CLIMATE COUNCIL

# FULLY CHARGED: RENEWABLES AND STORAGE POWERING AUSTRALIA

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# Key Findings

## 1

**Australia is on the cusp of an energy storage boom driven by supportive policies and falling costs.**

- Energy storage technologies, like batteries, solar thermal and pumped hydro, can be used to build greater reliability and flexibility into Australia's electricity grid. They can store wind and solar power to provide electricity 24/7.
- South Australia is already home to the world's most powerful lithium-ion battery, which is already benefiting the power grid by helping meet peak demand, and responding rapidly to coal plant outages. By 2020 the state will also have a 150MW solar thermal plant with heat storage.
- Victoria, Queensland and the Northern Territory are also investing in grid scale battery storage technology, while the Federal, Queensland and Tasmanian governments are considering developing large pumped hydro projects.

## 2

**The cost of energy storage solutions is falling rapidly.**

- The cost of lithium-ion batteries has fallen by 80% since 2010. Costs may halve again by 2025.
- The cost of energy storage technologies is rapidly falling and becoming competitive with peaking gas plants, particularly in light of the trebling of the domestic gas price over the last five years.
- SolarReserve are building Australia's largest solar thermal plant in South Australia for a levelised cost of no more than $78/MWh - significantly cheaper than a new coal power station. Solar thermal plants can both generate and store electricity.
- Pumped hydro powered by renewables is the cheapest form of large-scale energy storage. However, the Climate Council has significant concerns about the Federal Government's Snowy 2.0 mega-project, as the project is not accompanied by new investment in renewables.

## 3

**Australian households are increasingly embracing battery storage units to complement household solar.**

- In 2016, there were 6,750 new household battery installations with the market predicted to have tripled in size in 2017, with over 20,000 new installations.
- 74% of people polled from across Australia expect household batteries to be commonplace in homes in the next decade.

## 4

### Energy storage is critical for building a reliable, modern Australian electricity grid for the 21st century.

- Energy storage technologies are ideally suited to the needs of a modern, smart grid providing electricity when and where it is needed.
- Energy storage can complement high levels of wind and solar power in the electricity grid by storing excess renewable energy. Countries such as Germany, Spain, Ireland and Denmark together with major economies like California have all successfully integrated much higher levels of wind and solar (20% to over 50%) into their electricity grids without compromising reliability.
- Australia could reach 50% renewables by 2030 without significant new energy storage. Renewable energy currently produces just 16% of our electricity supply.
- Batteries, solar thermal and pumped hydro technologies are more flexible and can respond faster to changes in supply and demand than traditional coal and gas plants, and therefore can enhance the reliability of Australia's grid.
- The Australian electricity grid and old fossil fuelled power stations are increasingly vulnerable to worsening extreme weather events, particularly as these power stations age. Over half of Australia's coal fleet will be over 40 years old by 2030. Having a variety of storage technologies will improve the flexibility and resilience of the power system.

## 5

### Energy storage is a crucial technology for tackling climate change.

- Climate change, largely driven by the burning of coal, oil and gas, is worsening extreme weather events such as heatwaves and bushfires in Australia. Given our heavy reliance on coal power stations, the electricity sector in Australia is a major source of pollution.
- Australia's electricity supply needs to reach a minimum of 50% renewable energy by 2030 and zero emissions well before 2050 to effectively tackle climate change.
- Energy storage technologies are a vital complementary technology to renewable energy enabling Australia to transition to a clean, reliable, affordable electricity grid.

# Introduction

**Energy storage technologies - batteries, pumped hydro and solar thermal - ensure supply and demand of electricity are kept in balance and can strengthen the electricity grid to overcome major disturbances.**

In the past year, energy storage has become an increasingly prominent focus for policy-makers and commentators when considering the future of Australia's electricity grid. In particular, energy storage technologies can potentially address all three elements of the energy policy "trilemma": energy security and reliability; affordability; and emissions reduction. This report describes how the strategic use of distributed, utility scale energy storage in Australia's electricity grid can simultaneously ensure a secure, reliable, clean and increasingly affordable electricity supply.

Since the 1970s, the global average temperature has trended strongly upwards, with global temperature now 1°C above pre-industrial levels. 2017 was the third warmest year on record, and the warmest non-El Niño year ever recorded. This comes on the back of the world's hottest year in 2016. Greenhouse gas pollution from the burning of fossil fuels (coal, oil and gas) are driving increasing temperatures.

Rising temperatures and the accelerating impacts of climate change are affecting all nations, including Australia. Heatwaves are now hotter, lasting longer and occurring more often. Australia's ageing coal-fired power stations are vulnerable to extreme heat. The ocean is also warming. Rising sea surface temperatures, driven by climate change, are increasing the prevalence of "marine heatwaves", which can trigger coral bleaching events, like those seen in 2016 and 2017 on the Great Barrier Reef. The reef is an environmental treasure, as well as a key tourism and fisheries asset. Climate change has also increased extreme bushfire weather in the south and east of Australia since the 1970s, threatening people and property, while climate change is likely making drought conditions in southwest and southeast Australia worse. At the same time, sea level has been rising rapidly, exposing coastal infrastructure and property to increasing coastal erosion and higher risk of inundation from storm surges.

Australia's fossil fuel dominated electricity sector is the nation's single largest source of greenhouse gas pollution, accounting for over a third of Australia's total emissions. Tackling climate change requires transitioning away from fossil fuels for electricity to renewable energy generation and storage.

A number of countries rely on a significant quantity of renewable power.

# Storage technology allows renewable energy to be continuously provided.

Globally, the transition to renewable energy is seemingly unstoppable - driven by record-breaking capacity additions, rapidly falling costs and increasing capital markets appetite for renewable energy infrastructure (REN21 2017). Electricity from wind and solar power plants is already cheaper than that from new coal fired power stations (BNEF 2017a). As electricity grids around the world incorporate more low-cost renewable energy, power grids are adapting, becoming faster and more flexible.

Countries such as Germany, Spain, Ireland and Denmark together with major economies like California have all successfully integrated much higher levels of wind and solar (20% to over 50%) into their electricity grids without compromising reliability (Department of Environment and Energy 2017; IEA 2017). This is in contrast to in Australia where just 16% of our electricity was generated from renewable energy in 2016. The electricity grids of these countries are progressively reducing their reliance on inflexible, baseload power stations running on coal and nuclear energy.

Energy storage technologies can provide a range of services to the electricity grid. These include: storing excess renewable energy and discharging later when needed, reducing pressure on the grid; providing frequency control to maintain the stability of the grid and security of electricity supply; smoothing out minor variations in renewable energy output; and covering missing supply from fossil fuel generators when they experience outages. Careful deployment of energy storage across Australia's electricity system, together with higher levels of renewable energy, will improve the security and reliability of the electricity system and reduce the likelihood of blackouts.

Continuing the transition to a renewable powered, storage-backed power grid can bring jobs and investment across Australia. There are currently over 40 large-scale renewable energy projects under construction across Australia, projects which will create over 13,000 jobs (Green Energy Markets 2017), delivering $8.8 billion in new investment for regional Australia (Clean Energy Council 2017c). Modelling by Ernst and Young found that 28,000 additional jobs could be created with renewable energy growing to provide 50% of energy supply by 2030 (Climate Council 2016). The focus of renewable jobs growth will be in regional Australia. Increasing the supply of cheap renewable energy can also have significant flow-on benefits in terms of rebuilding energy system price competitiveness and assisting downstream industry energy costs.

Apart from in South Australia, where wind and solar PV already comprise over half of power generated (AER 2017), significant new energy storage is not yet a must-have for most Australian states. Indeed, the CSIRO indicates significant new battery storage is not required in Australia until wind and solar supply exceeds 30% of electricity supply (CSIRO 2017), while the Australian Council of Learned Academics has found that Australia could reach 50% renewables without a significant requirement for energy storage (ACOLA 2017).

South Australia has limited high voltage transmission lines (known as interconnections) connecting it to other states. This means the state can be vulnerable when the interconnector is not working optimally, as occurred in December 2016 due to an unplanned outage (ABC 2016a). Other states like Victoria or New South Wales have multiple interconnectors.

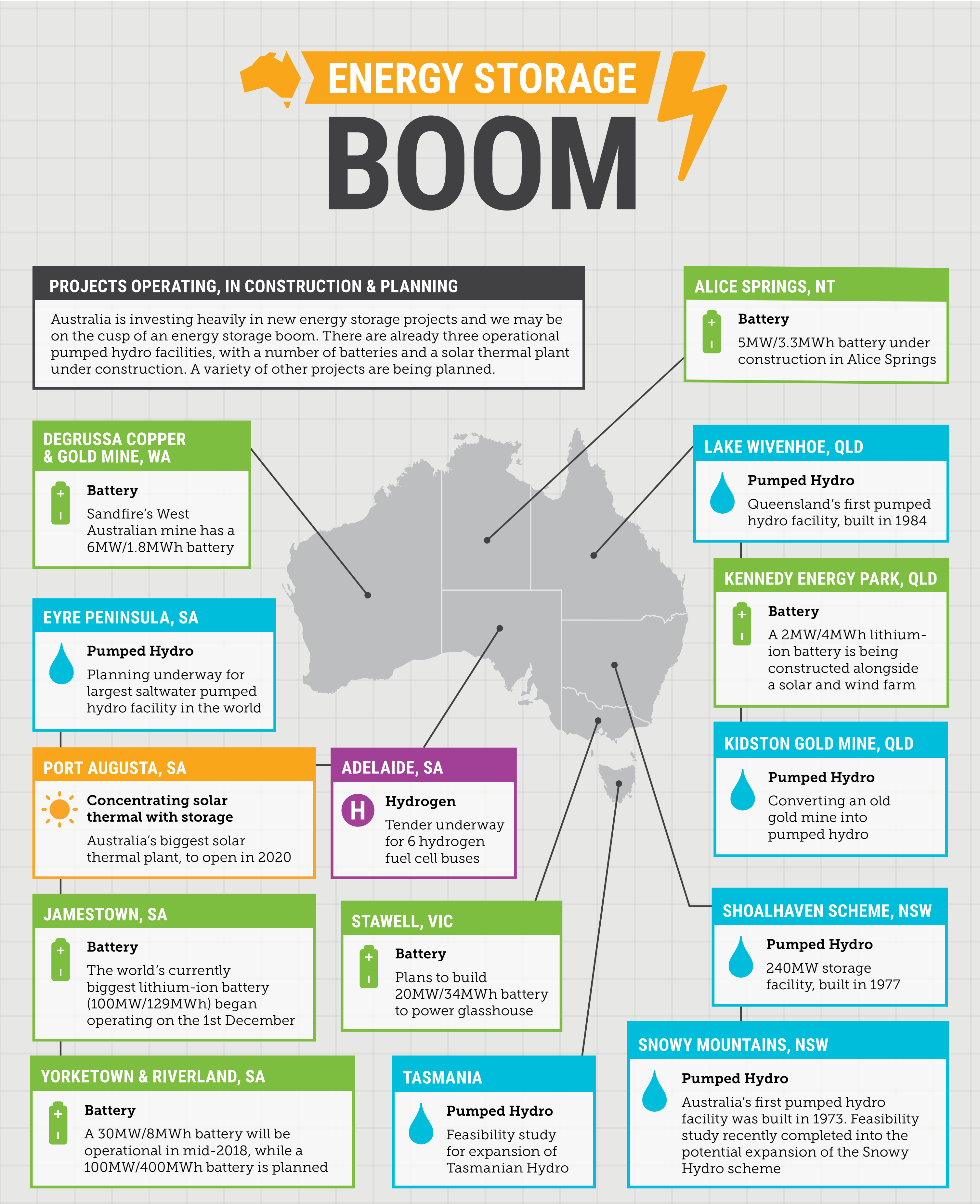
## More than 40 large-scale wind and solar projects are under construction in Australia.

As a result, South Australia is already pursuing a number of energy storage projects including large-scale batteries, solar thermal power with storage and potentially the world's second pumped hydro plant using seawater. In addition, many States and Territories, the Federal Government, residential homeowners and private companies are already putting in place plans to progressively add significant distributed energy storage across the power grid.

Just as a modern, clean electricity system relies on a mix of complementary power generation sources (solar, wind, biomass, hydro); a diverse mix of complementary energy storage technologies will help ensure a reliable, nimble renewable powered grid.

This report describes how the strategic use of distributed, utility scale energy storage in Australia's electricity grid can simultaneously ensure a secure, clean and increasingly affordable electricity supply. Section 1 will focus on the important roles that energy storage can play in providing essential grid services, such as balancing supply and demand, and providing ancillary services that ensure the power grid can safely respond to small variations in supply and demand and overcome major disturbances at particular points in the network. Section 2 will provide a technical overview of the major types of energy storage technologies such as pumped hydro, batteries and solar thermal, and the value that these storage technologies can provide to the grid. Section 3 demonstrates the cost effectiveness of energy storage technologies. The price of battery storage and solar thermal is falling rapidly while pumped hydro remains the cheapest form of large-scale energy storage. Section 4 outlines the major energy storage projects in planning and construction in Australia and identifies major opportunities for investment and job creation. See glossary at the back of this report for definitions of key terms.

Figure 1: Australia is on the cusp of an energy storage boom.




**Note:** This map does not include all storage projects planned in Australia. Only grid-scale projects are included.

# The Facts

**There is a range of misinformation about what energy storage can do and how much is needed. This section explains five key facts about energy storage that are not widely understood.**

## FACT 1. EVERY WIND AND SOLAR PLANT DOES NOT NEED 1:1 ENERGY STORAGE

Energy storage is not needed for every wind or solar plant, or on a 1:1 capacity basis. It is important that system wide planning takes account of the energy security benefits resulting from the increased diversity and geographic spread of generation technologies in determining how much storage may be needed, and where it should be located.

Demanding every wind and solar power plant to be backed up by energy storage is equivalent to requiring a large coal or gas power station to be backed up 100% to cover shutdowns – planned or unplanned. Historically in a high fossil fuelled power system, an excess of generating capacity across the electricity grid was installed to cover outages at any individual plant.

So it is with renewable energy, where each individual generating source is backed up by other diverse power sources in the system. While weather at a particular renewable power station site causes output to vary, as more renewable electricity supply is added across a broader geographic area and includes a diverse range of technology types (onshore and offshore wind, utility scale solar PV, hydro-electricity, rooftop solar and solar thermal), overall supply becomes less variable because weather systems move across the landscape.

Australia may eventually need 450GWh of energy storage to support a 100% renewable energy grid (Blakers, et al 2017). However, far less energy storage is needed with lower levels of renewable energy. For example, the CSIRO estimate that when variable renewable energy (wind and solar PV) reaches approximately 60% of total generation (today it is around 7%), the level of installed battery storage should be equivalent to just 20% of wind and solar generation capacity (CSIRO 2017). Another recent study has found that Australia could reach 50% renewables without a significant requirement for energy storage (ACOLA 2017).

Integrating renewable energy also requires greater flexibility. Storage is just one technology that provides this flexibility. Demand response management – where consumers are paid to reduce their electricity consumption at times of peak demand or lower supply – and improved transmission interconnectors between the states to transport electricity, will also significantly increase the flexibility of the power system (IEA 2017). These reforms can be pursued in conjunction with expanding energy storage.

## FACT 2. ENERGY STORAGE ENABLES HIGHER LEVELS OF RENEWABLE ENERGY TO REDUCE POLLUTION

In order to limit global temperature rise below 2°C, Australia's electricity grid will need to reach a minimum of 50% renewable energy by 2030 and zero emissions well before 2050 (ClimateWorks 2014; 2017). Energy storage – like battery storage, pumped hydro and solar thermal – will become increasingly important as Australia's electricity supply transitions to much higher levels of renewable energy.

## FACT 3. ENERGY STORAGE IS FASTER, MORE FLEXIBLE THAN COAL AND GAS

The electricity supply system must be fast and flexible, and able to respond to changes in supply and demand within seconds. This can be achieved with the addition of flexible power sources that are able to be quickly turned on and off, or ramped up and down to balance electricity supply and demand, as well as by making electricity demand more flexible through demand response management. Fast response technologies, such as batteries, pumped hydro and solar thermal, are able to respond from a cold start within milliseconds to minutes to produce electricity (IEA 2017).

Peaking gas turbine power plants can respond relatively quickly (generally within minutes) if they are already operating and at less than full power, but from a cold start they generally take much longer – it can take anywhere from many minutes to a couple of hours to reach full capacity (RenewEconomy 2017m). Coal fired power stations are even slower and they can take days to reach full output from a cold start (Engineers Australia 2017; Quiggan 2017).

Old coal power stations are relatively inflexible and increasingly unreliable as they age.

## FACT 4. BIGGER IS NOT ALWAYS BETTER

Australia needs a wide range of distributed storage technologies to ensure our future electricity grid is fit for purpose. The electricity grid would be made more resilient with a number of small storage facilities – such as small-scale pumped hydro and batteries – than with a handful of very large energy storage facilities. Distributed storage improves the flexibility and resilience of the power system by ensuring that there is a variety of energy storage facilities that can be drawn upon in the event of a disturbance.

This will become increasingly important in the future as climate change worsens extreme weather events, making the electricity grid more vulnerable to damaging heatwaves, bushfires and storms. This is already happening around the world and in Australia. In 2012, the year Hurricane Sandy hit the United States, it is estimated that the cost of power outages was between $27 and $52 billion (EESI 2017a). In South Australia, the September 2016 blackout caused by intense storms, cost businesses $367 million (ABC 2016b).

In the face of these challenges, increasing grid resilience is vital and this can be achieved by diversifying energy sources and having them distributed throughout the grid (EESI 2017a). In September 2017 in Puerto Rico, 80% of the electricity grid was damaged by Hurricane Maria. In order to restore power to the island as soon as possible, the local government are considering investing in distributed solar and batteries, which can be assembled quickly and will be more resilient to extreme weather events in the future (Washington Examiner 2018).

## FACT 5. LARGE-SCALE ENERGY STORAGE IS HERE TODAY

Large-scale energy storage is already improving the reliability and security of electricity grids in a range of countries around the world, and in Australia.

There is already over 150GW of pumped hydro around the world, contributing over 96% of the world's current installed energy storage capacity (IRENA 2017). Large-scale batteries have been in operation for several years in a number of countries, including the United States, the Netherlands and Chile, with many more under construction around the world (AES Energy Storage 2017). The Tesla-Neoen battery located at the Hornsdale Wind Farm, is already operating and improving the security and reliability of the grid. The Australian Government, and state governments in Tasmania, South Australia, Victoria, Northern Territory and Queensland are all investing in a range of large-scale energy storage solutions, including batteries, solar thermal, hydrogen storage and pumped hydro.

Large-scale energy storage is replacing polluting and expensive diesel generators in off-grid communities (ARENA 2016) and replacing gas peaking power stations in modern electricity grids (Energy Storage News 2017c).

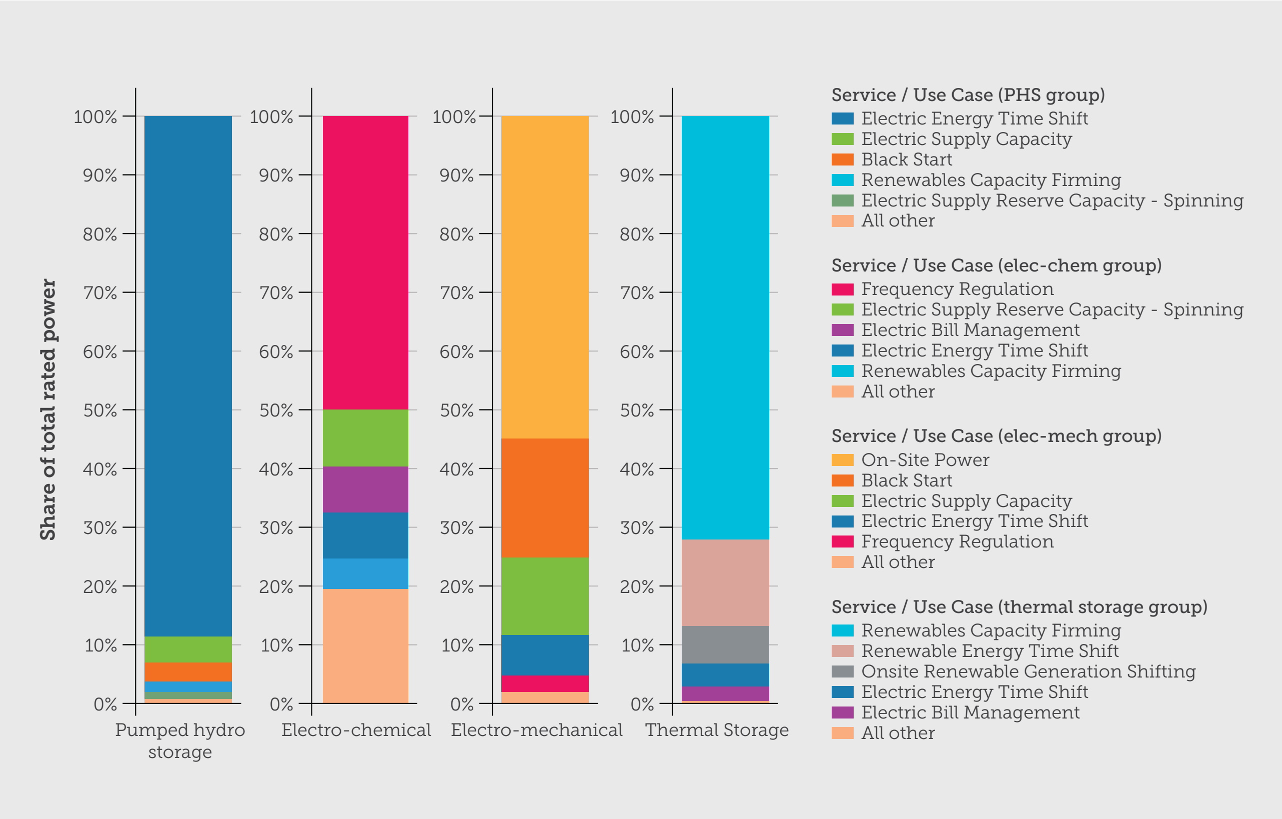
# 1. The Role of Energy Storage

**Energy storage technologies are not just about storing energy for later resupply as electricity. These technologies can provide a range of essential technical services to electricity grids (Figure 2). This section will focus on the important role that energy storage can play in providing essential grid services, such as balancing supply and demand, and providing ancillary services that ensure the power grid can safely respond to small variations in supply and demand and overcome major disturbances at particular points in the network.**

The services provided by energy storage will be increasingly important in the future. Extreme weather events, like heatwaves and storms have already increased in intensity in the last few decades (IPCC 2013; CSIRO and BoM 2015). The Australian electricity grid is vulnerable to worsening extreme weather events, having been built for a 20th century climate – not a 21st century climate. Having a variety of storage technologies distributed throughout the grid will improve the flexibility and resilience of the power system by ensuring that there is a variety of energy storage facilities that can be drawn upon in the event of a disturbance (EESI 2017a).

Energy storage technologies can provide a range of essential services to the electricity grid.

**Figure 2:** Global energy storage technologies are used for a variety of purposes. Pumped hydro is widely used for time shifting renewable generation while electro-chemical storage (eg, batteries) is mainly used for frequency regulation.




**Source:** IRENA 2017.

# 1.1 Balancing Supply and Demand

Energy storage has a cost effective role to play in managing periods of very high electricity demand, especially during summer heatwaves, smoothing out changes in renewable energy generation, and helping the grid handle the sudden loss of transmission or outages at old fossil fuelled power stations.

## MEETING PEAK DEMAND

Electricity demand varies over the course of the day. Times of high electricity use are called peak periods, whereas times of low electricity use are called off-peak periods. During the later parts of the night and early hours of the morning, electricity use is very low (off peak), while in the day and early evening, electricity use is high (peak).

Electricity demand also varies depending on the time of year. During summer and winter, electricity demand is high because people turn on their air conditioners and heaters respectively, which require a large quantity of electricity to run. In Tasmania, demand is highest in winter due to heating requirements while in other states, demand is highest in the summer (AEMO 2017c).

High levels of rooftop solar generation have significantly reduced electricity demand during the middle of the day, particularly in summer. This has led to peak electricity demand shifting from the middle of the day to the evening (Figure 3). Figure 3 illustrates that between 2012 and 2017 electricity demand in South Australia during the middle of the day – when the sun is the highest – declined dramatically.

The time during the year when peak demand is highest is called maximum demand (AEMO 2017c). This may only occur for a few hours a year but it is the time when Australia's electricity grid is most under pressure, often leading to significant spikes in wholesale electricity prices (ARENA 2015).

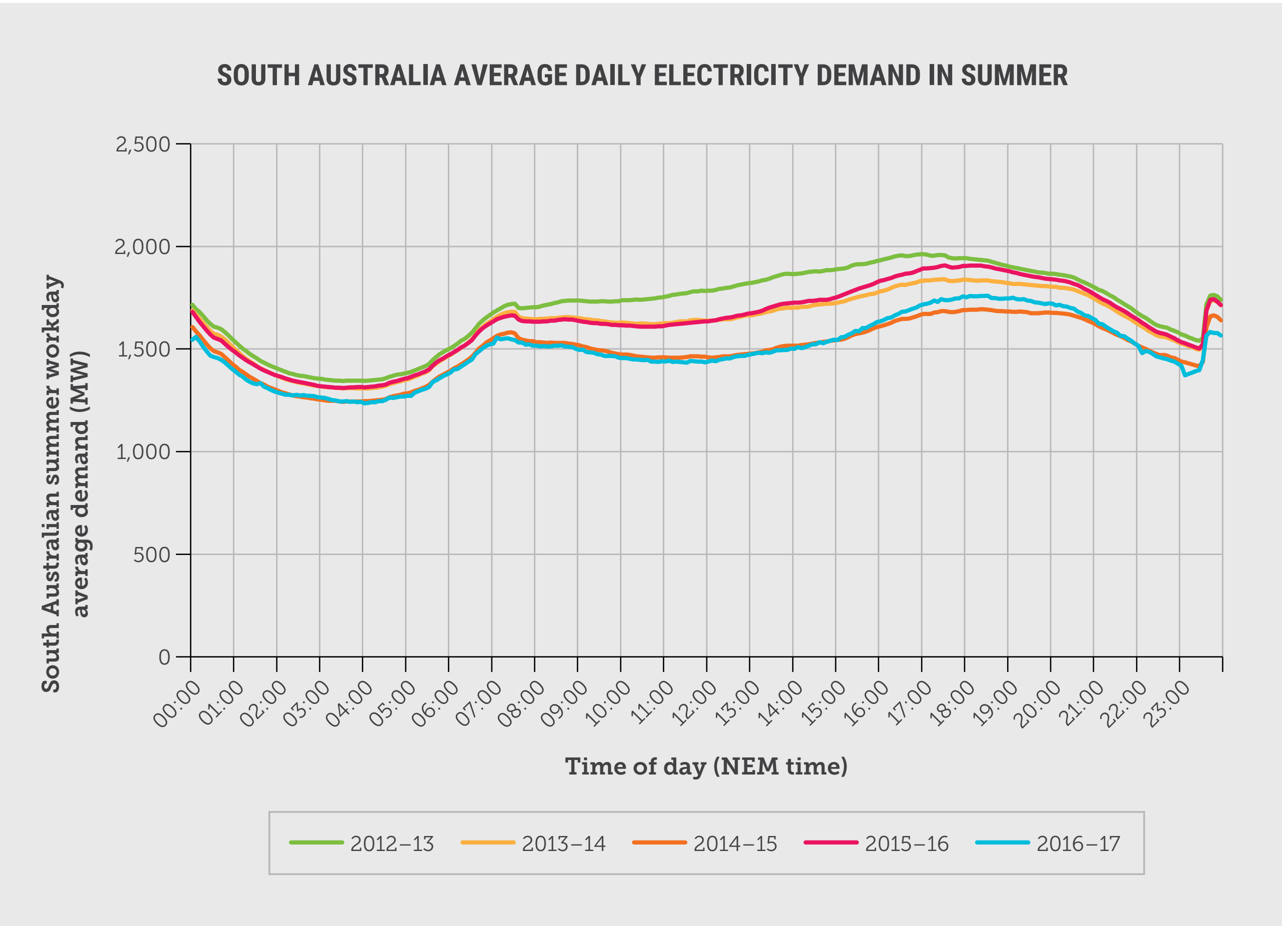
In the past, gas peaking power stations have generally provided electricity during times of maximum demand. These power stations are specifically built to operate for just a few hours a year when other generators cannot meet electricity demand. For example, the Quarantine gas power station in South Australia operated for just 7% of the time in 2015/16 and 13.5% of the time in 2016/17 (AEMO 2017h). These plants operate for short periods of time and only bid into the market when the price is high thus enabling cost recovery.

These gas peaking power stations turn on or off in response to changes in supply and demand much faster than coal fired power stations although this can vary depending upon the size and age of the turbine (IEA 2017).

Energy storage technologies can respond to fluctuations in demand much faster than peaking gas plants. They can increase their output from zero to 100% of their capacity within a fraction of a second in the case of a battery – much faster than any fossil fuel generator.

Adding storage can also assist gas-fired power plants to respond faster, by providing immediate power for short periods until the gas turbine is turned on (Box 1) (GE Reports 2017). Adding hybrid systems where solar and storage is integrated with existing gas turbines and diesel systems at off-grid locations like Australian mine sites allows fuel savings, reduced emissions and improved efficiency. Extra generators that were only used to ensure uninterrupted supply if the main unit stopped operating, can be replaced by batteries. Batteries can maintain supply until a standby turbine or diesel generator is started and brought to full capacity.

**Figure 3:** Rooftop solar in South Australia is reducing demand during the middle of the day.




**Source:** AEMO 2017. **Note:** The peak in demand at 23:30 hours reflects settings on electric hot water heating systems. These systems are often set to turn on at night, in part due to a historic need to use constant power generated from inflexible, coal fired generators.

## Energy storage can help make electricity clean, reliable and secure.

**Figure 4**: Benefits of energy storage.

# ENERGY STORAGE

## CAN HELP MAKE ELECTRICITY:

### → CLEAN

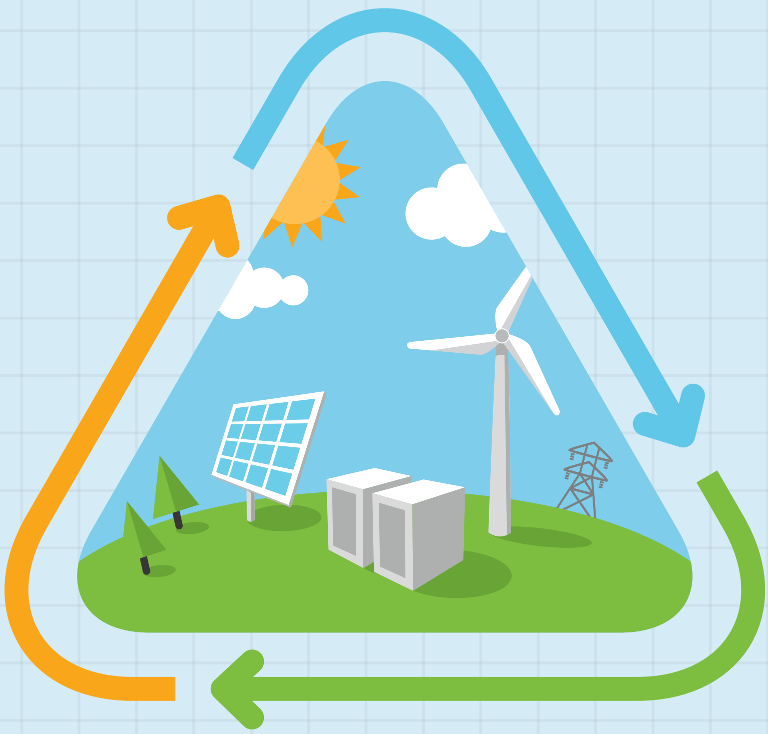
Energy storage can help Australia **transition to a clean electricity grid** powered by wind and solar.

### → RELIABLE

Energy storage can **ensure reliable electricity**, when the wind doesn't blow and the sun doesn't shine.

### → SECURE

Energy storage can **provide crucial grid services** that ensure the lights stay on.



## BOX 1: BATTERIES REDUCING POLLUTION IN CALIFORNIA

**In April this year, electricity utility Southern California Edison built a 10MW battery to add to a pre-existing 50MW gas turbine.**

The gas turbine is capable of producing power for several hours but it takes five minutes to reach full power. The new battery can only produce power for 30 minutes but it can respond far more quickly than the gas turbine. The addition of a battery to the gas turbine significantly improves the flexibility of the power system while reducing emissions by 60% (GE Reports 2017).

## MATCHING SUPPLY FROM RENEWABLE ENERGY WITH DEMAND

Renewable energy generators, like wind and solar, are variable, producing electricity when the wind is blowing and the sun is shining. Perhaps counter-intuitively, as more wind and solar power is added to an electricity grid, and spread over a wider geographic area, wind and solar become more predictable and more reliable (IEA 2017). This is because weather systems move across landscapes, bringing changing wind and cloud conditions. So while there may be no wind in one particular part of the grid, it is likely there will be wind elsewhere in the grid.

Energy storage can complement high levels of wind and solar power in an electricity grid by storing excess renewable energy (for example, at times of high wind or sunshine). Storage technologies can save electricity when supply is high and demand is low, and release it during periods of higher demand and lower supply. Energy storage will enable the electricity grid to cost-effectively handle variability in renewable energy generation (Box 2).

For households with solar PV, batteries can be very effective at shifting peak demand to later in the evening or even into the early morning, provided the battery has enough storage capacity relative to the household's demand. This effect will become significant as battery uptake increases, helping the rest of the grid to manage peak demand well into the evening.

This has become particularly important in South Australia. Due to the significant amount of rooftop solar generation in the state, AEMO forecast that by 2027-28 all electricity demand will be more than met by rooftop solar during the middle of the day (AEMO 2017e). Energy storage will be able to store this excess generation and then discharge it during periods of higher demand after the sun sets. Combined with increased transmission and demand response management, this will help balance the system.

Batteries can respond to changes in supply and demand in fractions of a second.

## BOX 2: EXTREME BIDDING IN THE ELECTRICITY MARKET

**The current bidding and settlement system of the National Electricity Market (NEM) favours slower fossil fuel generators over more flexible renewable energy and storage. Reforming the bidding and settlement system would "level the playing field" with renewable energy and storage and could help reduce electricity prices.**

The NEM is managed by the Australian Energy Market Operator (AEMO) to facilitate the transfer of electricity from generators to consumers (AEMO 2017f). The NEM has a spot market, where generators offer to supply a certain amount of electricity for a set time period at a certain price. AEMO assesses these bids and decides which generators will be called upon to produce electricity, with the cheapest generator called upon first. The price of electricity at any given time is determined by the highest cost generator that is called upon to produce electricity (AEMO 2017f).

The prices that are paid to electricity generators in the NEM are decided every 30 minutes. However, generators make bids every five minutes. This means that the price that is set for the entire 30-minute interval and generators are paid based on an average of the highest cost bid in each of the five-minute periods.

**This means that if there is a very high bid for just one five-minute interval, prices can be gamed to remain high for the whole 30 minutes.**

This has led to accusations that some generators, especially gas power stations, are engaging in "strategic late bidding". This involves withdrawing electricity generation for just five minutes, which can send wholesale electricity prices in the NEM sky-rocketing (AER 2017a). This behaviour has contributed to the significant rise in wholesale electricity prices over the past few years (SunMetals 2015).

This system of five-minute bidding and 30 minute settlements restricts more efficient and flexible energy storage technologies from getting the most benefit from the wholesale market.

The Australian Energy Market Commission (AEMC) has considered reducing the 30-minute settlement period to 5 minutes, bringing it into line with the 5-minute dispatch interval and making the system fairer. In September, the AEMC decided to delay the introduction of the 5-minute settlement period rule until 2021. Until this system – which favours slower fossil fuel generators over more flexible renewable energy and storage – is reformed, Australia will not get the full suite of benefits from energy storage technologies. Changing the electricity market bidding and settlement system would level the playing field for renewable energy and storage and could help reduce electricity prices.

# 1.2 Ancillary Services

As well as storing and dispatching energy, storage technologies have a key role to play in meeting technical requirements for grid stability (described by terms such as "frequency control" and "inertia"), ensuring the power grid can overcome disturbances.

These grid stability services are collectively referred to as ancillary services. Ancillary services are purchased and managed by the AEMO to maintain the safety, security and reliability of the electricity grid. There are three categories of ancillary services and the most relevant category for energy storage are frequency control ancillary services (FCAS) (AEMO 2015).

AEMO manages FCAS to maintain frequency in the electricity system at a steady level, keeping supply and demand in balance (AEMO 2015). This role is particularly important when there are unplanned outages.

However, an absence of competition in the ancillary market and a reliance on expensive gas (a traditional way of providing these services) has led to extreme spikes in the cost of FCAS services, contributing to rising power bills for consumers (Box 8) (AER 2017b). At certain times, just 1MW of extra FCAS supply has been priced by gas generators as high as $13,000/MW, pushing up the costs of FCAS by millions of dollars (AER 2017b).

Grid-scale batteries like the Tesla-Neoen battery, and other storage technologies in South Australia, can play a key role in reducing these extreme price spikes in the ancillary market (Box 4). Already the Tesla-Neoen battery has provided frequency control services on numerous occasions, helping to respond to outages at coal power stations (The Conversation 2018). The battery is also increasing competition in the South Australian FCAS market. In December 2016, the cost of one type of FCAS (called raise and lower regulation) was $502,320 but this is estimated to have fallen to just $39,661 in December 2017 - after the battery began operating (SMH 2018).

Grid-scale batteries and other energy storage technologies may help reduce extreme prices in South Australia.

## BOX 3: AUSTRALIAN'S HAVE A STRONG KNOWLEDGE OF ENERGY STORAGE

**As the relationship between consumers and energy supply changes, the public's knowledge of energy storage is also increasing (Climate Council 2017).**

In September 2017, the Climate Council commissioned a ReachTEL poll that asked the public questions about a number of energy storage technologies. The poll found that 74% of people polled from across Australia expect household batteries to be commonplace in homes in the next decade. When asked about the key motivation for adding a battery to rooftop solar power systems, over half said to "reduce power bills."

As well as the acceptance of household storage, the poll also explored the public's understanding of the role of large-scale energy storage. The majority polled (55%) thought large-scale batteries, would become commonplace in a decade.

More than half of those polled (52%) also understand that large-scale energy storage, like pumped hydro and batteries, enables wind and solar to provide power 24/7, on demand.

When asked what is the key benefit that large-scale batteries deliver, respondents said:

- Making our energy system more reliable (25%)
- Making our electricity cheaper (24%)
- Making our system more efficient (19%).

## BOX 4: SOUTH AUSTRALIA'S BIG BATTERY - WHAT HAS IT BEEN UP TO?

**The “big battery” is now over two months old. So what has it been up to?**

The 100MW/129MWh Tesla-Neoen battery has already demonstrated how it can improve the reliability and security of the electricity grid, helping to meet peak demand and providing grid stability services.

Although the battery was officially scheduled to open on the 1st of December 2017, it was called on by AEMO to begin operating a day early in order to help meet peak electricity demand. The battery ended up discharging as much as 59MW of electricity into the grid (ABC 2017f).

Since then, the Tesla-Neoen battery has demonstrated the huge versatility of batteries and their potential to improve the security of Australia’s ageing electricity grid. Already the battery has been used on numerous occasions to provide grid stability services, such as stabilizing the frequency of the electricity grid when fossil fuel plants experience faults.

On one occasion, a unit at the Loy Yang A brown coal power station in Victoria unexpectedly tripped, resulting in 560MW of electricity being withdrawn from the electricity grid. This caused a rapid drop in grid frequency. Within milliseconds of the fault, the battery responded by discharging electricity into the grid, stabilizing the fall in frequency (Reneweconomy 2017n).

Despite being located near the end of the grid in South Australia, the whole of the NEM is benefiting from the Tesla-Neoen battery. The electricity system will become more resilient to disturbances and unexpected faults at fossil fuel power stations when more batteries begin operating around Australia.

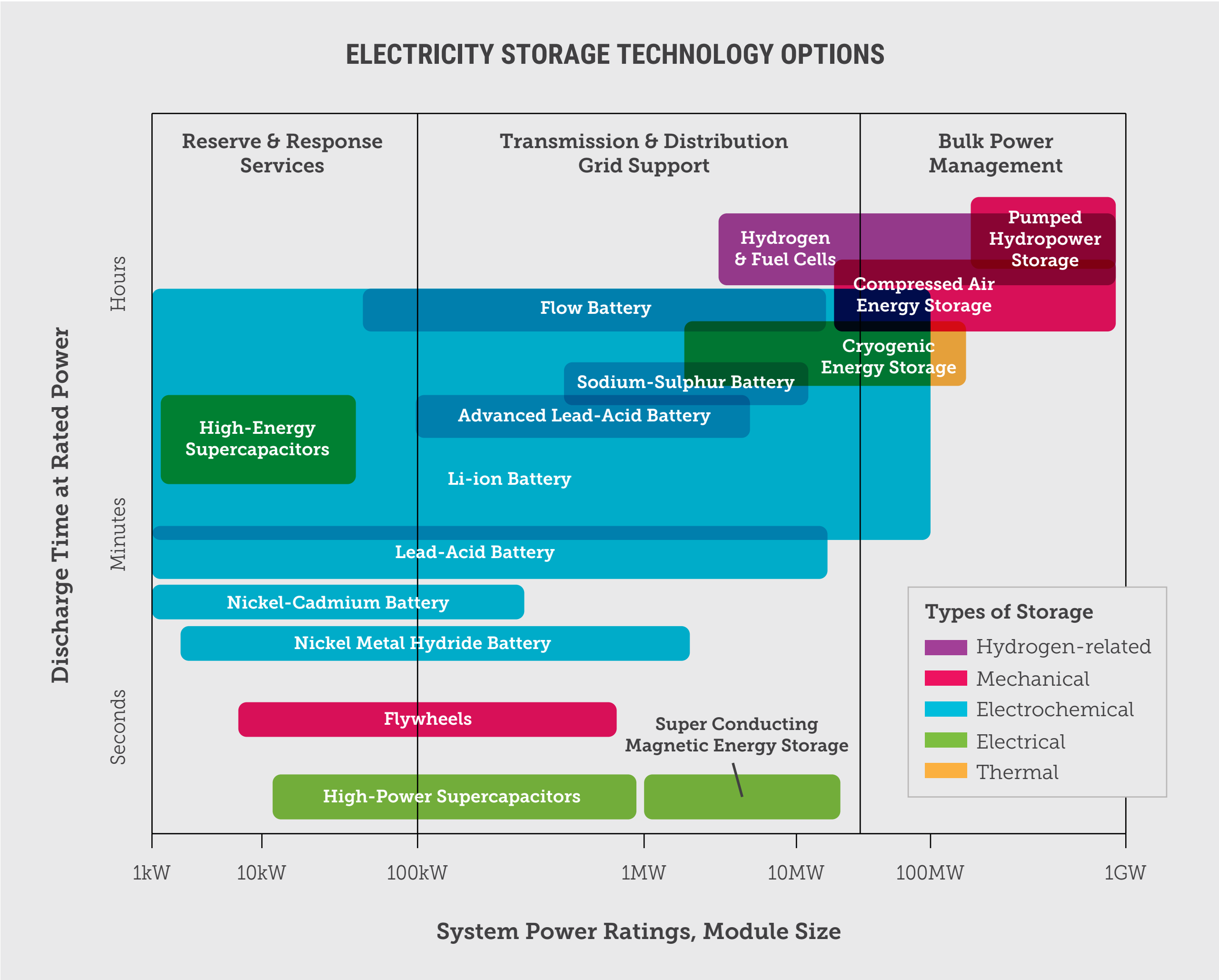
# 2. Storage Technology

There are a variety of different energy storage technologies. Some of these technologies, like pumped hydro and lead-acid batteries, are long established technologies whose effectiveness has been proven over the past century. Other technologies, like lithium-ion and flow batteries, are relatively new to large-scale applications. This section will provide an overview of the major types of energy storage technologies and the value that these storage technologies can provide to the grid.

All energy storage technologies have in common the ability to store energy for an extended period of time and then dispatch it when it is needed. However different storage technologies are better suited to different functions. A range of complementary energy storage technologies can ensure the electricity grid is reliable and flexible.

All energy storage technologies consume more electricity from the grid than they give back. Therefore, it is vital that the electricity that storage technologies draw from the grid is produced by renewable energy like wind and solar power, not by polluting coal or gas power stations. If the electricity stored comes from coal or gas, the losses in charging, storing and then discharging electricity will in effect increase pollution from coal and gas power stations.

**Figure 5:** Energy storage technologies can provide a range of services.




**Source:** Adapted from Liebreich 2015.

# 2.1 Types of Storage Technologies

## BATTERY STORAGE

Batteries are an electrochemical form of storage that are suited to responding very quickly to smaller changes in electricity supply and demand (Figure 6). The fastest growing form of battery storage for energy is lithium-ion batteries. These batteries have a high charging efficiency and low self-discharge. Lithium-ion batteries are also rapidly falling in costs and there has been significant uptake of batteries at both the household and grid-scale level (Lazard 2016). The modularity of batteries enables them to range from very small installations including just one battery (such as in households) to installations including thousands of batteries (such as South Australia's Tesla-Neoen battery). This also means they can be built alongside new wind and solar plants or retrofitted onto existing plants, effectively making these wind and solar plants dispatchable.

Since the nineteenth century, electricity has been stored in lead-acid batteries.

Lead-acid batteries are cheap but not very efficient compared to other more modern types of batteries. However, advanced lead-acid batteries have been developed that leverage older lead-acid battery technology with modern supercapacitors.

The latter store energy in a static charge, meaning they can be charged and discharged a much greater number of times (Lazard 2016), but at this stage of development, these advanced lead-acid are relatively limited in scale.

Figure 6: A battery storage installation in Sydney's Stucco apartments. Batteries are modular and can be upscaled or downscaled depending upon the quantity of storage that is required.

# Batteries can respond almost instantly to small changes in electricity supply and demand.

Compared to pumped hydro, which lasts many decades, current battery storage systems generally operate for one or two decades. The more times a battery is charged and discharged, the quicker it will degrade. However, this can be overcome by changing out battery system modules, so that system capability is maintained and battery system life can effectively become perpetual.

Flow batteries contain two electrolyte solutions in two separate tanks, which flow through two independent loops. A current is created when electrons travel from a negative solution to a positive solution across a membrane. Flow batteries have a 100% depth of discharge, meaning they can release 100% of their energy capacity (compared to 90-95% for lithium-ion and 50% for lead acid – Table 1) (IRENA 2017).

Flow batteries can also last indefinitely, in contrast to lithium-ion batteries that last for up to 10,000 cycles and lead-acid batteries for 1,500 cycles (IRENA 2017). Flow batteries are being produced in Australia by both Australian Vanadium and Redflow (Australian Vanadium 2017; Redflow 2017).

**Table 1:** Characteristics of Major Battery Storage Technologies in 2016.

| Battery Type | Depth of Discharge | Round Trip Efficiency | Life Cycles |
|---|---|---|---|
| Lithium-ion | 90-95% | 92-96% | 1,000-10,000 |
| Flow | 100% | 70% | 10,000+ |
| Lead-acid | 50% | 80-82% | 1,500 |

**Sources:** IRENA 2017.

# Pumped hydro is the most common type of energy storage worldwide.

## PUMPED HYDRO AND OTHER TYPES OF MECHANICAL STORAGE

There is a range of mechanical storage technologies which use potential energy storage and convert this into kinetic energy to generate electricity. The largest capacity and most widely installed globally of these mechanical storage systems is pumped hydro, but there are other forms of potential/kinetic energy storage including compressed air storage and flywheel systems.

Pumped hydro is the most widely deployed large-scale energy storage technology (IRENA 2017). It makes use of two vertically separated water reservoirs. Low cost off peak electricity is used to pump water from the lower to the higher reservoir. Once the water has been pumped up to a higher level, it runs as a conventional hydro power plant producing electricity, such as during periods when electricity prices are high. Pumped hydro utilises existing hydropower technology and typical schemes have a capacity of several hundred megawatts (Box 6) (Lazard 2016). To put it simply, energy is used to pump water from one reservoir to a higher reservoir. When energy is needed water is released driving a turbine.

There are already three operational river-based pumped hydro facilities in Australia: Wivenhoe, north-west of Brisbane (500MW; refer to Figure 7), Shoalhaven in New South Wales (240MW) and the Tumut 3 power station in the Snowy Mountains (1800MW).

## BOX 5: WILL SNOWY 2.0 BE GOOD FOR TACKLING CLIMATE CHANGE?

**Like all other storage technologies, pumped hydro is a net energy consumer – energy storage technologies consume more electricity from the grid than they give back. It is vital that the electricity that storage technologies use from the grid is not generated from polluting coal or gas power stations.**

Most conventional pumped hydro systems have a round-trip efficiency of around 80%. This means they use 20% more electricity than they generate. This is because pumped hydro consumes electricity in order to pump the water uphill again to recharge the system (ESA 2017b). However, the Snowy 2.0 project, with a capacity of 2,000MW, would have a far lower round-trip efficiency at just 67%. This means Snowy 2.0 would use one third more electricity than it would generate (Snowy Hydro 2017). This doesn't include losses from transmission, which would reduce efficiency even further.

With such a low efficiency, a significant amount of the electricity supply for Snowy 2.0 needs to come from renewable energy for the project to be less polluting than a peaking gas plant. However, Victoria and New South Wales (where Snowy 2.0 is located) currently have very low levels of renewable energy and electricity supply is highly unlikely to reach 60% by the time Snowy 2.0 opens in 2025. This means Snowy 2.0 could be as polluting – if not more so – than a gas peaking plant (because the electricity to pump the water comes largely from coal).

To reduce electricity sector emissions, large-scale pumped hydro should be constructed alongside major investments in new renewable energy. Otherwise, pumped hydro can make fossil fuel power even more polluting. For the Snowy 2.0 scheme, this is only assured if New South Wales and Victoria have very much higher levels of renewable energy than at present.

Energy storage technologies should be fit-for-purpose, incorporate a mix of available technologies and ideally be distributed around the grid. There is a risk that the Snowy Hydro 2.0 proposal would concentrate a large amount of energy storage in one location, would take many years to build and focuses on just one technology vulnerable to droughts and transmission failures. A more resilient system would see a range of energy storage technologies distributed throughout the electricity grid where needed.

Australia has 22,000 potential pumped hydro sites.

## BOX 6: THE POTENTIAL OF SMALL-SCALE PUMPED HYDRO IN AUSTRALIA

**A recent study by the Australian National University (2017) found that Australia has no shortage of sites that could be developed for small-scale pumped hydro, with 22,000 potential sites around the country. These sites have a combined storage capacity of 67,000GWh – vastly greater than Australia's energy storage needs.**

Only 450GWh (450,000MWh) of pumped hydro storage is required to back up an electricity grid with 100% renewable energy – equivalent to just 0.1% of the sites identified in this study (ANU 2017). This would eliminate Australia's reliance on coal and gas fired power stations. The small-scale of these sites also means that they can be constructed more quickly than large-scale pumped hydro projects (ANU 2017).

Hundreds of these small-scale pumped hydro sites are located comparatively close to demand, significantly reducing the need for major new transmission. Moreover, because these sites are not river based, many are not located in environmentally sensitive areas (Blakers, et al, 2017). An example of this is the Kidston pumped hydro project in North Queensland, which utilises an old gold mine and will have a minimal impact on the environment (Genex Power 2017).

**Figure 7:** Wivenhoe Dam spillway in Queensland, built in 1984.

Other forms of mechanical energy storage include compressed air storage (CAS) and flywheels. CAS uses electricity to compress air into confined spaces (such as disused underground mines or salt caverns) where the air is pressurised and stored. When required, this air is then released to drive a turbine and produce electricity. It is also possible for electric motors to drive the air compressors, which can be powered by renewable energy. CAS is low cost, can be flexibly sized and the technology is well-developed. However, it is dependent on suitable geology (Lazard 2016). CAS is well-suited to providing bulk power but it is not as good at providing fast response as other storage technologies.

Flywheels spin at high speeds, storing electricity as rotational kinetic energy, which is then released by decelerating the flywheels' rotor and generating electricity. Flywheel energy can be released slowly or in quick bursts, depending on the type of flywheel technology. Flywheels are best suited to providing small quantities of energy very quickly. They require minimal maintenance, can operate for over 20 years and have a high depth of discharge (Lazard 2016).

## THERMAL STORAGE

Thermal storage stores energy as heat (or cold) in materials such as concrete or rock (eg, in passive heating of dwellings), water (eg, domestic hot water systems), or in materials such as molten salts (eg, in solar thermal power plants or cool stores). Thermal storage is often low cost, flexible and can be deployed at large-scale and in a widely distributed manner to improve grid stability and reduce the costs of transmission capacity upgrades. A form of thermal storage is already used in solar heating systems and air conditioning (Lazard 2016).

The domestic electric hot water system is a simple and historically widespread application that was used to store electricity produced by "baseload" coal power stations. Hot water systems turned on over night to allow inflexible power stations to operate throughout the night when demand was otherwise low. The hot water was then used during the day. This essentially shifted electricity demand for heating from day to night.

More recently, thermal storage is being paired with concentrating solar plants (CSP) to produce electricity from sunlight for up to 24 hours a day. A concentrating solar plant converts solar energy into electricity by using the sun's rays, reflected from a solar mirror field of panels (Figure 8) to boil water to make steam, or heat molten salt. The molten salt in turn is also used to generate steam, to drive a turbine and a generator. If the mirror field is expanded in size, the surplus heat energy collected can be stored as hot molten salt until night, or when it is overcast, and then used to generate more power, so providing power up to 24 hours a day (Pelay et al 2017; SolarReserve 2017).

There are an extensive number of thermal storage materials but one of the best is molten salt. Molten salts are stable at high temperatures and are neither toxic nor flammable (Pelay et al, 2017).

**Figure 8:** Crescent Dunes solar thermal farm in Nevada. Solar thermal farms store the energy they produce, so they can provide reliable power 24/7.

## HYDROGEN STORAGE

Hydrogen storage involves using excess electricity to drive electrolysis; the separation of water into oxygen and hydrogen molecules. The hydrogen that is produced is then captured, stored and later fed into a gas turbine power plant or fuel cells to make electricity (Figure 9). Some industrial plants can also use hydrogen directly for chemical processes. Hydrogen storage stores energy for extended periods and is more suited to providing bulk power than rapid response. The technology has not yet been widely adopted (BNEF 2017b) although some regions with high levels of variable renewables, such as Germany and South Australia, are investing in or investigating the potential use of hydrogen to generate electricity from renewable energy, or run transport fleets, like buses (Our Energy Plan 2017).

**Figure 9**: The Maritime Hydrogen Fuel Cell project in Honolulu, Hawaii. This hydrogen fuel cell consists of four 30 kilowatt fuel cells that are capable of providing bulk power.

## BOX 7: CONSTRUCTION TIMELINES FOR STORAGE TECHNOLOGIES

**Energy storage projects can be constructed in very short periods of time compared to gas and coal fired power stations.**

New energy projects have to go through a number of stages before they can start operating including feasibility studies, planning approvals, construction and grid connection. In the case of batteries, this whole process can take as little as a few months (Table 2). This is why batteries are ideal for quickly adding energy storage to the grid, such as the Tesla-Neoen battery which was already storing electricity from the grid just two months after construction had started (ABC 2017a).

Solar thermal can be assembled within two to three years, while pumped hydro usually takes between two to four years to construct after completing an environmental impact statement, depending upon the scale of the project. All these storage projects can be constructed far more quickly than any coal or gas fired power station, which take six years or longer before they can begin operation (Table 2).

Snowy 2.0 is a mega-project which will take at least 7 years to build - similar to a coal or gas power station (Snowy Hydro 2017). Complex projects of this size are prone to delays so construction could take even longer.

**Table 2:** Construction timelines for storage technologies compared to coal and gas.

| Technology | Timeline from feasibility to completion |
|---|---|
| Large-scale battery storage | 4-6 months[1] |
| Solar thermal | 2-3 years[2] |
| Pumped hydro | Environmental impact assessment 1 year + 2-4 years to build[3] |
| Coal or gas power station | 6 + years |
| Snowy 2.0 Pumped Hydro | 7 years[5] |

Sources:

[1] Energy Storage News (2017) How California pulled off the world's fastest grid-scale battery procurement – Part 2. 3 May 2017. Accessed at: https://www.energy-storage.news/blogs/how-california-pulled-off-the-worlds-fastest-grid-scale-battery-procurement. ABC News (2017) Elon Musk: Tesla reaches halfway point of construction on 'world's biggest' battery. 30 September 2017. Accessed at: http://www.abc.net.au/news/2017-09-29/elon-musk-tesla-world-biggest-battery-reaches-halfway-mark/9001542.

[2] Premier of South Australia (2017) Port Augusta Solar Thermal to boost competition and create jobs. 14 August 2017. Accessed at: https://www.premier.sa.gov.au/index.php/jay-weatherill-news-releases/7896-port-augusta-solar-thermal-to-boost-competition-and-create-jobs.

[3] Snowy Hydro (2017) Snowy 2.0 Feasibility Study. Accessed at: http://www.snowyhydro.com.au/our-scheme/snowy20/snowy-2-0-faqs/.

[4] NSW Business Chamber (2009) Powering NSW. Accessed at: http://businesschamber.com.au/NSWBC/media/Misc/Lobbying/Submissions/Powering_NSW.pdf.

[5] Snowy Hydro (2017) Snowy 2.0 Feasibility Study. Accessed at: https://www.snowyhydro.com.au/our-scheme/snowy20/snowy-2-0-feasibility-study/.

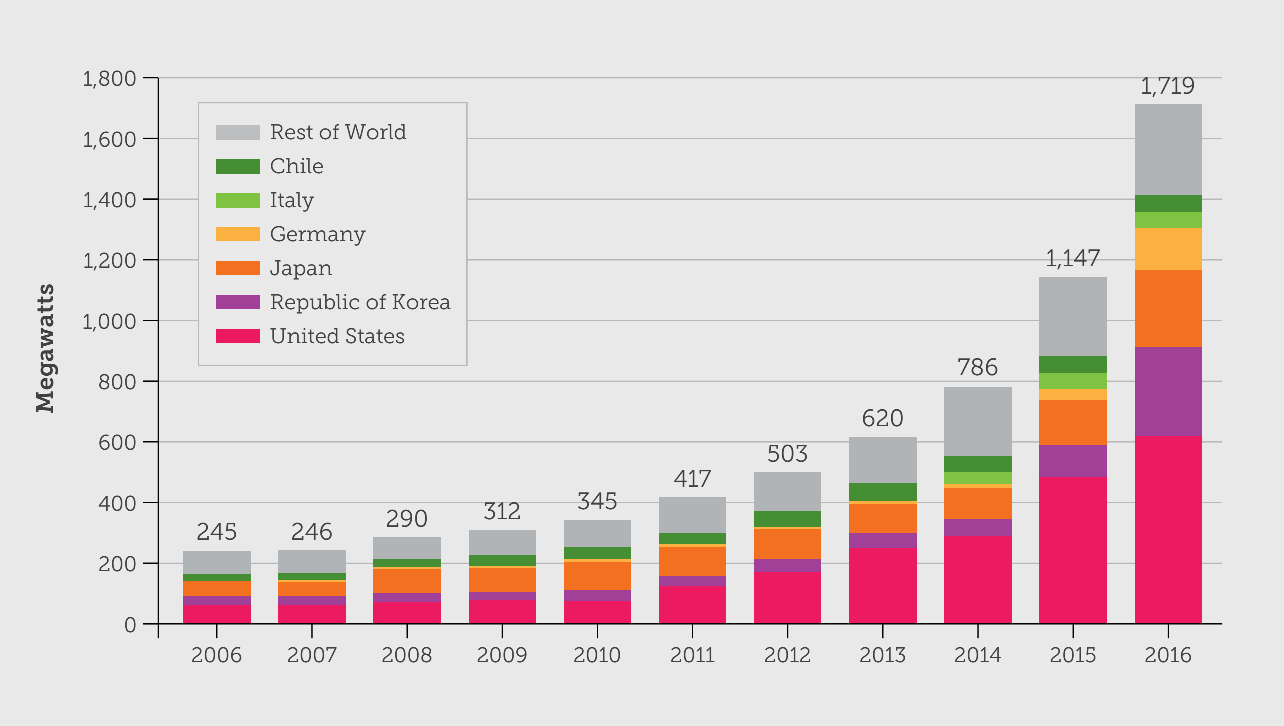
# 2.2 Attributes of Different Storage Technologies

## BATTERIES

Battery systems are well suited to providing support for the electricity network at household and grid scale. Batteries are well suited to storing small amounts of energy and discharging for shorter periods of time, although this will vary depending on the size and type of battery (AECOM 2015) as well as the power demand it is being called upon to supply. Batteries can provide a range of services to the grid and their modularity and quick assembly has made them a popular energy storage technology (Figure 10).

Batteries can also provide rapid response services to the electricity grid, called fast frequency response. Rather than responding to changes in frequency in minutes like other generators, batteries can respond in a fraction of a second. This enables better management of frequency and allows the electricity system to handle lower levels of inertia from coal and gas power stations (Clean Energy Council 2017d). Since it began operating, the Tesla-Neoen battery has already demonstrated how quickly batteries can respond to fluctuations in frequency. In December, the battery responded in a matter of milliseconds to stabilise the frequency of the grid after a unit at the Loy Yang A brown coal power station in Victoria unexpectedly faulted - despite being located nearly 1,000km away (Reneweconomy 2017n). However, the design of the ancillary market - which provides these frequency control services - currently does not recognize the value of fast frequency response provided by batteries (Box 8). In order for the electricity system to get the full range of benefits from batteries, the market design around fast frequency response should be reformed (Clean Energy Council 2017b).

**Figure 10:** Global grid-connected battery storage capacity by country, 2006-2016.




**Source:** REN21 (2017) Renewables 2017 Global Status Report (Paris: REN21).

## BOX 8: HOW BATTERIES CAN REDUCE EXTREME PRICES IN SOUTH AUSTRALIA'S ANCILLARY MARKET

**As well as storing and dispatching energy, storage technologies have a key role to play in meeting technical requirements for grid stability (described by terms such as "frequency control" and "inertia"), ensuring the power grid can overcome disturbances.**

One group of grid stability services are called frequency control and ancillary services (FCAS).

In South Australia, FCAS services were provided by just four gas power stations, all owned by major electricity companies Origin Energy, AGL and Engie. These companies are unique in that they own a significant amount of electricity generation while also selling electricity to consumers. When the Heywood interconnector – the transmission line that connects South Australia's electricity supply with Victoria – is not operating, AEMO needs 35MW of capacity in South Australia to provide these essential FCAS grid services. Between the four gas power stations, there are 386 to 446MW of electricity available (AER 2017b).

But over the past 18 months, there have been seven extreme price spikes due to a shortage of FCAS supply.

On 9 November 2016, the four gas power stations only made 34MW of FCAS available at a reasonable price. AEMO only required an extra 1MW to provide enough FCAS to ensure grid stability but the generators would only supply this last megawatt at an extremely high price. As a result, the cost of FCAS surged to $6,500/MW for over 14 hours (AER 2017b). Similar events occurred on 6 other occasions (AER 2017b).

Energy storage, like South Australia's 100MW/129MWh Tesla-Neoen battery, could significantly reduce the number of these price spikes if it provides FCAS at lower prices than the existing suppliers.

Since it began operating, it appears that the Tesla-Neoen battery may already be reducing the cost of FCAS. The cost of one type of FCAS (called raise and lower regulation) is estimated to have fallen to just $39,661 in December 2017, compared to $502,320 one year earlier before the battery began operating (SMH 2018).

On one day in 2016, electricity generators charged $6,500 to supply just 1 megawatt of extra power for frequency control.

## PUMPED HYDRO

Pumped hydro is the most widely used large-scale energy storage technology with at least 150GW of operational capacity at the end of 2016 (IRENA 2017).

Pumped hydro is a mature technology that has been around since the 1890s and it is the cheapest form of large-scale storage (Blakers, et al, 2017). This also means that costs are not expected to fall materially in the future. Although construction costs are high, pumped hydro benefits from economies of scale and they can operate for 40 to 60 years (compared to 10 to 20 years for lithium-ion batteries) (IRENA 2017). Pumped hydro also helps manage system stability and can reduce the occurrence of negative wholesale electricity prices by creating use at times of low demand (such as in the early hours of the morning) or when very high levels of renewable energy are being generated that would otherwise be “spilled” (ie. wasted).

Pumped hydro can be an important part of Australia’s energy system, providing bulk electricity for long periods. However, projects must be strategically located. Historically they have been located as an adjunct to existing hydro dams on river systems but they can also be located off-river between two dams with differing elevations or in disused mine pits, such as the Kidston gold mine (Figure 19).

Large-scale pumped hydro projects may also need to be supported by major upgrades in the transmission network in order to transport the extra energy from pumped hydro to the major population centers where it is needed. If an existing hydro system is used (such as in Tasmania), or a site is located near an existing abandoned mine (such as the Kidston gold mine) then this may not be the case. But if it is a major expansion of an existing hydro power station (such as Snowy 2.0) or it is a new storage facility that is not near existing power stations, transmission expansion will be required.

Small-scale pumped hydro can be more feasible than large-scale pumped hydro as there are a larger variety of possible sites, reducing the amount of new transmission required. There are 22,000 possible small-scale hydro sites located along Australia’s east coast, many of which are located relatively close to population centres, transmission lines and generation sources (Box 6). Upfront construction costs and environmental impacts are also lower (Blakers, et al, 2017). However, small-scale pumped hydro does not benefit from economies of scale in the same way as large pumped hydro projects.

96% of the world’s energy storage capacity is pumped hydro.

## THERMAL STORAGE

Thermal storage is suited to a wide number of applications and it is already widely used in domestic hot water systems. With the increasing uptake of concentrating solar power plants, thermal storage is increasingly used to store solar energy, ensuring these power plants can provide power 24 hours a day – even when the sun is not shining.

Although these plants can only directly store the energy they generate, they can store this energy when other wind and solar farms are producing a high amount of electricity and discharge it when renewable energy production is lower (Reneweconomy 2017d). The end result is similar to having a battery or some other form of storage directly storing electricity from a solar and wind farm. This means that solar thermal plants can in effect store electricity from other wind and solar plants.

There are not many concentrating solar plants with thermal storage operating around the world but new projects are being constructed in Australia, South Africa, Morocco, Chile and China. South Australia has recently invested in a concentrating solar plant with molten salt storage at a cost of no more than $78/MWh. This plant will provide a number grid services, including high electricity output over a short period to meet demand (Reneweconomy 2017d).

## HYDROGEN STORAGE

Despite having low levels of efficiency – only 30 to 40% of the energy injected into a hydrogen storage system is delivered – hydrogen storage has a large capacity compared to small-scale batteries. There are two large hydrogen storage facilities operating in Texas, with a third under construction. A range of American and European companies also provide hydrogen technology for small sites and offshore islands (ESA 2017a).

The South Australian Government is pursuing hydrogen storage, with a tender for at least 6 hydrogen fuel cell buses to be used by Adelaide Metro. The winner of the tender will have to produce hydrogen for the buses and build refuelling infrastructure (Our Plan 2017). The government have also developed a hydrogen roadmap as part of the state's transition to a low emissions economy (Our Plan 2017).

# 3. Prices

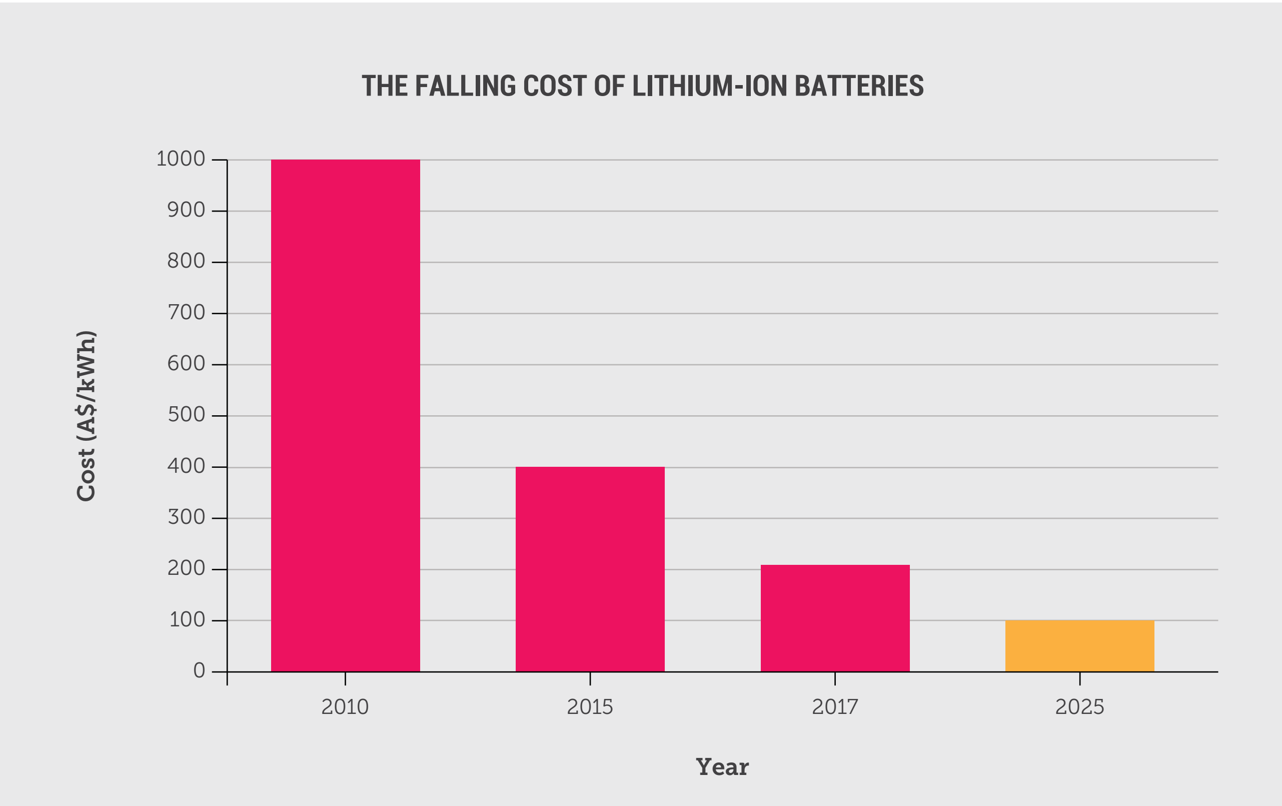
**This section explores the cost effectiveness of energy storage technologies. The price of battery storage and solar thermal is falling rapidly while pumped hydro remains the cheapest form of large-scale energy storage.**

## BATTERY STORAGE

Battery storage prices have been experiencing rapid cost reductions due to improvements in manufacturing scale (such as battery gigafactories), technological improvements in battery capacity and reductions in the cost of battery materials (REN21 2017).

In the early 1990s, lithium-ion batteries were as high as $10,000/kWh (Reneweconomy 2017a), falling to $1,000/kWh in 2010 and then to just $400/kWh in 2015 (SunWiz 2017) (Figure 11). By 2017, costs had fallen even further to $209/kWh (BNEF 2017b). Lithium-ion battery costs are falling at a rate almost as fast as rooftop solar over the past decade (Figures 12 and 13). Figures 12 and 13 show the falling price of solar PV and lithium-ion batteries respectively. For every doubling in lithium-ion battery installed capacity, prices have fallen by 19%.

**Figure 11:** The falling cost of lithium-ion batteries.




**Source:** Bloomberg New Energy Finance 2017b; SunWiz 2017.

# While gas is becoming more expensive, batteries are getting cheaper.

Analysts predict that the cost of lithium-ion battery systems will drop substantially into the future due to rapidly expanding global markets in energy storage for grid, domestic and transport applications (BNEF 2017b, SunWiz 2017, IRENA 2017 and RepuTex Carbon 2017). This has meant that batteries are fast becoming competitive with gas peaking power stations which provide electricity during times of peak electricity demand (Reputex 2017).

By 2025, lithium-ion batteries are projected to cost less than $100/kWh (BNEF 2017b), but some forecasts indicate this price will be reached as early as 2020 (Reneweconomy 2017a; SunWiz 2017).

The fall in lithium-ion battery costs over the past decade has been even faster than most forecasts predicted (Box 9). Back in 2015, the CSIRO forecast that the cost of lead acid and lithium-ion batteries would fall by 53% by 2025, with predictions that energy storage would be competitive against gas by 2035 (CSIRO 2015b). The more recent forecasts of BNEF (2017), SunWiz (2017), IRENA (2017) and RepuTex Carbon (2017) suggest that these milestones will be reached much sooner than predicted by the CSIRO.

Lithium-ion batteries are not the only battery technology falling in cost. Advanced lead-acid batteries and flow batteries are also experiencing rapid cost reductions (REN21 2017; IRENA 2017).

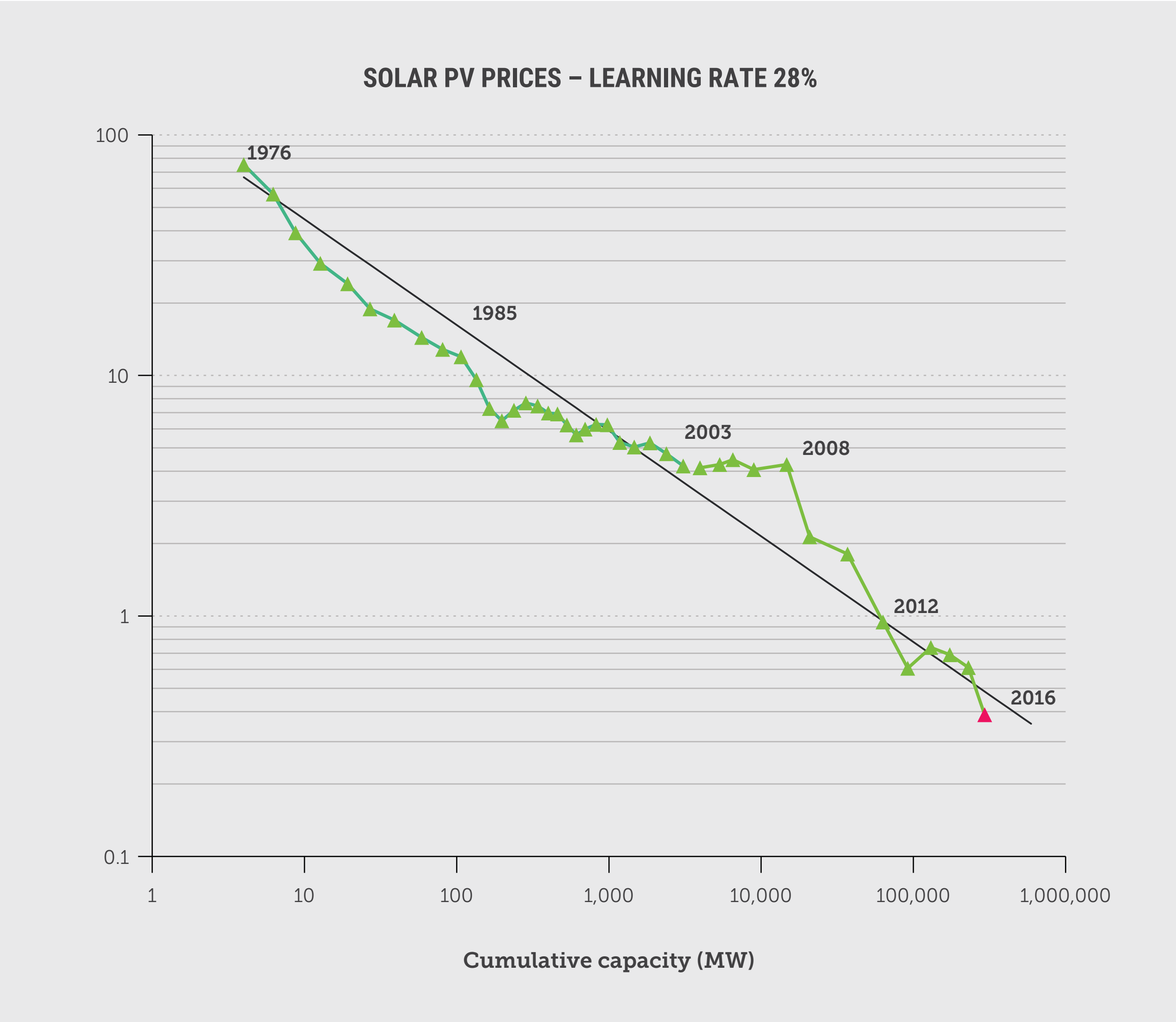
## BOX 9: HOUSEHOLD BATTERY STORAGE COSTS ARE FALLING RAPIDLY

**Household battery storage installations have been growing significantly over the past few years.**

In 2016, there were 6,750 new installations with the market predicted to have tripled in size in 2017, with over 20,000 new installations. These new installations will include over 170MWh of storage – bigger than South Australia's Tesla-Neoen battery (SunWiz 2017).

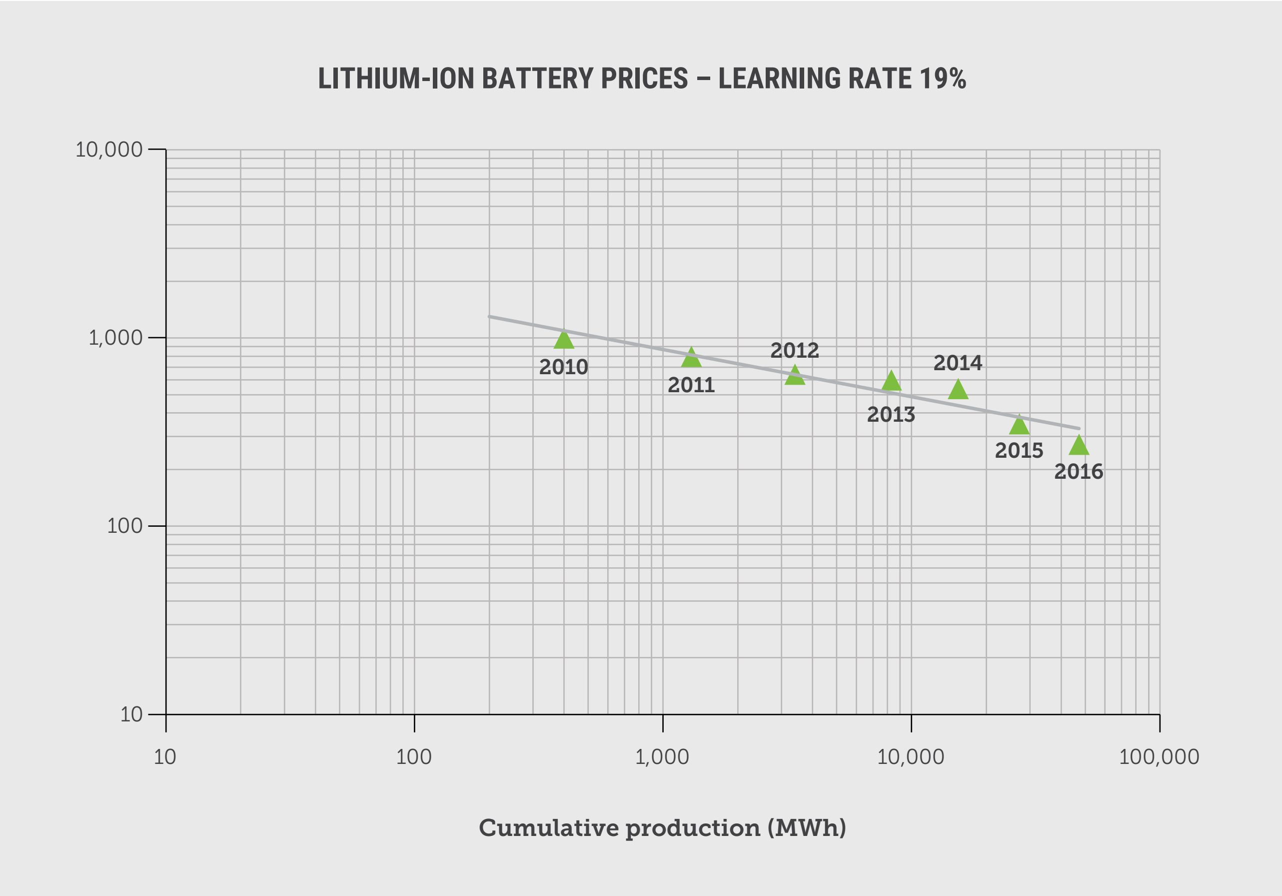
These batteries are being installed at the residential, industrial and commercial level, and can also be retrofitted onto existing rooftop solar systems or installed with new rooftop solar systems.

**Figure 12:** Over the past 30 years, the cost of solar PV has fallen significantly as capacity has increased. Lithium-ion battery prices are falling almost as fast (Figure 13).




**Source:** Adapted from: Bhavnagri K (2017) Presentation made by Kobad Bhavnagri, Bloomberg New Energy Finance, at the Australian Clean Energy Summit 2017, 18 July 2017.

Figure 13: As capacity increases, lithium-ion battery prices are falling almost as fast as solar PV (Figure 12).




Source: Adapted from: Bhavnagri K (2017) Presentation made by Kobad Bhavnagri, Bloomberg New Energy Finance, at the Australian Clean Energy Summit 2017, 18 July 2017.

## PUMPED HYDRO

Pumped hydro storage is the cheapest form of large-scale energy storage and it is likely to remain so for a number of years (Blakers, et al, 2017; IRENA 2017). Prices vary significantly depending upon the project but pumped hydro projects can take advantage of economies of scale, making them comparatively cheap at larger sizes. Unlike batteries, pumped hydro is a mature technology and prices are expected to be virtually the same in 2030 as they are today (IRENA 2017).

## SOLAR THERMAL

Concentrating solar plants with thermal storage are also experiencing significant cost reductions and becoming more viable. Solar thermal can already provide electricity at a lower levelised cost than fossil fuel plants (AEMO 2017g). SolarReserve are building Australia's biggest solar thermal plant in South Australia for a levelised cost of no more than $78/MWh – similar to a new-build solar plant and vastly cheaper than new coal power stations. The 150MW plant will be capable of providing electricity 24/7 and will supply the entire electricity needs of the South Australian government for the next 20 years (Premier of South Australia 2017b).

**Figure 14:** The Logan City Council battery storage system. Along with attached solar panels, the battery will reduce the council's energy costs by $50,000 per year.

## BOX 10: COMMUNITIES AND COUNCILS USING BATTERIES TO REDUCE POWER PRICES AND POLLUTION

**Batteries have the potential to enable whole communities to become self-sufficient in renewable energy. This is particularly the case in communities that are off-grid or on the edge of the grid.**

In Queensland, Logan City Council have recently had a hybrid solar and battery system installed by CSR Bradford on their new water treatment system. The 323 solar panels and 95kWh battery will reduce operating costs by $50,000 per year (Figure 14). This project has enabled the Logan City Council to avoid connecting their remote water treatment plant to the electricity grid (AFR 2017).

In the Victorian town of Yackandandah, 16 households are taking part in an Ausnet trial for one of Australia's very first mini-grids.

Rather than individual households disconnecting from the electricity grid, the households within Yackandandah will remain connected to each other. Different households will have solar panels and battery storage installed on their properties but these systems will be controlled remotely. This will enable all the solar and storage systems to effectively operate as one virtual power plant (The Border Mail 2017).

A similar scheme is underway in the off-grid community of Lockhart River in Cape York Peninsula. Electricity distribution company Ergon Energy will install 200kW of rooftop solar and a number of battery storage units. The system will supply 10% of the community's power needs and reduce reliance on expensive and polluting diesel power stations (Ergon Energy 2017).

# 4. Energy Storage Projects in the Pipeline in Australia

**Australia may be on the cusp of an energy storage investment boom. Australia's Federal, State and Territory Governments, along with a range of private companies, are investing in a number of energy storage solutions, especially grid-scale batteries and pumped hydro.**

Australia already has three pumped hydro energy storage projects that have been operating for over 30 years (Table 3). This section outlines the major energy storage projects in planning and construction in Australia and major opportunities for investment and job creation (Box 11).

Apart from in South Australia, where wind and solar PV already comprise 57% of power generated (AER 2017), significant new energy storage is not yet a must-have for most Australian states. Indeed, the CSIRO indicates significant new battery storage is not required in Australia until wind and solar supply approaches 30% of electricity supply (CSIRO 2017), while the Australian Council of Learned Academics has found that Australia could reach 50% renewables without a significant requirement for energy storage (ACOLA 2017).

South Australia has limited high voltage transmission lines (known as interconnectors) connecting it to other states (Clean Energy Council 2017a). This means the state can be vulnerable when the main interconnector with Victoria is not working optimally, such as during the outage that occurred in December 2016 (ABC 2016a). Other States like Victoria or New South Wales have multiple interconnectors.

As a result, South Australia is already pursuing a number of energy storage projects including the Tesla-Neoen battery that began operating in December last year, solar thermal power with storage and potentially the world's second pumped hydro plant using seawater. A number of State and Territory Governments are actively pursuing energy storage projects to enhance grid reliability (eg. South Australia, Victoria) and to expand renewable power potential (South Australia, Queensland, Victoria, Northern Territory). The Federal and Tasmanian Governments are investigating expanding Australia's pumped hydro capacity.

**Table 3:** Large-scale energy storage projects that are operating in Australia.

| Storage Facility: | Type of Energy Storage: | Capacity (MW): | Operational: |
|---|---|---|---|
| Tumut 3[1] | Pumped Hydro | 1800 | 1973 |
| Wivenhoe[2] | Pumped Hydro | 500 | 1984 |
| Shoalhaven[3] | Pumped Hydro | 240 | 1977 |
| Tesla-Neoen Battery[4] | Lithium-ion Battery | 100 | December 2017 |

Sources:

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## BOX 11: ENERGY STORAGE IS CREATING JOBS

**Appropriate government policy support of the Australian energy storage industry could create thousands of new jobs for both domestic and export markets, leveraging Australia's leading research and engineering capacities.**

In the United States, 90,000 people are now directly employed in the energy storage industry, with 47,000 people employed in the battery storage sector alone (EESI 2017b). This highlights the potential for energy storage projects to create jobs in Australia.

Jobs created in energy storage would be in addition to the 13,000 jobs being created as a result of the more than 40 large-scale renewable energy projects currently under construction in regional Australia (Green Energy Markets 2017). Investing in storage would potentially add thousands of extra jobs to the additional 28,000 jobs created under 50% renewables by 2030.

**Figure 15:** The 32MW Laurel Mountain battery farm in West Virginia, USA. The installation consists of lithium-ion batteries that store power from a nearby wind farm.

In the United States, 90,000 people are directly employed in energy storage.

## SOUTH AUSTRALIA

### Battery Storage Projects

In June, the South Australian government announced that Neoen and Tesla had won a tender to build the world's largest lithium-ion battery at the Hornsdale Wind Farm near Jamestown, South Australia. The battery (Figure 16) began operating in December and can store 129MWh of energy and produce 100MW of electricity (at maximum capacity) for the grid. The battery will primarily provide grid stability services, including fast frequency response, but it will also increase competition in South Australia's electricity market, reducing electricity prices for consumers by being an extra power supplier at peak times. The South Australian Government has retained the right to use up to 70% of the battery's output in the event of an electricity supply shortfall.

Since it began operating, the Tesla-Neoen battery has already demonstrated how useful batteries can be to the electricity grid. In December the battery responded in a matter of milliseconds to stabilise the frequency of the electricity grid after a unit at the Loy Yang A brown coal power station in Victoria unexpectedly faulted, resulting in 560MW of electricity being withdrawn from the grid (Reneweconomy 2017n). The whole of the NEM is benefiting from the Tesla-Neoen battery despite it being located near the end of the grid in South Australia. With more batteries, the electricity system will become more resilient to disturbances and unexpected faults.

Tesla and Neoen are not the only companies building batteries in South Australia. Power network provider ElectraNet will design and build a 30MW/8MWh battery at the Dalrymple substation, north of Yorketown on Yorke Peninsula to strengthen the regional grid. This battery will be leased to an energy retailer. The Australian Renewable Energy Agency will contribute $12 million to the $30 million battery cost, which will be operational by May 2018. ElectraNet's battery will supply network frequency security services and provide power to the NEM. In the event of a blackout, the battery will be able to be provide 2-3 hours of power to the local area (The Advertiser 2017; ABC 2017e).

There are also plans to build a 100MW/400MWh battery in Riverland, South Australia alongside a 330MW solar farm (ABC 2017b) while the Clean Energy Finance Corporation is financing a 10MW/10MWh battery at the Lincoln Gap wind farm (Clean Energy Finance Corporation 2017). The Lincoln Gap battery is on track to be complete in 2018. Tilt Renewables have announced plans to build a 21MW/26MWh battery alongside a new solar farm in Snowtown. The project was supported by the South Australian Government's Renewable Technology Fund (ABC 2018). The 300MW Bungala solar PV project, already under construction near Port Augusta is being built "battery storage ready" (AEOL 2017).

There will be three large-scale batteries operating in South Australia by the end of 2018.

## BOX 12: SOUTH AUSTRALIA'S 'VIRTUAL' POWER PLANT

**In February, the South Australian Government announced a plan to install 50,000 solar and storage systems on households in the state over four years, creating a "virtual power plant" (South Australian Government 2018).**

The project will begin with a trial across 1,100 community housing properties in 2019, which will have a 5kW solar system and a 5kW/13.5kWh battery installed. Systems will then be installed across another 24,000 community housing properties, with at least 50,000 properties to be connected by 2022 (subject to private investment in the project).

The solar and storage systems will be owned and operated by a retailer. Consumers will not have to pay for the installation of the systems but they will benefit from lower electricity bills.

If completed, this project will be able to produce 250MW at one time and store 650MWh of energy – over twice the power of the Tesla-Neoen battery and five times as much storage. It is predicted that this will produce enough electricity to supply 20% of South Australia's average daily energy requirements.

Although these solar and storage systems will be located at different households, they will be controlled by the same software. This enables the generation, charge and discharge of energy to be coordinated, so that all the systems effectively operate as one power station – hence the name, "virtual power plant".

Unlike traditional power stations, a virtual power plant is more resilient to disruptions as it is not reliant on long transmission lines and large centralized power stations.

Virtual power plants can help make the grid more reliable, efficient and resilient, complementing larger scale energy storage such as the big battery.

### Aurora Solar Thermal Power Plant with Storage

In August 2017, the South Australian government announced that SolarReserve had won a contract to build Australia's biggest solar thermal power plant. The Aurora Solar Energy project will supply up to 150MW of electricity at a levelised cost of no more than $78/MWh. The solar thermal plant will supply all of the State Government's electricity needs for 20 years and because government peak demand is 125MW – and often less – all extra generation will be sold into the NEM. The solar thermal power station will be able to provide continuous 24/7 power, operating in times of peak demand and increasing competition. This project will provide flow-on benefits to all electricity consumers in the NEM by increasing competition and providing a new reliable and dispatchable source of power. The facility has received development approval and will start construction in 2018, to be completed in 2020 at a cost of $650 million (Premier of South Australia 2017b).

### Saltwater Pumped Hydro

EnergyAustralia has completed a feasibility study into a pumped hydroelectric power station on the Eyre Peninsula in South Australia that runs on seawater. If built, it would be the largest seawater pumped hydro project in the world (EnergyAustralia 2017a). An initial feasibility study has been completed, concluding that the project is viable. The optimum size of the project would be 225MW with a storage capacity of 1,770MWh. However, the project would have a round-trip efficiency of only 72% (compared to 80% for a standard pumped hydro project and 92-96% for lithium-ion batteries).

Further study will determine whether the project will go ahead, with the final investment decision to be made in late 2018. The project is estimated to cost $2.1 million per MW of capacity (EnergyAustralia 2017b).

South Australia's solar thermal power plant will be able to provide reliable and low cost renewable power 24/7.

## Renewable Technology Fund and Hydrogen Storage

There is also likely to be further investment in other storage technologies as part of the South Australian Government's $150 million Renewable Technology Fund. The tender is designed to fund dispatchable or firming power to ensure renewable energy can provide secure and reliable power. The fund has received 60 proposals from companies investing in a wide variety of storage technologies, including hydrogen storage, batteries, pumped hydro, flywheels, compressed air storage and thermal storage (Reneweconomy 2017i). This fund has already provided support to Tilt Renewables, who plan to build a 21MW/26MWh battery alongside a new solar farm in Snowtown (ABC 2018), as well as South Australia's virtual power plant (Box 12) (South Australian Government 2018).

South Australia is also undertaking a tender for 6 or more hydrogen fuel cell buses to be used by Adelaide Metro. The winner will have to produce hydrogen for the buses and build refuelling infrastructure (Our Plan 2017). The South Australian government have also developed a hydrogen roadmap as part of the state's transition to a low emissions economy (Our Plan 2017).

**Figure 16:** The Tesla-Neoen battery Powerpack in South Australia. The battery began operating in December – less than 6 months after construction had started.

## STATE AND TERRITORY GOVERNMENTS INVESTING IN ENERGY STORAGE

### Queensland

In August 2017, the Queensland Government opened up early registration for companies to bid in a reverse auction to construct up to 100MW of energy storage by 2020, as part of their Powering Queensland Plan (as part of a 400MW solar and storage auction). (Reneweconomy 2017e). As part of the auction, all solar projects are required to provide storage for 20% of their average daily output. In the initial tender, 6000MW of energy storage was proposed, alongside 9000MW of renewable energy – greater than the capacity of the entire Queensland coal fleet (Reneweconomy 2017j). This demonstrates the huge potential of energy storage projects in Queensland.

### Northern Territory

In January 2018, the Northern Territory Government called for expressions of interest to build 25-45MW of large-scale energy storage to support the electricity grid in Darwin and Katherine. The project must provide between 30 and 90 minutes of energy storage and could produce either 25MW, 35MW or 45MW at any one time (Reneweconomy 2018). Energy storage will assist the Northern Territory in achieving its target of 50% renewable energy by 2030.

The Northern Territory Government-owned energy company Territory Generation have also awarded a tender to utility company Vector to build a 5MW/3.3MWh battery facility in Alice Springs. This project will reduce Alice Springs' gas consumption significantly and enable a further increase of Alice Springs' already significant solar PV installations. Construction has begun and the battery is expected to be operational in coming months (Reneweconomy 2017g; Ecogeneration 2017).

ARENA are also funding the construction of a 2MWh battery in conjunction with a 1MW solar system in the remote Indigenous community of Daly River. When completed, this project will halve the town's diesel consumption (Energy Storage News 2017b).

### Victoria

Last year, the Victorian Government opened a tender for two 20MW batteries with a combined storage capacity of 100/MWh (Energy Storage News 2017a). The batteries were originally intended to be operational by January 2018, although the winners of the tender have yet to be announced.

The Victorian government are also supporting a 204MW wind farm and 20MW battery that will power Nectar Farm's greenhouse in Stawell and send excess electricity into the grid. In total, the project will create 1,300 jobs and is scheduled to be operational by mid-2019 (Sydney Morning Herald 2018; Premier of Victoria 2017).

## FEDERAL AND TASMANIAN GOVERNMENT PLANS FOR PUMPED HYDRO

The Federal Government commissioned a Feasibility Study into increasing the capacity of the Snowy Hydro scheme by 50%. This project has the potential to add 2,000MW of energy storage into the grid and may involve both new tunnels and power stations (Prime Minister of Australia 2017a).

The Feasibility Study found that the project was technically and financially viable with a “base cost” of between $3.8 and $4.5 billion, excluding new transmission lines, which may cost a further $2 billion. If a final investment decision is made by the end of 2018, the project will come online over 2024 and 2025. This project could act as an enabler for 4,000MW of new wind and solar projects, however no commitments to new renewable energy have been made (Box 5) (Snowy Hydro 2017).

A feasibility study is also being funded by the Federal and Tasmanian governments to expand the Tasmanian hydro system to deliver up to 2,500MW of pumped hydro capacity. The study, to be led by ARENA and Hydro Tasmania, will examine Mersey Forth-1, Mersey Forth-2, Great Lake and Lake Bunbury (each with a capacity of around 500-700MW) and an alternative of nine small-scale sites with a total capacity of 500MW. The study will also examine the expansion of the Tarraleah and Gordon power stations (Figure 17) (Prime Minister of Australia 2017b).

**Figure 17:** The Gordon hydroelectric power station in Tasmania. The federal and Tasmanian governments are considering expanding this power station.

## UTILITIES AND LARGE INDUSTRIAL AND COMMERCIAL USERS

A large number of industrial and commercial energy consumers are responding to high and rising electricity prices by taking control of their energy by investing in renewables and storage in order to reduce their power bills. This includes mining and resource companies (GMA Garnet, Rio Tinto, Woodside Petroleum), food producers (Nectar Farms and Westpork), industrial users (GFG Alliance) and utilities (Endeavour Energy). Some of these projects are confirmed, while others are still in planning.

Western Australia's largest pork producer Westpork is planning to install 1.8MW of wind energy and battery storage to reduce their electricity bills. Westpork have already installed a 360kW solar array as part of the company's plans to become 100% renewable (One Step Off the Grid 2017a).

Victorian food producer Nectar Farms are planning to build a 20MW/34MWh battery storage installation alongside a 196MW wind farm. This facility will power a 40-hectare glasshouse 24 hours a day and meet the facility's entire energy needs (One Step Off the Grid 2017b). The project is expected to be operational by mid-2019, after receiving support from the Victorian Government (Sydney Morning Herald 2018).

Mining and resource companies are also taking advantage of the lower costs that storage and renewables can provide. In Sandfire's West Australian DeGrussa copper and gold mine, a 6MW/1.8MWh battery has been installed alongside a 10MW solar plant (ARENA 2016). Western Australian garnet miner GMA Garnet are purchasing the output of a 3MW wind and solar farm with battery storage, which will supply 70% of the miner's electricity needs (One Step Off the Grid 2017c).

Woodside Petroleum are planning to install a 1MWh lithium-ion battery on their Goodwyn oil and gas platform on the North West Shelf. The battery will replace a gas turbine and cut emissions by 5%. It will be operating in late 2018 (Sydney Morning Herald 2017).

Industrial energy users, GFG Alliance, which owns South Australia's Whyalla Steelworks, have announced plans to invest in 520MW of renewable energy and storage to provide cheap and reliable electricity to power their steel plant (Box 13).

In New South Wales, a 1 MWh battery is planned at the site of an electrical substation near Wollongong by network operator Endeavour Energy. The investment will reduce network costs by $1 million a year and defer investment in network infrastructure. The battery will begin construction in mid-2018 and it will supply electricity to around 600 new homes when it is fully operational just a few months later in late 2018 (Reneweconomy 2017k).

## BOX 13: RENEWABLES AND STORAGE POWERING STEEL PRODUCTION

**GFG Alliance, owners of South Australia's Whyalla Steelworks, have announced plans to invest in 520MW of renewable energy and storage to provide cheap and reliable electricity to power their steel plant.**

If it goes ahead, the project will include: the expansion of a solar farm from 80MW to 200MW; 100MW/100MWh of battery storage, and 100MW of demand response management. These projects will be complete by 2019 and could be followed in 2020 by the construction of a 120MW/600MWh pumped hydro facility located at a disused iron ore mine (Reneweconomy 2017l). The project will be carried out by Australian renewable energy and storage company Zen Energy.

High electricity prices are driving large energy users like GFG Alliance to invest in renewable energy and battery storage, with the potential of these technologies to cost effectively and securely power the significant energy requirements of heavy industry (ABC 2017d).

## HYBRID RENEWABLE AND STORAGE PROJECTS IN QUEENSLAND

### Lakeland Solar and Storage

The Lakeland integrated solar and battery storage farm will be the Southern Hemisphere's first large-scale integrated solar and battery storage facility (Figure 18). The project combines a 13MW solar power station together with 1.4MW/5.3MWh of battery storage and will be able to provide a reliable power supply 24 hours a day (Conergy 2016).

### Windlab's Kennedy Energy Park

Windlab has recently begun construction on the Kennedy Energy Park in northern Queensland. This is a hybrid project that will initially consist of 43.2MW of wind power, 15MW of solar and a 2MW/4MWh lithium-ion battery. If successful, this project may upscale to over 1,000MW. The first stage of the project is expected to be operational by the end of 2018 (Kennedy Energy Park 2017).

Figure 18: The Lakeland solar and storage facility. This is the Southern Hemisphere's first large-scale solar and battery storage installation. The batteries (bottom left) will enable the facility to provide a steady supply of reliable power.

## Pumped Hydro in North Queensland

A feasibility study was completed into building a pumped storage hydroelectric power station at the Kidston Gold Mine in North Queensland (Figure 19). The project, proposed by ASX-listed Genex Power, will be able to produce up to 250MW of electricity at one time and provide over 2,000MWh of energy storage (Genex Power 2017). The project is under construction (Genex Power 2017).

**Figure 19:** The former Kidston gold mine. Genex Power plans to construct a pumped hydro facility on the site by pumping water from one lake into the next.

# Glossary

## Ancillary services

Ancillary services include technical characteristics of the electricity system (such as frequency and voltage) that are managed and purchased by the Australian Energy Market Operator (AEMO) to maintain the safety, security and reliability of the electricity grid. There are three broad categories of ancillary services:

- Frequency control and ancillary services (FCAS)
- Network support and control ancillary services (NSCAS)
- System restart ancillary services (SRAS)

## Baseload power

Baseload power plants, like coal and nuclear power plants, run continuously, producing a constant output of electricity. These power plants are very inflexible, and slow to respond to changes in electricity demand.

## Demand response management, demand side management

Demand response management involves reducing consumer demand for energy by paying consumers to reduce their usage. Demand response management is useful for reducing demand during periods of very high electricity consumption and avoiding electricity shortages.

## Depth of discharge

The depth of discharge is a ratio of the energy released by a storage technology compared to how much energy the storage technology can hold. For example, an energy storage technology that can store 100MW of energy, and discharge all of this electricity back into the grid, has a 100% depth of discharge.

## Energy storage

Energy storage technologies, like batteries and pumped hydro, store energy to produce power later when needed.

## Dispatchable power

Dispatchable power technologies are fast responding power plants (and other technologies) which are able to be turned on and off, or ramped up and down quickly to balance electricity supply and demand. There is a wide range of technologies capable of providing dispatchable power including pumped hydro, solar thermal, batteries, peaking gas as well as demand response management.

## Frequency control and ancillary services (FCAS)

FCAS are used by AEMO to maintain the frequency of the electrical system at a steady level.

## Frequency response, Fast frequency response

Frequency is a measure that enables operators to know if electricity supply and demand is in balance. Frequency response is a service which can be provided to re-balance electricity supply and demand. This service can be provided by a range of technologies including battery storage systems, modern wind turbine technology and solar plants with smart inverter technology. Fast frequency response refers to providing very rapid frequency correction – in timeframes from less than a second up to several seconds.

## Generator

Generators convert one form of energy into another. Solar plants convert solar radiation from the sun into energy while fossil fuel power stations burn coal and gas to convert it into energy.

## Inertia

Power plants that generate electricity via large rotating steam or water turbines are sometimes called synchronous generators. These rotating steam and water turbines provide physical inertia. Inertia provides an initial, immediate response to keep the electricity system working when supply and demand are out of balance. Solar thermal, hydropower, and biomass power plants are synchronous generators capable of providing physical inertia. Renewable power plants (like wind and solar PV) and battery systems if configured with appropriate software controls, can provide similar services to physical inertia, sometimes called "synthetic inertia".

## Interconnectors

High voltage transmission (power) lines connecting states and/or regions. Interconnectors transport electricity very long distances, connecting up the electricity grids of Australia's eastern states. They significantly increase the flexibility of the grid.

## Lifecycle

The lifecycle (or cycle life) is the number of times an energy storage system can fully charge and discharge until the end of its life. After a certain period of time, batteries will degrade and the amount of storage capacity that is usable becomes significantly reduced. The more lifecycles a battery has, the longer it will be usable before it's capacity starts to degrade.

## Modern grid

A modern power grid has infrastructure and operating rules and is able make the most of new technologies such as solar, wind and battery storage and meet changing consumer demands.

## National electricity market (NEM), wholesale electricity market

The wholesale or NEM includes Victoria, Tasmania, South Australia, New South Wales and southeast Queensland. It is managed by AEMO, for the sale of electricity from generators to consumers. It operates as a spot market, where generators make bids to supply the market with a certain amount of electricity for a set time period at a certain price. AEMO then assesses all the bids and decides which generators to deploy, with the cheapest generator deployed first.

## Operating reserve

Operating reserve is planned spare capacity in the system that can be called upon when there are unexpected variations in electricity demand, or generation or transmission faults.

## Reliability

Balancing demand for electricity (from households, business and industry) with supply from power stations and energy storage while reducing demand.

## Resilience

Delivering reliable power in the face of increasingly severe weather events influenced by climate change.

## Roundtrip efficiency

The ratio of energy output to energy input in an energy storage technology. All storage technologies consume electricity. If a storage facility uses 100MWh of electricity but only produces 50MWh, this would result in a roundtrip efficiency of 50%.

## Security

Meeting technical requirements for grid stability (described by terms such as “frequency control” and “inertia”) and ensuring the power grid can overcome disturbances. These are characteristics which help to maintain a stable, operating grid when supply and demand becomes unbalanced over short time periods.

## Solar thermal power

A concentrating solar thermal power plant, concentrates solar energy to heat up a storage material, such as salt. The heat stored is then used to produce steam to drive a turbine and generate electricity. Some concentrating solar thermal power plants can store this heat energy to generate electricity when needed.

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