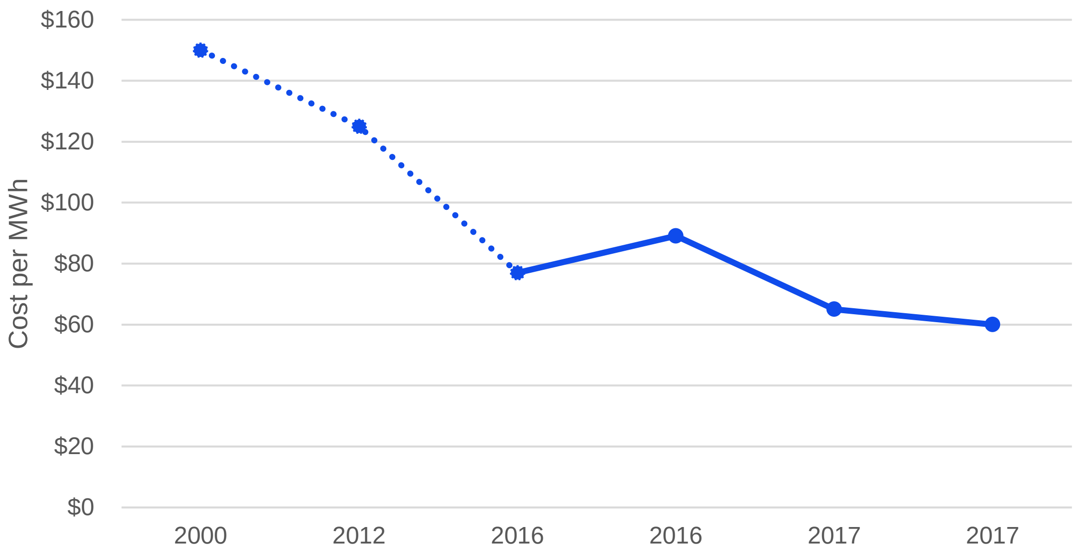
In any case, Snowy 2.0 cannot be considered as a viable replacement for Liddell because:

- It only provides capacity and no additional energy.
- It is more polluting than other forms of capacity.
- It is unlikely to be available by 2022.
- It is likely to be more expensive that other forms of capacity.

3.4 Wind energy

Wind energy is a mature technology and one of the mainstreamed renewable energy sources of electricity generation. Based on levelised cost of energy (LCE), wind energy is now one of the lowest-cost forms of centralised generation (see Figure 19 and Figure 20). In fact, the capital costs of wind energy have come down significantly in the last two decades (see Figure 15).

Figure 15: Wind farm costs over time



Source: Rutovitz et al., 2016, p. 4

In this analysis, we have used $2,047per kW of installed capacity for new wind farms. This figure reflects the capacity-weighted average for eight recent wind farms, based on the published costs (see Table 4).

As with any other generation source, not all of the installed capacity of wind farms can be relied upon to be available at any given time, and in particular at time of peak demand. In other words, the "firm capacity" is less than the "installed capacity". The "firm capacity factor" is the proportion of the installed wind capacity can be relied upon to be available at peak time. AEMO's estimate for the "firm capacity factor" for new wind farms, is 3 per cent for NSW during summer, and 4.2 per cent during winter (AEMO, 2016b). These estimates are based on AEMO's analysis of historical wind output over summers from 2011-12 to 2015-16, and winters from 2011 to 2015 (AEMO, 2017g). AEMO states that due to 'the intermittent nature of wind, wind generation capacities are de-rated to account for the output most likely to be available during times of maximum demand'. This means for every 100MW of new installed wind energy capacity, 3 MW can be relied upon to be available at the time of summer peak demand.

Table 3: Expected wind contribution during peak demand (% of registered wind capacity)

Minimum expected wind contribution during peak demand*	South Australia	Victoria	Tasmania	New South Wales
Five year summer average	9.4%	7.5%	8.5%	3.0%
Five year winter average	7.0%	6.8%	4.9%	4.2%

*Expressed as a percentage of registered capacity, with peak demand defined as the top 10% of demand periods

Source: AEMO (2016b) p. 17.

The relatively low firm capacity factor in NSW in part reflects the low penetration of wind energy in this state, which means that there is very little geographical diversity in wind generation output. We note that this NSW figure is very low compared to the average firm capacity factor used in other states and elsewhere in the world. For example, OFGEM's 2014 UK electricity capacity assessment examines different scenarios and estimates the equivalent firm capacity, which is needed to replace the entire wind fleet's contribution at peak times. With wind power modelled as approximately 20 per cent of all generation installed capacity, the firm capacity factor for total installed wind capacity in the UK was estimated at between 15 per cent and 22 per cent for. This is in a context where the average capacity factor in the UK over the last five years was 23 per cent, which is much lower than the average capacity factor of 33 per cent over the past six years in Australia (Rutovitz et al, 2016).

Table 4: Published costs for wind farms in Australia in 2017

Wind Farm	Total Cost $m	Capacity MW	Cost $/kW	Source
Silverton	450	200	2,250	AGL media release dated 18 Jan 2017
Coopers Gap	850	453	1,876	AGL media release dated 17 Aug 2017
Mt Emerald	380	180	2,111	Mt Emerald Project webpage
Mt Gellibrand	258	132	1,955	Mt Gellibrand Project webpage
Kiata	75	30	2,500	Kiata media release dated 21 March 2017
Crookwell 2	200	91	2,198	Media release dated 5 June 2017
Bodangora	236	113	2,088	Infigen media release dated 31 March 2017
Cattle Hill	300	144	2,083	Aurora media release dated 6 June 2017
Total	2,749	1,343	2,047	Weighted average costs

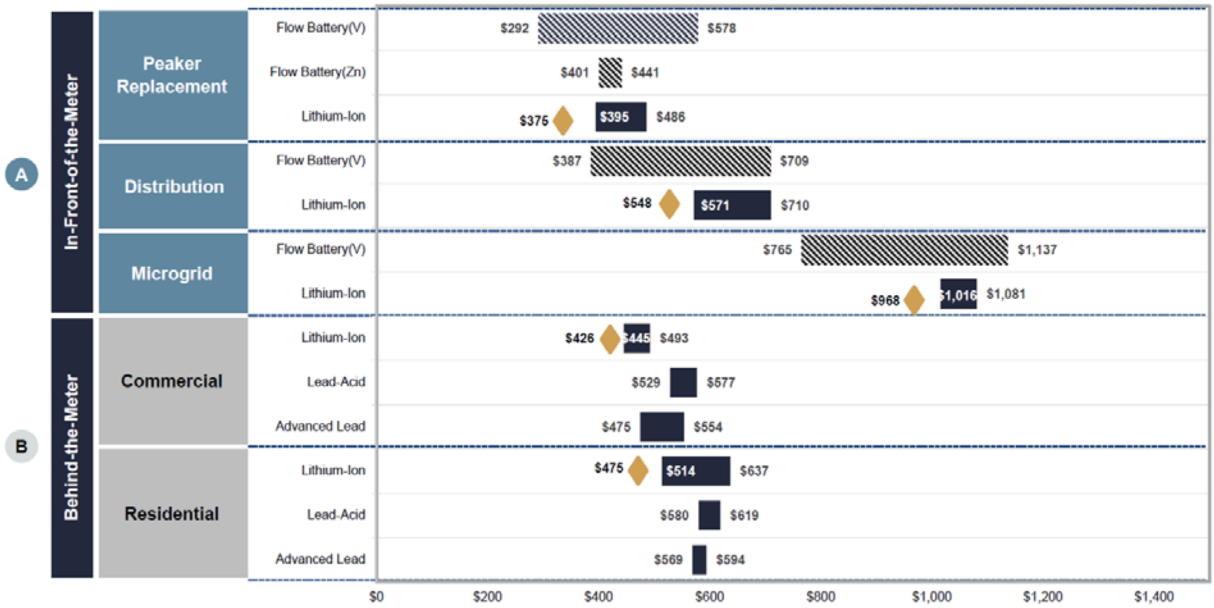
We note that for replacing peak capacity, wind energy is very expensive due to its low firm capacity factor. Yet, the technology's advantages are that it is a very cheap and clean energy source, which has high potential as a low-cost option, which, in combination with other technologies, can provide firm capacity.

3.5 Grid-scale battery storage

Large-scale battery storage systems are practical alternatives to establishing a peaking gas turbine facility. Grid-scale battery storage systems can be designed to provide capacity and energy at peak times. They can be brought online quickly in order to meet a rapidly increasing demand and they can be taken offline when demand diminishes. Hence, this technology is a highly dispatchable energy source that can provide fast frequency response. In the last five years, the capital cost for battery storage has declined significantly, and industry experts anticipate further large cost reductions in the next five years. These projected cost reductions are attributed to scale and related cost savings, improved standardisation and technological improvements. These are in turn supported by an increase in demand.

We assessed grid-scale storage as one option in our alternative clean energy scenario. For the modelling, we used data for lithium-ion batteries for a peaker replacement system from the Lazard's Levelised Cost of Storage 3.0 analysis published in November 2017. To reflect the fast moving market, we used the middle range of capital cost with AUD$586 per kW/ year.

Figure 16: Unsubsidised Levelised cost of storage comparison – US$/kW-year



Source: Lazard, 2017

Despite a capacity firmness of 92 per cent (AEMO, 2016a), the capacity costs of grid-scale batteries are significant. While battery storage in combination with wind energy could be a clean energy source, firm capital costs would be $8,666 per kW. Therefore, 100 MW of battery storage would increase the costs of the clean energy scenario by 13 per cent. Hence, we excluded grid-scale storage from the Clean Energy scenarios.

3.6 Distributed battery storage for existing solar

In the Hunter region, 16% of the households have solar PV on their roof i.e. over 49,000 households with the majority of systems under 10kW (Australian PV Institute, 2017). The cost declines in most battery storage technologies has opened new opportunities, in particular in combination with household solar. This combination has been well received by the Australian public. In order to harness the socio-economic benefits of distributed technologies, we have included the deployment of distributed battery storage in combination with existing solar PV systems in our Expanded Clean Energy scenario.

We used the capital cost for residential battery storage from Tesla's Powerwall 2.0 model with $5,500 per kW.[12] The firmness capacity is assumed at 90 per cent (Origin Energy, 2017). Our data for the capacity factor and fixed O&M are based on Lazard's report (Lazard, 2016).

The potential advantages of energy storage systems behind-the-meter in residential homes are: the provision of emergency backup power, power quality improvements and the ability to store "free" surplus rooftop solar energy and reduce peak tariffs later in the day, enabling customers to further reduce their electricity costs. In addition, battery storage can regulate the power supply and smooths the quantity of electricity sold back to the grid from distributed solar applications. However, the capital costs are still relatively high and the economic life (estimated 10 years) is low in comparison to some other options. In addition, existing solar households will have to bear the additional costs of an inverter replacement or the installation of an additional inverter. While private households can, and do, install these systems, such adoption depends on individual decision making which does not optimise the location and use of the systems.

[12] One 14 kWh Powerwall 2.0 battery costs a total of $11,000 including supporting hardware and equipment costs,

There is a potential role for utilities or State or Commonwealth Government to incentivise more efficient uptake of distributed storage by, for example, rebates, peak demand focussed incentive payments or “on-bill financing”.

3.7 Solar thermal with storage

Concentrating solar thermal power plants (CSPs) concentrate the sun’s heat to create steam and drive a conventional steam turbine. The addition of relatively cheap molten salt storage allows the plants to be dispatchable and increases the capacity factor. Today, all new solar thermal power plants incorporate thermal storage. The technology is still at the early stages of the cost reduction path, driven by a sharp increase in installations over the last ten years, coupled with the emergence of molten salt storage and the improved tower design. While there are 4,800 MW of CSP installed worldwide, Australia has only just announced its first large-scale CSP plant at Port Augusta in South Australia (Premier of South Australia, 2017).

The costs estimates in this study are derived from the Port Augusta project that will invest $650 million for the 150 MW plant. The assumed firm capacity is taken from a report into the potential for CSP to reduce grid constraints. The report examined the potential operation of CSP plants with various levels of storage during critical peak events in the NEM for both winter and summer afternoons and evenings (Rutovitz et al., 2013).

There is likely to be a cost penalty associated with the first few plants installed. However, the cost estimate used here is at the high end internationally to take this into account.

Northern and inland NSW is suitable for installation of CSP plants. Note that coastal conditions are not generally suitable because of the relatively high occurrence of cloudy conditions. Hence, we acknowledge that there are challenges associated with the required space for a solar thermal plant. For example, the planned solar thermal project in Port Augusta (150 MW) will feature about 12,000 billboard-sized mirrors measuring 100 sqm in a circle over an area of about 650ha (Beyond Zero Emissions, 2012). The site of the Liddell Power Station is smaller than this and potentially only suitable for 10MW, and is not in the optimum solar radiation area. Further investigations for appropriate location, probably west of the Hunter region should be made. CSP could also be used to avoid network augmentation in western NSW.

3.8 Energy efficiency

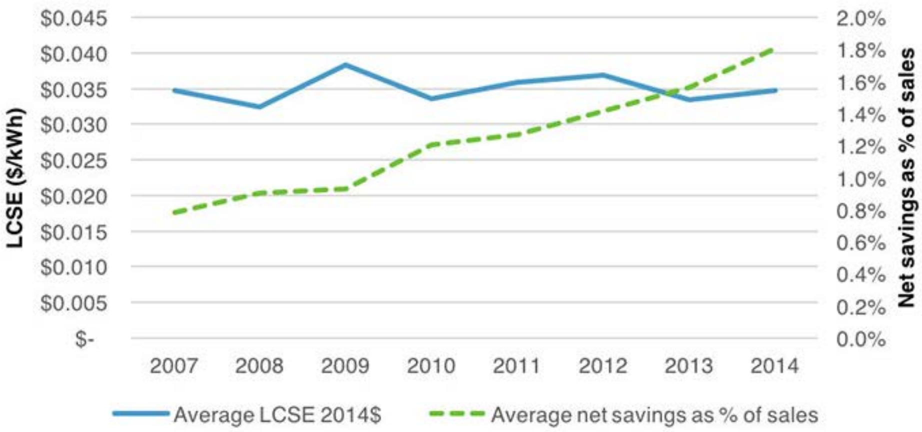
Improving energy efficiency is often referred to by analysts as the largest and cheapest energy resource, but it is often overlooked by policy makers and the media.

A study from Lawrence Berkeley Lab in the US collected and analysed more than 5,400 program years of data collected between 2009 and 2013 for energy efficiency programs run in 36 US states. The data was collected from 78 administrators of programs funded by customers of investor-owned utilities. These administrators provide efficiency programs to customers of investor-owned utilities that serve about half of the total US electricity load. The programs included residential lighting, behaviour-based programs, whole home retrofits, and Commercial and Industry (C&I) custom and prescriptive rebate programs. The study found that the average cost to program administrators of saving a kilowatt-hour (kWh) was $0.028/kWh over the five-year period (2009 to 2013) (Hoffman, Leventis and Goldman, 2017). Allowing for US inflation between 2013 and 2017 this equates to CPI/244.786/232.957 = 1.05 = $0.029/kWh in 2017. Given the current prevailing USD$ exchange rate (1USD = 1.30AUD), this gives a cost of AUD$0.038/kWh in 2017.

An earlier LBNL report estimated the program administrator cost of energy efficiency at USD$0.023/kWh. This cost excludes the participant cost of the energy efficiency which was estimated at USD$0.022. The participant cost is generally regarded as less relevant, as these costs are undertaken voluntarily on the basis that the customers perceives net benefits in achieving energy efficiencies and considers that the additional benefits of energy efficiency outweigh the costs (Hoffman et al., 2015).

Another study undertaken by ACEEE examined 14 program administrators and found that seven of these achieved savings levels higher than 1.5 per cent of total energy consumption in consecutive years. Three of the seven sustained that level of savings for more than four years. As Figure 17 shows, average savings as a percentage of sales more than doubled from 0.8 per cent to 1.8 per cent, while the average levelised cost of saved energy, the per kilowatt-hour cost of energy over the lifetime of a program, remains relatively stable around 3.5 cents per kWh. This equates to about AUD4.7c /kWh or AUD$47 /MWh for energy savings, adjusted to 2017 values. (Baatz and Gilleo, 2016)

Figure 17: Average LCOE and incremental net savings



Source: Baatz and Gilleo, 2016

The NSW Energy Savings Scheme and the Victorian Energy Efficiency Discussion also evidence on the cost of energy efficiency improvements, with both schemes delivering large energy savings at a cost of about $20/MWh. Extending or complementing these existing schemes at a national level could provide a very cost-effective means of providing the energy efficiency capacity discussed in the Clean Energy package and Energy Efficiency Only scenarios.

The cost of delivering this energy efficiency improvement could be further reduced by expanding the existing building energy efficiency and appliance and equipment minimum energy performance standards.

3.9 Demand Response

Demand Response (DR) refers to customers reducing or shifting their electricity demand for short periods in response to financial incentives offered by utilities or other parties responsible for electricity supply.

DR has been defined as “customer actions that are taken to reduce their metered electricity demand in response to an ‘event,’ e.g., a dispatch signal, whether in response to the high price of electricity, the reliability of the grid, or any other request for reduction from a grid operator, utility, or load aggregator” (Hledik and Faruqui, 2015).

AEMO has noted that there is already significant DR in the NEM – approximately 950 MW of demand-side participation (DSP) capacity across the NEM (AEMO, 2017f).[13] DSP can be rapidly deployed to complement potential supply-side market responses and provide greater contribution at peak demand times.

[13] Customer responding to high price signals.

In order to estimate the cost of demand response, we have drawn on the current DR program conducted by ARENA and AEMO. The $35.7 million initiative will deliver 200 MW of capacity by 2020, with 143 MW to be available for this upcoming summer. Including NSW funds, this amounts to $35.7million/(143MW +171MW +200MW[14]) = $69/kW.yr (AEMO, 2017c).

Network businesses have already capitalised on new technologies that can offer programs to help reduce peak demand and network costs, with consumers rewarded for participating. For example, Energex offers a PeakSmart program for air conditioners, which enables these devices to reduce their energy consumption during periods of high demand. Air conditioners in participating households are fitted with a signal receiver. At times of high demand on the network, Energex's control centre sends a signal, which reduces the device's energy consumption for a brief period. Households can claim a rebate of up to $400 off the cost of the air conditioner for participating in the program (Finkel et al., 2017).

3.10 Time varying prices

Time varying prices (TVP) for electricity refers to a range of strategies and approaches to vary electricity prices by time of day and time of year in response to demand and supply conditions. The higher that demand is relative to supply, the higher the prices are. Conversely, if supply is high relative to demand then prices should be lower. There is a range of approaches to TVP including:

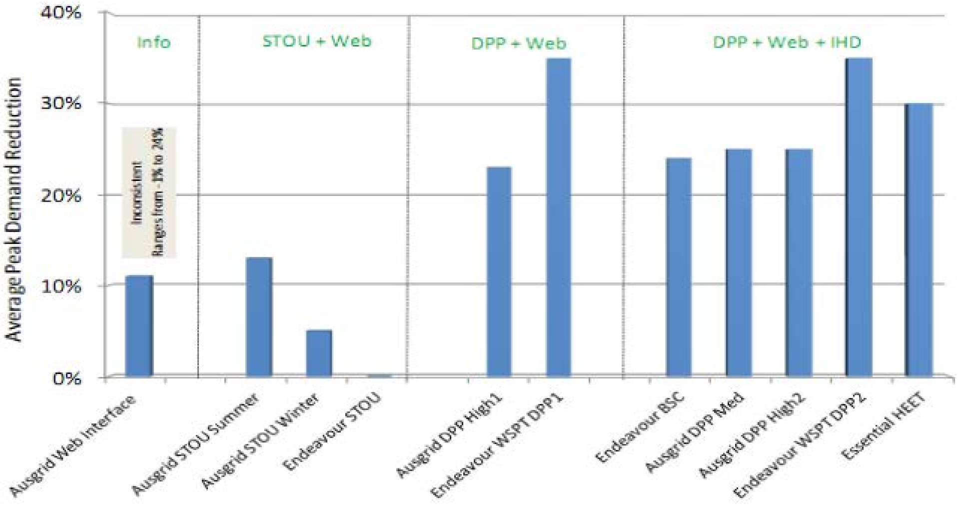
- Discounted off-peak tariffs, which have existed in Australia since the 1930s, often on a separate dedicated circuit.
- Time of use (ToU) pricing: A static ToU rate divides the day into time periods and provides a schedule of rates for each period, such as Peak, Shoulder, Off-peak.
- Variable peak pricing: This is where a higher peak price is charged for rare and short periods of the highest relative peak demand. Often, this will only be notified to customers the day before the event. This can include Critical Peak or "Dynamic Peak" Pricing.
- Peak time rebate: Where there are regulatory or political barriers to setting time varying prices, an alternative is to offer rebates (or "negative prices") for customers to reduce demand at peak times.

Discounted off-peak tariffs are common in Australia, particularly for off-peak electric water heating. Time of Use pricing is available in most parts of Australia, but is still relatively uncommon, and the large majority of residential consumers are still on "flat tariffs".

The great value of TVP is that it encourages consumers to shift discretionary loads like storage water heating and pool pumps away from peak periods, thus reducing the need to invest in expensive new generation and network infrastructure to meet peak demand for only a few hours per year (AEMC, 2012). Figure 18 provides a summary of the impact on reducing peak demand of TVPs.

[14] Note: 171MW is the assumed mid-point for between 143MW and 200MW for 2018/19.

Figure 18: Summary of peak demand reduction results from DSP trials in Australia



Source: AEMC 2012

The cost of offering time varying prices is likely to be low, but is difficult to estimate due to limited relevant precedents in Australia. One key cost is for the smart meters that allow for real-time monitoring of electricity consumption. In 2013, the cost of such meters was estimated at less than $240 (Landis+Gyr, 2012).

The current cost is likely be significantly less than this. Indeed, given that in some areas, smart meters are now the default replacements for aging meters, the net cost of installing smart meters is very low. Nonetheless, we have assumed a cost of $500/meter and a saving of 20 per cent or 0.5 kW per household. As smart meters offer a range of other non-demand related benefits and cost savings to electricity suppliers (e.g. remote meter reading and connection and disconnection, improved fault detection and management), we have only attributed half of the cost of the meter to the introduction of time varying prices. This gives a capital cost of $500/kW or $59/kW/year. In addition, we have assumed an operating cost in the form of an incentive payment of $100/kW/year. This cost could cover the cost of a customer "app" and/or in-home monitor to allow customers to respond effectively to TVP.

It should be noted that as for Demand Response, TVP are effective in providing capacity, but do little if anything to provide energy. They are therefore an ideal complement to variable output renewables and energy efficiency.

3.11 Other options

There are further alternatives that could be considered in the mix of a clean energy scenario. These include large-scale solar PV or wind energy in combination with battery storage and sustainable bioenergy deployment.

Bioenergy

Bioenergy involves using organic matter or biomass to generate energy in the form of heat and/or electricity. There are extensive bioenergy resources in the large and well established agricultural and forestry areas across the state. NSW also has a large urban population that generates significant urban waste resources, landfill and sewage gas. The Hunter region has large cities in Newcastle, Port Stephens and Lake Macquarie. It has been estimated that the Hunter region will have a biomass potential of approximately 1,000 kilotons per annum in 2030. For the state as a whole, most of the biomass that could be used to generate heat and/or electricity is in the form of wood followed by waste, grasses and a small amount of crop residue (Wade, Barry and Nelson, 2016). It has to be noted that further research is needed to estimate the potential for sustainably sourced biomass, and to ensure that no native forest biomass is considered.

Bioenergy technology is well-established globally and in Australia. Currently, there are 34 operational bioenergy power generators in NSW, and in 2015 they produced 1.5 per cent of the total electricity generated in the state (Wade, Barry and Nelson, 2016). There are biodiesel and biofuel facilities in various stages of commercialisation in the Hunter and central coast regions. A bio-renewables hub is being developed in Muswellbrook in the Hunter region (Bill, 2017). The region offers a large potential for bioenergy, as there are many under-utilised buffer lands and mine rehabilitation sites that could be used to grow biomass. There is significant potential for biomass to be a larger source of power generation than it currently is, including during peak demand periods.

We have used Arup's (2016, p. 139) estimates for dedicated biomass plant availability at 94 per cent, which reflects the time generators operating their assets. There has been an improvement reflecting progress in the way developers are operating generation assets, reducing plant downtime and improving maintenance regimes (Arup, 2016). A high firmness factor and a capacity factor of 85 per cent make biomass a reliable source of energy. We have used a capital cost of per kW installed of $4,700, which is the average of costs available from recent studies and published costs for existing plants (Yorke Biomass) (Stucley et al., 2012; IRENA, 2015; Arup, 2016).

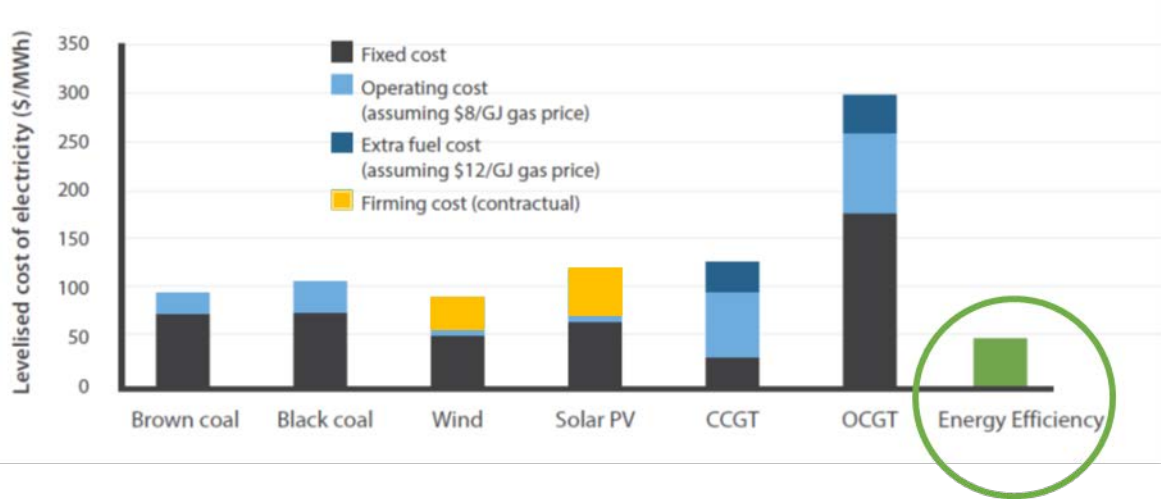
Grid solar or wind energy paired with battery storage

Other opportunities are associated with cheap renewable energy technologies such as solar PV and wind energy in combination with battery storage. While wind and solar are variable resources, the use of storage facilities increases their firmness and dispatchability. The costs of battery storage have significantly declined since 2015 and are expected to further drop in the next five years. Nonetheless, the capital costs are currently rather high in comparison to other technologies.

3.12 Comparison of technology options

There have been a number of recent comparisons of technologies for the supply of firm capacity and energy in the electricity sector. One comparison of the levelised costs of energy for various supply options is provided in Figure 19, from the Finkel Review, to which we have added a typical levelised cost of energy efficiency for comparison.

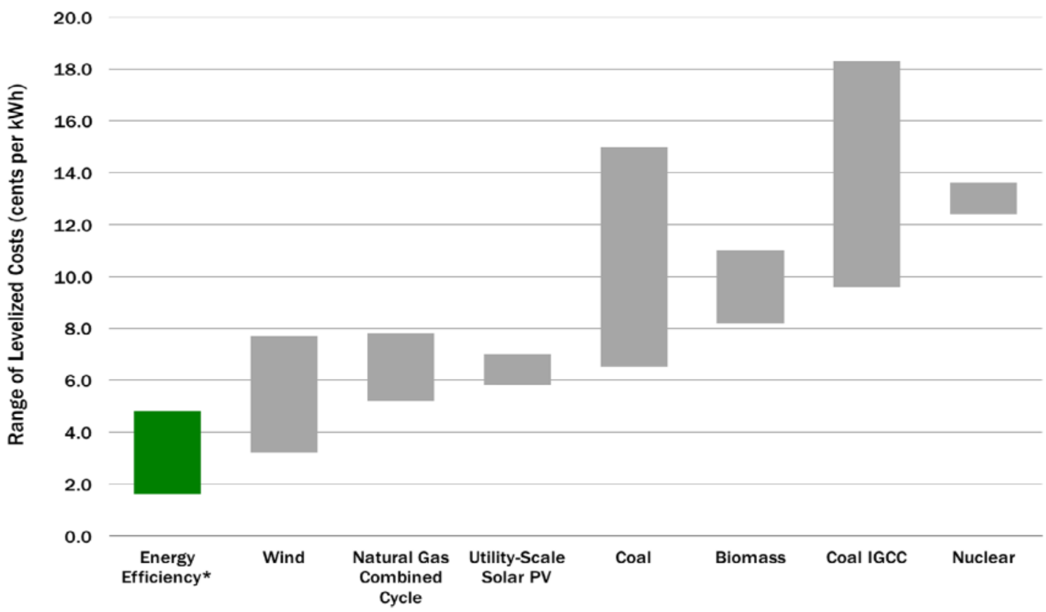
Figure 19: Comparison of levelised cost for supply options, with energy efficiency added.



Source: Amended from Finkel Review 2016, (Energy Efficiency added)

These results, and particularly the relative costs of energy efficiency, are confirmed in the data shown in Figure 20, from the American Council for and Energy Efficient Economy (ACEEE).

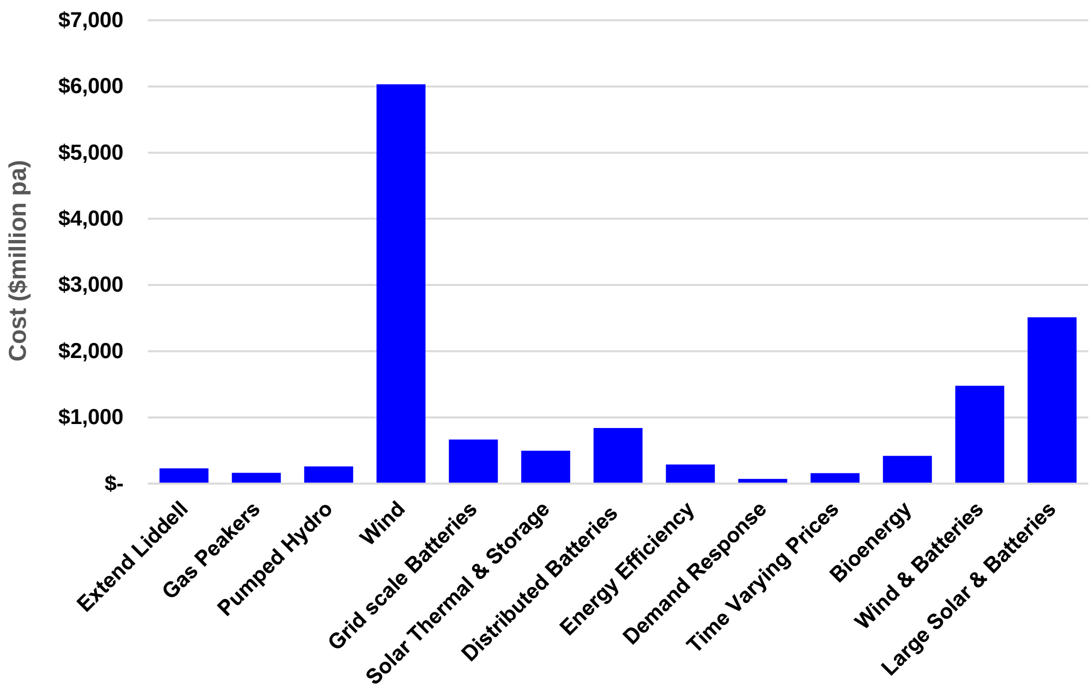
Figure 20: Comparison of costs of supply options and energy efficiency from ACEEE



Source: ACEEE, 2016

Note, however, that if *capacity* is the constraint on the system, then the levelised cost of energy is not the appropriate metric to compare options. This is illustrated Figure 21, which shows the results of modelling done for this report, comparing a set of technology options based on their relative costs of providing firm capacity, as distinct from the levelised cost of supplying energy.

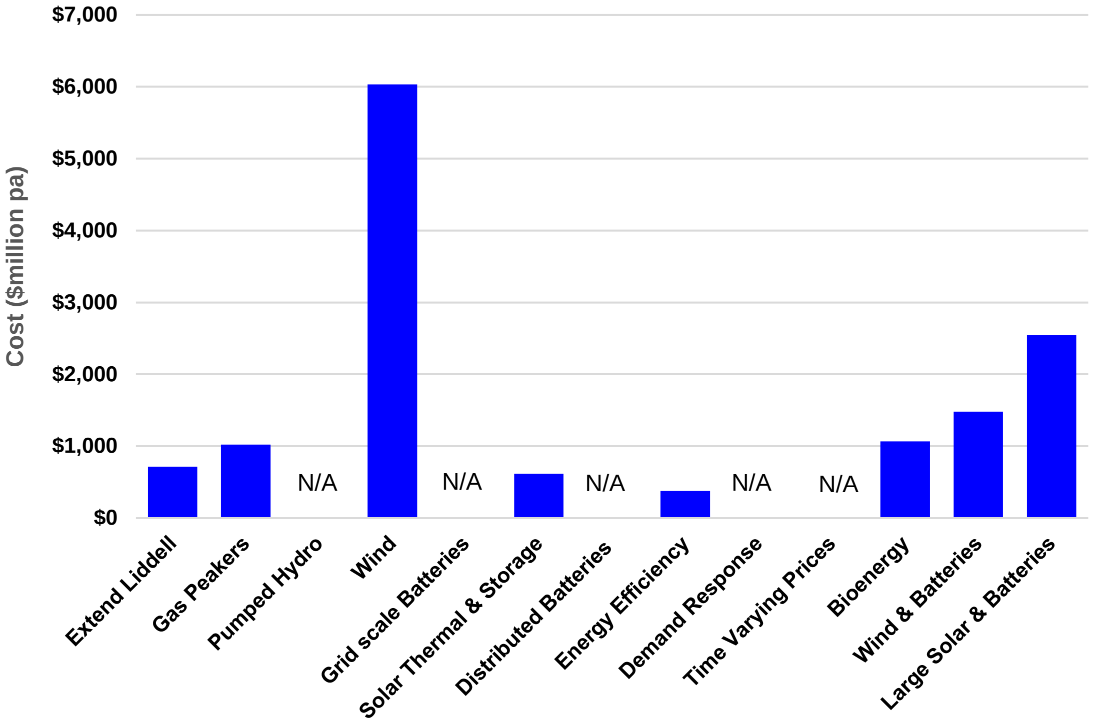
Figure 21: Costs of technology options to provide 1000 MW firm capacity



Source: ISF modelling.

For the comparison of technology options for providing both firm capacity plus energy, the comparison is shown below in Figure 22.

Figure 22: Cost of options to provide 1000 MW firm capacity and 8000 MWh pa energy



Source: ISF modelling.

The underlying technology option unit costs for providing energy and firm capacity have been used to model a set of scenarios, or packages of technology options, as described below.

4 From options to credible scenarios

In this section, we model a number of scenarios or technology packages, based on the technology options described above. These scenario packages were designed to address two different cases; a capacity-only constraint, and a capacity-and-energy constraint.

The capacity-only case addresses only the reliability challenge described by AEMO, while the capacity and energy case addresses all four related challenges: ensuring reliability; putting downward pressure on electricity prices and bills, the longer-term transition associated with aging power stations; and the need for climate action. The capacity and energy case is therefore more relevant for meeting the long-term interests of consumers with respect to the price, quality, reliability and security of supply of energy services.

4.1 Scenario 1: Extend Liddell

This scenario explores the costs and impacts of the Commonwealth Government's proposal to continue Liddell's operations beyond 2022. Over a five-year period, the estimated cost of the extension is $3.6 billion, with two thirds attributed to energy costs and just one-third for capacity costs.

Table 5: Scenario 1: Extend Liddell

Technology Option	Installed (Firm) Capacity Increase in MW	Energy provided in GWh per annum	Total Cost in $m (5 years)	Carbon Emissions in kt CO_2 (5 years)
Coal (extend Liddell)	2,000 (1000)	8,000	3,586	40,400

Extending the plant continues to provide a firm capacity of 1000 MW, generating 8,000 GWh of energy per annum. However, the technology does not have a very high capacity or firmness factor. Coal is not only an expensive fuel; it is also the most emission intensive option in this analysis, with an emission intensity of 1 tCO_2 / MWh. It has the highest emissions among the considered scenarios amounting to 40.4 Mt CO_2 over five years. This cost does not include the cost of pollution and carbon. Even at a modest carbon value of $10/t CO_2e this would add $400 million to the cost of the scenario.

4.2 Scenario 2: AGL Proposal

Prior to the Commonwealth Government proposal, AGL had already published a preliminary proposal to replace Liddell's energy and firm capacity. This proposal was presented at the AGL Annual General meeting on 27 September 2017. The proposal identifies the need for 8,000 GWh of energy per year and for 1,000 MW capacity. In order to meet this demand, the AGL proposal included:

- increasing the capacity of the existing Bayswater Plant by 100 MW to provide about 1,000 GWh of energy per annum
- repurposing the Liddell site (and other potential sites in Newcastle) with a 750 MW high-efficiency gas power plant to provide 1,000 GWh of energy per annum
- bringing on board 1,600 MW of new renewables capacity (wind) to provide almost 6,000 GWh energy per annum
- providing 150 MW of firm capacity from battery storage and demand response.

Table 6: Scenario 2: AGL Proposal

Technology Option	Installed (Firm) Capacity Increase in MW	Energy provided in GWh per annum	Total Cost in $m (5 years)	Carbon Emissions in kt CO_2 (5 years)
Upgrading Bayswater Plant	100 (100)	~1,000	420	-
High Efficiency Gas fired plant	750 (750)	~1,000	1,153	2,400
New Renewable Capacity	1,600 (50)	6,000	1,509	-
Batteries & Demand Response	150 (150)	-	222	80
Total	2,600 (1050)	8,000	3,303	2,480

ISF estimates the total cost of the project at $3.3 billion over a period of five years. Most of this cost (84 per cent) is the capacity cost[15] of the new upgraded technologies, and 16 per cent is energy costs[16] over this period. The energy costs are markedly lower than the previous scenario to Extend Liddell. This cost can further be split among the four alternative technologies proposed.

In this scenario, the gas-fired plant replaces most of the firm capacity, contributing 75 per cent of the anticipated shortfall. The current Liddell site can be repurposed with high efficiency gas technologies, taking advantage of the existing infrastructure. There is also potential for gas development at Newcastle and other parts of the state that needs further investigating. The cost per kW of $186 per kW per annum for this proposed refurbishment is one of the lowest capacity costs in a range of proposed conventional and clean energy solutions. However, with the increasing cost of gas, the energy cost is fairly high, escalating the total cost of the energy generated to $1,153 million.

The next element of this scenario is to upgrade the Bayswater coal-fired power station adjacent to Liddell to improve efficiencies and add 100 MW of capacity. Coal is an expensive source of energy in terms of both capital and energy costs. The total cost per unit is comparable to gas but the capital cost of coal is much higher, while gas has a much higher energy cost. As the anticipated capacity contribution of coal is small, the associated costs are moderate at $420 million. It is assumed this will be achieved via efficiency improvements, so there are no additional emissions.

Renewables, particularly wind, are expected to contribute 1,600 MW to overall capacity. About 653 MW of this is already under construction as part of the Coopers Gap and Silverton projects. The remaining 1,000 MW is expected to be fulfilled from within the AGL pipeline of developing projects. Though this estimate is large, as discussed in Section 3.4, wind energy has a fairly low capacity firmness of 3 per cent, compared to gas or grid-scale batteries that have a firmness factor of 92 per cent. Thus, the total firm capacity expected is only 50 MW but with a potential to generate over 6,000 GWh per annum.

Firm capacity is the amount of energy available for production or transmission, which can be guaranteed to be available at a given time, for example during peak demand hours. Given the

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[15] Capacity cost refers to the investment in the technology distributed over the age of the plant and includes the capital cost, fixed operation and maintenance costs, network costs and any incentives provided.

[16] Energy costs include recurring costs like the fuel cost, variable operation and maintenance and any incentives provided.

variability associated with wind, the firmness factor is quite low. AEMO also takes an extremely conservative approach. This has an impact on the cost of the technology. Even though there are no energy costs for wind technology, the total cost showcases the high capacity cost of this option at $1,509 million.

The final contribution comes from 50 MW batteries and 100 MW demand response. Both are characterised by a high firmness factor and a low capacity factor. Batteries have a high capacity cost adding $163 million to the cost of the project. Demand Response, on the other hand, will have low capacity costs but very high energy costs, contributing $59 million to the total cost of the project. Demand Response defers capital expenditure and can be progressively developed over the five-year time frame.

In keeping with AGL's commitment to manage carbon emissions as part of its Greenhouse Gas Policy, this scenario aims to reduce emissions by over 90 per cent to 2.5 Mt CO_2e. This still attracts an additional carbon value of almost $25 million.

4.3 Scenario 3: Clean Energy Package

The primary Clean Energy Package provides another response to Liddell's impending closure. It moves away from conventional coal and gas alternatives to a zero emission result with substantial cost savings compared to the baseline Extend Liddell scenario. In this scenario, the 1000 MW shortfall is met through a combination of renewable energy options and demand management solutions.

Table 7: Scenario 3: Clean Energy Package

Technology Option	Installed (Firm) Capacity Increase in MW	Energy provided in GWh per annum	Total Cost in $m (5 years)	Carbon Emissions in kt CO_2 (5 years)
Wind	600 (18)	2,288	543	-
Energy Efficiency	1,000 (900)	6,027	1416	-
Demand Response	250 (225)	5	133	-
Time varying prices	250 (180)	0.1	143	-
Total	2,050 (1323)	8,320	2,235	-

This combination provides 1,300 MW of capacity and 8,300 GWh of energy, significantly exceeding the shortfall generated by Liddell's closure. Energy efficiency is a low hanging fruit providing the majority of the incremental capacity with no capacity cost and a small energy cost. Similarly, employing time varying pricing strategies has a small capacity cost of smart meters and dispatch incentives. Thus, despite the high per unit costs of wind and demand response as seen in Scenario 2, the total cost over 5 years is only $2.23 billion. This is only 62 per cent of the cost of extending Liddell, creating savings of over $1.3 billion compared to Extend Liddell and $1.07 billion compared to the AGL proposal. Additionally, this clean energy package avoids over 40,000 kt CO_2 putting downward pressure on prices, while contributing to the country's Paris Climate Agreement commitments.

4.4 Scenario 4: Expanded Clean Energy Package

The Expanded Clean Energy Package comprises the same elements as Scenario 3 (Clean Energy Package) but also adds possible options that provide some regional development benefits.

Table 8: Scenario 4: Expanded Clean Energy Package

Technology Option	Installed (Firm) Capacity Increase in MW	Energy provided in GWh per annum	Total Cost in $m (5 years)	Carbon Emissions in kt CO_2 (5 years)
Wind	600 (18)	2,288	543	-
Solar Thermal	100 (85)	552	253	-
Bioenergy	50 (47)	372	249	-
Batteries	100 (90)	--	163	-
Energy Efficiency	1,000 (900)	6,027	1,416	-
Demand Response	250 (225)	5	133	-
Time varying prices	250 (180)	0.1	143	-
Total	2,300 (1,545)	9,244	3,114	-

The large cost saving relative of the primary Clean Energy Package compared to Extending Liddell and the AGL Proposal offers the opportunity to expand clean energy capacity further and diversify the capacity mix. This scenario includes solar thermal (with storage), batteries and bioenergy solutions. This enhances the firm capacity to 1,500 MW, providing more than 9,000 GWh of energy per annum.

As seen in AGL Proposal and the primary Clean Energy Package, wind is one of the more expensive options to provide firm capacity due to its low capacity firmness. In comparison, solar thermal with storage is more expensive in terms of energy produced, but provides much more firm capacity. In Scenario 4, the Expanded Clean Energy Package, solar thermal with storage contributes almost five times the firm capacity of wind, but the total cost is less than half that of wind. Solar thermal solutions coupled with storage can be deployed near power lines in western NSW where conditions are ideal in terms of the availability of large, flat and inexpensive land with an excellent solar resource.

Another component of this scenario is to add batteries to existing residential PV installations. The Hunter and Central Coast region has a fair penetration of 16 percent[17] of household solar installations. Addition of batteries for these existing installations can add another 100 MW of capacity. As with most storage options, there is a moderately high capacity cost, which is expected to come down in the coming years, and no direct energy cost.

The final component in this scenario is repurposing the current Liddell site for bioenergy using locally grown sustainable biomass. This option allows for using the existing infrastructure as well as land and mine site rehabilitation through biomass cultivation.

The total cost of this Expanded Clean Energy Package scenario is $3.1 billion, still resulting in a saving of almost $470 million over the five years relative to the Extend Liddell scenario. The Expanded Clean Energy Package is not the lowest cost scenario, but is likely to offer the greatest co-benefits in terms of emission reduction, land rehabilitation and local economic activity.

[17] Calculated from data sourced from the Clean Energy Regulator and APVI

4.5 Scenario 5: Energy Efficiency Only

The Energy Efficiency Only scenario relies solely on improved end use energy efficiency to provide firm capacity and energy.

Table 9: Scenario 5: Energy Efficiency Only Package

Technology Option	Installed (Firm) Capacity Increase in MW	Energy provided in GWh per annum	Total Cost in \$m (5 years)	Carbon Emissions in kt CO_2 (5 years)
Energy Efficiency	1,333 (1200)	8,036	1,888	-

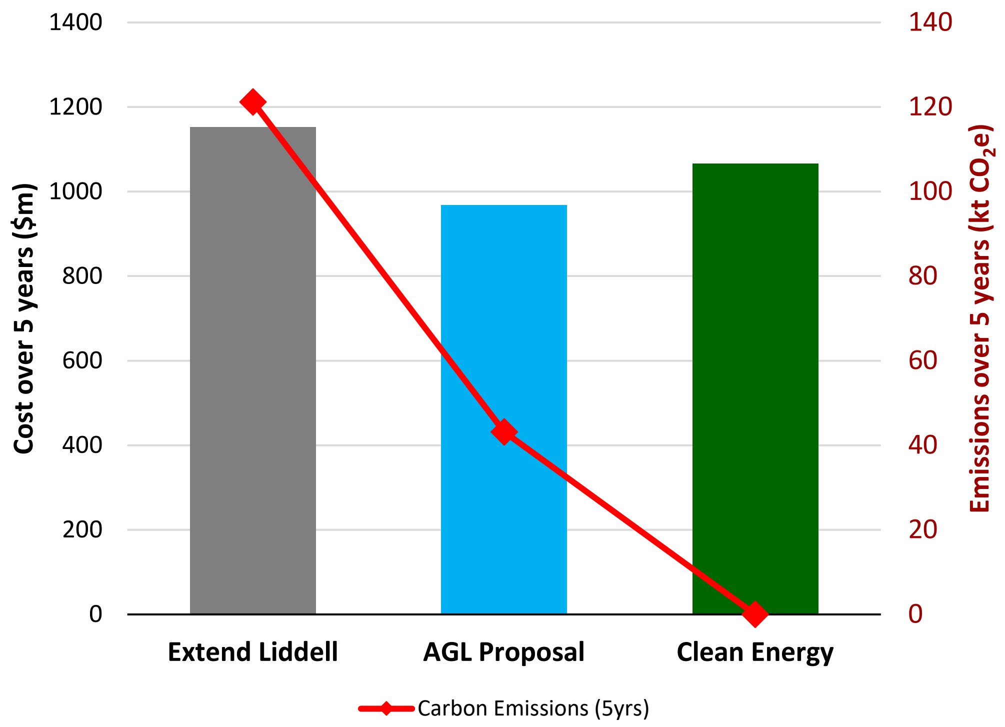
Australian and overseas experience indicates that this is a credible and viable alternative to extending the life of Liddell Power Station. However, the relatively low level of engagement on issues of energy efficiency and energy productivity in Australia means that policy makers and the community are likely to be sceptical of relying solely on energy efficiency as a solution. For this reason, we have chosen to limit the capacity of energy efficiency in the primary Clean Energy Alternative to only 1,000 MW of installed capacity. The total cost of the Energy Efficiency Only scenario is $1.9 billion, which is 47 per cent less than for the Extend Liddell scenario, resulting in savings of almost $1.7 billion over the five years.

4.6 Comparison of scenarios

This section shows the relative costs (total costs over five years) for the scenario packages, for the two different outcomes: capacity only, or capacity plus energy. The total carbon emissions expected over five years for each scenario package are also shown.

Firstly, in the capacity-only analysis, we compare three scenarios in Figure 23.

Figure 23: Capacity only analysis of scenarios

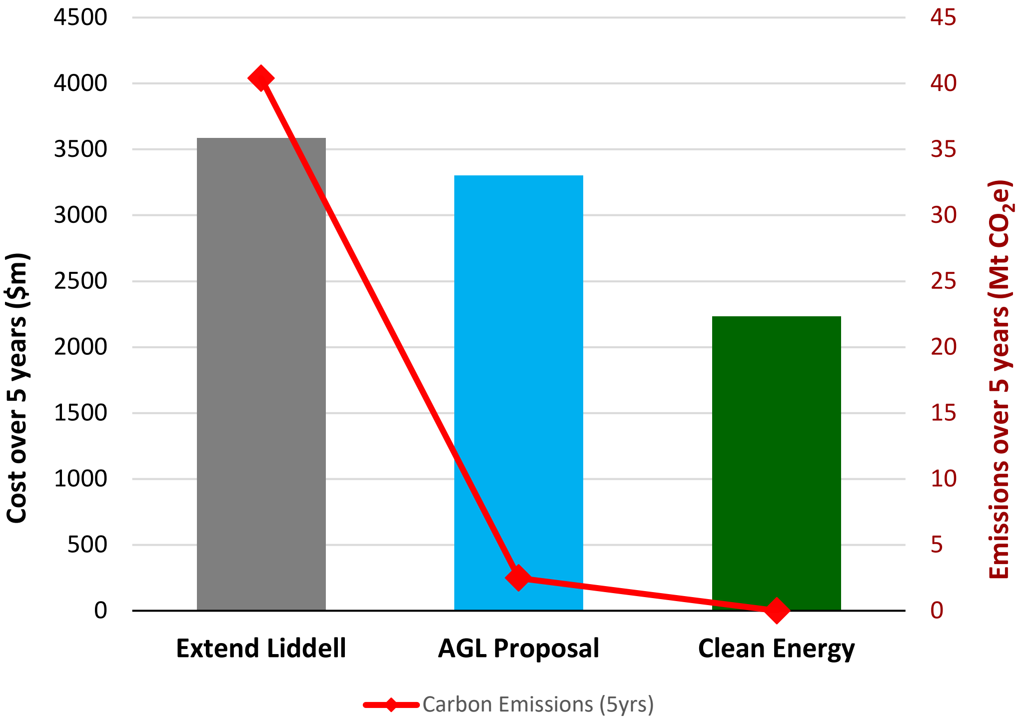


Source: ISF modelling.

If only capacity is considered, the AGL proposal is the lowest cost of the three primary scenarios considered. Note however, that in this capacity only case, significant energy generation is not required, so AGL's proposed 1600 MW of new wind generation is excluded from the scenario and the associated the energy output, capacity and cost are also excluded.

Figure 24 shows the results for the analysis of capacity and energy case, for the same three primary scenarios.

Figure 24: Comparison of capacity and energy outcomes analysis

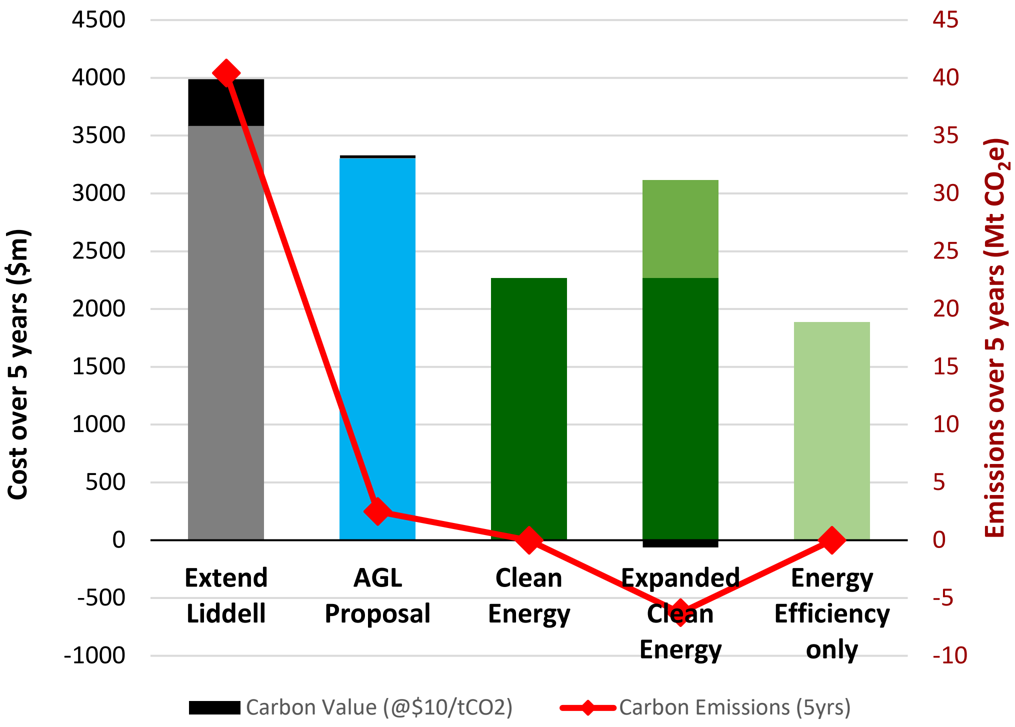


Source: ISF modelling.

Figure 25, shows the analysis for capacity-plus-energy outcomes for five scenario packages, adding the Expanded Clean Energy package (with regional development additions) as well as an energy efficiency-only package.

Figure 25 also illustrates the cost impact of associated carbon emissions, based on a modest carbon price of $10/tonne of carbon dioxide equivalent. Note that the carbon value does not impact on the clean energy or energy efficiency scenarios as they have zero emission. This carbon value is the cost applied to carbon pollution to encourage polluters to reduce the amount of greenhouse gas they emit into the atmosphere. It helps shift the burden for damage due to greenhouse gas emissions onto those who are responsible for it and who can reduce emissions.

Figure 25: Comparison of capacity and energy outcomes analysis



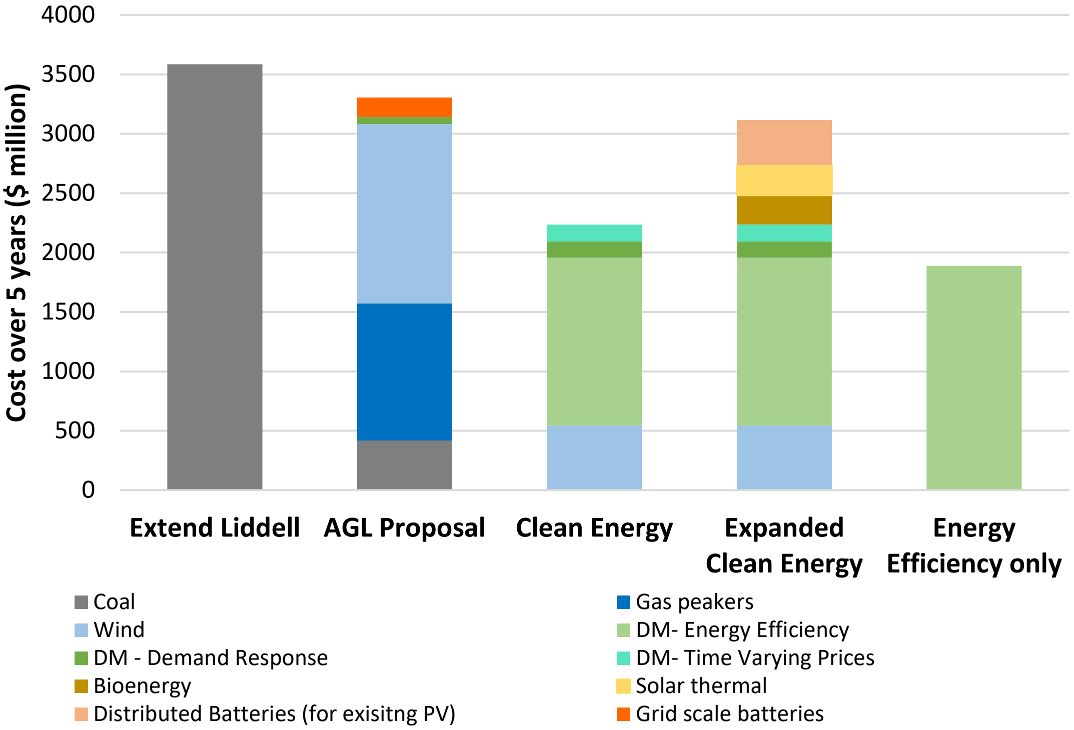
Source: ISF modelling.

The following charts provide a breakdown of the technology options in the various scenarios in the Capacity and Energy case. Figure 26 presents the technology mix that comprises the costs over five years for each of the five scenarios. This includes capital and operating costs.

Figure 27 illustrates the technology mix of the five scenarios as a share of the annual energy output. The significant contribution of renewable and clean energy options like wind and demand response is evident in the AGL Scenario. Note that the clean energy scenarios provide more energy than the Extend Liddell scenario. In fact, the Expanded Clean Energy package considerably exceeds the required 8000 GWh pa.

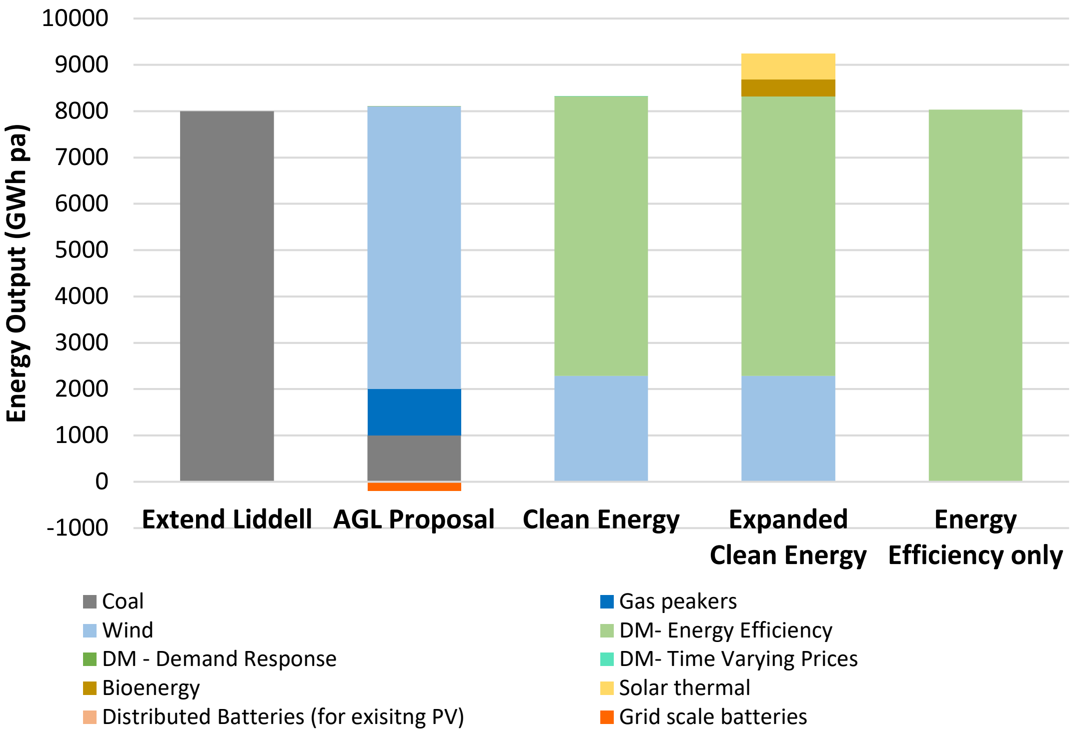
Similarly, Figure 28 and Figure 29 represent the installed capacity and firm capacity of the different technologies in each of the scenarios. As discussed above in Section 3.3.4., the firm capacity for wind is much smaller than the installed capacity, while for technology options like batteries and demand response the difference is modest. It is clear that the alternative scenarios proposed fill the capacity gap created by the forecast closure of Liddell power station. The Clean Energy Scenarios offer higher capacities for significantly lower costs, and therefore support the future reliability of the National Electricity Market.

Figure 26: Technology Mix for Scenarios – Capacity and Energy Cost Analysis



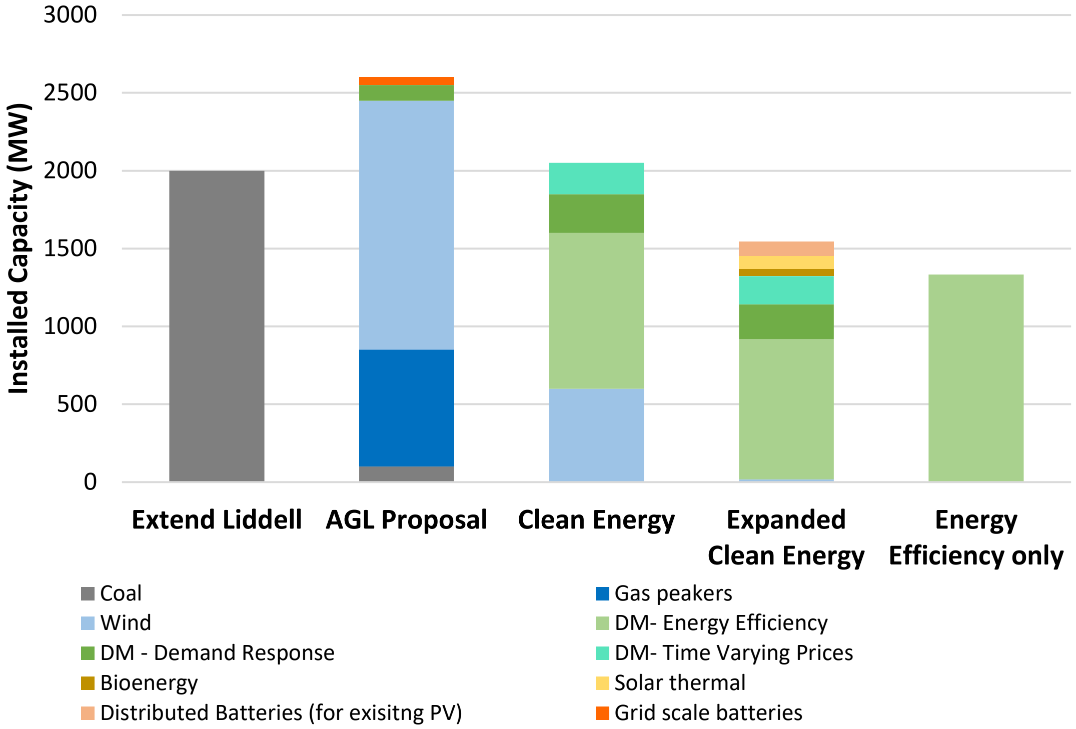
Source: ISF modelling.

Figure 27: Technology Mix for Scenarios – Energy



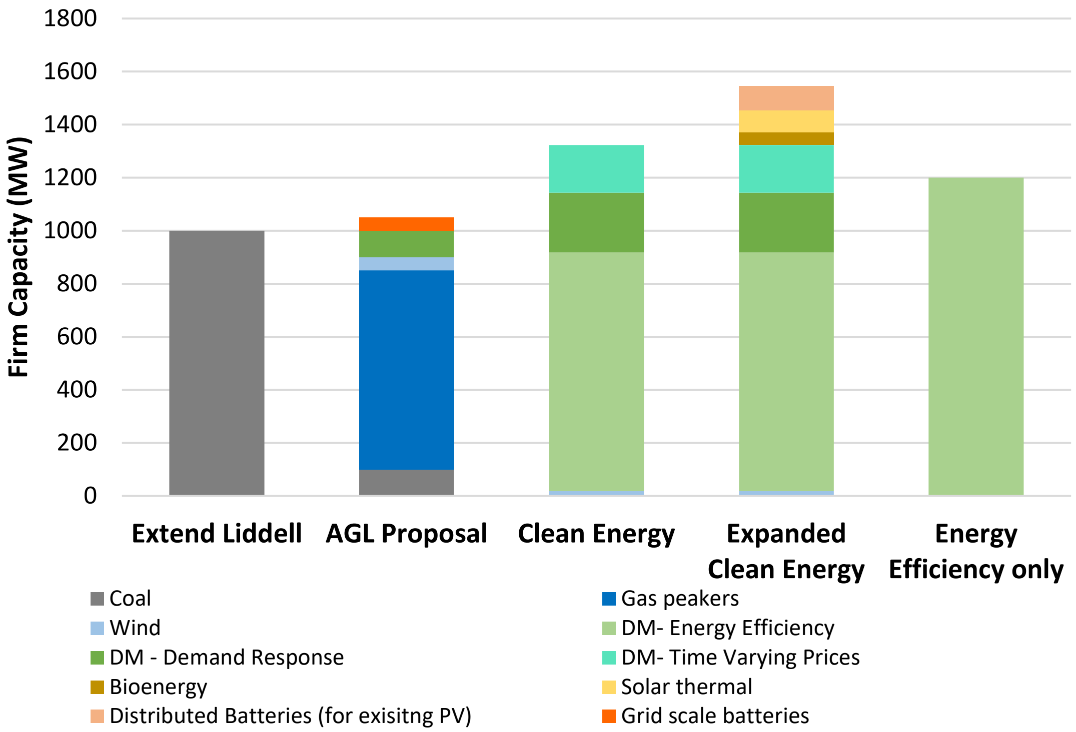
Source: ISF modelling.

Figure 28: Technology Mix for Scenarios – Installed Capacity



Source: ISF modelling.

Figure 29: Technology Mix for Scenarios – Firm Capacity



Source: ISF modelling.

5 Managing local economic and social transition

5.1 What is a just transition?

A “just transition” ensures environmental sustainability as well as decent work, social inclusion and poverty eradication (Smith, 2017) in the process of industrial or economic change. The Paris Climate Agreement has emphasised the “imperative of a just transition of the workforce and the creation of decent work and quality jobs in accordance with nationally defined development priorities“ (UN, 2015). Different stakeholders apply the just transition term in different ways. The Australian Council of Trade Unions particularly emphasises that previous industry transitions were often poorly executed in Australia, with workers and communities bearing the brunt of the change – suffering hardship, unemployment and generations of economic and social depression (ACTU, 2016).

A just transition is considered to be a process of social and economic restructuring “which aspires to move the region’s socio-ecological relationships rapidly towards sustainability through protecting the wellbeing of vulnerable workers, communities and ecosystems” (Evans, 2009). Indeed, a fair transition to climate-safe technologies addresses three main dimensions: firstly, the environmental impact; secondly, the equitable sharing of responsibilities and costs across society; and thirdly, a fair sharing of the benefits with communities actively co-creating the transition process. In this section, we look at what is needed to ensure a just transition for Liddell workers and the broader Hunter community.

5.2 Why is a just transition important?

Over the past five years ten coal-fired power stations have shut down in Australia, with an average of just four months’ notice given to workers and communities (see Table 1). This has meant that the communities around these power stations, and the workers employed there, have had little time to develop plans for alternative industries or employment. The shutdown of a power station like Liddell that employs 600 people (shared between Bayswater and Liddell Power Station), has huge implications for the lives and livelihoods of hundreds of people.

By providing more than five years’ notice of its intention to shut Liddell, AGL has given itself, its workers, the community and all levels of government time to put in place detailed plans for supporting the community and affected workers to make the transition away from coal power. However, it is imperative that this five-year period not be wasted. Work must begin now to develop alternative economic plans, and to begin retraining and other initiatives.

5.3 What are the options for renewable economic renewal in the Hunter?

The coal industry is a sector in transition. The international trend towards low-carbon societies is leading to the gradual phasing out of coal-fired power stations around the world. In particular, the more advanced economies of the OECD nations continue to reduce their reliance on coal-fired electricity generation (Smith, 2017). Hence, it is becoming obvious that the closure of the Liddell Power Station will only be the beginning of a broader transition in the Hunter Valley. Other fossil fuel-fired power stations will likely be phased out in the coming decades. Yet, a transition also offers opportunities; a solution oriented approach would see the creation of new sectors with new jobs – in particular in the renewable energy field.

A just transition for any industry in decline should involve broad-based local economic planning covering a range of sectors from health and education, agriculture, alternative industries and more. However, in the case of transitions in the energy sector, there are significant potential Hunter-based opportunities related to the different clean energy options modelled in this report. These opportunities, if implemented well, could drive new jobs. However, we note that ensuring these are decent and well-paid new jobs will require long-term planning and support.

Energy efficiency and demand response

Energy efficiency and demand response are the two major pillars of the clean energy scenario in this report. Since manufacturing and installation of energy efficient equipment and materials, and the provision of energy efficiency services are relatively labour-intensive, this sector could boost the local labour market. In fact, a report from Cambridge Econometrics (2015) suggests that 'investment in energy efficiency could create up to twice as many jobs as investment in new energy generation'. However, it has to be noted that the skills required are often quite specific, and hence policy programs to train and build up capacity in the local workforce are important (Cambridge Econometrics, 2015).

Household solar and storage

The Hunter community has started to embrace the new technologies with 49,143 solar homes and 156 MW of solar PV installed in the Hunter region (Australian PV Institute, 2017). Table 10 shows that an average of 16 per cent of all houses in the Hunter have solar systems installed. This provides great potential for the deployment of complementary battery storage systems at these premises. Indeed, supporting the adoption of battery storage in the region could help households to further cut their electricity bills, improve energy affordability and provide local employment for battery installation, sales, maintenance and operation.

Table 10: Solar PV capacity in all LGAs of the Hunter region

LGA	Estimated Dwellings	Installations	Installations in %	Estimated Installed Capacity kW
Upper Hunter Shire	6183	834	12.5%	3916
Muswellbrook	6242	835	12.5%	3914
Singleton	8494	1437	16%	6770
Dungog	3800	742	18.6%	2818
Gloucester	2503	554	21.2%	1961
Great Lakes	16764	3393	19.9%	9723
Port Stephens	28866	5178	17.6%	15620
Maitland	25265	4511	17.3%	16406
Cessnock	20107	3273	15.8%	11303
Newcastle	55297	7306	12.9%	22321
Lake Macquarie	74356	11830	15.7%	35136
Wyong	60515	9250	15.1%	26255
Total	308392	49143	15.9%	156143

Source: Australian PV Institute (2017).

Large-scale wind and large-scale solar plus storage

In addition, large-scale renewable energy deployment also has development potential in the region. There are currently a number of large-scale projects under construction, including the Kyoto Energy Park with a 137 MW solar farm and 34 wind turbines, and the 272 turbine Liverpool Range Wind Farm planned by Epuron.

Indeed, the Australian Wind Alliance reports that more than 1,000MW of wind and solar are currently being built in NSW, with a further 2,600MW of projects approved and starting construction (Ecogeneration 2017). The Climate Institute (2017) estimates that the Upper Hunter will benefit from the renewable energy boom with up to 866 new jobs, including 273 ongoing jobs and a peak construction workforce of 593.

The combination of cheap large-scale renewables with storage solutions, as recommended by Finkel et al. (2017), will further help to make the system more reliable, reduce electricity bills and potentially boost the grid-scale battery industry in the state.

Other opportunities

In addition, there are other opportunities such as solar thermal and sustainable bioenergy deployment. The example from Port Augusta shows what can happen when a coal community works with a range of partners to develop a clean energy future powered by decent jobs (see box below for details). There may be some small potential for solar thermal in the Hunter, particularly given the expertise available at the CSIRO in Newcastle. However, recent research by Ethanol Technologies Limited (Ethtec), Newcastle University and Muswellbrook Shire Council shows there is potential to transforming the Upper Hunter region into a national bio-renewables hub.

Case Study – Repowering Port Augusta

In August 2017 a 150-megawatt solar thermal plant with storage was announced for construction in the South Australian town of Port Augusta. This moment was the culmination of over five years of work by the local community to ensure the town's coal-fired power stations would be replaced with a concentrated solar thermal plant. Only a year before, Port Augusta's two coal power plants, Northern and Playford B, had shut their doors, without a transition plan in place.

"It was a fairly rude shock to most people – because they'd been saying it would be 2030 only months earlier," says Gary Rowbottom, a technical officer who worked at Alinta's power station. Gary is also chairperson for the Repower Port Augusta community group which has been leading the solar campaign alongside the city council, unions, local business groups, health groups, climate groups and renewable energy groups across Australia.

On the day of the announcement, resident and Repower Port Augusta spokesperson Lisa Lumsden said, "Premier Weatherill and the South Australian Government backing solar thermal in Port Augusta is a testament to the hard work and generous spirit of our community and everyone who has stood with us to make this happen. This will help us build a bright new future in Port Augusta and will ensure South Australia has clean, renewable electricity 24/7".

What has happened in Port Augusta offers many lessons about both what to do and what not to do in driving a just transition from coal to clean energy. There are plenty of opportunities for clean energy in the Hunter; the question is what governments at all levels, AGL, the local community and others will do to help make these opportunities a reality.

5.4 Driving a just transition for Liddell workers and the community

To ensure a just transition for communities and workers in and around Liddell, we strongly recommend that AGL work with all levels of government to implement the following recommendations.

- Coal-fired power station owners in the Hunter region including AGL should work with the local councils, NSW and Commonwealth Government to establish an independent statutory authority in the Hunter region responsible for a just transition. This authority should be similar to the newly established Latrobe Valley Authority and have responsibility for implementing programs to assist economic diversification and ensure workers and communities are retrained and supported through the period of change. It is important that such a Hunter Transition Authority is a statutory body empowered by legislation. This ensures it has a mandate that outlasts changes in government and short term political factors to deliver a steady transition plan and provide certainty for communities and workers.
- The Hunter Transition Authority should be tasked with developing an industry wide multi-employer pooled redeployment scheme that coordinates early offers of voluntary redundancies in nearby coal-fired power stations to free up positions for workers from Liddell as it closes, and also facilitates transfer to renewable energy jobs, particularly within other divisions of AGL.
- A “Job Hub” should be developed to provide retraining and worker support before Liddell closes.
- The Hunter Transition Authority should facilitate programs that support the entire community through closure of Liddell and beyond and drive industry diversification in the Hunter. This could include establishing community-driven economic renewal plans such as expanding the work on creating a national bio-renewables hub, as well as extending support to other local industries and the families of affected workers, for example through making mental health services available.
- The NSW Government should ensure that all owners of all power station in the Hunter region including Liddell meet their obligations for full decommissioning of, including site remediation. Further, they should ensure that Liddell workers have first priority to these employment opportunities. Since the Paris Climate Agreement, the world has come to expect companies such as AGL to have a plan to lower their emissions to ensure that warming is kept well below 2°C. In addition, we are starting to expect that this plan also include a just transition for the company’s workforce and communities where the company operates.
- AGL’s recently released Rehabilitation Report (AGL Energy Limited, 2017) and its Transition Plan are valuable contributions in progressing these issues, but the process will be long and complex and will require meaningful engagement of stakeholders from government, community and business.

6 Conclusions

There are a number of key implications and conclusions that can be drawn from this study.

First, clarify the problem

The electricity system is changing rapidly and it is appropriate that Commonwealth and state governments take steps to adjust policies and regulations in response. There are legitimate concerns around the closure of Liddell Power Station related to:

- impacts on available supply capacity (MW) and **reliability** of supply
- impacts on energy production output (GWh pa) and consequent potential impacts on electricity **prices and bills**
- precedents associated with Liddell and what this may mean for the **subsequent expected closure** of other coal-fired power stations over the next 15 years.

In addition, these constraints must be addressed in the context of Australia's stated commitments under the Paris Climate Agreement.

It is also crucial that the specific challenges be clearly defined so that optimal least-cost solutions can be developed in a timely manner. In order to address the above constraints, it is important that any response addresses peak capacity and energy requirements

Set policy to address the objectives and outcomes; allow the market to operate

The electricity market is complex and dynamic. The generation and retail sector has been established based on competitive principles. In order to deliver efficient and low cost outcomes for consumers, it is essential that policies focus on clear and stable policy settings that promote investor confidence and encourage competition. The proposed National Energy Guarantee has potential to offer such high-level, clear, stable, outcomes-focussed policy guidance. Prescriptive government intervention around individual investment decisions, such as extending the life of Liddell Power Station, would undermine investor and market confidence, even if the investment decision was prudent.

Any policy related to the potential extension of the life of Liddell Power Station should be linked to clear policy objectives around reliability, affordability, sustainability and optimising economic transition for the local community and the nation.

Extending the life of Liddell is expensive and not prudent

Based on the available evidence, extending the life of Liddell Power Station is not a prudent response to the challenges associated with the impending closure of Liddell.

Extending the life of Liddell would be a poor outcome which, over a five-year period, could cost energy consumers and the community $1billion more than a Clean Energy Alternative. It is likely to be a more risky, much more polluting option that would do little to support the inevitable economic transition in the region.

Responsibility for electricity market outcomes should be clear

Any policy related to the potential extension of the life of Liddell Power station should be linked to clear policy objectives around reliability, affordability, sustainability and optimising economic transition for the local community and the nation.

As Liddell and its owner AGL are operating in a competitive electricity market, the Commonwealth government should adopt competitively neutral policies that treat all market participants equitably. It is not the responsibility of AGL to replace the capacity and energy output of Liddell Power Station. It would be inefficient and anti-competitive to expect or oblige it to do so.

Other policy responses are urgently required

Some of the best options for replacing the capacity and energy of Liddell Power Station are beyond the control of AGL and require effective government policy. For example, energy efficiency, demand response and time varying pricing all require government policy to ensure they are given a fair opportunity to compete.

Liddell closure can provide a template for low-cost, clean energy transition

There are real and legitimate concerns about the closure of Liddell Power Station, particularly in the context of other recent coal power station closures and future expected closures. This demands a considered strategic response as the proportion of coal generation declines and the proportion of variable output renewable energy rises.

There are viable and practical technologies and policies available to facilitate a smooth, low-cost reliable transition that supports the local economy and community.

If such technologies and policies are adopted, the Liddell Power Station closure could provide a powerful model for how the economy and the community can successfully manage the current energy transition.

Further potential research areas

Drawing on this study, further detailed analysis and consultation is urgently required to develop practical clean energy alternatives to extending the life of Liddell Power Station. This analysis and consultation should include:

- A thorough and balanced assessment of the potential and cost of all available options to provide both peak capacity and energy. This should include all relevant supply-side and demand-side options. It should also consider integrated packages of solutions and community engagement strategies, as well as individual technology options.
- Developing detailed policy and programs to drive energy efficiency and time varying pricing in the context of the future energy market. (These options were largely neglected in the recent Finkel Review.)
- Developing detailed policies and programs to support local economic transition for communities around those coal-fired power stations that are expected to close over the next 15 years.

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Appendix A: Technology Assumptions

Technologies		1. Extend Liddell	2. Gas fired peaking plant	3. Snowy 2.0 upgrade	4. Wind	5. Grid scale Batteries	6. Solar thermal with thermal storage (6hrs)	7. Batt storage (6hrs) for existing solar PV	8. Energy Efficiency	9. Demand Response	10. Time Varying Prices	11. Bioenergy	12. Wind with storage (6hrs)	13. Large scale solar with batteries (6hrs)	14. Large solar
Total Capacity	(MW)	1871	1091	1068	33333	1087	1176	1111	1111	1111	1111	1064	1000	1333	20408
Capacity Firmness	%	53%	92%	94%	3%	92%	85%	90%	90%	90%	90%	94%	100%	75%	4.9%
Firm peak capacity	(MW)	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000
Capacity factor	%	48.8%	10.5%	-1%	33%	16%	63%	0%	69%	1%	0%	85%	33%	19%	19%
Energy	(GWh p.a.)	8,000	1,000	-	96,360	1,523	6,493	-	6,697	97	10	7,921	2,891	2,219	33,967
Economic lifetime	years	10	20	30	22	10	25	10	10	10	15	25	22	10	25
Cost	($m)	$ 980	$1,000	$2,000											
Capital cost	$/kW (installed)	$ 524	$1,404	$1,000	$2,047	$3,487	$4,333	$5,500	$1,949	$876	$500	$4,700	$8,116.00	$ 6,352	$1,800
Capital cost (firm)	$/kW (firm cap)	$980	$1,532	$1,068	$68,233	$3,790	$5,098	$6,111	$2,166		$556	$5,000	$8,116	$8,469	$36,735
WACC	%	-12.94%	-7.4%	-7.0%	-7.0%	-8.5%	-7.0%	-7.0%	-7.0%		-7.0%	-7.0%	-7.0%	-8.5%	-6.8%
Annualised cost	$/kW/yr	$169	$145	$84	$5,990	$637	$426	$829	$288		$59	$418	$712	$1,223	$3,014
network cost	$/kW	0	TBA	$1,068	0	0	0	0	0	0	0	0	0	0	0
	$/kW/yr			$84											
Emission Intensity (tCO2e/MWh)		1.01	0.48	0.31	0	0.08	0	0	0	0	0	0	0	0	0
								7.37	7.52						
Capacity cost															
Capital cost (firm)	$/kW/yr	$169	$145	$169	$5,990	$637	$426	$829	$288		$59	$418	$712	$1,223	$3,014
Fixed O&M	$/kW/yr	$60	$20	$5	$45	$30	$71	$10				?	$55	65	25
Network Cost	$/kW/yr	$0	TBA	$84	$0		$0	$0				$0			
Incentive	$/kW/yr							$0		$70	$100		$712	$1,223	
Total Capacity Cost (firm cap)	**$/kW/yr**	$229	$165	$258	$6,035	$667	$498	$839	$288	$70	$159	$418	$1,480	$2,511	$3,039
Energy Cost															
Fuel Cost	$/MWh	$60	$100	$13	$0	$3	$0	$0	$0	$0		$73			
Variable O&M	$/MWh	$1	$7	$5	$0		$15	$5				$8		5	$5
Incentive	$/MWh								$47	$2,000					
Total Energy Cost	**$/MWh**	$61	$107	$18	$0	$3	$15	$5	$47	$2,000	$0	$81	$0	$5	$5
Cost per 1 GW & 6GWh	**$m p.a**	$229	$165	$258	$6,035	$667	$498	$839	$288	$82	$159	$419	$1,480	$2,511	$3,039
Annual energy cost per 8 MWh		$488	$856	$141	$0	$26	$120	$40	$376	$16,000	$0	$648	$0	$40	$40
Cost per 1 GW & 8TWh	**$m p.a**	$717	$1,021	N/A	$6,035	N/A	$618	N/A	$376	N/A	N/A	$1,066	$1,480	$2,551	$3,079
over 5 years	$m	$3,586	$5,104	N/A	$30,174	N/A	$3,088	N/A	$1,880	N/A	N/A	$5,331	$7,400	$12,754	$15,395

Black = data input

Blue = calculated