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Energy Storage in Australia

Commercial Opportunities, Barriers and Policy Options

Clean Energy Council

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Executive Summary

Energy storage is emerging as a potential means to support our existing electricity networks, facilitate the efficient operation of electricity markets, improve the stability of our grid as it becomes more dependent on intermittent renewable generation sources, provide for the needs of remote communities, and meet the private[1] needs of residential and commercial customers. This report examines the commercial potential of six energy storage applications, or sub-markets, in Australia:

- Supporting Fringe and Remote Electricity Systems
- Network Support
- Market Participation
- Grid Stability
- Residential Storage Systems
- Business Storage Systems

Our simplified model of the demand for energy storage shows:

- A material existing opportunity for supporting fringe and remote electricity systems
- As storage becomes more cost-competitive in future, there is likely to be an emerging and rapidly growing market in large grids such as the NEM
- A partly latent market exists for storage in electricity backup applications for business, currently served by other solutions.
- Growth to a total commercial market of approximately 3,000 MW in Australia by 2030 – a significant proportion of the current generation fleet.

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[1] We use the term ‘Private’ here to denote a storage system that is operated primarily for the benefit of residential or business customers, rather than for the benefit of the electricity system – even if in actuality, the storage system is community-owned, or not located on the customer’s premises.

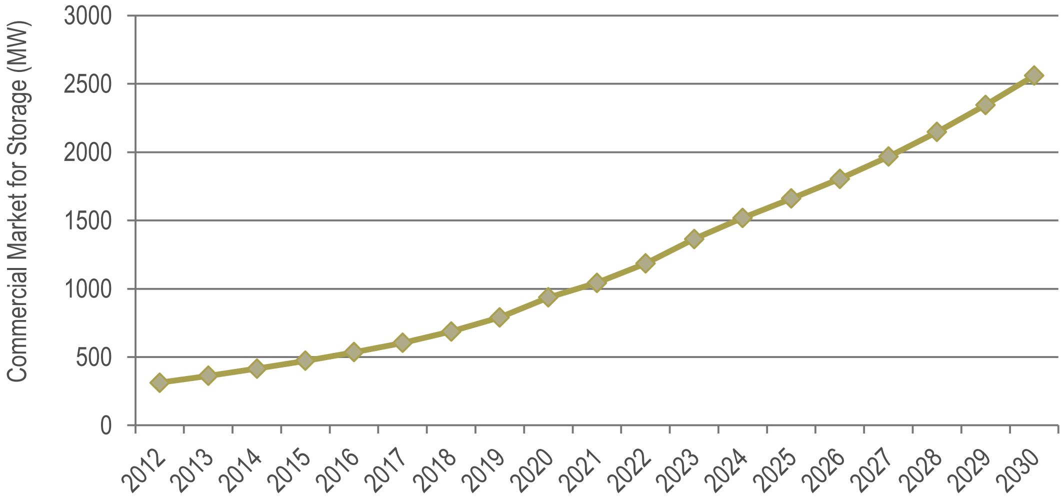

Figure 1: Total Forecast Commercial Market for Energy Storage in Australia

However, the market for storage that we have shown here will in reality be highly competitive, and will therefore not belong to storage alone. We do not model the competitive dynamics between storage and other emerging solutions.

Finally, we offer the following key policy options to overcome the technical, economic, regulatory and cultural barriers that energy storage faces today:

- Create a standard storage control system specification that allows a plug-and-play approach between vendors and electricity network businesses
- Support the wider adoption of the AS4755 standard, designed to enable remote demand response, load shifting, energy storage and/or storage discharge of compliant electrical products, via a protocol for managing third party devices connected to the grid.
- Commission an independent study of actual safety performance of currently-produced storage devices, and the limits of their safe operating conditions
- Encourage the establishment of price signals to capture benefits from storage that currently accrue to multiple parties, correcting the under-investment problem
- Encourage the AER to standardise and lower the threshold at which electricity transmission and distribution businesses must publically request tenders for solutions to network constraints caused by growing peak demand and other problems, and to ensure that these RFTs specify all the information necessary for storage providers to assess their market and invest accordingly
- Adopt a levelised cost of energy (LCOE) based standard that would communicate the total ownership cost of energy storage systems, amortised over their lifetime energy output
- Encourage the Commonwealth Government to affirm its policy commitment to the RET
- Encourage the Commonwealth Government to remove the diesel fuel-tax credit scheme
- Encourage Commonwealth or State governments to directly subsidise storage units, boosting uptake, and thereby facilitating the spread of expertise in deploying and managing storage.

- Support the *Connecting Embedded Generators* and *Small Generation Aggregator Framework* electricity rule change proposals currently being considered by the AEMC, and encourage the AEMC to explicitly recognise energy storage technology as a qualifying form of small / embedded generation. Encourage the IMO in Western Australia to consider a similar change
- Promote a business model wherein energy storage is provided as a peak-reduction service, rather than an installed hardware product, to network businesses
- Encourage network businesses to request competitive tenders for storage services that guarantee long term contracts
- Engage with regulators to establish the requirement for a "burden of proof" against storage and other non-standard technologies in the submissions that network businesses make, such that storage is assessed as a credible solution alongside traditional network augmentation
- Expand the CEC's Energy Storage Working Group into a directorate, and encourage all network utilities in Australia to represent themselves on it

The strongest theme across our findings is that efforts to spur the uptake of energy storage in Australia should be focused on the software interfaces, technical standards, and regulatory rules that enable straightforward, consistent, and manageable connections of storage to the grid. We believe it is not optimal to direct efforts at looking for improvements in underlying storage technologies that enable it (e.g. lithium, flow, and lead-acid based batteries). Australia is too small a market to enable R&D investment in, and competitive production of these materials. .

1 About this Report

1.1 Purpose of the Report

Australia has a sparse population, peaky demand profile, and extensive untapped renewable energy resources. Its energy sector understands that continuing on the path of traditional power generation and system augmentation is becoming ever-more expensive. The situation is seemingly right for the broad-scale adoption of alternatives such as energy storage – but the storage industry is still in its infancy, and the best way to grow it is not yet clear.

This report was commissioned by the Clean Energy Council's (CEC's) Energy Storage Working Group (ESWG), in order to help storage proponents and the broader energy industry understand:

- Where the demand for storage – both effective and latent – exists in Australia
- The scale of the commercial opportunity to meet this demand
- At what price points the uptake of storage is likely to take place
- What specific applications have the best chances of underpinning a viable market for storage, individually or together

This report also aims to identify what specific barriers stand in the way of an effective, economically viable implementation of energy storage – and to suggest policy options that might overcome those barriers.

1.2 Our Approach

There are a number of broad ways in which the size of any market can be assessed:

- **Conceptual Potential** – Describe the opportunity without quantifying its size
- **Technical Potential** – Quantify the maximum volume of products that could be conceivably bought, irrespective of the cost
- **Economic Potential** – Quantify the maximum volume of products that could be bought, as long as their benefit outweighs their cost
- **Commercial Potential** – Quantify the likely volume of products that could be bought, given reasonable rates of consumer uptake and the availability of substitutes from competitors

So far, most studies of energy storage have fallen into the first category, and some in the second. Very rarely has the economic or commercial potential of storage been assessed for an actual electricity system. This report, however, aims to do that.

- In **Section** 2, we give a brief overview of Australia's electricity sector, and describe the apparent issues that may encourage energy storage to be adopted.
- In **Section** 3, we describe in detail the applications, or sub-markets, for storage that we have identified in Australia, what specific needs storage can fulfil, and what deployments have occurred to date.
- In **Section** 4, we present the results from our model showing the commercial potential for storage in Australia. For the purpose of our modelling, we quantify the opportunities where the

use of storage would make economic sense in its own right – in contrast to attempting to assess the private financial case for the use of storage from the point of view of an end user, or an energy generation, transmission, distribution or retail business. This approach recognises that a single storage device is not limited to fulfilling a single role, or addressing a single application: its benefits to various stakeholders in the sector can be “stacked” together, and used to justify its cost.

We have sourced our model inputs from publically available data, interviews with people working in the Australian energy industry, and our own library of information and analysis gleaned from previous work in the sector.

- In **Section** 5, we present the barriers we have identified to the adoption of energy storage, and recommend tools or strategies that the Energy Storage Working Group can use to help inform key decision makers on energy storage and advance the case for policy options that might overcome these barriers.

  As with the previous section, we have sourced our information from publically available data, interviews with people working in the Australian energy industry, and our own library of information and analysis gleaned from previous work in the sector.

- In **Section** 6, we outline the most common storage technologies in use today. This report is not intended to be a technology-focused one, and it attempts to remain technology-agnostic wherever possible. This section therefore does not recommend one storage technology over another; rather, it is intended only to provide the reader some useful background information.

ABB	Acciona	AECOM	AEGPS	AEMC	AEMO
Australian Solar Systems	Balance Group	Bosch	CSIRO	Ecoult	ENERNOC
Ergon Energy	Essential Energy	General Electric	Greensync	Horizon Power	Hydro Tasmania
IMOWA	Infinity Solar	ISS	IT Power	Magellan Power	Marubeni
Queensland University of Technology	RedFlow	University of Sydney	Verve Energy	ZBB Energy Corporation	ZEN Energy Systems

Figure 2: Organisations who agreed to be interviewed or to supply information for this study

For the purpose of the report, we limit our definition of ‘energy storage’ only to forms of storage that are connected to an electricity system (whether local or national), and whose charging and discharging can be controlled for the benefit of the grid. Under this definition, the following examples (non-exhaustive) qualify as forms of energy storage that can serve the commercial demand we are forecasting:

- A traditional battery that can convert energy from electrical to chemical form, and back again

- Pumped hydro systems that convert energy from electrical to potential form, and back again[2]
- ‘Smart’ hot water heating systems that can respond to signals from the grid in order for their heating load to follow the output of intermittent/renewable generation, and that afterwards convert this heat energy directly to an end use[3]

1.3 Limitations to our Approach

1.3.1 Modelling Limitations

A complete and rigorous approach to modelling the energy market, and storage's role in it over the next 20 years, would be possible in theory. However, it would also be an immensely complex, costly and time-consuming task. Also, much of the data that would be needed for this approach is privately held, is too expensive, does not exist in a usable form, or does not exist at all. There is also inherent uncertainty when modelling the future of large, complex and dynamic electricity systems, which produces diminishing returns on incremental analytic effort. We have therefore modelled a rather simplified version of the electricity grid and market.

In practical terms, it is impossible to know with much certainty the amount of storage that will actually be needed in the future energy system, or which storage technologies will be dominant, or what currently unknown applications of the technology might emerge.

Our modelling attempts to paint the best possible picture that we can paint today, using the limited resources we have. All models are wrong, but some are useful;[4] we believe this is one of the useful ones.

1.3.2 Renewable Energy Assumptions

There is a reciprocal feedback effect between the uptake of renewable energy and the uptake of storage – otherwise known as the chicken-and-egg, or infrastructure problem. Above certain penetration thresholds, the two are commonly seen as co-dependent.[5] This makes it near-impossible to authoritatively predict the one, since the other will both influence it and be influenced by it in turn.

We have therefore assumed renewable energy proliferation as a given, with our modelled uptake levels tied to the forecasts of the Commonwealth Government’s RET scheme.[6] Note also that this report also doesn't analyse barriers to renewable energy, or options to increase its uptake (other than coupling it with energy storage).

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[2] Dam-fed or run-of-river hydroelectric systems without pumping (i.e. charging) capability, however, would not qualify

[3] Traditional hot water heaters than are programmed to run in a fixed off-peak time window, however, would not qualify

[4] Source: George E.P. Box, *Empirical Model-Building and Response Surfaces (1987)*, p424

[5] This is particularly true of intermittent renewable energy such as solar and wind power. Some ‘baseload’ technologies, such as geothermal and wave power, do not call for storage in the same degree.

[6] The current review of the RET scheme may alter these forecasts. More information on the review can be found at http://climatechangeauthority.gov.au/ret

1.3.3 Technical Analysis

Connecting any device to a modern AC electricity grid – especially a complex device such as a kW- or MW-scale energy storage installation and its associated inverter and electronics – is complicated. The commonness of its happening happens shouldn't be mistaken for triviality. Despite the existence of this real complexity, this report is not intended to be a technical study, and does not examine:

- Physical / functional specifications for energy storage technology
- Voltage specification and inverter standards
- SCADA system interfaces
- Any other issues along these lines

1.3.4 Geographic Limitations

We have divided Australia's energy system into a number of regions for the purpose of our modelling, and analysed the role for storage in each of them. However, we have not drilled down into examining the specific physical locations on Australia's electricity grid where energy storage may be justified.

We have also confined our analysis to Australia; we did not examine overseas opportunities for energy storage. However, our forecast price reductions for storage technology do account for the growing global market for storage technology, the associated economies of scale this will bring, and impact on the pricing point of storage within Australia.

1.3.5 Market Dynamics

This report does not make a detailed attempt to examine what other technologies and solutions may emerge in the coming years that will compete for market share with storage.

We have also not studied the feasibility, or likelihood of success, of specific storage deployment projects.

1.4 About the Energy Storage Working Group

The Clean Energy Council's Energy Storage working group was formed in December 2011. Members of the Energy Storage Working Group include renewable energy developers, construction companies, energy retailers, energy distributors, market operators and managers, consultancy firms, and providers of supporting technologies for renewable energy and energy efficiency applications.

The Energy Storage Working Group aims to promote energy storage as an enabling complement to clean energy development, and as a viable solution to many of the problems the sector in Australia is facing, by increasing awareness, directing research, and fostering dialogue within the sector.

2 Background: Australia's Energy Sector

2.1 About the Sector

Electricity supply can be divided into four stages: generation, transmission, distribution, and retail.

Although there is a growing base of renewable energy supply in Australia (e.g. wind, hydro, solar), most of our electricity is generated by burning fossil fuels (e.g. coal, gas and oil) at large scale conventional power stations. These generators, and their fuel, are typically located a long way from where the electricity is consumed. Moving this electricity across these long distances therefore requires a capital-intensive transmission network to deliver electricity to substations located near demand centres.

From these substations, smaller-scale distribution networks supply low-voltage electricity to industrial, commercial, and residential customers. Electrical energy, it should be noted, is not "stored" in this network, in the same way that gas or water are stored in the network of pipes that transport them. Energy is produced by the movement of electrons in a current; when an appliance is switched on, energy is instantly transmitted to it from the generator (via this current) at close to the speed of light. If the generator were to be turned off, the current would instantly stop.

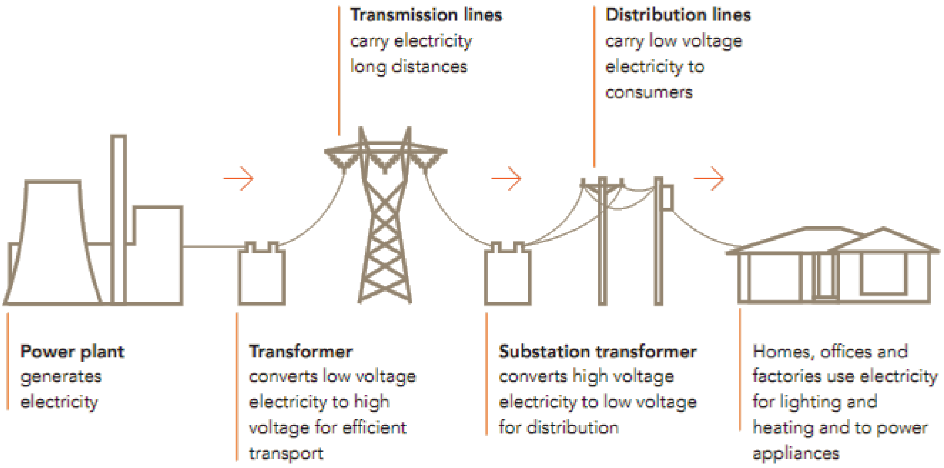

Figure 3: The components of the Electricity Grid[7]

The market operator AEMO must continuously balance short term supply from generators with demand from energy consumers throughout the day. AEMO has successfully deployed a highly complex market and dispatch mechanism so that retailers can buy power from generators in real time. The system enables generators to compete to sell the energy they produce, so that retailers and ultimately consumers pay a fair market price for the energy consume.

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[7] Source: AEMO, *An Introduction to Australia's National Electricity Market*, http://www.aemo.com.au/About-the-Industry/Energy-Markets/National-Electricity-Market

2.2 Why Consider Storage?

Storing energy for electrical consumption has been successfully practiced since the 19th century, when chemical batteries became common. However, with the advent of large scale electricity generation, transmission, and distribution, it became clear that it was far more economically efficient to generate energy in real time as it is being consumed, rather than storing it for consumption at a later point. This has in the past substantially been due to the large upfront cost of building a storage system, which is in turn compounded by the costs associated with energy losses that occur in converting electrical energy into a storable form (such as chemical energy), and back into electrical energy later.

Recent trends in the energy sector, however, are undermining this historical logic:

- Rising peak consumption, which is driving network costs beyond politically acceptable levels (see Figure 5 below)
- Rising price of the fossil fuels that power the vast majority of our generators, driven partly by carbon pricing, partly by use of more expensive fuels (e.g. gas rather than coal), and partly by a tightening global market for these fuels.
- Renewable energy is proliferating, due to falling prices, more efficient/effective plant technology, and the Commonwealth Government's Renewable Energy Target – but beyond a certain point, the incremental value of intermittent renewable output falls away sharply, unless it can be stored to meet demand.
- Cheaper and more effective storage technology is appearing (see Figure 7 below)
- Awareness of alternatives to the traditional, centrist approach to electricity generation and transmission is growing (e.g. as outlined in the AEMC's *Power of Choice* report, promoting demand-side participation)

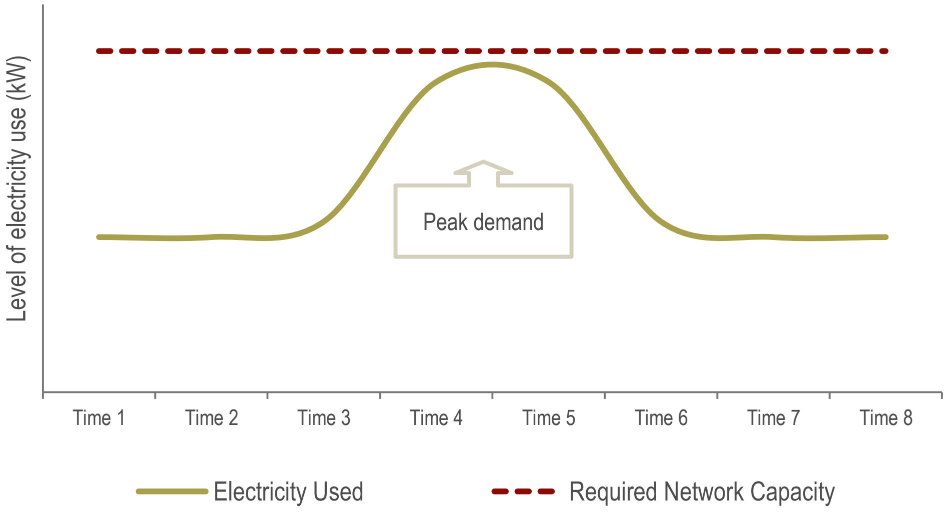

Figure 4: Peak demand and its effect on required network capacity

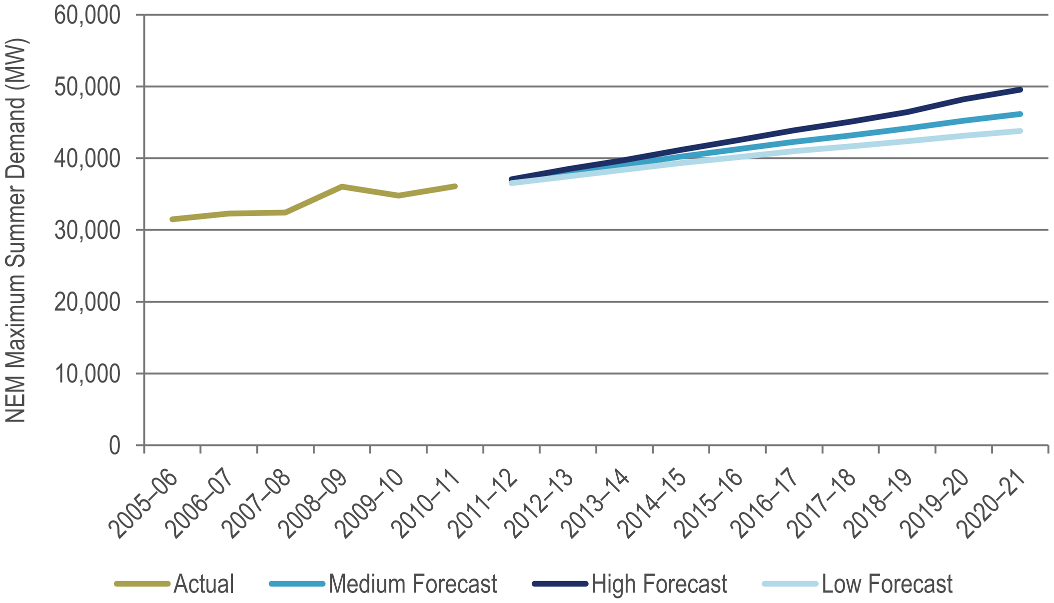

Figure 5: Forecast peak load, Australia[8]

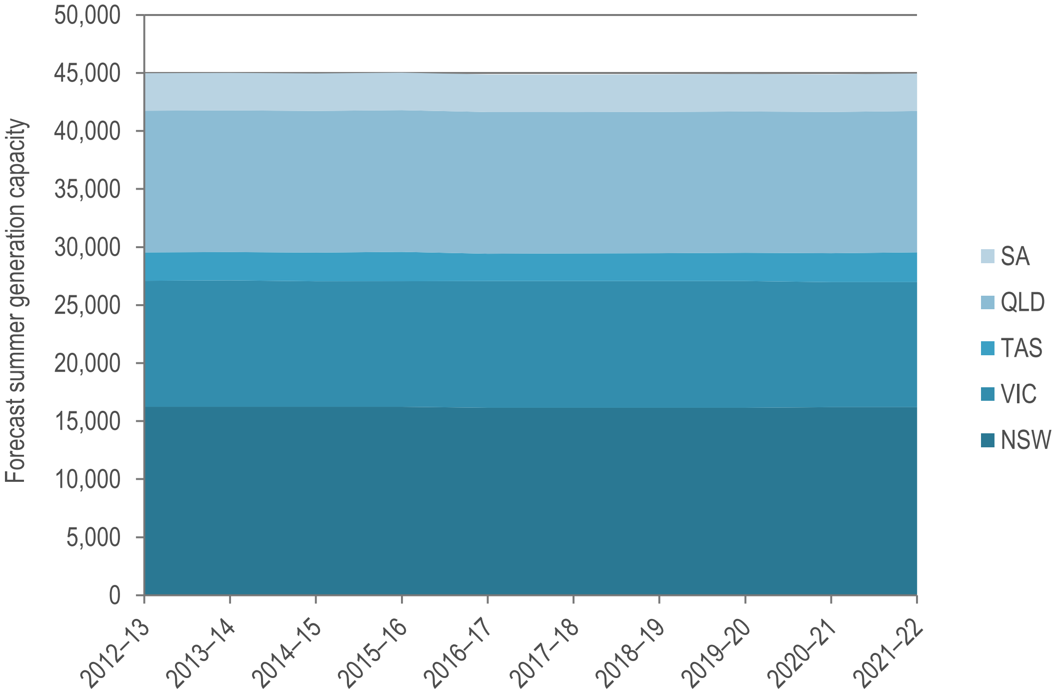

Figure 6: Forecast summer generation capacity in the NEM, 2012-22[9]

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[8] Source: AEMO, *Electricity Statement of Opportunities (2011)*, http://www.aemo.com.au/Electricity/Planning/Reports/Archive-of-previous-Planning-reports/Electricity-Statement-of-Opportunities-2011

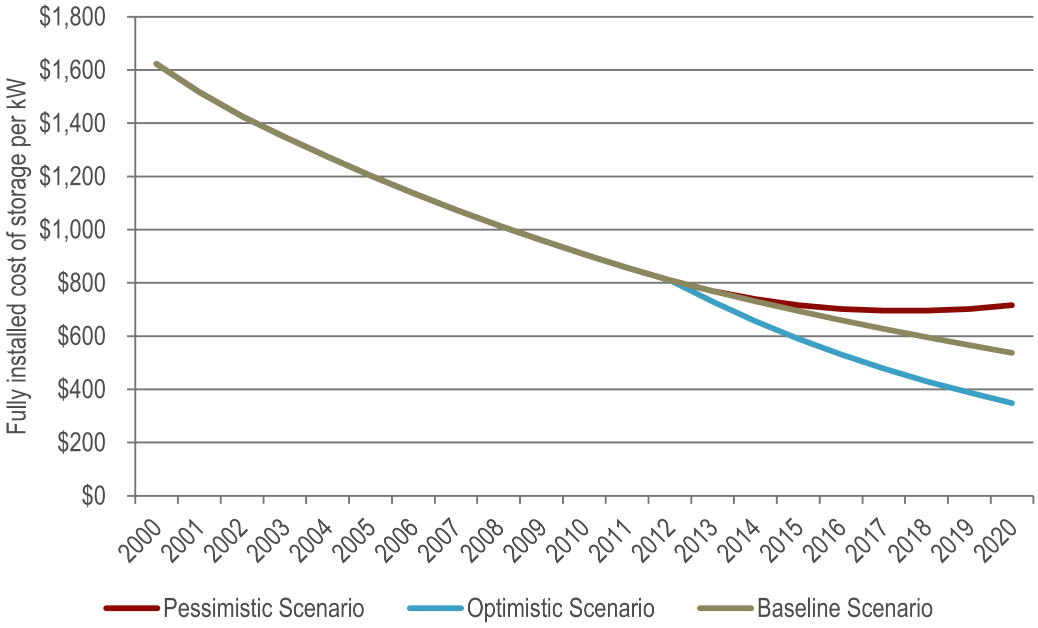

Figure 7: Historical and projected prices for energy storage (benchmark)[10]

Storage is therefore emerging as a potential means to support our existing networks, facilitate the efficient operation of electricity markets, improve the stability of our grid as it becomes more dependent on intermittent renewable generation sources, provide for the needs of remote communities, and meet the needs of residential and commercial customers. This report examines the commercial potential of six energy storage applications, or sub-markets, in Australia:

- Supporting Fringe and Remote Electricity Systems
- Network Support
- Market Participation
- Grid Stability
- Residential Storage Systems
- Business Storage Systems[11]

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[9] Source: AEMO, *Electricity Statement of Opportunities (2012)*, http://www.aemo.com.au/Electricity/Planning/Reports/Electricity-Statement-of-Opportunities

[10] Note that our 'Pessimistic' scenario includes the possibility of future cost rises in raw materials (e.g. rare earths) and manufacturing processes. Source: MHC Analysis

[11] We use the term 'Private' here to denote a storage system that is operated primarily for the benefit of residential or business customers, rather than for the benefit of the electricity system – even if in actuality, the storage system is community-owned or not located on the customer's premises

3 Applications for Energy Storage in Australia

In this section, we describe in detail our six applications, or sub-markets, for energy storage. The diagram below depicts their conceptual location and role within Australia's electricity systems.

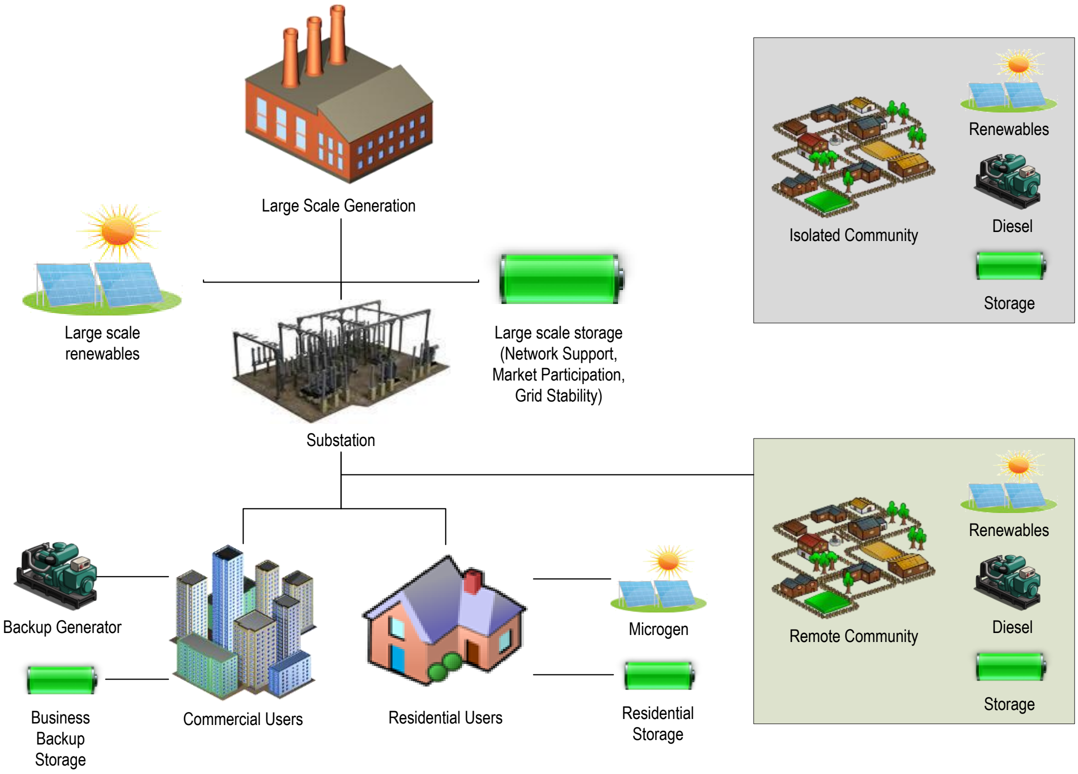

Figure 8: Schematic diagram of storage opportunities

Some of these applications can be 'stacked', representing situations where investment a single storage option can yield multiple sources of benefit, which when combined may help justify its cost.

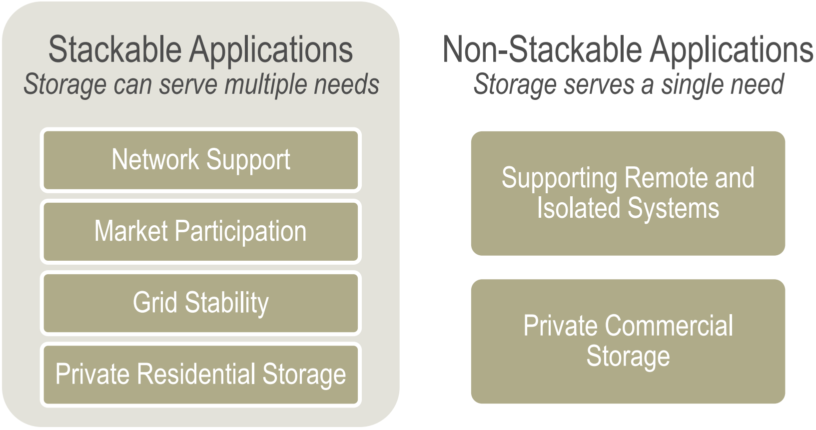

Figure 9: Conceptual diagram of 'Benefit Stacking'

3.1 Supporting Fringe and Remote Electricity Systems

3.1.1 Background

In this section, we deal with electricity systems with little or no access to the major grids and electricity markets of Australia. We make the distinction between two categories of such systems:

Fringe Systems: These exist as offshoots of larger regional grids, and are ultimately linked to a high-voltage transmission network. This link, however, is tenuous and costly. Usually these systems hang off long single-wire earth return (SWER) lines, which are expensive to maintain (by virtue of their length, lack of telemetry, and remote location) and are prone to failure, having by definition no redundancy. Voltage regulation is also very difficult to maintain on these lines, and the difficulty increases with their length and the number of communities served along it. Nevertheless, this limited network infrastructure has been the only viable choice to date; the capital cost of strengthening their connection to a regional or urban standard would be prohibitive.

Typically these systems will also contain local generation (e.g. diesel engines), for use at peak times when demand is outstripping the capacity of their connection to the grid, or when the connection fails.

Remote Systems: These are completely physically separated from regional grids and other electricity systems, and therefore are totally dependent on their own generation capacity. This local generation is typically supplied by diesel plant in smaller systems, and by gas plants in some larger systems, although significant moves towards renewable energy in these systems are occurring.

3.1.2 Complications

Pressures are now growing on these systems, threatening to add to their local utilities'[12] already-high cost of serving them.

- The **unreliable supply** of electricity in these areas via long, remote transmission lines and the inevitable faults that occur on all generation hardware, is not a new issue. However, it remains as a disadvantage to residents living in these communities, and an impediment to their economic output and quality of life.
- The **cost of delivered fuel** is rising sharply. Both Fringe and Remote systems depend on fuel, delivered over long distances, to run their generators. It is not unusual for this fuel to be delivered monthly, via road tankers, at a cost of more than $3.00 per litre. Consensus forecasts indicate that this cost is set to increase even further, given historical and projected increases in the cost of diesel itself (see Figure 10 below).
- **Population and peak demand** are growing, mirroring an Australia-wide trend. This is a problem when considered in conjunction with the following point:
- **Constrained capacity** of generation and transmission in these systems represents a limit of allowable safe peak demand. If a utility's forecasts show demand outstripping this limit, then

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[12] In this section we largely refer to 'utilities', since vertical integration tends to be the rule for these Isolated and Remote systems. Later we will reintroduce the distinction between disaggregated retail, generation, transmission, and distribution businesses.

(in the absence of better solutions) significant capital expenditure in generation plant and transmission capacity is required. The cost of doing this, in per-kW terms, dwarfs the equivalent cost in major urban centres, which itself has been the subject of angst over rising electricity bills in recent years.[13] The implication for remote systems is that this expenditure would need to be heavily subsidised, as it has been in the past, to avoid politically unacceptable (and economically unviable) impacts on customers.

- **Renewable Energy** is proliferating, in both central and distributed form. Utilities have invested in medium-scale wind and solar generation for remote communities, to reduce the fuel consumption of their generating plant. And households have invested in their own PV systems, as elsewhere, for their own reasons. However, there are limits to the amount of renewable energy capacity that any traditional electricity system can safely integrate (see Figure 11 below). The hosting capacity limit for a given system is generally around 15-25%, although this should be read only as an indication; each system's particular configuration of generator sizes, response times, and network layout will permit a different 'safe' level of renewable uptake.[14]

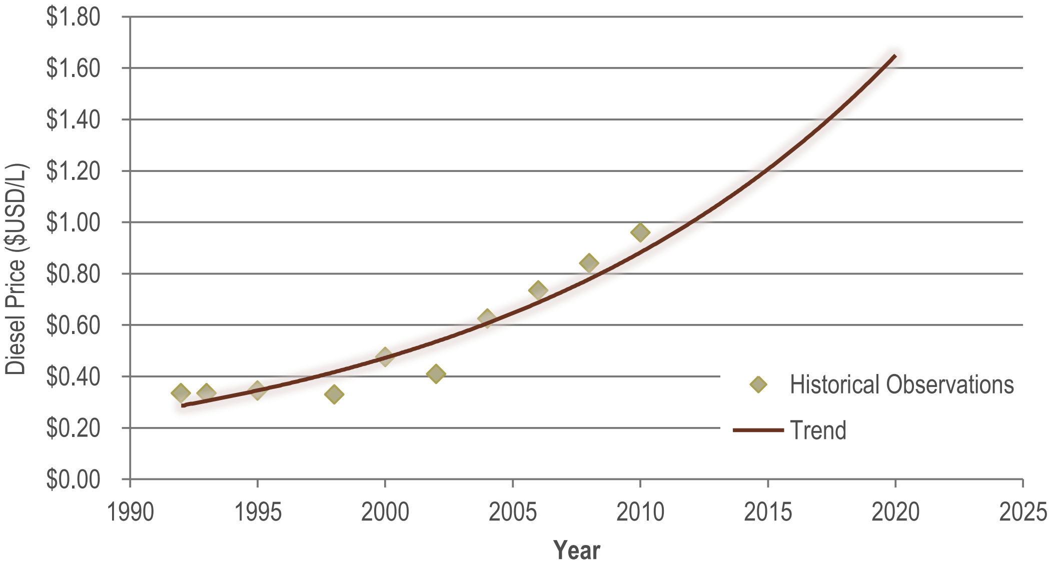

Figure 10: Diesel Prices in USD, Historical and Projected. Taxes not included.

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[13] See section 4.2 for details on these comparative costs

[14] This point should not be taken to mean that the RET's 20% target is unachievable. As we will see later, there are solutions available to raise this hosting capacity limit.

Sources: Sayeef et al, *Solar Intermittency: Australia's Clean Energy Challenge*, http://www.csiro.au/science/Solar-Intermittency-Report; *Tarnowski et al, Frequency Control in Power Systems with High Wind Power Penetration,* www.cigre.cl/bienal_9_10_nov_11/.../10_nov/Vestas_2.pdf

Constraints on integrating renewables into a traditional system

- Voltage instability in high-penetration pockets of the network
- Likelihood of backfeeding incidences, and associated safety risks
- Constantly variable output of wind and solar generation leading to grid frequency fluctuations outside acceptable bands
- Inability to substitute intermittent renewable plant for dispatchable plant (e.g. diesel, gas, coal)

Figure 11: Constraints on integrating renewable energy into a traditional electricity system

3.1.3 The Case for Storage

These systems would seem to be ideal first candidates for energy storage deployment:

- They are the costliest systems to supply using conventional generation and network infrastructure; an alternative proposition of storage coupled with renewable generation therefore has a lower economic hurdle to clear.
- These systems operate in much the same way as a larger grid such as the NEM or WEM, but in miniature. Their small size makes them easier to comprehend, the need of storage easier to analyse, and the deployment of storage (or indeed other infrastructure) easier to manage. At the same time, the models of storage integration developed in these small systems can be feasibly scaled up to meet the needs of a larger grid.

How, then, would storage benefit these systems?

- Storage could mitigate **unreliable supply** by allowing these systems a much greater degree of energy independence – both from remote transmission lines, and from externally delivered fuel. This has the value of decreasing their exposure to risks of supply interruption and cost escalation outside their control.
- Storage, in combination with renewable generation plant, could mitigate the **cost of delivered fuel** by allowing energy generated from intermittent renewable sources to be stored, and thereafter to serve load even when the sun and wind are not producing energy.
- Storage could ameliorate the combined impact of **Growing population and peak demand** and **constrained capacity** of generation and transmission, by charging during off-peak times and discharging at peak times – in effect, creating "negative demand" and therefore lowering the total peak (see Figure 12 below). This then avoids the need for capital investment in new transmission and generation capacity.
- Storage allows a higher hosting capacity limit of **Renewable Energy** to be integrated into an electricity system than would otherwise be the case. It allows this higher hosting capacity through three key mechanisms:
  - It creates **firm capacity** for renewable generation plant, by allowing intermittent output to be stored at the time of generation, and released at the time of day when it's needed most. This makes renewable energy more valuable, and allows gas or diesel generation plants to be retired, or their construction to be avoided or deferred. This then improves the economic justification for building new renewable plant.

- It allows for **ramp rate control** of intermittent renewable output. In a small remote system, there is a limit to how quickly generating engines can ramp up their power output. When PV and wind turbines are generating at their maximum capacity, diesel engines are typically running at low capacity, or are turned off entirely. If this PV and wind output suddenly drops off due to cloud cover or lack of wind (events termed 'cloud shear' and 'wind shear' respectively), the diesel plant may not be able to ramp up its output quickly enough to avoid a brownout, or power system failure. The spectre of this happening has led most remote utilities to constrain the amount of renewable energy output they are willing to rely on at any given time. Storage can, like an uninterruptible power supply, allow renewable output in the event of cloud shear or wind shear to gradually peter out, instead of sharply ceasing. This in turn allows diesel generation to gradually ramp up to serve the load, at a safe rate.
- It can protect the **stability of the grid** as a whole from the fluctuations in renewable energy output. Electricity in Australian AC grids is kept to a target frequency of 50 Hz, and only allowed to deviate from this target by a small amount. Renewable generation naturally produces a supply of electricity with fluctuating frequency, owing to the variable intensity of sun or wind over short periods of time. If renewable penetration is high enough, this variation can start to strongly influence the overall frequency across the entire grid, reducing power quality. Some storage technologies are suitable for continuously 'smoothing out' this variable frequency, again allowing for a much higher safe hosting capacity limit.

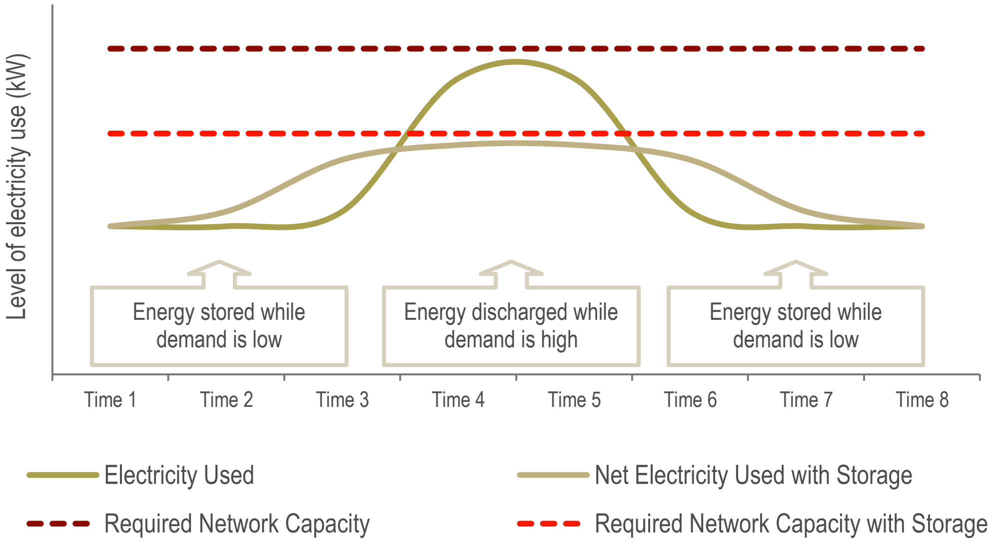

Figure 12: Peak shifting using energy storage

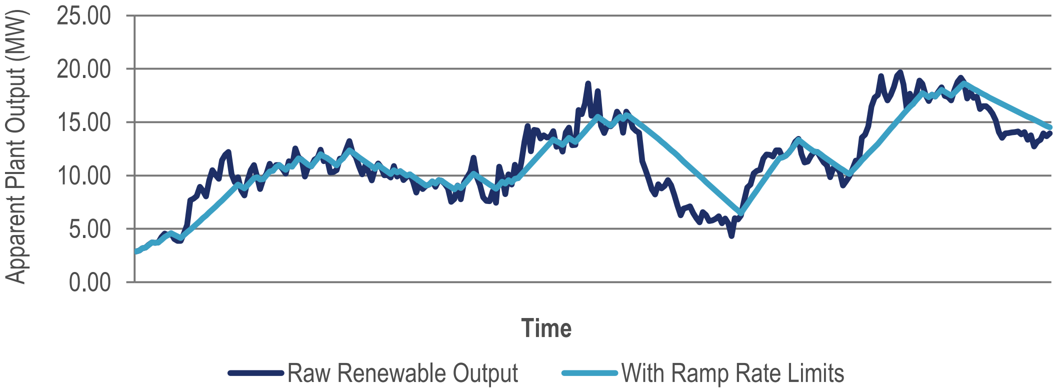

Figure 13: Illustration of Ramp Rate Control

3.1.4 Deployments to Date

In Australia, most storage trials to date have focused on remote systems. As noted in section 3.1.3, the economics are more attractive, storage deployment is easier to manage, and the costs and benefits easier to measure. A selection of these are described briefly below.

However, storage is not yet appearing as a proposed substitute for traditional network augmentation, in any regulatory submissions we have seen to date. There remains a gap between its recognised potential, and its acceptance as a credible "go-to" solution to network problems.

Horizon Power, who supply the large majority of North Western Australia's smaller and remote communities, have used flywheel storage systems in Marble Bar and Nullagine to address the ramp rate control issue outlined in section 3.1.3 above. The two towns, with a combined population of around 600, required over 1,000,000 litres of diesel per year to be delivered by truck.

The solar power stations in these towns, supported by 2 x 500 kW (5 kWh) flywheel energy storage systems now:

- Generate 1048 MWh of solar energy per year
- Provide 65 per cent of daytime energy demand from solar power
- Save 1,100 tonnes of greenhouse gas emissions per year
- Save between 35-40 per cent diesel consumption per year (405,000 litres of fuel per year)[15]

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[15] Source: Horizon Power, http://www.horizonpower.com.au/marble_bar_nullagine_power_stations.html

Figure 14: Marble Bar Power Station

More recently, Horizon have moved from a strategy of deploying their own centralised storage, to a "bring-your-own", rules-based approach. As of July 2012, customers of some systems who wish to install their own distributed renewable generation are required to supplement it with their own device ensuring adequate ramp rate control.

Ergon Energy, who supply regional and rural areas in Queensland, have conducted trials of storage on Magnetic Island, typically using modular 5kW (20kWh) batteries as part of their Solar Cities project. As a result of that project:

- Peak demand has been reduced by 40% compared to 'Business as Usual' predictions
- Energy consumption has returned to 2007 levels, reducing customer bills as a result.
- The installation of a third cable to the island (at an estimated cost of $17 million) has been deferred for another 8 years.
- 33 520 tonnes of greenhouse gas emissions have been saved (as at 30 June 2011).[16]

Hydro Tasmania deployed a large scale Vanadium-Redox flow battery (VRB) on King Island in the Bass Strait. The battery was installed in 2003 as part of the King Island Renewable Energy Expansion (KIREX) project. The objective of the storage system was to increase the recoverable portion of renewable energy and to smooth the variable output of the wind farm to enhance the use of wind power to displace diesel generation. A renewable energy penetration of over 80% on the island was achieved.

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[16] Source: Ergon Energy press release, http://www.ergon.com.au/about-us/news-room/media-releases/regions/northern/trial-project-to-save-customers-money-and-power

Figure 15: Electrolyte storage tanks comprising the King Island VRB

Following an operational event, the VRB is currently out of service. Hydro Tasmania is currently evaluating options to replace the energy storage system.[17]

3.2 Network Support

3.2.1 Background

In this section, we deal with the networks comprising the principal grids of Australia: the NEM on the East coast (including Tasmania), the SWIS and the NWIS in Western Australia, and the Darwin-Katherine grid in the Northern Territory.

Australia's electricity networks serve an inherently costly market. We have a sparse population that is dispersed over a geographically expansive area, and a "peaky" load profile, driven by air conditioners and many other electrical demands. This **peak demand level grows** each year, as consumers progressively accumulate more electricity-consuming devices in businesses and homes.[18] Politically, it is imperative that we cater for these peak loads, as they tend to occur when we are relying on our energy the most.

Networks, with the assent of policymakers, have historically taken account of this in their load forecasts, and have allocated large sums of money to invest in building the network assets required to cope with this ever-rising peak.

The increasing penetration of distributed renewable generation also puts pressure on networks, where peaks in distributed renewable output do not coincide with peaks in load. This can create cases of 'backfeeding' (a situation where power on a grid is flowing opposite to its normal direction) which in some instances can outstrip the capacity of feeders and substations.

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[17] Source: Hydro Tasmania, King Island Renewable Energy Expansion (KIREX), http://www.kingislandrenewableenergy.com.au/history/kirex#VRB

[18] In AEMO's most recent National Electricity Forecasting Report, they note that this annual peak growth rate has slowed in recent years. Negative peak growth (i.e. a fall in year-on-year peak demand) is expected to occur in 2012-13; however, positive peak growth forecasts persist thereafter. Source: http://www.aemo.com.au/Electricity/Resources/Reports-and-Documents/National-Electricity-Forecasting/National-Electricity-Forecasting-Report-2012

3.2.2 Complications

In recent years, significant public anger has brewed over the impact of this capital spending on electricity bills. The cost of electricity is now the issue of largest concern to residential customers.[19]

At the same time, overall throughput of energy in recent years has declined or stayed flat. The causes for this new trend are still not fully understood, but we draw out two key ones:

- The growing availability of energy efficiency measures and distributed generation that reduce load at non-peak times, thus lowering energy throughput without materially reducing peak consumption
- As unit costs rise, customers become more conscious of their energy consumption and seek ways to voluntarily reduce it. However, this again has little impact on peak demand. And worse, it creates a "death spiral" of interdependent unit cost rises and throughput reductions.

Other mooted causes have included the impacts of the global financial crises, the collapse of the manufacturing sector, weather events, and state energy efficiency programs.

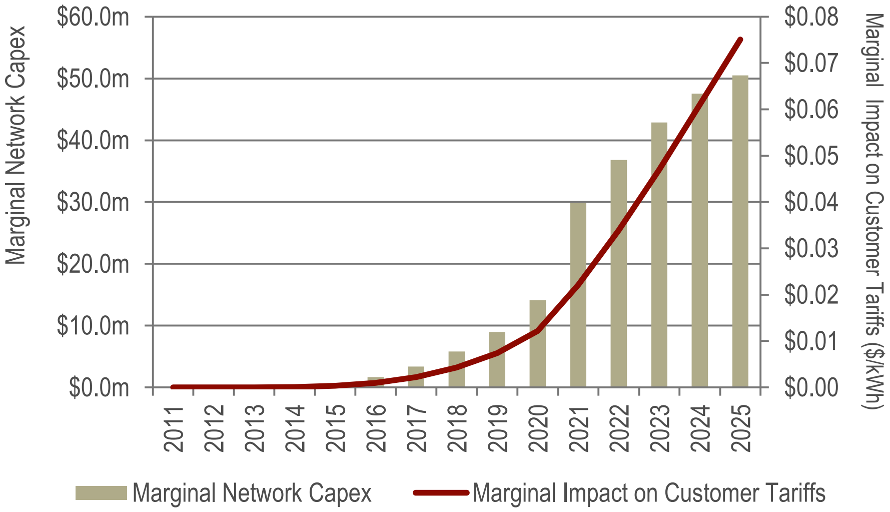

Figure 16: Example scenario of rising network capital expenditure and its effect on customer tariffs[20]

Continued investment in our networks to relieve this **constrained capacity** means that the marginal cost of supplying power at peak periods is escalating ; this cost is inevitably passed on to customers.

This story is quite similar to parts of the situation in remote systems described in section 3.1 above. But at the scale of the grids in the NEM, the stakes are much higher, subsidies to hide the problem are impractical, and the unsustainability of the situation is therefore more apparent.

3.2.3 The Case for Storage

There are, however, alternatives to the traditional approach of building successively bigger networks:

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[19] Source: CHOICE magazine, http://www.choice.com.au/media-and-news/media-releases/2012-media-releases/choice%20research%20shows%20electricity%20main%20household%20concern.aspx

[20] Source: MHC Analysis

- Demand-side participation, promoted most recently by the AEMC in its draft Power of Choice report, can reduce peak consumption by giving energy consumers tools to reduce their individual peak demand, and rewarding them appropriately for doing it – the ‘carrot’ approach.
- Cost-reflective pricing is another possibility, and can be similarly seen as the ‘stick’. Such a pricing scheme would rebalance bills away from charging according to energy consumption, and toward charging according to their impact on peak demand, i.e. their maximum demand during peak times. This too would align customers' and networks' interests by penalising customers for excessive peak consumption, and conversely rewarding them for reducing their contribution to peak demand.

Policy responses can of course include a combination of these ‘sticks’ and ‘carrots’. This report won’t examine these alternatives further. Storage, though, is a third alternative:

- Storage could ameliorate the combined impact of **Growing population and peak demand** and c**onstrained capacity** of generation and transmission, by storing energy during off-peak times and discharging at peak times – in effect, offsetting demand and therefore lowering the total peak (see Figure 12 on page 20). This then avoids the need for capital investment in new transmission and generation capacity
- Consider a T&D system whose peak electric loading is approaching the system’s load carrying capacity (design rating). In some cases, installing a small amount of energy storage downstream from the nearly overloaded T&D node will defer the need for a T&D upgrade.
- Storage in the form of a portable battery installation could also perform this same role on a temporary basis while asset construction or maintenance is underway, also thereby negating the need for emergency measures to avoid unserved load until the point where the construction or maintenance is complete.
- Although the emphasis for this application is on T&D upgrade deferral, a similar rationale applies to T&D equipment life extension. That is, if storage use reduces loading on existing equipment that is nearing its expected life, the result could be to extend the life of the existing equipment. This may be especially compelling for T&D equipment that includes aging transformers and underground power cables.
- In future, storage may also help networks cope with the proliferation of Electric Vehicles, and the immense new demands they will place on the network. Using storage facilities at charging points can provide fast DC-to-DC recharge for vehicle owners, while spreading the load on the network from a sequence of rapid charging sessions, more evenly over time (i.e. creating a lower peak level of demand, for the same level of energy throughput).

We should recognise, however, that there will be no “silver bullet”, either in the form of storage or any other alternative, that will remove the need for network augmentation entirely. In section 4.1 below, we outline our modelling approach which recognises the need for a portfolio of complementary approaches to solving the peak demand problem, of which storage will comprise one part.

Example case study:

A 20 MVA substation is at 95% capacity, and serves load growing at 2% per year.

The local electricity distributor can decide between two options:

1. Upgrade the substation with 5 MVA of additional capacity in the next two years.

2. Install enough storage to meet the expected peak load growth

For this substation, the load growth during the next year will be 320 kW (2% × 20 MVA x 0.8 PF). This relatively small amount of storage can be used to provide enough incremental capacity to defer the need for a multi-million dollar lump-sum investment in distribution network assets.

This reduces pressure on customer bills; improves utility asset utilization; allows use of the capital for other projects; and reduces the financial risk associated with lump investments.

3.2.4 Deployments to Date

As with fringe and remote systems, storage is not yet appearing as a proposed substitute for traditional large-scale network augmentation in any regulatory submissions we have seen to date. There remains a gap between its recognised potential, and its acceptance as a credible “go-to” solution to network problems.

There are several trials in Australia, both completed and still underway, that aim to demonstrate the technical and economic feasibility of storage – usually as one technology among others in a ‘Smart Grid’ suite.

The Australian Government's **Solar Cities** program is designed to trial new sustainable models for electricity supply and use, and is being implemented in seven separate electricity grid-connected areas around Australia (Adelaide, Alice Springs, Blacktown, Central Victoria, Moreland, Perth and Townsville). It is administered by the Department of Climate Change and Energy Efficiency, in partnership with local and state governments, industry, business and local communities. An example of storage being integrated into these trials is shown in Figure 17 below.

Bendigo Solar Park

The lead acid battery storage system designed and built into the inverter room is rated at 22MWh annual storage capacity, which is equivalent to approximately 60kWh storage and discharge capacity per day. Given that the average daily generation capacity of the park is 1,200kWh, the batteries can nominally store and discharge 5% of the daily generation capacity.

The intent of installing this battery system was to test the feasibility of storing energy from the peak generation times to discharge at other periods (typically peak demand periods) and for running equipment in the inverter rooms in the evening and night periods.

Figure 17: Battery System, Bendigo Solar Park, (part of the Central Victoria Solar City Program) [21]

AusGrid and EnergyAustralia are leading the development of the **Smart Grid, Smart City** project in partnership with the Australian Government, across five sites in Newcastle, Sydney and the upper Hunter Valley.[22] The project aims to gather information about the benefits and costs of different smart grid technologies in an Australian setting. The following storage deployments are planned to take place:

- **Newcastle:** 40 battery storage devices will be installed at volunteer households in the Newcastle area. These will be able to output a total of 200kW for two hours at full capacity, with each device able to deliver up to 5kW of power
- **Scone**: 20 battery storage devices will be installed at selected volunteer properties. They can provide a total of 100kW for two hours at full capacity, with each device able to deliver up to 5kW. These will be concentrated on one section of a rural 11kV power line.
- **Newington**: Battery storage will be attached to the network to test the ability of the smart grid to help absorb more solar energy without affecting reliability or power quality, and to manage energy flows on the network to maximise the benefits of solar power.

Ergon Energy have taken the next step by commissioning a detailed model of the possible role for storage across their network. This work is currently being carried out jointly with the Queensland University of Technology.

3.3 Market Participation

3.3.1 Background

Australia comprises two separate major electricity markets:

- The **National Electricity Market** (NEM) began operating as a wholesale market for the supply of electricity to retailers and end-users in Queensland, New South Wales, the Australian Capital Territory, Victoria and South Australia in December 1998. Tasmania joined the NEM in 2005. Operations today are based in five interconnected regions that largely follow state boundaries. The NEM operates on the world's longest interconnected power system – from Port Douglas in Queensland to Port Lincoln in South Australia – a distance of around 5,000 kilometres. More than $10 billion and 180,000 GWh of electricity is traded annually in the NEM to meet the demand of more than eight million end-use consumers.[23]

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[21] Source: Central Victoria Solar City, *Annual Report 2010-11*, http://www.centralvictoriasolarcity.com.au/documents/CVSC-Annual-Report-web.pdf

[22] Source: Smart Grid Smart City Program, *Innovative Energy Generation Factsheet*, http://www.smartgridsmartcity.com.au/About-Smart-Grid-Smart-City/Factsheets.aspx

[23] Source: AEMO, *An Introduction To Australia's National Electricity Market,* http://www.aemo.com.au/About-the-Industry/Energy-Markets/National-Electricity-Market

- The **Wholesale Electricity Market** (WEM) operates in the south-west region of Western Australia where most of the population live (estimated at just over 2 million). Western Australia's geographical isolation from other electricity markets in Australia makes the WEM unique. It is for this reason that the design of the WEM is centred around ensuring self-sufficiency as the state of Western Australia is not physically connected to the eastern states' National Electricity Market, and therefore cannot rely on it in times of short supply or an emergency.[24]

In each market there exists a market operator (AEMO and the IMO respectively) which must continuously balance short-term supply from generators with demand (also known as load) from energy consumers throughout the day: a process to guarantee that supply and demand are matched in real time, as described in section 2 above.

One consequence of this real-time matching is that Electricity is the commodity with the most price volatility in the world; in the NEM its price can change by over four orders of magnitude each day.

3.3.2 Complications

The Australian electricity industry is being challenged to incorporate ambitious amounts of renewable energy into the generation mix. Australia's RET scheme commits to achieving 20% renewable penetration by 2020.[25] This poses problems beyond simply finding enough renewable reserves to meet the target. Solar and wind are intermittent sources of energy, and therefore cannot meet demand at all times. Today, readily available reserve generation "fills the gaps" when renewable energy is not being produced.

However:

- As noted in section3.2.1 above, peak demand continues to rise, albeit more slowly than historically, in Australia. From the energy market's point of view, this nominally requires a rising peak generation capacity capable of meeting demand. The costs of building this peak generation capacity are, just like peak network capacity, ultimately borne by energy consumers. The alternative is to allow the price of energy to rise prohibitively at times when peak load cannot be served.[26]
- Equilibrium in the market has historically depended on the market operator's ability to continuously dispatch generators in order to meet demand at least cost. Renewable generation, however, cannot be dispatched in this way: although not wholly unpredictable, there is no guarantee that the bulk of its output will be produced at times comprising the bulk of energy demand. This per se makes it harder for non-intermittent plant to "fill the gap", thus leading to increasing market volatility.[27]

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[24] Source: Independent Market Operator, *Overview of the WEM*, http://www.imowa.com.au/wem_overview

[25] The current review of the RET scheme may alter these forecasts. More information on the review can be found at http://climatechangeauthority.gov.au/ret

[26] In the NEM, the price of energy is currently capped at $12,500 per MWh, which is approximately 50 times higher than the typical consumer's retail tariff.

[27] In practice, this will mean that the traditional approach does not become impossible, but does become more costly. Previous analysis from ROAM and SKM has shown that meeting the RET is still technically feasible using non-intermittent generation to "fill the gap".

- Renewable energy suppliers currently have no choice but to accept the price that is available at the time when their plant is generating electricity; they cannot choose the times at which they run.
- Carbon pricing will increase the cost of carbon-intensive baseload generation plants (primarily coal, and to a lesser extent gas), and to some extent will encourage them to scale down their operations, or spur their decision to retire from the market completely. This same driver will increase the cost of carbon-intensive peak generators, which are currently relied on to meet peak demand.

There also exist some sub-optimal conditions for the deployment of renewable energy in the market: most renewable energy plant produces a significant portion of its output when that energy has a low value (e.g. at night, on weekends and during holidays – generally referred to as off-peak times).

3.3.3 The Case for Storage

Carbon-based generation will remain an important component of the supply side, and demand management will increasingly be used during periods where renewable generation is not running. However, there is an opportunity to deploy storage in energy markets stressed by peak demand, and supporting renewables at the same time, by allowing supply and demand for energy to be matched across time rather than needing to be matched instantaneously.[28]

In the context of Australia's electricity markets, this activity would be carried out by a market participant that buys surplus output and sells into periods of shortfall, being in effect an arbitrageur or energy trader, using energy storage as a technical means to consume their energy purchases and supply their energy sales. This trading might take place either in the spot market, or in the contract market.

Typically, the storage discharge duration needed for energy time-shift would range from four to six hours, depending on the duration of peak price periods, and the duration of the intervals between them.

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[28] In this section we deal with the concept of 'shifting' energy output across the span of hours. At the micro level, there is also value in shifting energy output across the span of seconds or a few minutes. We address this separately in section 3.4 below.

There is also theoretical value in shifting renewable output across seasons, e.g. PV output from summer to winter. This report doesn't examine that possibility.

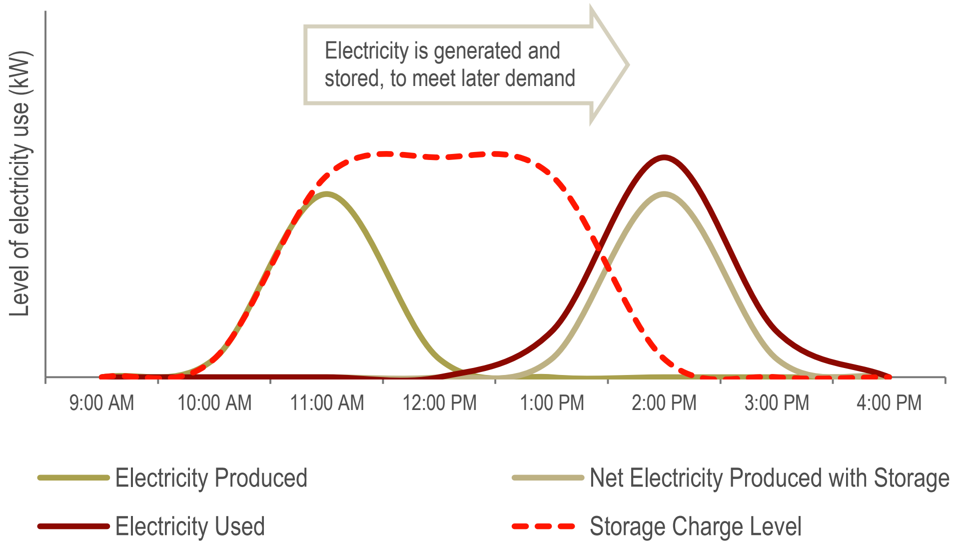


Figure 18: Matching supply and demand across time using Energy Storage

In the short term, this should:

- “Flatten out" peak prices, and reduce the incidence of peak price events – lowering both the volatility and average price level of the market
- Reduce the opportunity for current generators to earn super-returns during peak price events, which will impact particularly on the ‘peak generators’ who tend to run only at these times.
- Flatten the apparent load curve (i.e. the load curve as seen by generators, after it has been ‘modified’ by energy storage) over the course of a day.

In the long term, this may also:

- Defer or remove the need for new peak generation being built
- Potentially strand existing peaking generators, forcing them to exit the market

Note that arbitrage is inherently risky in any market, and particularly so in a market for a commodity as volatile as electricity. It is virtually impossible to make perfect decisions about price developments before the fact, and the rate of return for market-participating storage schemes will be heavily dependent on the optimality of their forecasting and dispatch algorithms.

Arbitrage opportunities also in general have the tendency to self-destruct, since price differences tend to disappear as the number of players aiming to leverage them increases. However, this only tends to apply where markets are in a reasonably steady state. We foresee that the arbitrage opportunities yielded by the continuing growth of renewable generation forecast in the coming years will counteract the erosion of previous opportunities by arbitrageurs.

3.3.4 Deployments to Date

The situation here is simple to report: there are no known instances of storage participating in the energy market (as a primary application) in Australia, although we are aware of some confidential studies by prospective energy traders that have investigated the opportunity for doing this. For now, there appears to be no economic justification for installing and managing energy storage in this way.

In section 4 below, we model this economic justification in some detail, and forecast how it might change in future, especially when considered in the context of a battery that performs energy arbitrage along with other value-creating functions.

3.4 Grid Stability

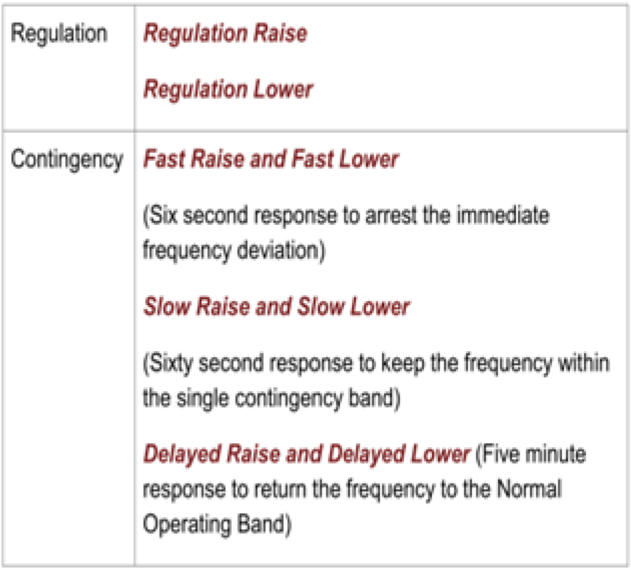
3.4.1 Background

Section 3.3 above deals with the balancing of supply and demand in the NEM over the course of a day – or, to be more exact, in each 5-minute dispatch interval.

However, the grid also needs to be kept in balance over the course of seconds.

Any change in the supply-demand balance on an AC electricity grid will result in a change of the observed frequency (number of current and voltage cycles per second) on that grid. Keeping this frequency stable, therefore, is effected through rapid and small-scale injections or withdrawals of generation and load.

In the **NEM**, this balancing service is provided through Frequency Control (FCAS) – a category of ancillary services (i.e. ancillary to the trading of energy) that are specified in the design of the market. AEMO procures this frequency control from market participants – usually existing generators and customers with very large loads – to maintain the frequency on the electrical system, at any point in time, close to fifty cycles per second as required by the NEM frequency standards. Their cost is spread amongst all market participants (and ultimately, to energy consumers)



Regulation	*Regulation Raise* *Regulation Lower*
Contingency	*Fast Raise and Fast Lower* (Six second response to arrest the immediate frequency deviation) *Slow Raise and Slow Lower* (Sixty second response to keep the frequency within the single contingency band) *Delayed Raise and Delayed Lower* (Five minute response to return the frequency to the Normal Operating Band)

Figure 19: Categories of FCAS required in the NEM [29]

In the **WEM**, frequency control is effected through:

- Load Following Ancillary Services (LFAS), which compensate for variations in load and intermittent generation relative to what system management anticipated when issuing dispatch instructions for the trading interval, and also compensates for normal generation deviations.
- Spinning Reserve Ancillary Services (SRAS), which can respond rapidly should an online generation facility experience a sudden forced outage.

Load following and spinning reserve ancillary services for the WEM are currently provided by the state-owned incumbent generator, Verve Energy (with the exception of a small quantity of spinning reserve provided by interruptible loads under ancillary service contracts).

Internationally, this function is known by a variety of different names, e.g. the “balancing market” in the United States.

Currently, the market for these services in Australia is unattractive to prospective entrants, owing to the low price these services command. This is for two reasons:

- **The supply is plentiful**: Generators who are already running at less than full capacity can afford to offer their spare capacity to the market operator for frequency control purposes quite cheaply.
- **The demand is limited**: The Australian mainland is a relatively stable system, in the sense that sources of generation and load are disparate, and geographically well interspersed. In Tasmania the demand for frequency control is somewhat higher, due to the requirement to

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[29] Source: AEMO, *Guide To Ancillary Services In The National Electricity Market*, http://www.aemo.com.au/Electricity/Market-Operations/Ancillary-Services/Guides-and-Descriptions/Guide-to-Ancillary-Services-in-the-NEM

keep the Basslink interconnector stable.[30] However, countering this is Hydro Tasmania's current dominant position with respect to supplying frequency control services.[31]

3.4.2 Complications

The balance of supply and demand for frequency control to maintain grid stability can, however, be expected to change in the near future:

- **Supply will be tightened** as coal generation plant is displaced by gas, and to some extent by renewable energy - driven by the introduction and escalation of a carbon price. Both of these substitute generation technologies lack the inherent inertia of coal-fired generation, which makes them less able to cheaply offer frequency control services
- **Demand will increase** as renewable penetration expands: Renewable generation naturally produces a supply of electricity with fluctuating frequency, owing to the variable intensity of sun or wind over short periods of time. If renewable penetration is high enough, this variation can start to strongly influence the overall frequency across the entire grid, reducing power quality. In simple electrical loads such as lighting, this poor quality power can cause flickering or an occasional blown fuse; in more complex electronic loads, it can result in permanent damage. There are also risks to frequency stability when distributed power generators connect in the lower capacity sections of the electricity network, and feed back into the grid.

Currently, this potentially oversupply of renewable energy is being avoided, in most cases, by fiat: electricity distributors have created rules about how much distributed generation they believe is safe on any given feeder, or downstream of any substation; they now routinely refuse applications to connect solar installations large enough to breach this limit.

3.4.3 The Case for Storage

Storage can protect the stability of the grid as a whole from the fluctuations in renewable energy output. Some storage technologies are suitable for continuously 'smoothing out' this variable frequency, again allowing for a much higher safe renewable hosting capacity limit.

As noted in section 3.4.1 above, the mechanism for smoothing frequency is a familiar one: rapid and small-scale injections or withdrawals of generation and load. This can equally be done through rapid charging and discharging of energy storage.

Leaving its cost aside, storage has some natural advantages as a provider of frequency control:

- When frequency needs to be lowered, this is traditionally done through generators ready to disconnect (i.e. withholding energy), or loads ready to connect (i.e. consuming energy), at short notice. In the case of storage, energy is neither consumed nor withheld – it is stored, and can be discharged at a later time in order to raise the frequency (or for any other purpose). Effectively, storage can be 'paid twice': an option not available to other providers.

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[30] A similar situation exists in New Zealand, where the majority of load exists on the North Island, and the generation on the South Island. The difficulty in keeping this system stable contributes to a higher demand for frequency control.

[31] Hydro's instantaneous hydroelectric generation capacity would be very difficult for a new entrant to compete against.

- Most storage technologies can operate at partial output levels relatively efficiently, and can respond to signals from the market operator very quickly (compared to most types of conventional generation)
- A single storage device can be used effectively for both frequency raising (as load increases) and frequency lowering (as load decreases); conventional providers can usually only offer one service or the other.

Note: there are two other categories of ancillary services procured in the NEM alongside FCAS which are intended to stabilise the grid, which we have not modelled as an opportunity for energy storage:

- *Network Control Ancillary Services* (NCAS): Intended to control the voltage at different points of the electrical network to within the prescribed standards, and to control the power flow on interconnectors to within the physical limitations of those elements. This is effected through the generation and absorption of reactive power (VAR), as opposed to the real power (W) we have been dealing in so far. Some storage technologies have the capacity to generate or absorb reactive power through their inductive or capacitive elements, but:
    - These inductive or capacitive elements do not per se require being coupled with storage, and can far more cheaply be implemented on their own
    - The need for this service is highly dependent on particular network configurations at each location, and does not lend itself well to the whole-of-grid modelling approach we have adopted.

  We have therefore not further examined the opportunity to provide this service commercially.
- *System Restart Ancillary Services* (SRAS): Reserved for contingency situations in which there has been a whole or partial system blackout and the electrical system must be restarted. It is theoretically possible for energy storage devices to provide this service, but with two critical caveats:
    - The volume of energy storage required would be well beyond what existing or foreseeable storage technology could offer
    - Providing the service would require always having stored (undischarged) energy at hand - which would effectively reduce the storage device's available capacity for every other application to which it might be put.

  For these reasons we have also excluded SRAS from consideration

3.4.4 Deployments to Date

In Australia, as noted in section 3.4.1 above, the market for FCAS is currently not attractive to new entrants. So it is not surprising that we have seen no commercial deployments of batteries with the purpose of providing grid stability support.

Some trials, however, have experimented with this application:

At Hampton Park Wind Farm, a 1.32 MW wind power station southeast of Lithgow in NSW's Blue Mountains, Ecoult (in partnership with the CSIRO) have integrated a MW-scale wind output smoothing system large enough to absorb the power station's entire output, which can limit the 5-minute ramp rate to 10% of the power station's raw output.[32]

Although there is no market or network condition placed on the wind farm that requires them to limit their ramp rate in this way, the CSIRO and Ecoult are using the installation to experiment with what is technically possible using such an energy storage installation.

Figure 20: Energy Storage installation at Hampton Park Wind Farm

The *Smart Grid, Smart City* pilot (described in section 3.2.4) has also monitored the ability of battery storage to effectively provide frequency control services.

Ecoult in partnership with PJM (Pennsylvania-Jersey-Maryland) Interconnection, a regional transmission business in the Northeast United States, have launched a Regulation Services project in Lyon Station, PA to provide 3 MW of continuous frequency regulation services to the grid. The system will also be used for peak demand management services to the local utility, Met-Ed.[33]

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[32] Source: Ecoult, Case Study, http://www.ecoult.com/case-studies/hampton-wind-farm-australia-wind-smoothing/

[33] Source: Ecoult, Press Release, http://www.ecoult.com/east-penn-and-ecoult-launch-pjm-regulation-services-project/

Figure 21: Storage Installation at PJM Regulation Services Project

3.5 Residential Storage Systems

3.5.1 Background

Australian residential households have enthusiastically adopted distributed renewable generation – overwhelmingly in the form of solar PV.

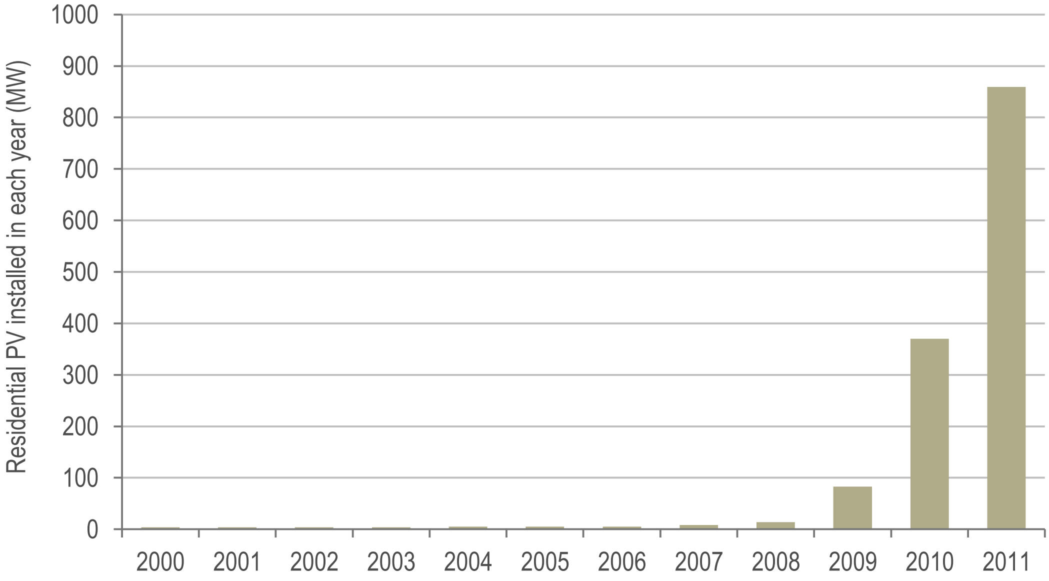

Figure 22: Uptake of residential solar PV, Australia[34]

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[34] Source: Clean Energy Council, *Review of the Australian solar PV industry 2011*, https://www.cleanenergycouncil.org.au/resourcecentre/reports.html

This uptake has been concentrated in the last 15 years, with noticeable 'spikes' at points where premium feed-in tariffs were introduced, and more recently when the underlying cost of solar panels rapidly declined in 2010-11.

Along with the economic incentives of avoiding utility power bills, solar PV has also been driven by people's desire to live more virtuously, at least so far as their energy consumption is concerned.[35]

3.5.2 Complications

There are reasons to believe that PV will not, on its own, satisfy the underlying desires of the consumers who adopt it:

- Intermittent generation (including PV) doesn't remove customers' dependence on the electricity network, or on the upstream fossil generation that generally supplies it, owing to the mismatch between the time that energy is generated and the time when it needs to be consumed.
- It is no longer so attractive to export surplus energy to the grid during the middle of the day, when PV output is at its peak, and the house is often empty. Premium feed-in tariffs have been abolished for new installations; the trend now (as has been seen with IPART's recent decision on a 'fair and reasonable solar feed-in tariff' of 7.7c to 12.9c per kWh) is toward 'subsidy-free' feed-in tariffs that reflect a wholesale market price for generated energy.[36]

3.5.3 The Case for Storage

The price of energy storage has fallen slowly but steadily in recent years, to a point where a storage system of meaningful capacity could conceivably be purchased for household use – as long as the purchaser was motivated by non-economic motives, and did not expect a reasonable financial return on their investment.

This situation for storage today is comparable to that of solar PV in the mid 1990's, when the technology was expensive, the electricity it supplanted was cheap, and it was therefore attractive only to a small, committed coterie of leading-edge adopters.

At the same time:

- The cost of grid-delivered energy is rising, and causing angst in the community.
- The community's awareness of storage is slowly growing, through news from utility-led trials.
- Householders, due to the reduction in favourable feed-in tariffs, are now motivated to use as much of their own PV output as possible, and avoid it 'going to waste' in the grid.
- The incentive above may also be motivated by the desire to be fully reliant on their own generation, and independent from the grid.

We foresee that this may trigger a similar 'values-driven' early adoption of storage at the household level, paired with existing (or new) PV – or some other form of distributed household generation.

This application primarily derives its value from a "feel good factor", in satisfying consumer desires. There is also a secondary value of storage in lowering domestic power bills, whereby householders:

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[35] And, arguably, by their desire to show that they can afford to.

[36] Source: http://www.ipart.nsw.gov.au/Home/Industries/Electricity/Reviews/Retail_Pricing/Solar_feed-in_tariffs_-_2012-2013

- Store energy at off-peak times
- Draw on stored energy at peak times
- Maximise their reliance on local PV generation and minimise their reliance on the grid

In the foreseeable future, this secondary value is likely to be very small: the gap between peak and off-peak prices is simply not large enough to justify this form of arbitrage (unlike the enormous gaps that can occur between wholesale peak and trough prices in the NEM), and could not be made large enough without bankrupting a large portion of people.

Nevertheless, residential storage may supplant (or be supplanted by) storage used for the *Market Participation* application, described in section 3.3 above. If energy storage is used to 'flatten out' wholesale prices in the market, this should ultimately be reflected in a flattening of peak/off-peak retail prices, which will diminish the case for private residential systems. Similarly, energy storage used in households to cut peak consumption should lead directly to an attenuation of the peak price events in the wholesale market that would encourage storage to be used for market participation.

3.5.4 Deployments to Date

Practically no households have yet taken up domestic storage technology independently. Up until very recently it has been cost prohibitive to do so, and the value proposition has been (and, for most, still is) unclear. That said, some trials (e.g. Ausgrid's *Smart Grid, Smart City*) have involved the utility-funded installation of energy storage and other similar devices into customer's homes.

In section 4 below, we model the likely uptake in future.

3.6 Business Storage Systems

3.6.1 Background

Many businesses employ their own backup generation facilities (generally off-the-shelf diesel generators), designed to meet all or some of their electricity demand in the event of a network outage.

In some cases, only a small portion of their electrical equipment is "backed up" in this way. For example, it is common for networks of computer servers to be fitted with UPS devices ensuring their ability to ride through outages, but for other devices such as dishwashers to be left offline when this happens.

We infer from this that their need for electric power continuity justifies the investment in backup generation.

3.6.2 Complications

The shortfall of most backup generation is that it is not available immediately. Diesel engines take some time – usually between15 and 60 seconds – to warm up and begin producing a usable energy supply. During this brief period, customers will still be without electricity.

We have identified a group of commercial customers who would place an extraordinarily high value on continuity of supply, and who would consider this delay in backup generation coming online to be an unacceptable risk:

- Data centres and network service providers
- Hospital divisions (operating theatres, intensive care units, life-support machines)
- Traffic control and signalling centres (airports; seaports; rail networks; road traffic lights)

Currently this risk is managed in a variety of ways, usually with a high implicit cost: redundant hardware, redundant energy network supply, or the acceptance of a highly disruptive outage.

3.6.3 The Case for Storage

Storage here can provide a bridging capability, in the form of instantaneous power during the time interval after grid supply is interrupted, but before backup generation can come online.

We have analysed storage only for this time-limited use; for extended periods of backup support lasting hours or days, diesel-fuelled generation is a far better solution. It is much more economical to 'store' enough energy in form of fuel containers to provide for the necessary worst-case scenario, than to store it in the form of a sufficiently large (and therefore expensive) storage device.

Storage in this application would therefore complement diesel generation, not replace it.

Note: We have not analysed the demand for commercial storage facilities designed to improve power quality (i.e. frequency and voltage) received from the grid – in effect addressing a public network problem with a private, beyond-the-meter solution. Any situation where power supply degraded to a point where private commercial storage systems were necessary to produce safe and usable electricity, would be politically unacceptable, and therefore unlikely in our view.

4 The Commercial Market for Energy Storage

4.1 Model Structure

We have modelled a highly simplified and aggregated Australian electricity system in order to estimate the commercial market for energy storage, as shown in Figure 23 below.

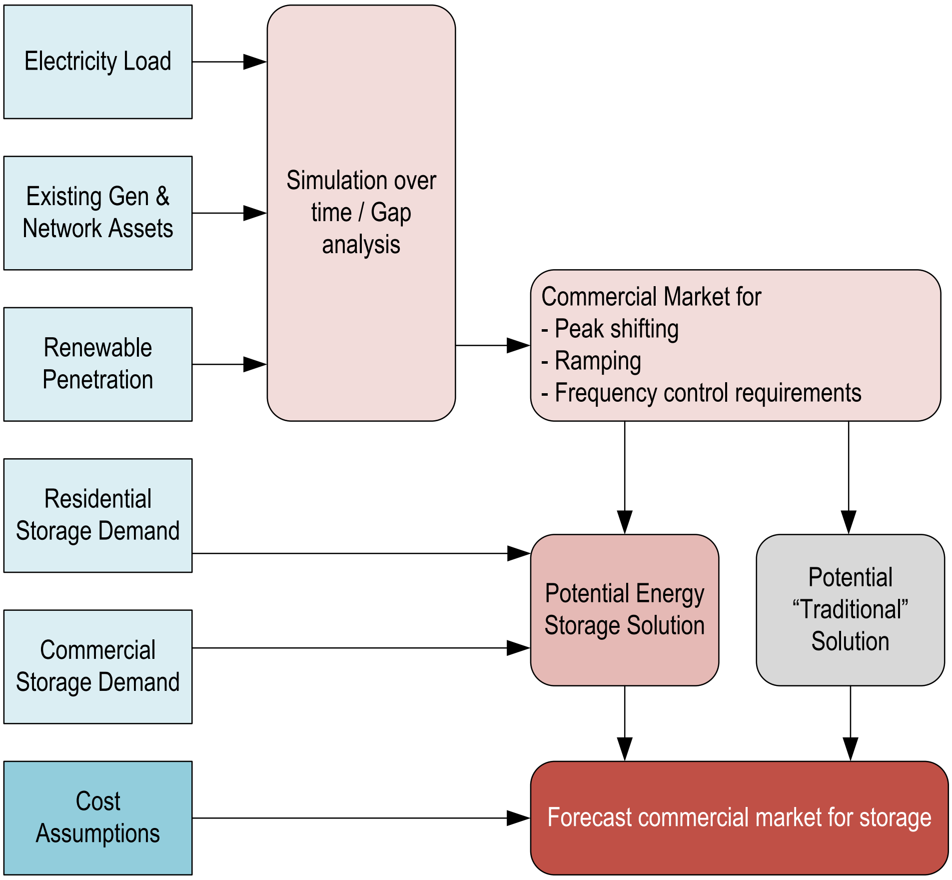

Figure 23: Model Structure

The key elements of this framework are described below.

Electricity Demand	• We have based this on publically available current data from AEMO • We have assumed[37]: – Gradually growing population – Flat energy use per capita

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[37] Precise values for these assumptions are given in section 4.2

	– Flat, gradually growing, or moderately growing peak demand per capita *(scenario dependent)*
Capacity of Generation and Network Infrastructure	• We have based this on publically available current data (see Figure 6 on page 14 for an illustration)
Renewable Penetration	• We have used wind and solar generation to represent all intermittent renewable energy output • Assumed that new renewable plant is built over time sufficient to meet the RET target • We have developed a composite profile of wind and solar generation output over time (at a 5 minute resolution) from a variety of actual power stations' recorded output • No assumed difference in capacity factor between regions • We have not considered the presence of additional significant base load renewable generation (e.g. hydro and geothermal power)
Costs of energy storage infrastructure	• We have sourced benchmark fully installed per-kW costs of energy storage separately for short term (e.g. flywheels, supercapacitors) and long term (e.g. flow batteries, pumped hydro) energy storage • We have assumed that over time this cost will decline by a range of possible factors each year *(scenario dependent)*
Costs of generation and network infrastructure	• We have sourced benchmark fully installed per-kW / kWh marginal costs of meeting demand through: – Constructing new distribution and transmission capacity – Constructing new large-scale generation (OCGT) – Constructing new small-scale generation (Diesel) • We assume that infrastructure costs stay constant over time in real terms, but that fuel costs gradually escalate
Residential Demand for Storage	• Driven by relative costs of storage and grid-sourced electricity • We assume storage will follow a similar price-to-uptake pattern as residential PV – however, it is inherently very hard to quantify the benefits associated with lifestyle decisions
Business Demand for Storage	• We assume a fixed proportion of the market for commercial backup generation will also represent a market for instantaneous storage

4.2 Tables of Inputs

4.2.1 General Inputs

These assumptions are based on MHC analysis.

Discount Rate	10%
Wind capacity factor	30%
Solar capacity factor	20%
Cost of energy used for charging (as % of LRMC of generated energy)	150%

4.2.2 Regional Characteristics

The following table outlines our model's estimated inputs of local demand and capacity, by region.

- *Central* locales drive the demand for 'On Grid' storage applications (*Network Support*, *Market Participation*, *Grid Stability*)
- *Fringe* and *Remote* locales drive the demand for storage applications in *Supporting Fringe and Remote Electricity Systems*
- All locales drive demand for *Residential Storage Systems* and *Business Storage Systems*

Demand and capacity figures are largely driven by simplified per-capita calculations for the sake of estimating a commercial storage market in aggregate; these do not purport to be an accurate ground-up analysis of each region, and we do not recommend that readers rely on them for another purpose.

State	Locale	Population	External Generation (MW)	Local Generation (MW)	Available Wind (MW)	Available Solar (MW)	Avg Dist. from Trans.
VIC	Central	5,224,621	3,313.6	0.0	361.0	217.8	200
NSW	Central	6,828,822	4,331.0	0.0	151.1	284.7	400
QLD	Central	2,635,126	1,671.2	0.0	6.2	109.8	500
NT	Central	135,477	85.9	0.0	0.0	5.6	200
WA	Central	1,937,641	1,228.9	0.0	166.3	80.8	600
SA	Central	1,289,796	818.0	0.0	640.2	53.8	500
TAS	Central	356,998	226.4	0.0	90.5	14.9	300
VIC	Fringe	349,879	86.6	86.6	40.3	24.3	100
NSW	Fringe	736,817	182.4	182.4	27.2	51.2	200

QLD	Fringe	1,751,017	433.4	433.4	6.9	121.7	250
NT	Fringe	75,358	18.7	18.7	0.0	5.2	100
WA	Fringe	153,730	38.0	38.0	22.0	10.7	300
SA	Fringe	319,361	79.0	79.0	264.2	22.2	250
TAS	Fringe	150,628	37.3	37.3	63.6	10.5	150
VIC	Remote	0	0.0	0.0	0.0	0.0	25
NSW	Remote	38,780	0.0	19.2	1.9	3.6	25
QLD	Remote	194,557	0.0	96.3	1.0	18.0	25
NT	Remote	18,840	0.0	9.3	0.0	1.7	25
WA	Remote	27,129	0.0	13.4	5.2	2.5	25
SA	Remote	35,485	0.0	17.6	39.1	3.3	25
TAS	Remote	0	0.0	0.0	0.0	0.0	25

4.2.3 Technology Costs

The table below outlines the model's cost inputs.

- Cost and lifecycle inputs for storage technology sourced from: EPRI, Electricity Energy Storage Technology Options: 2012 System Cost Benchmarking (draft)
- Network augmentation costs sourced from MHC composite analysis of various transmission and distribution projects

Large- and small-scale generation infrastructure and fuel costs sourced from MHC analysis of client projects

Storage	
Short Duration	
Cost per MW	$216,539
Cost per MW (Fully Installed)	$330,000
Hours of storage	0.01
Lifecycles	160,000
Long Duration	
Cost per MW	$531,800
Cost per MW (Fully Installed)	$810,451
Hours of storage	4.00
Lifecycles	10,000

Network Augmentation	
Cost per MWKM	$958
Cost per MW (substation)	$41,656
Change in cost (annual)	0%
Large Scale Generation Plant (OCGT)	

Cost per MW	$1.49m
Cost per MWh	$22.50
Change in fuel cost (annual)	+5.0%
Small Scale Generation Plant (Diesel)	
Cost per MW	$2.1m
Cost per MWh	$54.00
Change in fuel cost (annual)	+5.0%
Retail Costs	
Retail Tariff ($/MWH)	$250.00
Change in cost (annual)	+3.0%

4.3 Results

Our model shows a potential market for Energy Storage in Australia growing to over 2,500 MW by 2030 (in our base case scenario).

The commercial market for storage that we have shown here will not, in reality, belong to storage alone. As noted in section 1.3.5, we do not model the competitive dynamics between storage and other emerging solutions. The results shown here therefore have an inherent degree of optimism, and should be interpreted accordingly.

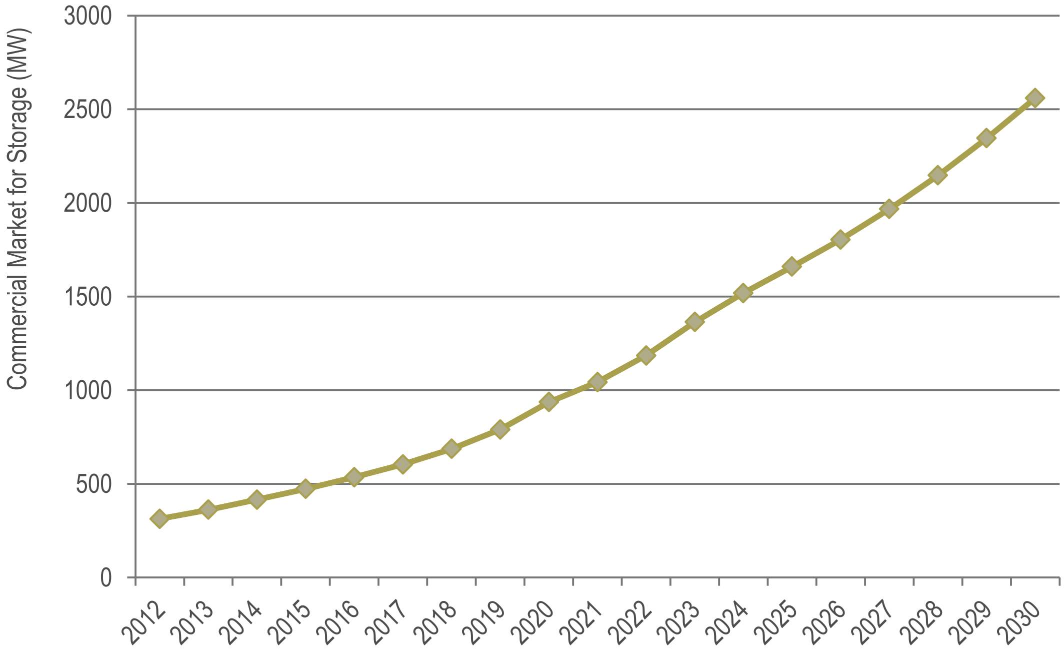

Figure 24: Total Forecast Commercial Market for Energy Storage in Australia, Base Case

In the sections overleaf, we present more detailed breakdowns of this total figure, and subject it to scenario analysis.

4.3.1 Scenario Analysis

We have modelled three scenarios, which are shown in the table below:

- **Base Case:** gradually declining storage costs, gradually rising peak demand per capita, and renewable plant growth that aims for the RET target.
- **Favourable**: moderately declining storage costs, moderately rising peak demand per capita, and renewable plant growth that overshoots the RET target.
- **Unfavourable**: immaterially declining storage costs, flat peak demand per capita, and renewable plant growth that undershoots the RET target.

	Base	Favourable	Unfavourable
Change in storage cost (annual)	-5.0%	-10.0%	-1.0%
Average peak growth per capita (annual)	+0.3%	+0.5%	0.0%
Average growth in renewable plant (annual)	+3.0%	+3.8%	+2.3%
Resulting 2030 Market Forecast (MW)	**2,559.7**	**3,291.3**	**1,895.4**
- Variance to Baseline (%)	0.0%	+28.6%	-26.0%

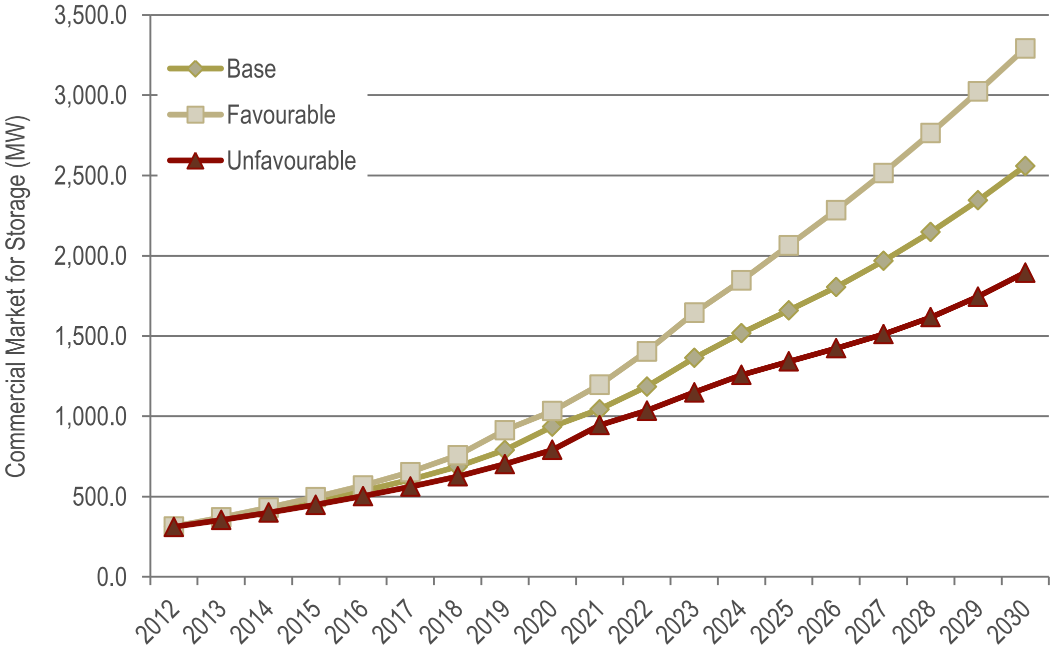

Figure 25: Scenarios of Forecast Commercial Market for Energy Storage in Australia

Under these scenarios, the market for storage in 2030 can vary by around 25% in either direction.

4.3.2 Application Analysis

In Figure 26 below, we break the market down into the demand for energy storage for each application that we identify in section 3. (Note: it is not possible to sensibly separate demand for Network Support (3.2) and Market Participation (3.3); these have been combined into 'Peak Shifting' in our final results).

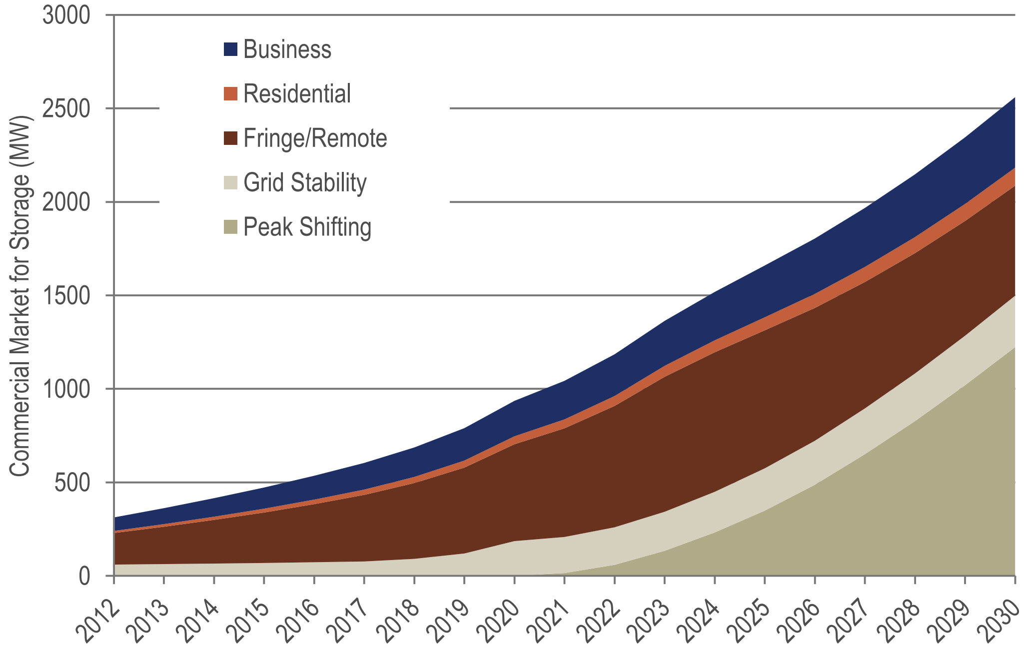

Figure 26: Forecast Commercial Market for Energy Storage in Australia, by Application

Business demand for storage to supplement backup generation today makes up a material proportion of the potential market, grows modestly over time. Existing Residential demand also grows, but only ever forms a very small part of the market.[38]

Support for Fringe and Remote Electricity Systems also makes up a material proportion of the market today, and grows strongly out to 2030.

The 'Grid Stability' opportunity increases after 2020-21, and the 'Peak Shifting' opportunity accelerates noticeably between 2025 and 2030. In our model, this effect is the result of a "tipping point" between declining storage prices and increasing fuel prices.

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[38] The 'narrowness' of the Residential component in total MW terms, compared to other applications we have analysed, may underrate the attractiveness of this market. The typically small capacity of residential storage systems implies a very high number of units per MW of total capacity required.

4.3.3 Regional Analysis

In Figure 27 below, we break the market down into the demand for energy storage for each application that we identify in section 3.

The 'Fringe and Remote' opportunity is shown to taper off slightly between 2025 and 2030. This is a non-intuitive outcome, caused by a demand-to-generation imbalance which grows to the point where storage is of limited usefulness, as there is not enough spare energy available to charge adequately. In these later years, the model prefers to build more conventional generation instead.[39]

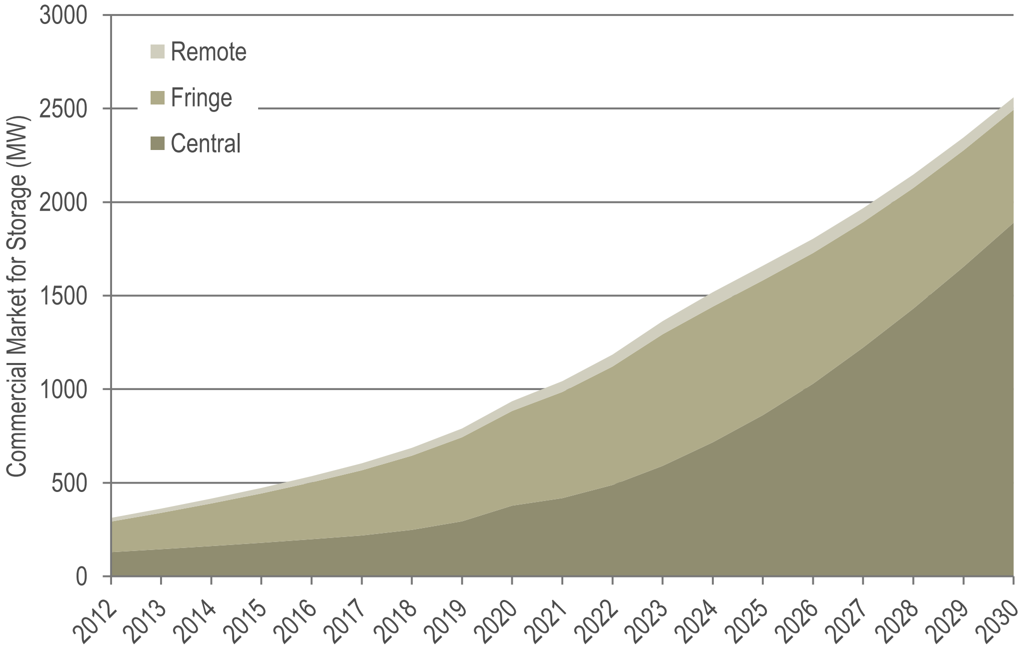

Figure 27: Forecast Commercial Market for Energy Storage in Australia, by Locale

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[39] This should be taken with a grain of salt, as should any forecast more than five years into the future.

4.3.4 Regional Application Analysis

In Figure 28, we can see the intersection of the analyses in the sections above. This helps make it clear that, other than demand from businesses for backup storage devices, there is likely to be no significant need for storage in urban (i.e. grid-connected) areas until around 2020.

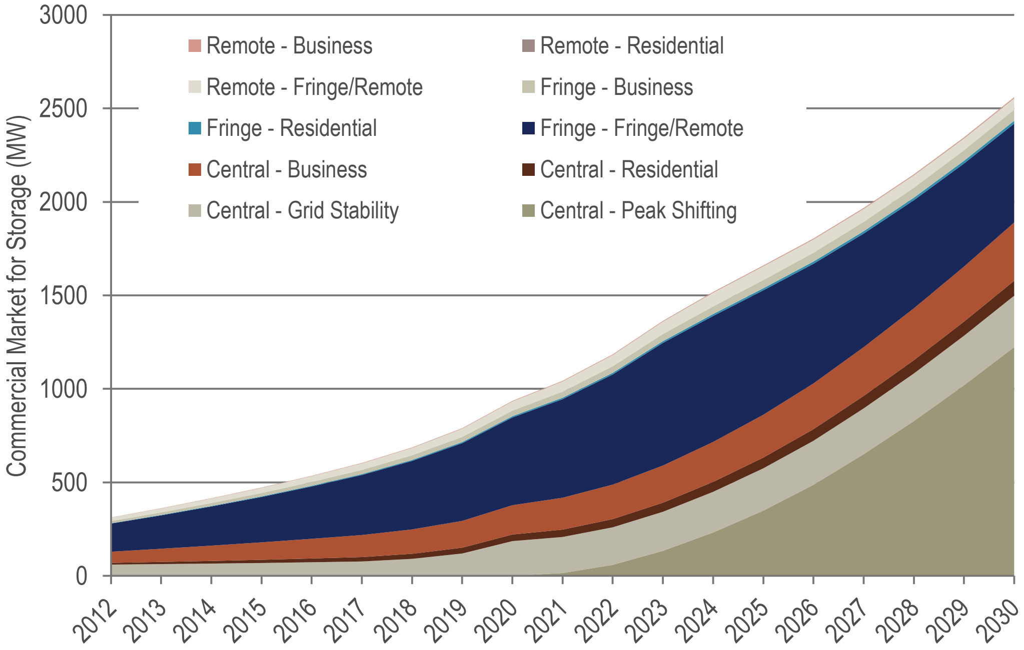

Figure 28: Forecast Commercial Market for Energy Storage in Australia, by Region and Application

5 Barriers and Policy Options

This section explores the specific barriers which stand in the way of an effective, economically viable implementation of energy storage – and how those barriers might be overcome.

The strongest theme across our findings is that efforts to spur the uptake of energy storage in Australia should be focused on the software interfaces, technical standards, and regulatory rules that enable straightforward, consistent, and manageable connections of storage to the grid. We believe it is not optimal to direct efforts at looking for improvements in underlying storage technologies that enable it (e.g. lithium, flow, and lead-acid based batteries). Australia is too small a market to enable R&D investment in, and competitive production of these materials.

5.1 Technical Issues

5.1.1 Systems

Most of the Electricity distributors we interviewed nominated one or more of the following points as a barrier to the integration of storage into their existing network management systems, including information and communications technology.

- **There is no consistent control interface for energy storage**. Most storage vendors supply their own storage management systems, and claim these systems offer an ideal way for networks to control the underlying storage technology. But this risks ‘reinventing the wheel’ with each deployment.
- Conversely, there exists **no accepted standard for a 'utility battery'**[40] that could be used by vendors to standardise their product designs, and supply batteries to networks based on a universal, “widget-like” specification.
- **Existing SCADA systems lack the symbols and logic** that would allow them to deal with storage as a new type of network asset, which has some characteristics of both generating units and load, but behaves differently to both.
- The **infrastructure needed to control and coordinate large network of storage in the field**, especially smaller distributed systems at the sub-1MW scale, **is limited or does not exist.**[41] For example, it would be challenging to implement a communications backbone capable of receiving and sending signals to many individual, decentralised storage devices across a network.

Potential Solutions

- Create a standard energy storage system specification that allows a plug-and-play approach between vendors and electricity network businesses. The most natural body to develop this standard would be an ENA working group on energy storage; the ESWG may suggest a collaborative effort, based on its ability to bring key storage players to the table.

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[40] We use this term in the sense of a generic label for energy storage

[41] It may be possible for storage devices to be monitored and controlled via a residential smart meter, using the ZigBee protocol (which is currently a standard in Victorian smart meters) or similar.

Such a standard might include:

  - Safety and emergency guidelines
  - Voltage specifications, which may depend on the capacity of the battery in question (e.g. 800V DC for distribution-level systems)
  - Documentation of the electronics associated with the storage management system
  - Form factor requirements
  - Documentation of safe operating conditions, maintenance timetables
  - SCADA system interface

- Support the wider adoption of the AS4755 standard, designed to enable remote demand response, load shifting, energy storage and/or storage discharge of compliant electrical products, via a protocol for managing third party devices connected to the grid. AS4755 has been accepted by Standards Australia; there is no restriction on who can proactively drive its uptake.
- Encourage communication between utilities regarding how well various storage trials achieve these needs (where there is evidence)

5.1.2 Safety

Some storage technologies are not yet seen by many in the energy sector as being safe for widespread deployment in the field, or for use by end customers. Some battery technologies in particular are believed by some to carry the risk of thermal runaway and explosion.[42] The anecdote of "laptop batteries catching fire" was a common touchpoint in our discussions.

Potential Solutions

- Commission an independent study (potentially accredited by the relevant government agency or technical regulator) of actual safety performance of currently-produced storage devices (e.g. using Lithium- and Sodium-based technologies), and the limits of their safe operating conditions

5.1.3 Performance

The following issues were nominated by our interviewees:

- Material wear and tear contributing to a lifespan shorter than that claimed by manufacturers
- Perceived frequency and onerousness of maintenance requirements on flow and lead acid based batteries
- The reliability of storage systems in general, and a lingering question mark over their ability to supply energy at critical times with the same certainty as existing network assets

At the same time, it was recognised that many of these perceptions were formed from experiences with outdated storage technologies, and that some have been addressed by recent technical advances in current models.

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[42] An analysis of the actual safety record of these systems was beyond the scope of this report.

Potential Solutions

We cannot see an obvious action that can be taken to overcome these views, other than the progressive trialling of storage in real-world applications, and the need to better disseminate storage trials results.

5.2 Economic Issues

5.2.1 Incentives and Vested Interests

- The disaggregated structure of most of Australia's electricity industry means that no single party can capture all the benefits of storage, without first setting up rules & the right market constructs to do so. The value of some of the services that storage can provide therefore cannot be easily captured by the party that incurs their cost, under existing market arrangements. This is likely to lead to under-investment in storage.
- The financial incentives of electricity distributors are not necessarily aligned with the interests their customers, in situations where energy storage could be advantageous. Despite the seeming unsustainability of the historical approach to meeting peak demand (outlined in section 3.2.2), network businesses are still more heavily incentivised to continue on this capital expansion trajectory, than to find alternatives. Their income, to a large extent, is determined by the amount of capital they accumulate in their regulated asset base. Their incentive is not necessarily for least-cost alternatives to building their regulated asset base, and there is no retrospective test applied by the regulator to determine whether they could have met the grid's needs more efficiently.[43]
- Electricity retailers per se also are unlikely to have the incentive to deploy storage. Although storage could insulate them (or any other market participant) from peak prices, most retailers are already covered by financial hedges, or physical hedges in the form of a wholly- or partly-owned generation portfolio. These hedges represent a more developed market, and likely a cheaper option, than storage-based hedges.

Potential Solutions

- Encourage the establishment of price signals to capture benefits from storage that currently accrue to multiple parties, correcting the under-investment problem. A discussion of the specific possibilities here and their implications for the market is beyond the scope of this report, but in principle these goals should be well addressed by the *Connecting Embedded Generators* and *Small Generation Aggregator Framework* electricity rule change proposals described in section 5.3.
- A particular type of price signal that may help storage is the establishment of cost-reflective peak (or congestion) pricing to customers, which will put the onus on them to find a solution to

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[43] The AEMC recently considered a rule change proposal from the Major Energy Users groups that would permit ex-post (i.e. retrospective) review of networks' regulated asset bases. In September 2012 the AEMC decided not to proceed with the rule change. Source: http://www.aemc.gov.au/electricity/rule-changes/completed/optimisation-of-regulatory-asset-base-and-use-of-fully-depreciated-assets.html

the problems they create, and let them capture all the benefits of that solution – whether the solution involves energy storage, demand reduction, or finding a more suitable energy retail product.

5.2.2 Lack of Transparency / Asymmetric Information

There is a general lack of information for the market, relative to what would be ideal to allow storage to take root.

- All parties – including regulators, network operators, and technology providers – are unsure of the value and the extent of the role storage will play in the future energy system, creating a barrier to innovation and deployment
- Some of our interviewees felt there was a lack of clarity from networks and system planners about infrastructure planning, particularly development of infrastructure that could substitute for storage technologies, which does not give parties sufficient confidence to invest in R&D or deployment
- While it is recognised that there are many network problems that storage *could* solve, the actual problems that need solving at any point in time are not transparent outside the distribution business, with respect to their location, scale, and required price point.
- The costs of possible storage solutions are likewise not clear to prospective utility customers. Though quotes in terms of cost per kW or kWh of capacity are readily available, utilities tend to believe these are often misleading, omitting as they do the operating cost of the storage unit.

Potential Solutions

- Encourage the AER to standardise and lower the threshold at which electricity transmission and distribution businesses must publically request tenders for solutions to network constraints caused by growing peak demand and other problems,[44] and to ensure that these RFTs specify all the information necessary for storage providers to assess their market and invest accordingly. This would in effect open up more network problems to the market, allowing storage proponents to compete to solve them.
- In conjunction with the point above, establish an accessible database which collects the information published in these RFTs, and which may optionally even collect information on network constraints that have been identified internally, but fall under the cost threshold for RFTs, or are expected to bite too far into the future to merit attention now. This would give storage proponents (and potential customers) more visibility of where the opportunities for storage are
- In conjunction with the storage specification standard recommended in section 5.1.1 above, manufacturers could adopt a like-for-like, levelised cost of energy (LCOE) based standard that would communicate the total ownership cost of their systems, amortised over their lifetime energy output.

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[44] Currently this threshold varies by state jurisdiction, but is generally set around $10m – well above the cost at which storage units could typically make a difference

5.2.3 Market Signals and Distortions

- Currently, diesel used in fixed and stationary generators is eligible for a fuel tax credit of approximately 32 cents per litre.[45] The origins of this policy are understandable: in a previous time when diesel represented the only feasible means to generate power in remote communities and it was taken as read that there was inherent value in remote communities continuing to exist, subsidised diesel was a convenient means to relieve the onerous cost of energy to these areas. But diesel is no longer the only option, and this subsidy holds back energy storage (and renewables) in the very segment where it finds its best initial chances of success (i.e. fringe and remote communities).
- The existing market practice of capping price spikes at -$1,000/MWh and $12,500/MWh in the NEM can act as a disincentive for storage schemes, as it limits their potential revenue from taking advantage of peak price events. Admittedly this is a somewhat myopic view: these caps exist to limit the risk exposure of spot market participants, and without them the risk-adjusted cost of funding for energy market participants would be expected to rise, and ultimately raise the cost of delivered energy to consumers too.
- Recent uncertainty over the future of the RET has given pause to renewable energy developers, and indeed generation developers of all stripes. This, in turn, is a barrier for storage, in that the renewable-dependent portion of its future market is currently unclear.

Potential Solutions

- Encourage the Commonwealth Government to remove the fuel-tax credit scheme as it relates to diesel used for energy generation. Replacement of this scheme with direct subsidies for eligible remote communities which could be applied to any energy solution would have the benefit of removing this relative price distortion favouring diesel.
- Encourage the Commonwealth Government to affirm its policy commitment to the RET, giving industry certainty on the portfolio of renewable energy that will be created, and its implications as a contributor to the commercial market for storage.
- Encourage Commonwealth or State governments to directly subsidise storage units, boosting uptake, and thereby facilitating the spread of expertise in deploying and managing storage. This may also offset the loss of the diesel subsidy to energy end-users. As with any subsidy, however, this will distort the market and create an economic loss; policymakers would need to assess whether the cost of this distortion is outweighed by the long term benefits to the energy sector.

  Such a direct subsidy could have a similar effect to the pro-PV policies, and their results, over the last decade in Australia – but we should recognise that the Australian market is too small to drive economies of scale; the global cost of storage technology is outside our control.

5.2.4 Competitiveness of Storage

- As highlighted in section 4, the cost of storage is a key determinant of its uptake. To the extent that it can be cheapened, the opportunity for storage vendors will be increased. We

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[45] Source: http://www.ato.gov.au/taxprofessionals/content.aspx?menuid=42891&doc=/content/00174722.htm&page=2&H2

offer no specific solution here; the cost of materials, manufacturing and supporting systems will be determined by factors beyond any party's control, but will likely enter a virtuous circle similar to that seen by solar PV panels, as gradually increasing uptake and gradually decreasing costs spur each other on.

- *Quasi-barrier*: The price and quality of grid-supplied power are, rightly or not, highly sensitive political topics,. We cannot foresee a future where regular reliance on private storage is justified for either households or commercial customers, as noted in section 3.5.

5.3 Regulatory Issues

The rules that govern our electricity system were originally designed to suit a profile of large-scale centralised generation and transmission, with customers and their loads at the periphery of the system. They did not take distributed generation, demand-side participation, or storage into account, and this is not surprising – these are all relatively recent developments, which are only now sparking debate and proposals for accommodating rule changes.

- The lack of a framework connecting distributed / embedded generation to the electricity network has hindered the uptake of solar PV, among other technologies, in the past. For this purpose, dischargeable grid-connected storage fits the definition of "embedded generation", and the lack of such a framework will hinder its future uptake too. Although a connection process currently exists in the National Electricity Rules, the process is not prescriptive, leaving much discretion in the hands of asset managers in distribution businesses. It has been suggested that "this uncertainty can result in significant delays in projects and therefore increases the costs to connection applicants... the terms and conditions for connection vary significantly between distributors."[46] There is also a lack of a technical standard under the National Electricity Rules, for embedded generators – the technical requirements are not transparent and can vary markedly between managers and distributors. This leads to inefficiencies and uncertainty in the connection process. [47]
- The lack of a framework for aggregating many small generating devices into an entity large enough to participate in a large-scale Electricity Market has historically prevented these small generators' owners from capturing the full value of their investments, and therefore hindered their uptake. Currently, generators under 5 MW of nameplate capacity do not need to register as market participants in the NEM – but without registration:
    - They cannot participate[48] in the market, ruling out the opportunity we explore in section 3.3 (Market Participation). Without access to market prices, there is also little incentive to produce during peak price periods.
    - They cannot offer ancillary services including frequency control, ruling out the opportunity we explore in section 3.4 (Grid Stability)

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[46] Source: ClimateWorks Australia, Seed Advisory and the Property Council of Australia

[47] AEMC, *Information Sheet: Connecting Embedded Generators*, http://www.aemc.gov.au/Electricity/Rule-changes/Open/connecting-embedded-generators.html

[48] In the NEM, 'participant' has a specific meaning, defined in Chapter 2 of the National Electricity Rules. Source: http://aemc.gov.au/Electricity/National-Electricity-Rules/Current-Rules.html

The costs and time requirements of registration, on the hand, are generally not worth it for small generators. Here again, dischargeable grid-connected storage fits the definition of “small generation”, and the lack of such a framework will hinder its future uptake too.

- Economic Regulators of electricity transmission and distribution networks (i.e. the AER, and the ERA in Western Australia) are seen by industry stakeholders as having a limited understanding of storage, seeing it as a technical, 'surgical' solution for particular parts of the network with little relevance to the proposals for expenditure on network construction, upgrades, and maintenance which they are responsible for analysing and approving.

  Traditional means of solving problems on the network (substations, feeders, etc) comprise a de facto ‘accepted list’ of measures, and when proposed by network businesses these measures are scrutinised to ensure that they are done efficiently. But there is little or no scrutiny to ensure that they are really the right solutions. Storage – and other more innovative potential network solutions – are not privileged in this way: network businesses must in practice argue their case from first principles.

  This situation leaves utilities uncertain regarding how investment in energy storage technologies will be treated, how costs will be recovered, or whether energy storage technologies will be allowed in a particular regulatory environment.
- The lack of a capacity market in the NEM arguably increases the risk profile for peak generators and others – including potential arbitrageurs using storage – who rely heavily on peak price events to earn revenue.
- In order for the concept of benefit stacking (explored in section 3) to apply, and therefore to justify the investment in storage, network businesses who employ storage devices would need to also act as ‘generators’, earning revenue from the discharging of stored energy. Network businesses are rightly wary of this idea. Generation is required to be separate from transmission / distribution in the Australian grid in order to protect competition in the energy market. There are ring-fencing provisions that can circumvent this problem, but:
  - Benefit stacking still implies a requirement to participate in the energy market – which is not a core skill for network businesses
  - An internal business case which relies on these ancillary benefits is unlikely to be approved, since these benefits would not typically serve the network business’s core objectives
  - There is uncertainty over whether the regulator might treat investment in energy storage technology as being uncontestable services related to generation or transmission/distribution – which determines whether the investment can be recouped through regulated customer charges, or not

Proposed Solutions

- Support the *Connecting Embedded Generators* electricity rule change proposal currently being considered by the AEMC, and encourage the AEMC to explicitly recognise energy storage technology as a qualifying form of embedded generation. We also believe that the

IMO in Western Australia should be encouraged to consider a similar proposal. The current proposal suggests that :[49]

  - Clearer timeframes be added to the connection process and there be standardisation of terms and conditions
  - Distributors be allowed to charge a 'fee for service' as an incentive for distributors to work more cooperatively with embedded generators
  - A technical standard for embedded generators be introduced

- Support the *Small Generation Aggregator Framework* electricity rule change proposal currently being considered by the AEMC, and encourage the AEMC to explicitly recognise energy storage technology as a qualifying form of small generation.[50] We also believe that the IMO in Western Australia should be encouraged to consider a similar proposal. The current proposal suggests that: [51]
  - Introduce a new category of market participant, the "Market Small Generation Aggregator" (MSGA), which would be financially responsible for trading the output of small generating units in the NEM.
  - The MSGA will be able to add small generating units to its portfolio through the Market Settlement and Transfer Solution (MSATS) system, similar to how market customers currently add loads.
  - This rule change may provide more flexibility for the owners of small generating units. Under this draft rule they will have the option to join an MSGA and not be required to individually register and classify each unit with the Australian Energy Market Operator (AEMO) to participate in the NEM. Therefore the draft rule could provide the owners of small generators with more options to sell their output.
- Promote a business model wherein energy storage is provided as a peak-reduction service, rather than an installed hardware product, to network businesses. This would give the network clarity on the regulatory treatment of the service's cost, and allow the service provider (rather than the network itself) to participate in the energy market, ancillary services market, and consumer storage device market (i.e. to create the necessary benefit stacking arrangements)
- Encourage network businesses to request competitive tenders for storage services that guarantee **long term** contracts. This would:
  - give the market more visibility of opportunities that are available
  - allow vendors to loss-lead in the initial years of the contract (in order to make their storage products more cost competitive), with the expectation that more efficient large-scale production will recoup losses in the later years of the contract.

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[49] AEMC, *Information Sheet: Connecting Embedded Generators*, http://www.aemc.gov.au/Electricity/Rule-changes/Open/connecting-embedded-generators.html

[50] This recognition would align with the findings in the AEMC's recent *Power of Choice Review: "Distributed generation... can provide cleaner sources of power, reduce line losses, and defer the need for more network infrastructure. Market arrangements regarding the ownership, connection and operation of these resources should not constrain their use"*

[51] Source: AEMC, *Information Sheet: Small Generation Aggregator Framework*, http://www.aemc.gov.au/electricity/rule-changes/open/small-generation-aggregator-framework.html

  - give the market more visibility of the long-term cost targets that storage is able to achieve, encouraging its uptake elsewhere.[52]
- Explore alternatives to the *Small Generation Aggregator Framework* electricity rule change proposal, which may move the NEM and WEM toward a more 'decentralised' market model, and allow small-scale generators and storage providers to participate in the market without the need to aggregate into an artificial large-scale entity.

5.4 Cultural Issues

- Energy storage, despite the many trial deployments it has undergone, is still an unfamiliar technology to many network engineers whose experience is in centralised AC systems. The skill-base in Australia for operating storage-enabled systems is still nascent. Storage assets also have a very different lifetime and maintenance profile compared to the assets that make up the rest of the network – and thus will require a rethink of asset management practices in these utilities.
- Network engineers are not rewarded for their adventurousness, and there is still a perception in many of their asset management departments that most storage technologies (other than lead-acid based batteries and pumped hydro storage) are "unproven", and that the storage-free practices that have served them well for the past three decades do not need improving. We should emphasise that network businesses also contain many forward-thinking decision makers who are keen to test the promise of storage and other innovative practices to solve their network's problems – but without widespread 'grassroots' support, the business may not be able to execute a sustainable commercial deployment.
- There is an observed lack of ongoing dialogue between renewable energy vendors, storage vendors, the integrators of hybrid systems, and transmission and distribution businesses. This predictably can lead to misunderstood opportunities, requirements, and possible solutions – hindering the successful commercialisation of storage.

Potential Solutions

- Engage with the AER and ERA to establish a practice of requiring a "burden of proof" against storage and other non-standard technologies in the regulatory submissions that network businesses make, such that storage is assessed as a credible solution alongside traditional network augmentation
- Expand the CEC's Energy Storage Working Group into a Directorate, and encourage all network utilities in Australia to represent themselves on it. This directorate would ideally act as a forum to:
  - Establish ongoing dialogue between renewable energy vendors, storage vendors, the integrators of hybrid systems, and transmission and distribution businesses
  - Share lessons and success stories between network businesses that have attempted storage integrations

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[52] A similar concept can be seen in the ACT Government's recent reverse auction process which invited bids from providers of large-scale solar systems. More information can be found at http://www.environment.act.gov.au/energy/solar_auction

  - Connect with utilities overseas to learn from their experiences with storage
  - Establish a more widespread awareness that storage technologies can work as a mature, credible solution to network problems

6 Appendix: Technology Overview

This report is not intended to evaluate and compare specific storage technologies; however, it is helpful to have a basic understanding of how different storage technologies work, and in particular, which technologies are best suited to different commercial applications. We present a non-exhaustive selection here.

Compressed Air

A CAES facility consists of a power train motor that drives a compressor. CAES pre-compresses the air using off-peak electrical power which is taken from the grid to drive a motor and stores it in large storage reservoirs. When the GT is producing electricity during peak hours, the compressed air is released from the storage facility and used in the GT cycle.

Advantages	Disadvantages
• High storage capacity • No need to purchase, maintain and dispose of waste chemicals • In addition to supplying electrical power, the by-product heat may be utilised	• High Cost • Low efficiency • Requires specific geological structures for large scale underground storage • Safety risks associated with the storage of high pressure gases

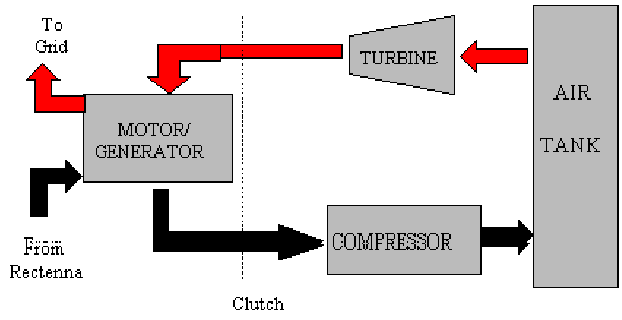

Figure 29: Diagram of Compressed Air Storage System

Li - Ion

The cathode in these batteries is a lithiated metal oxide and the anode is made up of graphitic carbon with a layer structure. The electrolyte is made up of lithium salts dissolved in organic carbonates. When the battery is being charged, the Lithium atoms in the cathode become ions and move through the electrolyte toward the carbon anode where they combine with external electrons and are deposited between carbon layers as lithium atoms. This process is reversed during discharge.

Advantages	Disadvantages
• High energy / power density	• Charging forms deposits inside the electrolyte that inhibit ion transport. Over

• Wide variety of shapes and sizes efficiently fitting the devices they power. • High open circuit voltage in comparison to aqueous batteries. This is beneficial because it increases the amount of power that can be transferred at a lower current. • No memory effect. • Low Self-discharge rate • Components are environmentally safe as there is no free lithium metal.	time, the cell's capacity diminishes. • High charge levels and elevated temperatures hasten capacity loss. • High Cost • Risk of thermal runaway / fire

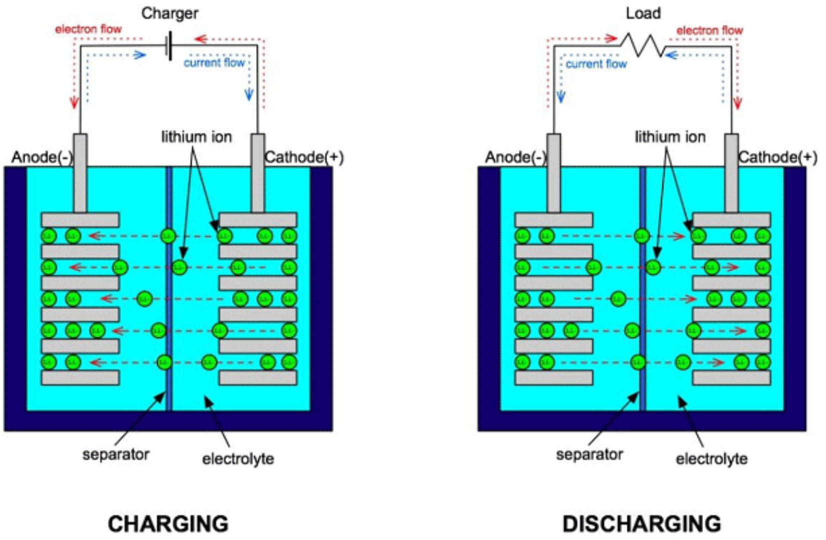

Figure 30: Diagram of Lithium Ion System

Flywheel	
Flywheel energy storage systems consist of a massive rotating cylinder that is substantially supported by magnetic bearings that eliminate bearing wear and increase system life. In order to increase efficiency, flywheel systems are often operated in a vacuum environment to reduce drag. Actual delivered energy depends on the speed range of the flywheel as it cannot deliver its rated power at very low speeds	
Advantages	**Disadvantages**
• Efficiency - 85% (approx.) • Environmentally friendly. • Wide range of shapes and sizes available, ranging from kilograms to hundreds of tons	• Complex designs - require materials that can withstand the huge amount of rotational inertia • Expensive

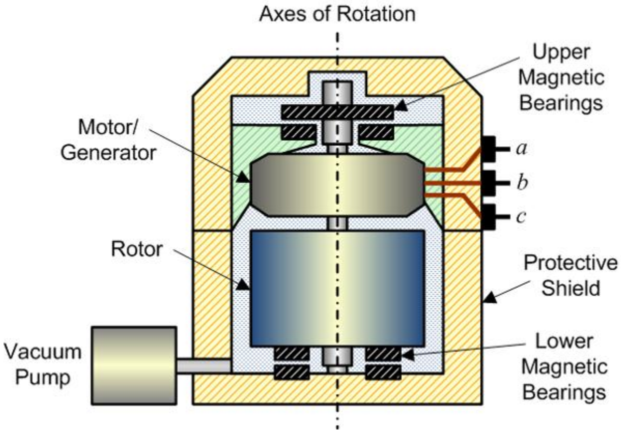

Figure 31: Diagram of Flywheel System

Pumped Hydro	
Pumped storage is the most widespread energy storage system in use on power networks. Its main applications are for energy management, frequency control, and provision of reserve. Conventional pumped hydro uses two water reservoirs, separated vertically. During off-peak hours water is pumped from the lower reservoir to the upper reservoir. When required, the water flow is reversed to generate electricity. Some high dam hydro plants have a storage capability and can be dispatched as a pumped hydro.	
Advantages	**Disadvantages**
• Once the facility is operational it can quickly respond to energy demands • No pollution or waste	• Expensive to build. • Requires specific geological structures

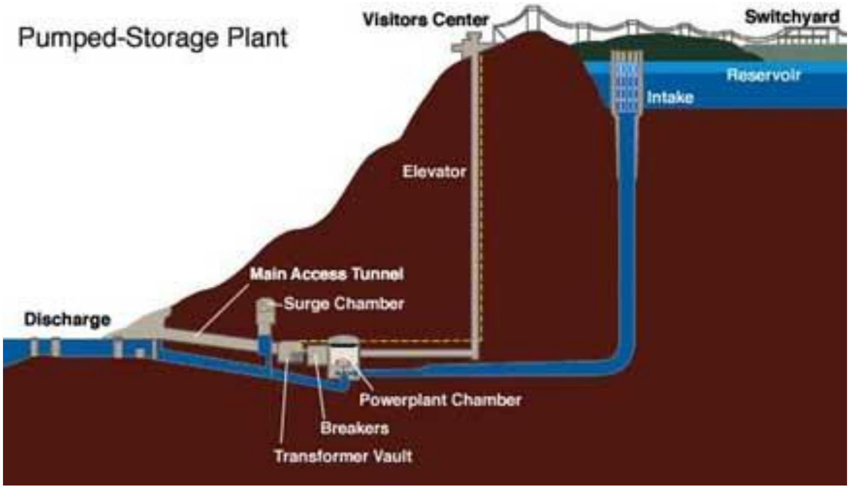

Figure 32: Diagram of Pumped Hydro System

Flow Battery

In a flow battery the electrolytes (the chemical reactants) are generally stored in tanks that are external to the battery cells, which are collectively called stacks. During operation, the electrolyte is pumped through the stacks to facilitate the chemical reaction in the cells. The exact materials and operation of a flow battery is dependent on the battery chemistry, but typically stack materials are low-cost plastic and carbon composites separated by a membrane	
Advantages	**Disadvantages**
• Flexible layout (due to separation of the power and energy components), • Long cycle life (because there are no solid-solid phase transitions), • Parts can be replaced individually • High depth of discharge during cycling • Quick response times • No harmful emissions. low maintenance and • Tolerance to overcharge / over discharge.	• Flow batteries are rather complicated in comparison with standard batteries as they may require pumps, sensors, control units and secondary containment vessels. • Energy densities vary considerably but are, in general, rather low compared to portable batteries, such as the Li-ion. • auxiliary power requirements during operation (typically ~ 5% additional loss)

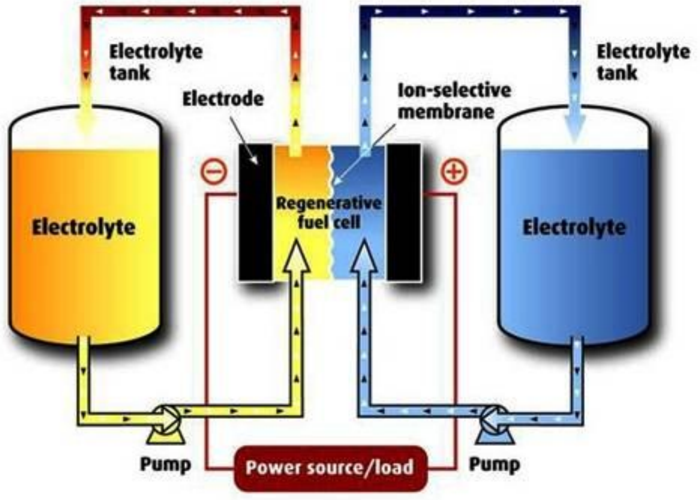

Figure 33: Diagram of Flow Battery

Lead Acid	
LA batteries are the most common energy storage device currently in use. Both the power and energy capacities of lead-acid batteries are based on the size and geometry of the electrodes. The power capacity can be improved by increasing the surface area for each electrode, which means greater quantities of thinner electrode plates in the battery.	
Advantages	**Disadvantages**

• Regular industrial use, therefore a widely understood technology • Lead acid battery is simple and inexpensive to manufacture. • Their self-discharge rate is among the lowest of rechargeable battery systems. • Capable of high discharge rates (used in car's to power starter motor)	• Cannot be stored in a discharged condition. • Low energy density, poor weight-to-energy density ratio. • High depth of discharge and wide ambient temperatures can significantly reduce the battery's cycle life • Environmental spillage and maintenance safety concerns due to Lead and electrolyte acidity

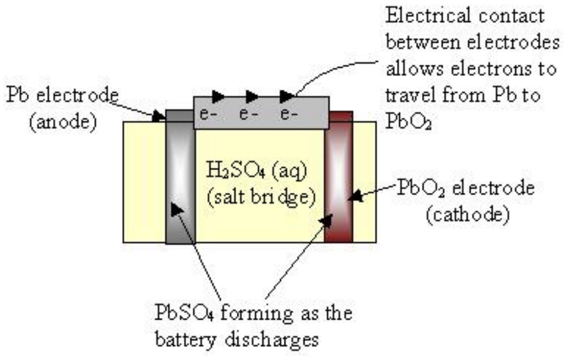

Figure 34: Diagram of Lead Acid Battery

Nickel - Based	
Nickel based batteries are commonly used in commercial products where light weight, portability and recharge ability are important. Most Nickel based batteries are made up of a positive electrode made of nickel oxyhydroxide and a negative electrode composed of metallic cadmium. During discharge the nickel oxyhydroxide combines with water and produces nickel hydroxide and a hydroxide ion. To charge the battery the process can be reversed.	
Advantages	**Disadvantages**
• Can withstand high temperatures (some as high as 49°C). • Life of these batteries is relatively high at 10 to 15 years • Can respond at full power within milliseconds. • Have a much longer cycle life (50,000 cycles) than other batteries.	• The life can be greatly reduced due to rapid charge/discharge cycles. • Suffer from 'memory' effects and also lose energy due to self-discharge • Environmental problems when disposing of the batteries

<table>
<tr><th colspan="2">Metal - Air</th></tr>
<tr><td colspan="2">The anodes in these batteries are metals with high-energy density like aluminium or zinc that release electrons when oxidized. The cathodes or air electrodes are often made of a porous carbon structure or a metal mesh covered with a catalyst. The electrolyte may be in liquid form or a solid polymer membrane saturated with Potassium Hydroxide.</td></tr>
<tr><td>Advantages</td><td>Disadvantages</td></tr>
<tr><td>• High-energy density
• Environmentally friendly</td><td>• The main disadvantage is that electrical recharging of metal-air batteries is very difficult and inefficient.
• Not many developers offer an electrically rechargeable battery.
• Rechargeable metal air batteries that are under development have a life of only a few hundred cycles and an efficiency of about 50%</td></tr>
</table>

<table>
<tr><th colspan="2">‘Smart’ Hot Water Systems</th></tr>
<tr><td colspan="2">In household and commercial usage, most water consist of a cylindrical vessel or container in which water is kept continuously hot and ready for use. Typical sizes for household use range from 75 to 400 litres. These may use electricity, natural gas, propane, heating oil, solar, or other energy sources.[53]
We define ‘smart’ hot water heating systems as being able to respond to signals from the grid in order for their heating load to follow the output of intermittent/renewable generation.</td></tr>
<tr><td>Advantages</td><td>Disadvantages</td></tr>
<tr><td>• Low incremental cost of enabling functional energy storage
• Can fulfil applications that require energy storage to act as a controllable load (e.g. market participation)</td><td>• Cannot convert energy back into electrical form
• Cannot fulfil applications that require storage to act as both a load and generator (e.g. raising frequency on the grid; business storage systems)</td></tr>
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[53] Source: http://en.wikipedia.org/wiki/Water_heating

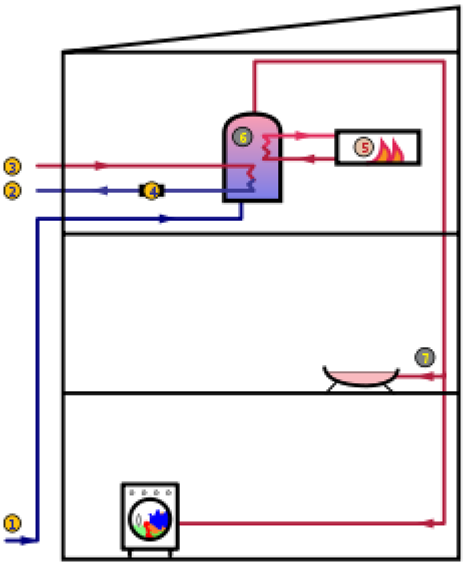

Figure 35: Diagram of Hot Water System

About Marchment Hill Consulting

Marchment Hill Consulting's offices serve Australia and New Zealand, Asia and the Pacific Rim, the United Kingdom and the Middle East. We are continually developing our geographic footprint.

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