LOW CARBON LIVING
CRC

RP1013: Distributed Energy Storage

Draft Scoping Study Issues Paper

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Executive Summary

Based on recent and growing interest in energy storage, the CRC for Low Carbon Living is undertaking a scoping study to better understand the key issues, challenges and opportunities for distributed energy storage within Australia. This paper discusses distributed energy storage framed around a series of key questions which were brought forward during initial scoping study discussions with a number of CRC stakeholders and the project team, and a preliminary CRC stakeholder meeting for the project held in December 2013. This paper was further amended after a secondary stakeholder meeting held in July 2014. These key questions are:

- What are the possible roles for distributed energy storage within Australia's current and possible future energy systems?
- How can energy storage reduce carbon emissions?
- What is the status and critical uncertainties of distributed energy storage technologies?
- At what locations and scales might distributed energy storage be best integrated within Australia's energy system?
- What are the barriers to widespread deployment of distributed energy storage?
- What solutions are available to address the foreseen barriers?
- What is the current status of distributed energy storage globally?
- What can the CRC for Low Carbon Living do to facilitate the short and medium term development and deployment of distributed energy storage within Australia's energy system with an aim to reduce carbon emissions?

Our key preliminary conclusions drawn from our review of the existing literature on energy storage, along with stakeholder discussions are:

- There are some definitional issues around the meaning of distributed energy storage that add considerable potential complexity to the analysis. The focus of the scoping study will be electrical energy storage, largely through battery systems. There will be some consideration of thermal energy storage including 'smart' control of heating and cooling loads.
- Distributed energy storage can play a wide range of potential roles in an electricity industry where supply must meet demand at all times and across all locations in the electricity network. Energy storage can provide similar services to both generation and loads, and even some network equipment, in some contexts. Distributed storage can play an even greater range of roles than centralised storage given its location within the distribution system including at end-user premises. However, this does require that its operation can be coordinated appropriately to provide an aggregated response. Different roles are likely to best provided by different storage technologies and different electricity industry stakeholders
- The majority of the literature on energy storage to date focuses on centralised electrical energy storage, an outcome seen more generally within our current supply-side oriented electricity industry. There has been relatively little focus on distributed electrical and thermal energy storage, although this is changing rapidly given growing research, commercial and policy interest.
- Only small amounts of distributed energy storage are currently used within Australia on the main electricity grid, typically through demonstration projects. Distribution network service providers have played a key role in these trials to date. A broader definition of distributed storage that includes ripple controlled residential hot water systems and Uninterruptible Power Supplies in critical commercial and industrial applications does, however, mean far higher levels of deployment have already been achieved.
- Another key area of existing deployment is battery storage systems for off-grid applications. This storage is already cost effective, or indeed essential, for many smaller stand-alone systems. Energy storage applications for larger off-grid community sized systems and edge of grid applications represent a high value application that may already be potentially cost effective in Australia in many contexts.
- It is important to distinguish between cost effectiveness in terms of industry or even broader societal economics versus private commercial cost-effectiveness for existing stakeholders. Existing electricity industry arrangements do not provide cost-reflective prices and tariffs to key stakeholders, notably end-users, meaning that industry and private cost-effectiveness is often poorly aligned. Given the high capital costs associated with battery energy systems, cost-effectiveness must also be considered over long time frames.
- The industry economics of electrical energy storage do not seem particularly compelling at present in the major population centres within Australia on the main grid. For end-users, the private cost effectiveness for distributed energy storage depends critically on both the load profile and the available energy tariffs.

- The cost of some key storage technologies including batteries seems likely to continue to fall in coming years, and their present high capital costs may well not continue to prevail as the preeminent barrier in the uptake of distributed energy storage.
- Carbon emission reductions are not an assured outcome of distributed energy storage, given its potential to facilitate greater operation of relatively inflexible high emission thermal plant – a key role that centralised storage has played in electricity industries to date.
- The question of what the most prospective roles for distributed energy storage is a complex issue. A common framework is to assess the potential value and hence cost effectiveness of distributed storage. The ongoing operation of the current electricity industry highlights that there are no roles where energy storage systems are critical and no other alternatives are available. Instead, distributed energy storage must provide greater net value (benefits – costs) than existing arrangements.
- Social acceptance and interest in novel energy technologies can be difficult to predict, but often plays a key role in its eventual success or failure to achieve significant deployment. Many end-users are motivated by a range of concerns other than strict private economic returns arising from deployment.
- For Australia’s future electricity industry, current research suggests that energy storage seems likely to play an important role in enabling increased levels of highly variable and somewhat unpredictable distributed renewable generation and hence facilitating reductions in greenhouse gas emissions through displacement of high emission existing centralised generation. Other potential high value applications appear to be in providing greater levels of reliability to customers seeking very assured supply for critical loads, and for reducing network expenditure driven by short periods of high peak demands.
- Current electricity market arrangements and broader regulatory and policy frameworks need to better align overall industry and private economics for all distributed energy technologies, not just storage. At this time, some storage applications that may soon become privately cost-effective may not also deliver net overall economic benefits, whilst some potentially valuable roles for distributed storage within the electricity industry may fail to achieve commercial success given present commercial arrangements.
- A number of critical uncertainties exist around energy storage technologies and their operation, maintenance and safety. In particular with reference to the reliability, ease of use and performance guarantees of energy storage, in addition to the lack of a consistent framework to describe the performance of storage technologies for different applications and from different manufacturers.
- Beyond technology uncertainties, broader uncertainties based around the complex relationship between stakeholders and technologies exist.
- Globally, Germany, Japan, Puerto Rico and California (USA) have implemented policies to increase the uptake of distributed energy storage.
- Australia presents some opportunities for facilitating storage that are not evident in many other jurisdictions including high per-capita levels of residential PV, and high network expenditure. However, identifying, understanding and then capturing these opportunities will require context specific research, development and demonstration efforts.

As a conclusion to this scoping study, the CRC has identified a number of key research areas that clearly seem worthy of further consideration by the CRC in terms of its mission. The areas of research include:

1. Urban (residential and business) distributed renewable energy and storage:

To identify the potential for urban renewable energy and storage systems by investigating:

- Technical performance and costs of commercial and near-commercial systems
- Potential business models of ownership, service and maintenance
- Capacity and installation location (i.e. community precinct systems vs. household based systems)
- Other Issues like barriers to deployment and operation and opportunities for both existing and new commercial and residential developments.

2. Off-grid and Edge of grid solutions:

To identify the potential for photovoltaics, storage and other forms of generation to supply a feasible solution to network issues of reliability for edge of grid communities. The aim will be to identify whether a standard scalable design can be generated. As per the urban PV and storage project, issues of feasibility, costs, business models etc. will be investigated. A key component of such a project is tools to appropriately compare centralised grid versus decentralised energy options within these contexts.

3. RE penetration study:

To identify the current penetration capacity of renewable energy generation on the distribution network and to identify how the penetration capacity can increase with the inclusion of distributed energy storage (electrical and thermal). Such a project would hinge on tool development that effectively integrate renewable and storage models. There are opportunities to link this work with wider international efforts underway in this space and it will be important to link distributed energy storage assessment with other possible measures for managing high PV penetration.

4. Distributed energy markets and broader regulatory and policy frameworks to facilitate distributed energy storage.

Distributed storage falls within the broader context of a growing range of distributed energy opportunities through distributed generation and smart end-use technologies. A key question is what retail market and broader policy and regulatory arrangements might best facilitate appropriate deployment and use of all of these options. Note that some options might establish a greater value proposition for storage such as PV generation, whilst others might potentially represent competition for particular storage deployments, such as low-cost smart controllable loads. Such industry arrangements would certainly include retailer 'energy' network tariffs, broader connection requirements and planning frameworks, as well as the wider policy frameworks and institutional arrangements that are required.

5. Living Laboratories with distributed storage

Whilst there have been a number of trials of residential and network storage options here in Australia, there are still a range of technical, economic and wider uncertainties that will almost certainly require further trials. The living laboratories provide a framework for such trials that includes monitoring and opportunities for wider community engagement. A number of existing and proposed developments exist in this space.

Introduction

The electricity industry here in Australia, and worldwide in many jurisdictions, has recently seen profound changes that are amongst the most significant experienced by the industry over its 120 year history. These include growing energy security and environmental drivers, most notably climate change. Furthermore, there are a range of new technologies, both demand-side and supply-side, that have seen increasing capabilities and deployment. These include end-use equipment including residential heat-pumps (air-conditioning and hot water systems) which are now found in most Australian residences, and greatly improved energy efficiency options like lighting and refrigeration. On the supply-side, residential photovoltaic systems are now owned by around 15% of Australian households (25% in South Australia and 23% in Queensland) [1]. Such PV systems will often supply most of these households consumption, albeit exporting to the grid during the day whilst drawing from the grid overnight. Meanwhile, smart metering and associated grid side and end-user side applications, including direct load control, are also now seeing growing penetrations.

Energy storage has always played an important role in the electricity industry given the special characteristics of electricity (instantaneous energy flows through a dedicated and shared electrical network that has no inherent storage) and the electricity industry itself, in its role of ensuring that supply precisely meets changing and uncertain end-user energy service demands at all times and locations across the network. In a general sense, energy storage is the storing of some form of energy that can be drawn upon at a later time to perform some useful operation. In the current electricity industry, most energy storage resides in the fuel supplies for major generation - notably water reservoirs for hydro generation, coal stockpiles for coal plant and gas in reservoirs and the pipe network for gas generation. One limitation here has been the operational constraints associated with some thermal generation, notably coal-fired plants (and in numerous countries nuclear) that can typically only operate down to around 50% of its rated capacity and has only limited ramping up and down capabilities within this range. Given variable and uncertain demand over daily, weekly and seasonal cycles, this has raised challenges in economically and efficiently maintaining the supply-demand balance at all times. Another limitation has been the capital costs of generation required only to meet occasional peak demands. A key response to this, where resources make it possible, has been pumped storage systems integrated into reservoir hydro systems. In recent decades however, the low capital cost and high operational flexibility of gas-fired peaking plants has often provided a lower overall cost solution for new applications. Some electricity industries have also taken advantage of the inherent energy storage available in some end-user services, notably through off-peak hot water systems, to better manage the supply-demand balance. Through either timers or active ripple control, such systems can represent a very significant dispatchable load resource.

Recent electricity industry developments in numerous jurisdictions, including Australia, have raised new challenges yet also opportunities for the electricity industry and its operation. One has been the growing deployment of highly variable and somewhat unpredictable renewable energy, primarily wind and solar. These technologies have high capital costs yet low operating costs, and hence storage to move their variable and uncertain generation across time is potentially highly valuable. Another challenge is that of increasingly peak demand in the residential, and to a lesser extent commercial, sectors where average demand has been falling due to a range of reasons including energy efficiency and distributed generation, yet peak demand has not, or certainly not to the same extent. Until relatively recently, residential peak demands were generally increasing due to factors such as increased air-conditioning deployment. The distribution network assets, and hence associated capital expenditure, required to ensure that projected future peak demands can be met has seen growing network expenditure and hence overall industry costs. Indeed, network expenditure represents the greatest component of small end-user electricity bills. Technologies that can assist in better managing such peaks therefore offer potential network value in avoiding or deferring such expenditure.

At the same time, a range of emerging distributed energy storage technologies has seen growing technical and commercial progress. These particularly include a range of battery technologies whose development has been driven by factors including portable electronics and electric vehicles. Others include compressed air storage and flywheels. There are also a range of thermal energy storage options. More generally, there are other emerging technologies such as remotely controlled end-user appliances [2] (for example, 'peaksmart' remotely controllable air-conditioning now being deployed in Queensland) that effectively take advantage of the inherent energy storage available with some end-user energy services such as heating and cooling. Some of these technologies, particularly the battery and smart load options are highly scalable from residential to commercial, industrial and utility applications within the distribution network.

There is nothing new about variable and uncertain electrical loads and unpredictable generation, nor peak demand challenges in terms of both supply balance and network management. Neither, is there anything fundamentally new in the use of battery technologies for electricity supply (they have been in use for standalone systems in remote areas as well as in Uninterruptible Power Supplies (UPS) for critical end-user loads for decades). However, trends with both these electricity challenges and energy storage technology opportunities would seem to have created a potentially important valuable role for greater deployment of distributed energy storage in the electricity industry.

This seems particularly true for Australia which has growing deployments of wind (now greater than 3GW) [3] and household PV (amongst the highest per-capita residential PV deployment in the world) [1], very large distribution networks with low customer densities by international comparisons [4] and hence high rising costs and by some measures globally high residential and commercial electricity prices [5].

As always, a key question is what might come next. Recent work published as part of the Future Grid Forum [2] indicates that Australia's electricity system is at a significant crossroad with Forum participants believing that Australia's electricity landscape will change significantly in the decades to 2050. The study indicated that the expected shift is uncertain but did identify that three key technology drivers would be further progress in renewable generation, notably distributed PV, 'smart' technologies that facilitate greater end-user engagement, and low-cost electricity storage. As part of the study four potential future scenarios were presented; all involved a growing use of energy storage, highlighting its importance in Australia's future energy system. Further evidence of the interest in energy storage within Australia's current and future energy system has been demonstrated through a series of recent reports and forums regarding this topic within Australia [6-11] and globally [12-16].

There is growing interest and some early commercial availability of residential storage systems to complement household PV systems [17], particularly given current net metering arrangements where self-consumption is far more valuable than exporting PV to the grid [18, 19]. A number of trials have been undertaken by various Australian Distribution Network Service Providers [20, 21] and some early commercial deployment has commenced [22].

The CRC for Low Carbon Living is undertaking a scoping study to better understand the technical and economic potential for distributed storage of electrical and thermal energy to facilitate greater penetrations of distributed renewable energy technologies within the grid - a key part of its vision for facilitating a low carbon built environment in Australia, and beyond. Some key requirements of this scoping study are that it:

- Maps the territory of distributed storage, including key risks and opportunities, key players and stakeholders

- Focuses on the role that distributed storage can play in reducing carbon emissions

- Considers the whole value chain including storage technology, precinct planners and developers incorporating localised generation, electricity network providers, electricity retailers, electricity market regulators, energy advocates and policy makers, and

- Identifies key research directions and potential projects for the CRC-LCL.

The purpose of this paper is to examine a series of key issues and questions that have arisen through discussions between the project team and a range of CRC-LCL stakeholders as the first step for undertaking this scoping study. In particular, the project undertook an initial stakeholder meeting on distributed energy storage in December 2013 which has significantly guided the approach taken in this report.

In particular this paper aims to highlight what the project team currently sees as the key issues, challenges and opportunities for distributed energy storage within Australia. In addition, this paper aims to identify gaps within the existing knowledge and the work required to facilitate the uptake of distributed storage with the aim to mitigate future greenhouse gas emissions. The key questions discussed in this issues paper are:

- What are the possible roles for distributed energy storage within Australia's current and possible future energy systems?
- How can energy storage reduce carbon emissions?
- What is the status and critical uncertainties of distributed energy storage technologies?
- At what locations and scales might distributed energy storage be best integrated within Australia's energy system?
- What are the barriers to widespread deployment of distributed energy storage?
- What solutions are available to address the foreseen barriers?
- What is the current status of distributed energy storage globally?
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What are the possible roles for distributed energy storage within Australia's current and possible future energy systems?

Existing Storage Roles

Moderately significant amounts of energy storage are already used within Australia's energy system. The most common form of energy storage used in Australia's energy system and energy systems globally is pumped hydroelectricity energy storage (PHES), with about 1490 MW of PHES in operation within Australia [11, 23]. Most but not all of this capacity is integrated within hydro generation schemes - notably the Snowy Scheme. This represents around 2.5% of total installed generation capacity. It's primary role within the commercial framework of the Australian National Electricity Market is energy arbitrage - storing electricity at times of low economic value and hence low price (for example, times of low demand or, increasingly, high renewable generation) and generating electricity at times of high value and hence price (for example, periods of high demand, low renewable supply or supply contingencies). As such, it can provide peaking capacity that avoids the requirement for other peaking plant such as combustion gas turbines.

Another significant storage resource in the Australian electricity industry is ripple control of residential off-peak water systems. This represents some hundreds of MW of highly distributed controllable load within some States (35% of households in Australia utilise off-peak electrical hot water [24]). The historical role of this system was largely to reduce day-time and increase night-time demand to assist in better managing the operational constraints of large thermal plants (primarily coal but also gas generation to a lesser extent) and improve their utilisation factors. One potentially surprising aspect of this storage is that peak demands on some sections of the electricity distribution network are sometimes seen at the time these hot water systems are activated. UPS and backup diesel generators also represent a significant distributed storage resource, although these are not generally seen as such at present, residing behind the customer meter and generally only used at times of grid failure.

Another existing role for energy storage in Australia and internationally is not particularly significant in terms of the deployed capacity, but does highlight a potentially valuable future role. Distributed energy storage is widely used in stand-alone electricity systems for remote households and, to a lesser extent, off-grid communities. In this situation energy storage is used in conjunction with an alternative energy generation source like photovoltaics or a diesel generator to provide a constant and reliable source of energy in the absence of the grid. The Energy Storage in Australia report by Marchment Hill Consulting [6] suggested that a material opportunity for supporting fringe and remote electricity systems already exists. The report indicates that the role of storage in these applications could mitigate unreliable supply, reduce the dependence on the cost of delivered fuels like diesel, ameliorate the combined impact of growing populations, peak demand and constrained capacity of generation and transmission, allow more renewable energy to be integrated into the electricity system, provide firm capacity for renewable energy generation by allowing intermittent output to be stored when generated and released when needed, allow for ramp rate control of intermittent renewable output, and protect the stability of the grid as a whole from fluctuations in renewable energy output.

Frameworks for categorising distributed energy storage roles

Energy storage generally can perform a variety of key functions including [25]:

- Smoothing the supply of electricity generated from variable renewable energy sources
- Ensuring the stability and quality of electricity
- Decreasing the reliance on combustion power plants to meet peak demand
- Enhancing the efficiency of the grid by dispatching energy when electricity is needed rather than when it was originally generated
- Reducing the need for new transmission lines and power plants
- Providing grid security when there is a transmission and distribution interruption (blackouts)

There are a range of international and Australian frameworks for categorising the potential role of storage within the electricity industry. One challenge with such frameworks is the diverse range of roles that storage can play. It is, in effect, a universal energy technology that can operate as generation, load and even, to some extent, network elements. As such, these frameworks can be rather complex. Consideration of distributed energy storage adds further complexity as it can undertake a range of roles within the distribution network and at customer premises that centralised storage cannot while, if appropriately aggregated, it can likely fulfil most if not all roles that centralised storage can offer.

The DOE/EPRI Electricity Storage Handbook [12] provides a comprehensive list of services that energy storage may play. Brief descriptions of these services from the DOE/EPRI handbook are listed and categorised below. Readers are referred to the DOE/EPRI Electricity Storage Handbook [12] for detailed descriptions of these services.

Distributed Energy Storage Services:

Transmission infrastructure services

- Transmission upgrade deferral - Involves the delay or avoidance of utility investments in transmission system upgrades, by using relatively small amounts of storage in strategic locations. Typically transmission upgrades are required to handle peak loads which only occur across a few hours on a handful of days per year. Storage in this application can be used to meet these peak load occurrences and prevent the need for transmission upgrades.
- Transmission Congestion relief - Storage installed at appropriate substations may mitigate congestion due to increasing demand. Distributed storage in this role would be located downstream of the point of congestion and used to store energy when there is no congestion and discharged during periods of congestion (i.e. during peak demand periods).

Distribution infrastructure Services

- Distribution upgrade deferral - As per transmission upgrade deferral with the storage located downstream of the distribution nodes/hubs
- Voltage support - Distributed storage in this role can be used to dampen voltage fluctuations on distribution lines

Customer energy management services

- Power quality - Storage can be used to protect customer loads against short duration events (i.e. variations in voltage, frequency, harmonics and power factor) which affect the quality of power delivered to the customer.
- Power reliability – Storage in this role can be used to meet energy demand when there is a total loss of power (blackout) from the network.
- Retail electric energy time-shift – Storage in this role can be used by a customer with time of use tariffs (TOU) to minimise their overall cost of electricity by charging storage during off-peak pricing periods and discharging storage during periods of peak pricing.
- Demand charge management – Storage in this role can be used by a commercial customer (currently demand charges are only relevant to commercial/business customers) to reduce their maximum recorded load and hence their overall electricity costs.

Centralised Energy Storage:

Bulk energy services

- Electric energy time-shift (arbitrage) - Storage can be used to shift energy through time to reduce generation costs by storing excess electricity at off peak times and discharging during peak periods.
- Electric supply capacity – Storage can be used to offset or defer the need for new centralised generation capacity.

Ancillary services

- Regulation – Storage can be used to manage short term differences caused by fluctuations in the generation and demand for energy.
- Spinning, non-spinning and supplemental reserves – Storage is this role is used as a capacity reserve which can be utilised when some portion of the normal supply of electricity becomes unexpectedly available.
- Voltage support - Storage in this role can be used to provide reactive power support to maintain voltage within specified limits.
- Black start – Storage in this role can be used to provide an active reserve of power and energy to energise transmission and distribution lines and provide power to bring power plants back on line after a catastrophic failure of the grid.
- Other related uses – Storage could be used to provide load following/ramping support for renewable energy sources

Similar lists of services of energy storage and their descriptions can be found within [6, 10, 15]. The International Electrotechnical Commission's White Paper on electrical energy storage [15] also categorises the role of energy storage from the viewpoints of the utility, customer and renewable energy generators.

From the viewpoint of the utility, energy storage can be used for:

- Time shifting – Storage can be used to shift energy through time to reduce generation costs by storing excess electricity at off peak times and discharging during peak periods.
- Power quality – Frequency and voltage control.
- Deferral of transmission and distribution upgrades – Storage installed at appropriate substations may mitigate congestion due to increasing demand.
- Isolated grids – Storage can be used in remote or isolated grids to stabilise power supplied by diesel or other generation sources.
- Emergency power supply for protection and control equipment – Storage can be used in the case of a line outage.

From the viewpoint of the customer, energy storage can be used for:

- Time shifting/cost savings – Customers may use storage to shift energy through time by storing electricity at off peak times and discharging during peak periods to achieve cost saving. Customers may also use storage to obtain greater utilisation of household PV systems that are paid a low tariff for energy exported to the grid.
- Emergency power supply – Storage can provide a backup source of power supply in the event of network outages.
- Electrical vehicles and mobile appliances – Storage in electric vehicles and mobile devices.

From the viewpoint of generators of renewable energy, energy storage can be used for:

- Time shifting – Renewable energy generation such as solar and wind are intermittent generation sources. In some cases generators may need to operate at less than their potential capacity if there is no demand for the power. Storage can capture surplus power production and release the power when demand calls for it.
- Effective connection to the grid – Renewable energy generation sources are inherently intermittent which makes connecting them to the grid difficult. Storage can be used to not only time shift the generated power but to absorb the fluctuations due to intermittency.

Possible future roles for distributed energy storage

With regards to Australia's future energy system, the CSIRO's Future Grid Forum [2] explored the questions of what Australia's electricity system might look like in 2050 and what issues and options might arise along the way. In the Forum's main report, four potential future scenarios were proposed, with the report indicating that the actual future might include elements of each of the presented scenarios. The report also highlights the uncertainty in predicting Australia's future energy system, as it will be dependent on future fuel prices, any carbon and energy policies and their specific targets and mechanisms, changes in the costs of other technologies and any adaption to a changing climate. Ignoring the fact that the specific construction of Australia's future energy system is unknown, a significant finding from the Future Grid Forum report is the need for energy storage, particularly distributed energy storage, within all four of the presented possible future scenarios, highlighting the important role energy storage may play within Australia's future energy system. Within the four scenarios the following uses of storage were proposed:

- Scenario 1: 'Set and forget': In this scenario, customers select a demand management plan and the energy utility controls the use of on-site storage. In this scenario on-site storage controlled by the energy utility is used to shift energy demand when it is not practical to reduce the customer's energy demand.
- Scenario 2: 'Rise of the prosumer' (a customer who both produces and consumes energy): In this scenario, customers take a strong interest in on-site generation and management of their energy use. Distribution, retailers and energy service companies provide opportunities for trading power generated on-site or by using it on-site through storage systems. Batteries from electric vehicles are also used as a medium to store power.
- Scenario 3: 'Leaving the grid': In this scenario disconnection from the grid becomes a viable option by coupling on-site storage and energy generation. Energy storage in this scenario is used to balance the supply and demand of electrical energy.
- Scenario 4: 'Renewables thrive': In this scenario renewable energy generation increases significantly with a phased 100 percent renewable target by 2050. Storage becomes deployed both at utility-scale and network locations as well

as on-site with customers, shifting demand and storage charging loads to the middle of the day to take advantage of high large scale solar and decentralised rooftop solar output.

A 100 percent renewable energy scenario was also investigated by AEMO in their 100 percent renewable energy study [26]. This study used least-cost modelling to determine the optimal combination of generation, storage and transmission investments to match the forecast customer demand for energy under four possible future scenarios. The report states that maintaining energy system security requires supply and demand to be balanced at all times, and preserving this balance is more challenging in a 100 percent renewable power system. The study highlights that energy storage would be central to providing system flexibility to achieve the balance traditionally provided by fossil fuel generators, due to the inherent variability of key renewable energy sources which depend on weather conditions that vary on several time scales (minutes, daily, seasonally, annually). The least cost modelling suggested that the existing pumped hydro in the National Electricity Market (NEM) would need to be supplemented with a mix of concentrated solar thermal (CST) with molten salt storage, biogas (stored in the existing gas system), biomass and additional pumped hydro, with the model selecting CST with storage as the primary storage technology. The report also indicated that investment in specific storage solutions such as batteries and compressed air did not emerge as being economic for large-scale deployment and were not included in the modelling. In addition the study reported that energy storage in a 100 percent renewable energy system is likely to be required predominantly to meet demand after sunset and in particular to manage evening peak loads. Storage would also be used to cover periods of low wind speed or solar radiation and to provide backup in case of contingency events such as the loss of a transmission line or a large generator. Although this study highlights the need and importance for storage in a 100 percent renewable energy system, the study focused on large utility and network dispatched storage systems and didn’t consider the contribution that distributed energy storage could play in a future 100% renewable electricity system.

Conclusion

In general, distributed energy storage can play a wide range of potential roles in an electricity industry where supply must meet demand at all times and at all locations across the electricity network. Future developments towards higher levels of renewable generation, particularly distributed renewable generation, will further expand these roles. Smart grid developments and greater end-user participation will also assist in distributed storage playing valuable roles where an aggregated response is required.

A review of the existing literature has indicated that energy storage may play a significant role in Australia’s future energy system. However, the specific role, or more likely roles, it will play remains speculative and may vary considerably based on the outcomes of future fuel prices, any carbon and energy policies and their specific targets and mechanisms and changes in the costs of other technologies [2]. Fundamentally, the determination of the potential role for storage will require an in depth examination of the technical and economic impacts of storage in comparison to potentially competing technologies that may provide demand response, transmission, flexible generation, improved operating practices and enable higher integration levels of variable renewable energy sources [27]. In particular the current review has highlighted the need for specific studies on (i) the potential for distributed energy storage, as current studies have largely focused on the potential of utility and network scale storage systems and (ii) what scenarios and outcomes are most likely to occur in the short term under the current regulatory and network frameworks. For example, would a large deployment of residential storage occur based on the existing stock of residential PV systems; could current tariffs lead to higher emissions and higher rates of network investment due to arbitrage which may cause peak demand spikes; and could current regulatory frameworks prevent grid scale storage.

Besides the actual role energy storage can play within Australia’s current and future energy system, the role that individual stakeholders of storage will play also needs to be further investigated. It’s envisaged that stakeholder’s perspectives of energy storage, its costs and benefits, ease of implementation, use and maintenance and their particular role and interaction with energy storage will have a significant impact on the role both distributed and centralised energy storage will play within Australia’s energy system.

How can distributed energy storage reduce carbon emissions?

It is notable that the role of energy storage to date in the Australian electricity industry, and industries worldwide, has likely been to increase rather than decrease carbon emissions by facilitating greater use of large fossil-fuelled thermal plant. There are, clearly, risks as well as opportunities in deploying greater levels of energy storage.

Although it is not the only measure, energy storage in general has been proposed as a key strategy to help enable higher renewable energy penetration levels within the grid, in an attempt to meet renewable energy targets, avoid the use of fossil fuel based energy production and reduce carbon emissions. Other strategies proposed for further integration of renewable energy technologies include, demand response strategies that discourage consumption when electricity is scarce, renewable energy forecasting techniques for improved generation scheduling, and improved grid operating practices [25]. Of these other strategies, demand responses to discourage consumption, improved end use efficiency and improved grid operating practices are strategies that should both be employed regardless of the renewable energy penetration level. Similarly, knowledge about when renewable technologies will produce power does not eradicate the carbon emissions associated with energy generated from the fossil fuel/combustion generators (typically gas) that are currently used to level out the intermittency of power generated from renewable energy technologies. Hence, energy storage is currently one of the best options available for reducing greenhouse gas emissions by enabling greater penetration levels of renewable energy generation sources to be connected to the electricity grid, without the need for additional combustion based load following generation plants. Similarly, energy storage can also reduce greenhouse gas emissions via greater utilisation and improved efficiency of existing network infrastructure.

As an example, research undertaken to investigate how California can meet its 33 percent renewable portfolio standard (RPS) target by 2020, indicates that the use of energy storage avoids greenhouse gas emission increases associated with committing combustion turbines strictly for regulation, balancing and ramping duties [25]. Another perspective is to consider the increase in peaking plant capacity that would be required to cope with the increased level of intermittency of supply due to renewable energy sources. For the United States, a study by the U.S. Department of Energy (DOE) indicated that to supply 20 percent of the nation’s electricity with wind energy (300 GW) would require approximately 50 GW of new peaking plant gas turbines just to compensate for the variability of wind power [28, 29]. For the example of California, the California Independent Systems Operator (CAISO) predicts that without energy storage California will need an additional 4800 MW of load following energy to meet the 33 percent RPS in 2020 [25]. For the Australian 100 percent renewable scenario, the AEMO study [7] indicated that a 100 percent renewable system is likely to require much higher capacity reserves than a conventional power system, with capacity reserves over twice the maximum customer demand possibly being required.

Within the Australian context, the issue of intermittency due to renewables was investigated by the CSIRO [30]. The study indicated that for some network areas, the installation of additional renewable generation sources has already ceased due to perceived intermittency issues. The study advocated a critical need to determine the level at which intermittency on the grid becomes significant, as there currently exists a conservative response to inhibit further installations due to the lack of knowledge/information about the impact that existing and additional renewable energy sources have on the electricity network. In this context, energy storage provides an ideal solution to the intermittency problem as it can smooth the power output from renewable technologies. As such, energy storage can remove intermittency as the current limit of renewable energy penetration on the grid, enabling carbon emission reductions within Australia’s energy system. ARENA has recently undertaken a stocktake of their funding programs, and in particular projects that they have supported which are intended to facilitate higher levels of renewable generation in the grid [31]. A number of these, but a minority, involve the use of distributed energy storage.

What is the status and critical uncertainties of distributed energy storage technologies?

A detailed review of the available technologies is not presented in this document. For detailed information on available energy storage technologies the reader is referred to chapter 2 of the DOE/EPRI Electricity Storage Handbook [12] which provides an up to date review of electrical storage technologies, their cost (in US 2012 dollars), performance and maturity. The technologies covered within the DOE/EPRI handbook include both distributed and centralised energy storage technologies:

- Pumped Hydro (primarily a centralised storage technology)
- Compressed Air Energy Storage (CAES) (primarily a centralised storage technology)
- Sodium-sulfur Battery Energy Storage
- Sodium-nickel-chloride Batteries
- Vanadium Redox Batteries
- Iron-chromium Batteries
- Zinc-bromine Batteries
- Zinc-air Batteries
- Lead-acid Batteries
- Flywheel Energy Storage
- Lithium-ion Family of Batteries
- plus a list of other Emerging Technologies

In addition to the DOE/EPRI handbook, the CSIRO as contracted by the Australian Energy Market Operator (AEMO) undertook a study [7] to investigate the costs and examine the opportunities for several storage technologies including: solar thermal molten salt storage, biomass, biogas, CAES and batteries. The study found a significant potential for energy storage in Australia. In addition the study presented data and methodologies for determining costs which are dependent on the scale of storage required.

The publishers of EcoGeneration have also compiled a guide titled ‘The Ultimate Guide to Solar Energy Storage’ [10] to answer what they see as the important questions that solar system designers and installers need to ask before choosing solar storage products. The guide focuses on battery technologies and discusses the advantages and disadvantages of the use of different battery technologies in combination with solar energy systems. When purchasing a lead acid battery for a renewable energy application, the guide indicates that the most important factor to consider is the cycle life. This parameter was listed as the most important factor as it should allow the designer/purchaser/system owner to determine the cost of ownership of the battery over its life cycle.

The results of the distributed generation and distributed storage trials [32] run by Ausgrid as part of the Smart Grid Smart City (SGSC) program highlighted a number of issues with respect to implementing pre commercialised battery technologies. The SGSC trials involved the installation of 60 RedFlow R510 zinc-bromide flow batteries which were sized to store up to 10kWh of electricity or about half the daily requirements of a typical household. The RedFlow zinc-bromide flow battery technology used for the SGSC trials was just emerging from the research and development stage when the trials began. The distributed generation and distributed storage (DGDS) technical compendium [32] indicated that many of the challenges that occurred with the RedFlow battery technology was due to the lack of demonstrated practical application and lack of experience implementing this type of technology in the field. The compendium also reported that the maturity of the devices tested in the SGSC trial had a significant impact on their reliability. These results highlight the importance of both product maturity and the need for in-field demonstrated performance for new storage technologies. For example it was reported that the RedFlow battery technology performed relatively well initially, with the battery export meeting the device expectations over the first five months of the trial. After this time period it was reported that the performance then started to decline as was visible from a reduction in the time for which the battery could export energy.

The SGSC RedFlow Final Report [33] also indicated that most of the faults reported by the R510 battery systems was due to the electricity storage system (ESS), which encompasses the electronics and enclosure components, rather than from the zinc-bromide battery module (ZBM). During the trial period from 01/02/2012 till 31/01/2013, the zinc-bromide battery module (ZBM) had a reported availability of 91.67% in comparison to an availability of 75.52% for the electricity storage system (ESS) as per Figure 1. From November 2011 to March 2013, a total of 374 operational, manufacturing and installations issues were recorded with 74% of the faults occurring due to system components other than the ZBM. The breakdown of the other system component faults, Figure 2, indicated that the primary cause of the faults were due to the power conversion system issues (inverter and AS board faults) and analogue loom/sensor issues.

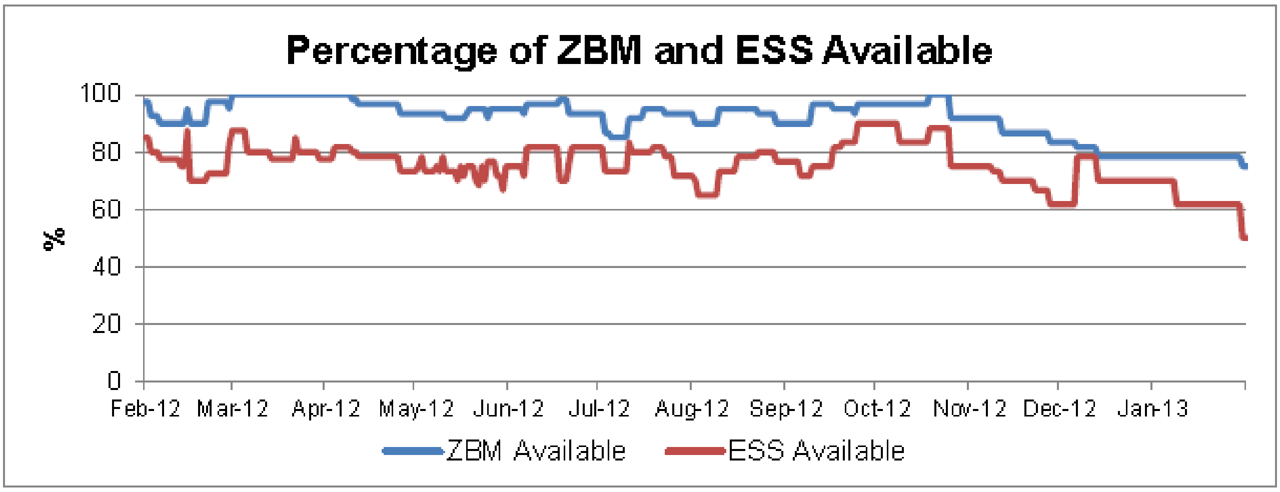


Figure 1: Overall percentage of ZBM and ESS faults over the trial period (Fig. 2 [33])

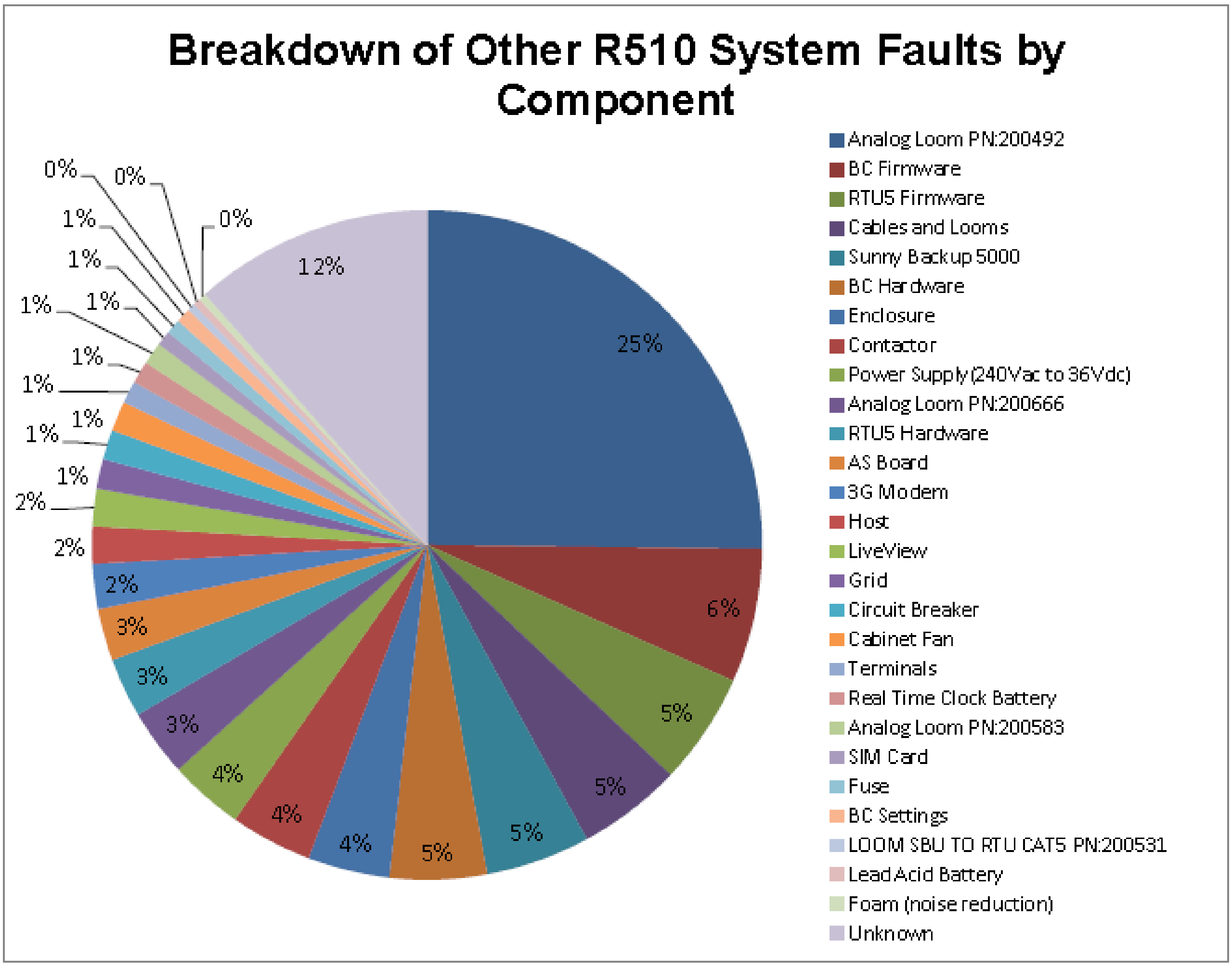


Figure 2: Breakdown of Other R510 System Faults by Component (75% of total faults recorded) (Fig. 4. [33])

The SGSC trials also found that various battery characteristics affected the battery system output, including the discharge/charge profile, full cycle efficiency and ambient temperature. For example the RedFlow battery systems were found to take about six hours to fully charge a battery from 0% capacity at a rate of around 3kW. The example presented in the DGDS compendium [32] indicated that the charge rate for the RedFlow technology was acceptable for summer peak reductions, which would only require one charge/discharge cycle per day. However for winter, it was found that there was not enough time for the batteries to go through the full cycle of discharge, strip and recharge between the two morning and evening peaks. Another issue reported for the RedFlow technology was parasitic losses amounting to 300W when the battery system was in float or standby mode. These losses had an impact on the overall system performance. The parasitic losses arise due to the fact that the RedFlow battery technology requires a flow tank for the liquid zinc-bromide solution and incorporates a mechanical pump and fan to supply continual fluid movement and cooling [32].

A number of other issues were also highlighted with reference to the accessibility of the RedFlow battery technology for residential customers. In particular the DGDS technical compendium [32] highlighted that a number of residential customers who volunteered for the DGDS trials were assessed as unsuitable for the RedFlow technology due to difficult access and/or insufficient room for installation. The footprint area required for the installation of the RedFlow R510 technology was 1.7m x 2.0m which was found to be a challenging requirement for residential customers as most houses within the targeted SGSC trial area only had up to 1.4m clearance between the walls of the residential dwelling and the property boundary. In the 4th Monitoring and Measurement report [20] it was reported that over 80% of households were not suitable for installation of customer based batteries due to the physical installation requirements, access to communication systems or the building electrical system. The size of the RedFlow battery systems was described as about the size of a two door fridge and weighing approximately half a tonne. The results of the residential customer trials also indicated concerns about noise levels of the battery technology, with two participants withdrawing from the registration process due to noise concerns, citing that they did not want an air conditioning unit (level of noise) outside their window. Installation lessons learnt from the SGSC trials were reported in the RedFlow Final Report [33] which indicated that future installations would also require that the battery system be installed undercover or in areas that receive shade during the hottest times of the day to minimise the likelihood that the system would shut itself down due to excessive ambient heat.

The results of the SGSC trials of the RedFlow R510 battery systems highlight that critical uncertainties exist with regards to the operational performance, maintenance and installation requirements of new and emerging storage technologies. The SGSC trials demonstrate the importance and need for field trials of storage technologies to highlight potential operational performance, maintenances and installation issues and how they vary with the commercialisation phase of the technology.

In addition to electrical energy storage there is also thermal energy storage. Essentially there are three ways in which heat can be stored [34]:

- Sensible heat storage
- Latent heat storage
- Thermochemical heat storage

The most common form of thermal energy storage is residential and commercial hot water storage systems (tanks). The commercialisation and use of hot water storage has been in practice for many decades. However questions have been raised whether the existing stock of hot water storage in Australia is being fully utilised and operated at its most efficient point. Other forms of thermal energy storage technologies include storage of hot or cold water underground, phase change materials (PCM) and thermochemical storage. As highlighted within the CSIRO Intelligent Grid Report [35] thermal storage options also include the coordination of refrigerant and heating cycles of large cold stores and commercial HVAC systems so that temperatures, and hence energy demand, are adjusted to correspond with times of low and high energy demand on the electricity grid. For additional information on thermal storage options, the Centre for Low Carbon Futures report [34] provides a summary on thermal energy storage technologies.

The literature review of current energy technologies revealed that a number of questions with regards to energy storage technologies exist. Primarily, the existing literature lacks a comprehensive overview on how different storage technologies perform in the field in comparison to manufacturer tests and specifications, and how the performance of these technologies may vary depending on the operating scheme. In particular the following questions need to be resolved:

- How do management strategies vary between technologies?
- What is the best storage technology for each application? (i.e. management of peak loads, network reliability or for reducing carbon emissions)
- How reliable and easy to use are home energy storage systems? (PV systems are essentially seen as plug and play with minimal maintenance. Is this achievable for energy storage - experience with existing technologies would certainly suggest that this is not the case, whilst novel technologies inevitably face questions regarding this given the lack of long-term experience in actual applications?)
- Is there a consistent way to describe the performance of different storage technologies?

The U.S. Department of Energy have partially provided an answer to the last question by developing a protocol to provide a uniform way of measuring, quantifying and reporting the performance of energy storage for various applications [36] along with a supplementary report which provides documentation on how to determine the duty cycle of an energy storage system in a micro grid operated in an islanded mode [37]. The aim of the developed protocol is to enable end users a method to evaluate the performance of energy storage technologies on a uniform and comparable basis. The initial protocol that has been developed focused on the storage applications of peak shaving and frequency regulation. The authors of the protocol acknowledge that other applications and metrics in addition to those of the initial protocol need to be addressed and that development and enhancement of the protocol is intended to be a dynamic process that will occur over time through a phased approach.

Beyond technology uncertainties, broader uncertainties based around the complex relationship between stakeholders and technologies exist. These include social acceptance of different storage technologies which will depend critically upon the performance of these systems. These are addressed in the discussion of barriers in a latter section of this paper.

At what locations and scales might distributed energy storage be best integrated within Australia's energy system?

The question of what the most prospective roles for distributed storage might be is a complex one. A common framework is to assess the potential value and hence cost-effectiveness of distributed storage. One issue here is whether value is assessed on an industry (or even better societal) perspective, i.e. on the underlying industry economics, or rather from the commercial perspectives of particular stakeholders. While in ideal markets, these perspectives are merged through the invisible hand which ensures private profit maximisation also maximises overall societal welfare. However, current commercial arrangements within the electricity industry are far from economically optimal. This is particularly the case in retail markets where almost all end-users reside. Tariffs for both energy and network services are generally far from cost reflective. Hence, what is cost-effective for particular end-users might not be economically worthwhile from an industry perspective, and vice versa.

Within Australia, the Energy Storage in Australia report [6] and the Alternative Technology Association report on standalone power systems [38] identified a potentially cost effective opportunity for storage to support remote (rural locations) and end of line communities, where the costs of providing energy or maintaining end of line networks are high. Under such a scenario, storage in conjunction with renewable energy technologies and/or backup generators provides the role of the generator. The capacity of storage under such a scenario is dependent on the demand for energy.

More broadly, four levels of installation for energy storage have been proposed [6, 12, 15]. These are:

- Generation level – typically large scale energy storage (not distributed energy storage) used for arbitrage, balancing and reserve power.
- Transmission level – typically used for frequency control and investment deferral.
- Distribution level – typically used for voltage control and capacity support.
- Customer level (residential and commercial) – typically used for peak shaving and time of use cost management.

The capacities and locations of storage in these four scenarios are dependent on the service to be provided by the storage system. For example the most recent Monitoring and Measurement report from the Smart Grid Smart City project [20] indicated that device reliability is an important consideration when determining the capacity of storage required to meet network peak demand as you cannot assume that 100% of the storage devices on the network will be available for discharge. Generally however, energy storage can be physically installed at any level within Australia's energy system when appropriate planning for the storage is undertaken with reference to the energy demand (peak and time of use), network requirements (voltage), charge and discharge cycles of the storage or the required level of carbon emission reductions. The economics of installing energy storage at any level within Australia's energy system are however unlikely to be favourable at all levels.

The CSIRO Energy Storage report [7], developed as part of the AEMO 100% renewable energy study, investigated the cost and potential for energy storage within 42 segmented areas across the National Electricity Market (NEM). The general observations from the report indicate that in most cases the storage technologies investigated would be available for deployment across all of the 42 segmented areas. The main exception was underground compressed air energy storage (CAES) which is reliant on salt caverns as a storage vessel, limiting the potential of this storage option to one segmented area in the Advale Basin in Queensland. For solar thermal molten salt storage the study indicated this technology has significant opportunities in all areas, but costs were found to be lower in regions with greater solar resource and lower component costs (western Queensland and NSW and across South Australia). Battery storage technologies had the advantage of being locatable in any of the 42 segmented areas, in a variety of configurations and applications. The study found that the duality of use from battery technologies improved their economics which enabled them to be competitive with the other forms of storage technologies investigated. It should be noted that pumped hydro storage was not within the scope of CSIRO's work and hence the potential of this technology across each of the 42 segmented areas was not reported.

The Energy Storage in Australia report [6] provides a forecast of the commercial market for energy storage in Australia by application (reproduced in Figure 3). The study indicates that storage in the short term will predominantly be located within fringe/remote communities. In the long term the report predicts that the storage market for grid stability and peak shifting applications will grow significantly indicating that greater levels of storage will be installed at the transmission and distribution levels. Interestingly the results indicate only a small residential market for energy storage will exist. The reasoning's listed for the small residential market proportion included the high cost of storage and small differential between peak and off-peak retail prices which would not be large enough to justify arbitrage. The study also indicates that it is no longer attractive to export surplus energy to the grid since premium solar feed-in tariffs have been abolished for new installations. However, this statement was made with reference to the adoption of new PV systems and hasn't been considered as a potential driver for the uptake of storage from existing PV system owners who will come off these premium solar feed-in tariffs in the next couple of years (e.g. the 60c/kWh premium solar feed-in tariff in NSW ends in 2016).

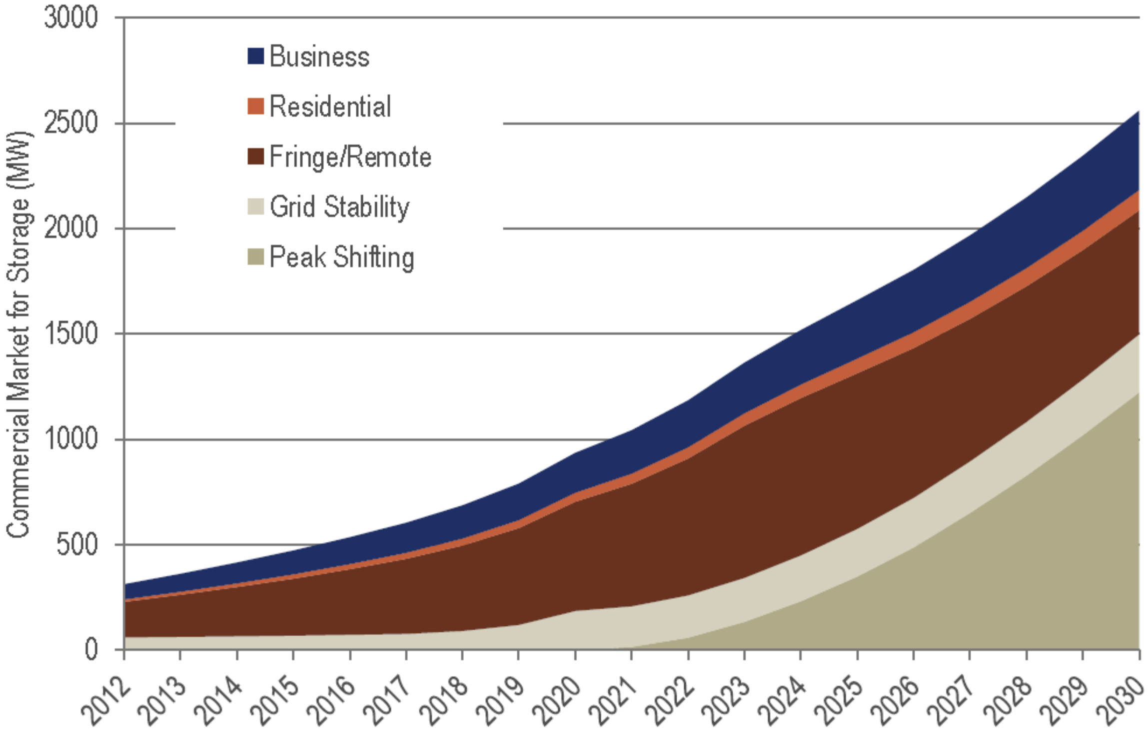


Figure 3: Forecast commercial market for energy storage in Australia, by application (Fig. 26 [6])

In other work [39], Sue and colleagues have undertaken a valuation estimation for a range of potential distributed storage options on an overall industry economics basis for the Australian NEM. As highlighted in Table 1, end user reliability and network augmentation deferral appear to offer the greatest potential value although both are extremely context specific. These findings are perhaps not so surprising given that there are fewer competitive alternatives for these roles than for those where centralised storage and other options can also contribute.

Table 1: Annualised Indicative Benefits ($k/MWh) for a range of potential distributed storage options [39]

	Indicative Annual Benefit ($k/ MWh)	
Application	Minimum Value	Maximum Value
End-User Reliability	32.25	1,469.03
Energy Time-shift	0.90	42.66
Energy Capacity	44.93	87.31
Network Augmentation Deferral	153	1,635.25
Substation On-site Power	280	560
Frequency Regulation	8.41	52.56

Beyond those flagged above, there are also a growing number of studies assessing the private residential value of storage for households with PV [18] that suggest growing cost competitiveness, under existing tariff arrangements.

Generally, the best use and location for distributed energy storage in Australia is still currently unknown and will be dependent on how well the barriers to energy storage at the different levels are addressed. In general, a key objective should be to determine the most valuable roles from an overall industry (societal) perspective, although commercially attractive applications will have a key role in driving deployment and hence progress with the technologies. In general, a number of questions with reference to the capacity and location of storage still need to be addressed within the Australian context. These are:

- What capacities, locations and at which levels will distributed energy storage help mitigate against network issues like peak demand and grid stability?
- How do you leverage/aggregate numerous small distributed storage systems if storage is installed at the customer level?
- How might particular distributed energy storage systems benefits from the range of potential roles that they can actually play? and
- What broader market frameworks might need to be addressed to better align the public and private value of distributed storage?

What are the barriers to widespread deployment of distributed energy storage?

A large number of foreseeable barriers exist preventing the widespread deployment of distributed energy storage [6, 16]. The current primary barrier for distributed energy storage is high technology costs. The economic and business case for storage will vary considerably depending on the storage technology selected, where and why the storage is needed and whether the benefits and their cost recovery can be achieved under the current regulatory structure. For example, [40] reported that the cost of providing arbitrage and ancillary services using a sodium sulphur battery was US$1150-2250/kW, whereas the cost for pumped hydroelectric storage was $500-600/kW; and the cost of a sodium sulphur battery providing arbitrage only is between US$3100 and $3300/kW, while the cost of the same battery offering voltage support is between $3200 and $4000/kW. In addition, most storage technologies have difficulty competing with the standard electricity network, due to their stage of commercialisation and the lack of magnitudes of scale in manufacturing [25]. Fortunately, the cost of energy storage is declining, whilst the cost of energy purchased from the existing electricity network is increasing. The historical and potential future price scenarios for storage in Australia, from the Marchment Hill Consulting (MHC) Energy Storage in Australia report [6], are presented in Figure 4. The modelling from the MHC report suggests that a “tipping point” between declining storage prices and increasing fuel prices is likely to occur between 2025 and 2030. Similar research from McKinsey & Company has indicated that the price of lithium-ion batteries could fall from $500-600 per kWh in 2012 to about $200 per kWh by 2020 and to about $160 per kWh by 2025 [41]. Similarly, costs summarised in a recent RenewEconomy article indicated that Citigroup cited a price of $230/kWh as the key mark where battery storage wins over conventional generation [42] with an approximate payback period of 7 years in Australia for PV with battery storage in 2020 (Figure 5) [43]. Hence, the impact of technology costs as a barrier to storage deployment is declining and is unlikely to persist past 2020-2030.

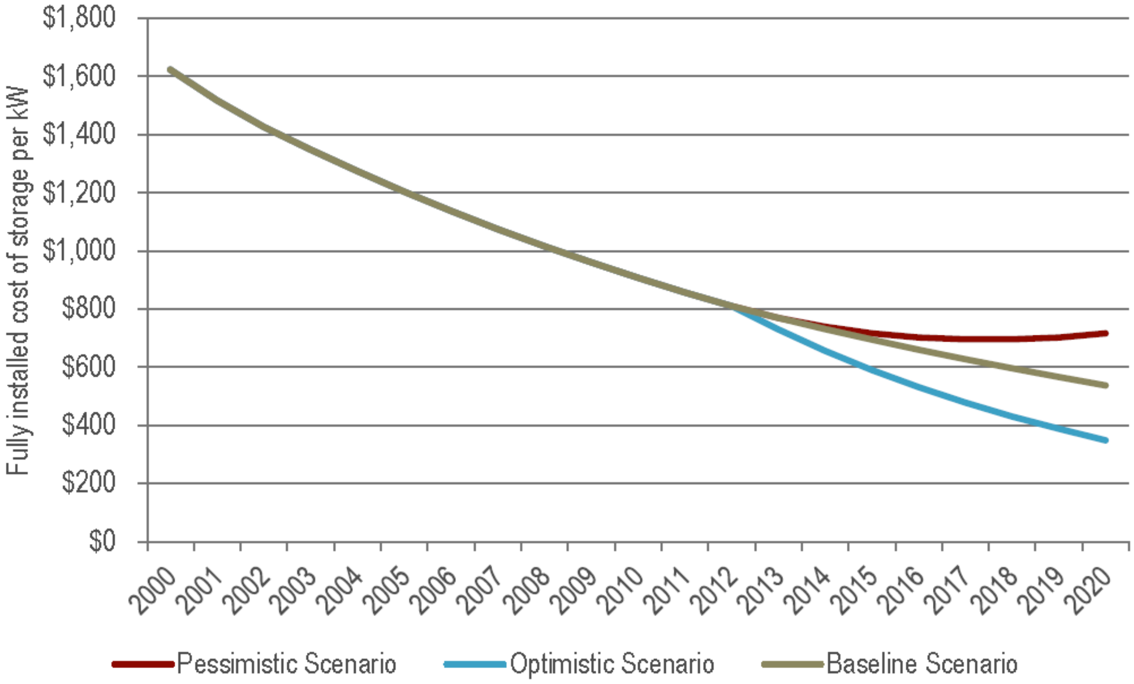
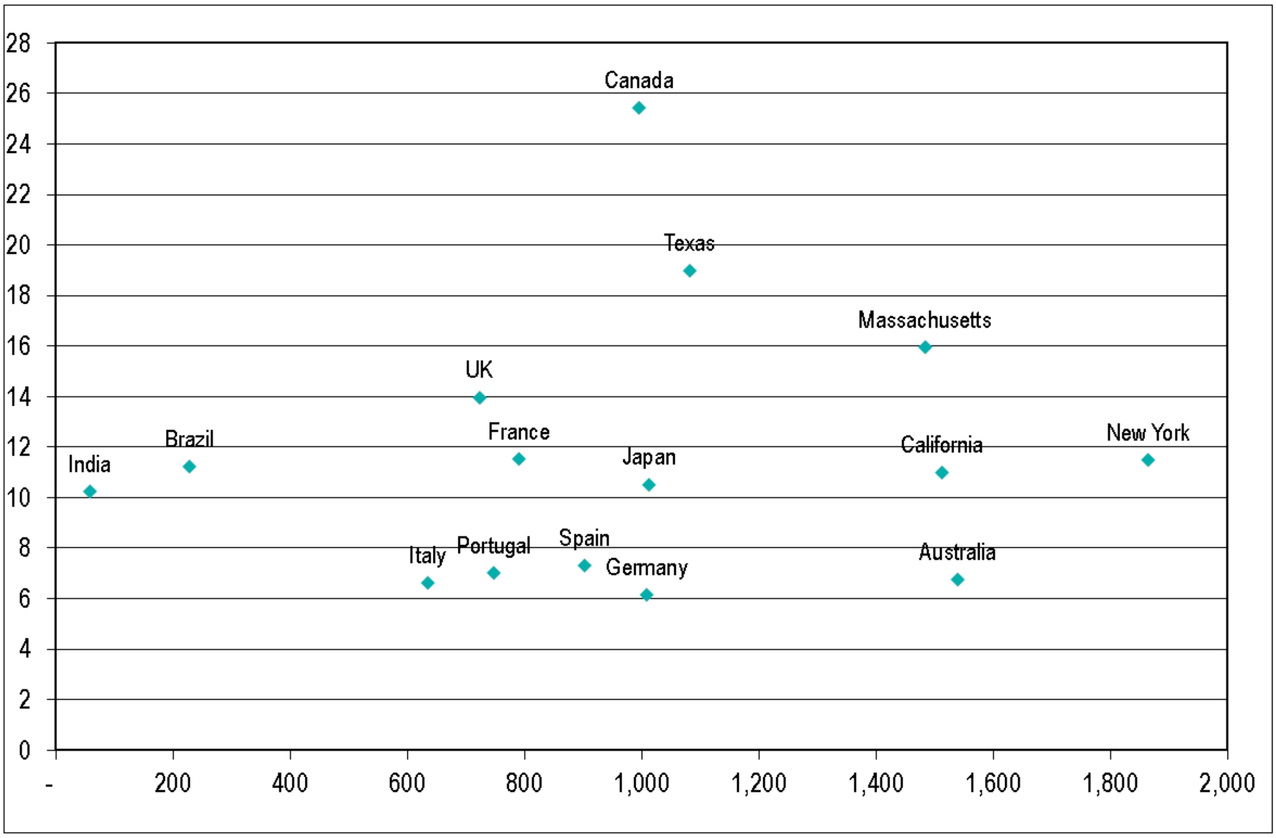


Figure 4: Historical and projected prices for energy storage (Fig 7 [6])



Source: Citi Research estimates

Figure 5: Payback in years (Y axis) vs average annual household electricity bill in € (X axis) for solar PV with battery storage in 2020 (Fig. 28 [43])

In addition to high capital costs a number of other barriers have been identified within the literature including [6, 16, 40]:

Economic Barriers:

- The inability of a single party to capture all the benefits of storage
- Lack of market and price signals to capture all the benefits of storage
- Financial disincentives/penalties for connecting storage with renewable energy generation e.g. SA Power Networks policy in South Australia to cease the payment of the solar feed-in tariff once an energy storage device is installed [44] .
- Lack of incentives (both at the retailer and customer levels) to install storage
- Lack of proven business models for energy storage, which incorporate utility and developer uncertainty and risk
- Disparity between the financial incentives of electricity distributors and the interests of their customers

Regulatory Barriers:

- Procedural issues
- Discrepancies in rules across markets
- Functional classification restrictions and cost allocation issues
- Market Signals and Distortions
- Uncertainty of carbon pricing policies and their impact on electricity prices and potential cost benefits of energy storage.

- Uncertainty over the future of the renewable energy target (RET)
- Tax credits for diesel fuel used in stationary energy generators limits the potential of energy storage and renewables in the off-grid/end of line energy market.

Lack of Transparency/Asymmetric Information:

- Limited knowledge of energy storage technologies among power system stakeholders
- Uncertainty/lack of knowledge for all parties on the role storage will play in the future energy system.
- Modelling restrictions and lack of modelling capabilities
- Lack of transparency on network issues, infrastructure planning and network upgrades which storage maybe a suitable solution for.
- Lack of clarity around the cost of storage i.e. upfront costs of storage via quotes versus ongoing long term operating costs which are unknown.
- Lack of uncertainty and knowledge about grid stability and reliability i.e. uncertainty about the level of intermittency on the grid and what penetration levels of renewable technologies are acceptable.

Technology Barriers:

- Issues of power quality and safety in connecting large numbers of energy storage installations, mostly together with renewable energy, not currently thoroughly researched.
- Infrastructure needed to control and coordinate large numbers of energy storage is unknown, limited or does not exist.
- There are no accepted standards/procedures for measuring and reporting the performance of energy storage technologies available for the different potential use applications i.e. peak shaving, voltage and frequency control etc.
- There are no consistent control interfaces for energy storage
- Maturity of energy storage technologies insufficient
- Lack of proven pilot projects demonstrating the ability of energy storage interaction with the grid and its ability to meet different applications.
- Uncertainty about the reliability of storage systems with regards to; shorter lifespans than specified by the manufacturer; Maintenance frequency; and the ability to provide energy at critical times with a high level of certainty.

Environment Barriers:

- Reuse and recycling of storage technologies at the end of their product life
- Land use required for the implementation of storage.

Cultural Barriers:

- Energy storage is still an unfamiliar technology for many network engineers/operators
- Lack of proven performance guarantee from energy storage
- Community attitudes and acceptance levels of energy storage is unknown
- Lack of dialogue between the different stakeholders of energy storage which can lead to misunderstood opportunities, requirements and possible solutions i.e. between storage vendors, renewable energy vendors, network and distribution operators, energy retailers etc.

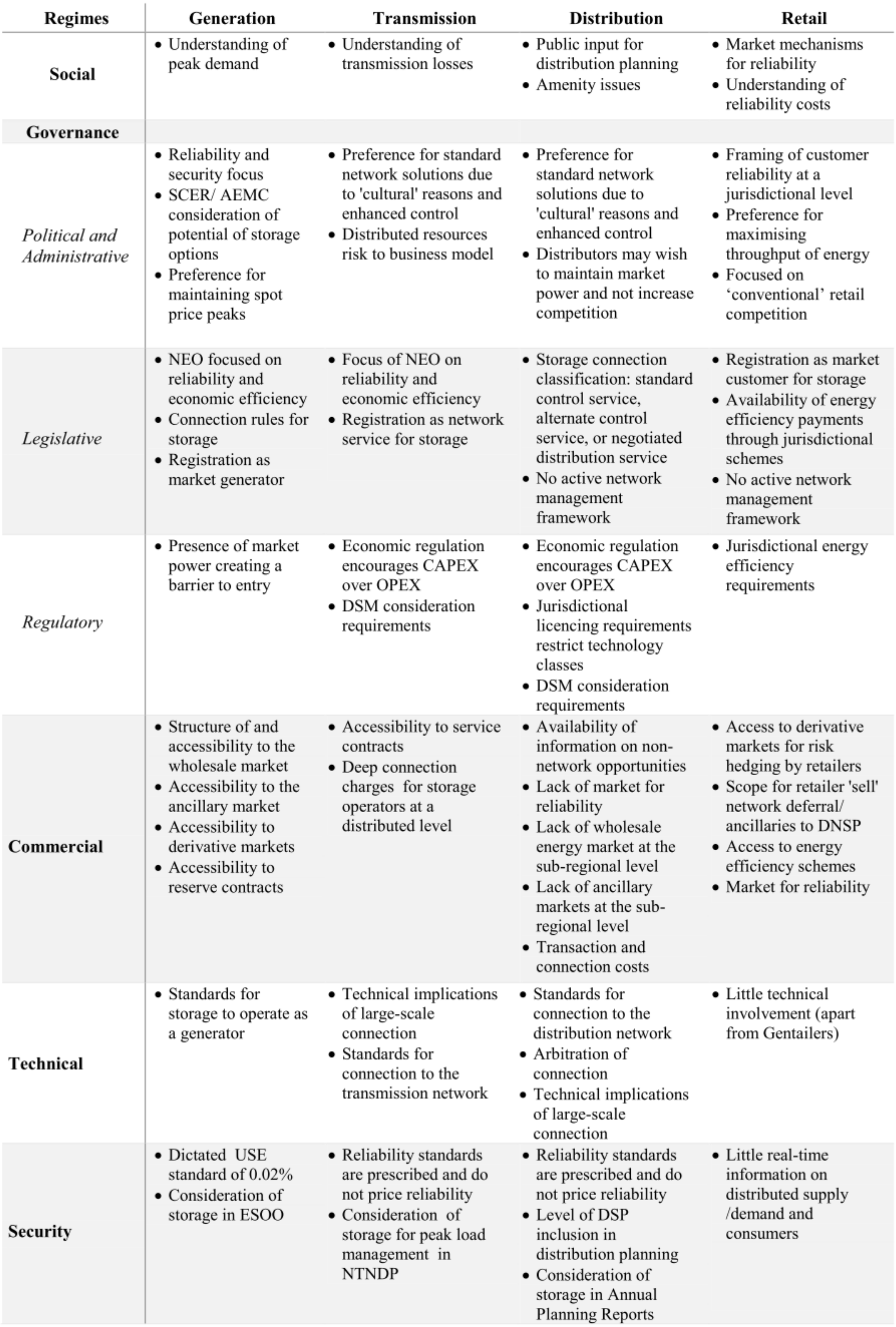
Safety Issues:

- Lack of proven safety standards and guarantees

In addition to the barrier identified above, a broader framework for distributed storage barriers in the Australian context with a focus on present institutional frameworks has been established by Sue and Colleagues [39] that provides another possible basis for systematic analysis, as per Table 2. A key focus here is on the key decision making regimes for the NEM.

The review of the literature has suggested many potential barriers to the uptake of distributed energy storage within Australia. In particular, the literature identified that the current primary barrier to deployment (high technology costs) appears unlikely to persist within the mid to long term future. Hence the other barriers to energy storage will need to be addressed before the price of energy storage is no longer a hindrance. Questions however still remain over the impact each identified barrier will have and hence which of the barriers need to be addressed with a high priority. In addition it is likely that a number of significant barriers to the deployment of distributed energy storage have yet to be identified and will only emerge if and as deployment grows.

Table 2: An institutional framework for the National Electricity Market [39]



Regimes	Generation	Transmission	Distribution	Retail
Social	• Understanding of peak demand	• Understanding of transmission losses	• Public input for distribution planning • Amenity issues	• Market mechanisms for reliability • Understanding of reliability costs
Governance				
Political and Administrative	• Reliability and security focus • SCER/ AEMC consideration of potential of storage options • Preference for maintaining spot price peaks	• Preference for standard network solutions due to 'cultural' reasons and enhanced control • Distributed resources risk to business model	• Preference for standard network solutions due to 'cultural' reasons and enhanced control • Distributors may wish to maintain market power and not increase competition	• Framing of customer reliability at a jurisdictional level • Preference for maximising throughput of energy • Focused on ‘conventional’ retail competition
Legislative	• NEO focused on reliability and economic efficiency • Connection rules for storage • Registration as market generator	• Focus of NEO on reliability and economic efficiency • Registration as network service for storage	• Storage connection classification: standard control service, alternate control service, or negotiated distribution service • No active network management framework	• Registration as market customer for storage • Availability of energy efficiency payments through jurisdictional schemes • No active network management framework
Regulatory	• Presence of market power creating a barrier to entry	• Economic regulation encourages CAPEX over OPEX • DSM consideration requirements	• Economic regulation encourages CAPEX over OPEX • Jurisdictional licencing requirements restrict technology classes • DSM consideration requirements	• Jurisdictional energy efficiency requirements
Commercial	• Structure of and accessibility to the wholesale market • Accessibility to the ancillary market • Accessibility to derivative markets • Accessibility to reserve contracts	• Accessibility to service contracts • Deep connection charges for storage operators at a distributed level	• Availability of information on non-network opportunities • Lack of market for reliability • Lack of wholesale energy market at the sub-regional level • Lack of ancillary markets at the sub-regional level • Transaction and connection costs	• Access to derivative markets for risk hedging by retailers • Scope for retailer 'sell' network deferral/ ancillaries to DNSP • Access to energy efficiency schemes • Market for reliability
Technical	• Standards for storage to operate as a generator	• Technical implications of large-scale connection • Standards for connection to the transmission network	• Standards for connection to the distribution network • Arbitration of connection • Technical implications of large-scale connection	• Little technical involvement (apart from Gentailers)
Security	• Dictated USE standard of 0.02% • Consideration of storage in ESOO	• Reliability standards are prescribed and do not price reliability • Consideration of storage for peak load management in NTNDP	• Reliability standards are prescribed and do not price reliability • Level of DSP inclusion in distribution planning • Consideration of storage in Annual Planning Reports	• Little real-time information on distributed supply /demand and consumers

What solutions are available to address the foreseen barriers?

A number of solutions have already been proposed to address the barriers identified in the previous section. The proposed solutions from the literature [6, 13, 15, 16] are presented below:

Economic Barriers:

In addition to the capital cost barrier, the majority of the identified economic barriers within the literature revolved around the lack of price signals and incentives to invest in energy storage. The Energy storage in Australia report [6] suggested a cost-reflective peak (or congestion) pricing structure for customers, which would put the onus on the customer to find a solution to the peak demand problem they create. Such a solution would allow the customer who invests in storage or other solutions like demand response to capture the benefit of that solution. With regards to financial disincentives, like the SA Power Networks policy to cease payments of the solar feed-in tariff once energy storage is connected, alternative monitoring, reporting and tariff structures could be implemented that still incentivise the installation of renewable technologies without penalising energy storage. For example, a residential PV-battery storage system with the addition of an energy meter at the PV output (before it is used by the load, exported to the grid or transferred to the batteries for storage) could enable network/retail providers a method to incentivise renewable energy generation without the worry of potential revenue lost from customers who may game the system. This would be in comparison to the network/retail provider issuing a tariff incentive for the power exported to the grid, which could come from either the PV system or the battery (such a setup would allow system owners the ability to game the system by purchasing electricity at a lower tariff to charge the battery whilst exporting power back to the network at a higher tariff). The economics barriers listed within the literature indicate that further research around price signals, incentives and tariff structures needs to be undertaken to find the best set of solutions to incentivise/encourage the installation of energy storage without discouraging the installation of renewable energy technologies.

Regulatory Barriers:

One of the regulatory barriers inhibiting renewable energy technologies and hence the future requirements for energy storage, is the uncertainty around carbon pricing policies like the tax on carbon emissions and the renewable energy target (RET). To remove this barrier Governments will need to provide additional certainty over the longevity of their policies. For example the RET is currently reviewed every two years which provides little stability for investment. A better solution would be to decrease the frequency of reviews from every two to four years. Another regulatory barrier to storage and renewable energy technologies is the current tax credit for diesel fuel used in remote electricity generation. This tax currently incentivises the generation of electricity by diesel in remote/end of line energy systems over other potential energy generation systems like renewable technologies combined with storage. The Energy storage in Australia report [6] recommended the removal of this tax credit and replace it with a direct subsidy for electricity production in remote communities which could be applied to any energy solution. The Energy storage in Australia report also encouraged for Commonwealth and State governments to directly subsidise storage units, which could boost the initial uptake of storage and facilitate the spread of expertise in deploying and managing energy storage.

Lack of Transparency/Asymmetric Information:

A number of the barriers to energy storage are due to the lack of knowledge or transparency of information within the energy sector. A number of these barriers will dissipate over time as personnel within the energy sector become familiar with energy storage technologies. Similarly, as noted within both the CSIRO's intermittency study [30] and the Smart Grid Smart City Monitoring and Measurement report [20] additional monitoring of the network would be required to understand the true nature of perceived grid stability and reliability issues like intermittency and voltage. As additional monitored information of the grid is collected and disseminated, research institutions could build a series of energy storage and network models that can be used by the Network services and retail providers to determine optimum locations and capacities of storage within the network to mitigate grid stability and reliability issues.

With regards to the asymmetry of information between energy storage providers, investors, and network/retail businesses, the Energy storage in Australia report [6] suggested that manufacturers of storage technologies could adopt a like-for-like, levelised cost of energy standard that would communicate the total cost of ownership of a technology. Similarly, the report suggested that the threshold at which electricity transmission and distribution business must publically request tenders for solutions to network constraints be lowered to open up more network problems to the market, allowing storage to compete for projects where it is a viable option.

The literature has also advocated for the encouragement of storage manufacturers to report the performance of their technologies according to performance protocols/standards as they become available. An initial protocol for uniformly measuring and expressing the performance of energy storage systems [36] was compiled by Sandia National Labs in 2013. This initial protocol was intended to be used to foster the uniform measurement and expression of performance of electrical energy storage used for peak shaving and frequency regulation applications. This initial protocol should be expanded upon to include all use applications and be advocated for use by storage manufacturers.

Technology Barriers:

With regards to the technology barriers, further research is required into issues of power quality and the safety and control of connecting large numbers of electrical energy storage to the grid, mostly coupled together with renewable energy technologies are required. Such research will help identify what technical requirements and necessary regulatory frameworks for storage are required [15]. Similarly, additional pilot projects demonstrating the ability of energy storage to meet different use applications are required. Dissemination of the results of all pilot programs is an important factor in overcoming the perceived technology barriers which exist due to the lack of or transparency of information. For example the U.S. Department of Energy have developed a global energy storage database [45] which aims to provide free information on grid connected energy storage projects and relevant state and federal policies. Currently the database only contains policy information for the United States; however the storage database does includes storage projects from across the globe, including Australia. Such a database could also include information on system performance issues like maintenance, wear and tear and lifecycle reliability.

With regards to energy storage standards and procedures, the literature indicates that a series of documents need to be produced detailing the requirements for measuring and reporting the performance of energy storage technologies. Specifically, the Energy storage in Australia report [6] called for a standard that could include safety and emergency guidelines, operating conditions and maintenance timetables, voltage specifications, documentation of the electronics associated with storage management systems and form factor requirements. The Energy in Australia report also recommended 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 [6].

A number of institutions have already begun work to address these foreseen technology barriers. For example the International Electroctechnical Commission (IEC) have created TC (Technical committee) 120 [46] to oversee the development of international standards that address all different electrical energy storage technologies and other aspects such as safety and environmental compatibility. Similarly, as previously mentioned, the U.S. Department of Energy have also developed an initial protocol [36] to provide a uniform way of measuring, quantifying and reporting the performance of energy storage for peak shaving and frequency regulation.

Environment Barriers:

Both of the environmental barriers listed can be easily managed via inclusion of environmental guidelines in any proposed storage specific standard.

Cultural Barriers:

A number of the cultural barriers to energy storage are likely to be resolved with time as people share and obtain more information and knowledge about the issues surrounding energy storage. In particular the perceived lack of proven performance guarantee will change as more information on energy storage performance becomes available as existing systems age and with the advent of more installations of energy storage. One of the recommended methods presented in the literature is the development of a user’s guide containing suggested criteria to apply when planning and using each specific storage technology for a specific application [15]. Inclusions for the guide are full lifecycle and disposal costs, regulatory considerations and environmental advantages and disadvantages in addition to data on storage technology behaviour and characteristics.

What is unknown and hard to predict is the community’s attitude and acceptance to energy storage. However, recommendations from the CSIRO’s report on understanding the residential customer perspective to emerging electricity technologies [47] can be applied to energy storage technologies.

Safety Issues:

The main safety barrier highlighted within the literature was a lack of proven safety standards and guarantees around energy storage. This barrier can be overcome by developing a storage specific safety standard that will cover safety issues of energy storage with regards to installation, operation and maintenance of the system over its lifetime and the safe disposal of the storage product at the end of its life [15]. The Energy storage in Australia report [6] also advocated for the commission of an independent study of actual safety performance of currently-produced storage devices and their limits of safe operating conditions.

What is the current status of distributed energy storage globally?

Globally there is a lot of interest in energy storage and its potential ability to mitigate future network reliability and stability issues that are predicted to occur as increasing levels of renewable energy generation are connected to network infrastructures to meet current and future renewable energy or carbon emission reduction targets. The list below includes a sample of the reports that have been published on the topic of energy storage globally within the past two years.

- Sep 2014 – Energy Storage – Power to the People (HSBC Global Research) [48]
- Sep 2014 – Energy Darwinism II (Citi Research) [43]
- Jun 2014 – Determination of Duty Cycle for Energy Storage Systems Integrated with Micro grids (U.S. DOE) [37]
- Mar 2014 – Technology Roadmap: Energy Storage (IEA) [49]
- Feb 2014 – The Economics of Grid Defection (Rocky Mountain Institute) [14]
- Dec 2013 – Grid Energy Storage (DOE) [13]
- Dec 2013 – The Future of Grid-Connected Energy Storage – 2014 Edition (IHS) [50]
- Sep 2013 – Market and Policy Barriers to Energy Storage Deployment (Sandia) [16]
- Aug 2013 – Protocol for Uniformly Measuring and Expressing the Performance of Energy Storage Systems (Sandia) [36]
- July 2013 – DOE/EPRI 2013 Electricity Storage Handbook in Collaboration with NRECA (Sandia) [12]
- Jun 2013 – Cost-Effectiveness of Energy Storage in California (EPRI) [51]
- Apr 2013 – Battery storage – the next solar boom? (Citi Research) [52]
- Dec 2012 – Methodology to Determine the Technical Performance and Value Proposition for Grid-Scale Energy Storage Systems (Sandia) [53]
- Nov 2012 – Evaluating Utility Procured Electric Energy Storage Resources: A Perspective for State Electric Utility Regulators (Sandia) [54]
- Oct 2012 – Substation Energy Storage Product Specification (EPRI) [55]
- Oct 2012 – Grid integration of large-capacity Renewable Energy sources and use of large-capacity Electrical Energy Storage (IEC) [56]
- Aug 2012 – PV Output Smoothing using Energy Storage (Sandia) [57]
- Aug 2012 – Energy storage: Asian Systems & Apps (Smart Grid Insights) [58]
- Jun 2012 – National Assessment of Energy Storage for Grid Balancing and Arbitrage (DOE) [59]
- Mar 2012 – Pathways for energy storage in the UK (Centre for Low Carbon Futures) [34]

Driven by the demand for energy security and reliability since the 2011 earthquake, tsunami and Fukushima nuclear accident, Japan is a country actively undertaking research in energy storage [60]. Japan has initiated both subsidies and provided direct funding for the installation of demonstration storage projects. For example, Japan has built a commercial scale energy storage system from 16 recycled lithium-ion electrical vehicle batteries, which has been deployed at a 10 MW solar farm. Other battery storage projects have also been announced which are designed to assist PV installations [61]. The DOE/EPRI Electricity Storage Handbook [12], the DOE Global Energy Storage Database [45] as well as EcoGeneration's Ultimate Guide to Solar Energy Storage [10] provide details on existing energy storage systems that have been installed globally. Readers are referred to these resources for further examples of energy storage systems installed around the globe.

In addition to the afore listed research reports, a handful of federal and local Governments have introduced incentives and regulations to increase the uptake of distributed energy storage within their relative Government jurisdictions. Germany for instance introduced an energy storage financing program in 2013 to help facilitate the uptake of PV systems with battery storage at the residential and commercial levels, via rebates and financial loans. Grants in Germany are expected to cover approximately 30% of the battery costs [62, 63]. However the uptake of this scheme so far has been patchy as applications for the scheme have been reported to be quite complicated [63]. Japan has also launched a subsidy program to support the installation of lithium-ion battery storage systems, offering to pay individuals two-thirds of their purchase price up to a cap of US$10,000 with a limit for businesses set at US$100,000 [64, 65]. IHS has reported [65] that they expect the ¥10 billion (~$98M) budget set asides by Japan's Ministry of Economy, Trade and Industry for this project, will be sufficient to subsidize approximately 60 MW of behind the meter energy storage installations. Similarly, California currently offers subsidies for storage systems up to 3 MW in size. The success of these grant/subsidy schemes is currently unknown due to their recent implementation, however IHS have reported [50] that they expect these subsidies will drive the storage market globally with 6 GW of storage to be installed in 2017 with 1.5 GW of this being co-located with utility scale renewable sources and over 2 GW in behind-the-meter systems. IHS have also reported that these and other subsidies will drive the price of energy storage systems down by nearly 30% by 2017, enabling energy storage to become economically viable solutions in several markets and applications.

On the regulatory side, California has initiated a procurement target for storage that utilities must adhere too. The mandate states that utilities must connect 1.35 GW of storage to the grid by 2024, of which 200 MW must be procured in 2014 [63]. The United States Federal Energy Regulatory Commission (FERC) also adopted a new ruling, Order 792, which recognises energy storage as a power source that is eligible to connect to the grid. This rule essentially puts energy storage in the same category as the existing small generator interconnection procedures which makes it eligible for the existing fast track connection process [66]. Another example of regulation comes from Puerto Rico where regulation for energy storage has been introduced in connection with the installation of large scale solar systems. The regulation requires the installation of energy storage which must meet a minimum technical requirement to provide 30% of the installation's rated capacity in the aid of frequency control as well as keeping 45% of the project's capacity in reserve for at least one minute enabling ramping control to compensate for fluctuations in the generated power [67]. IHS have reported [68] that they expect this regulation will increase upfront renewable generation system costs by 15%. However IHS also reported that this regulation would help enable the global market to grow by over 90% per-year to reach 1.5 GW of energy storage installed with renewable technologies in 2017.

What is the status of distributed energy storage in Australia?

Interest in energy storage within Australia has also been gathering pace over the past decade due to increasing electricity prices and decreasing costs of PV. The list below includes a sample of the research published on energy storage within Australia over the past two years, with the CSIRO aiming to produce an energy storage white paper in the near future. These efforts would seem to place Australia in a globally relevant research position on some key aspects of distributed energy storage.

- July 2014 – Distributed Generation and Distributed Storage Technical Compendium (Ausgrid [32])
- Feb 2014 – What Happens When We Un-Plug? – Exploring the consumer and market implications of viable, off-grid energy supply (Energy for the People) [8]
- Feb 2014 – Opportunities for Pumped Hydro Energy Storage in Australia (Arup-MEI Research) [11]
- Dec 2013 – Change and choice – The Future Gird Forum's analysis of Australia's potential electricity pathways to 2050 (CSIRO) [2]
- July 2013 – 100% Renewables Study - Modelling Outcomes (AEMO) [69]
- 2013 – Smart Grid, Smart City Program: Monitoring and Measurement Report IV: Energy Resource Management Stream: Distributed Generation & Storage [20]
- Dec 2012 – Distributed energy storage in the Australian NEM: assessing potential benefits and a framework for integration (ANU and UNSW) [70]
- Nov 2012 – Energy Storage in Australia – Commercial Opportunities, Barriers and Policy Options (Marchment Hill Consulting for the Clean Energy Council) [6]
- Sep 2012 – AEMO 100% Renewable Energy Study – Energy Storage (CSIRO) [7]
- Aug 2012 – Standalone power systems as an alternative to grid connection at the fringe of the grid: Summary for policy makers (ATA) [38]
- The Ultimate Guide to Solar Energy Storage (EcoGeneration) [10]

Summary of the Outcomes of the Smart Grid Smart City Trials with Energy Storage

Of particular interest for distributed energy storage is the Smart Grid Smart City study on distributed generation and distributed storage lead by Ausgrid and Energy Australia [20, 71, 72]. The study consisted of field trials, advanced modelling and simulation of trial elements. Generally the study sought to:

- Understand the maturity and suitability of distributed generation and distributed storage devices
- Assess the impacts on the grid from increased penetration of distributed generation and distributed storage devices
- Understand the value distributed generation and distributed storage devices can potentially deliver for network operators and customers.

With respect to distributed storage, the study aimed to examine the following list of questions:

- Whether distributed storage can be used to reduce or defer capital investments in the grid network
- Whether distributed storage can improve the efficiency or capability of intermittent generation sources
- Whether distributed storage can deliver benefits for consumers
- Determining the key characteristics of storage devices, as they pertain to a smart grid, as well as their operation and management
- The potential for electric vehicles to be used as distributed storage
- The technical, economic, environmental and societal impacts on consumers, electricity retailers, electricity distributors and electricity generators.

The findings from the final Smart Grid Smart City final report [72], the Distributed Generation and Distributed Storage technical Compendium [32] and the 4th Monitoring and Measurement report [20] contains a number of findings relevant to distributed energy storage. In particular:

- One of the key drivers of capital expenditure for the electricity supply industry is peak demand where failure to supply peak demand results in disruption of supply to all customers, not just the last customer to increase their load. Distributed energy resources have the potential to replace assets that are installed to meet peak demand by providing alternative sources of electricity (generation or storage) at or near the point of use and hence offset the need for installation or operation of base load or peaking power generation and/or the need for network augmentation.[32]
- Predicting when the network peak is going to occur, and its duration, is a significant issue for batteries being used for peak demand management. For example, if the batteries were discharged too early, particularly on hot days when high temperatures reduced the effective battery capacity, the output dropped off before the peak demand event occurred, or had ended. Similarly, if the batteries were dispatched too late the peak had already occurred.
- The predictability of network peaks is generally better for larger sections of the network compared to load profiles at the individual feeder or customer level. This suggests the deployment of grid batteries connected higher up in the network for charge and discharge may be more effective in achieving network peak reduction than customer based batteries [32].
- It is difficult to forecast the exact time of peak for an individual network asset and operating the battery charge and discharge cycle appropriately to reduce the peak demand is a key consideration for battery management control.
- A good understanding of when network peaks occur is required to avoid diluting the peak shaving effect of batteries if incorrect or broad discharge windows are setup.
- The trails of customer batteries showed that the potential customer value from the technology was highly dependent on battery characteristics such as discharge/charge efficiency, storage capacity and control functionality.
- For DNSP’s, the trials have shown the potential for additional network value through central control customer batteries.
- For DNSP’s one of the main benefits from the installation of grid-connected distributed generation and storage technologies is the potential reduction in peak demand and associated capital expenditure savings related to the need for network investments driven by peak load constraints.
- DNSP’s will have to develop a better understanding of demand within the context of distribution networks. Traditional forecasting is based on assumptions about one-way flow of power, from centralised generation cascading down to customers, which is insufficient when there are significant numbers of distributed resources. Without a thorough predictive model of load at all levels of the network on hand, the opportunities for distributed generation and storage to be used by DNSP’s to realise the greatest potential will be limited. [32]
- With the exception of voltage levels, there was little or no observable impact from storage on other power quality parameters (either positive or negative)
- Benefits in power factor (PF) can only be seen in areas where PF is poor or in industrial load (higher inductive load).
- Simulations of high PV penetration with DG demonstrated that customer-based distributed storage, when used to store excess PV generation, has some potential to mitigate voltage increases that are likely to occur at very high levels of PV penetration. [32]

- The average National Energy Market (NEM) pool price obtained while discharging battery systems would need to be at least three times the NEM pool price paid to charge the battery to provide a benefit to the retail sector.
- Distributed storage devices need careful planning, analysis and predictive algorithms to operate during peak events due to the lead times to charge the devices and the limited discharge cycle times available.
- The benefit to customers is heavily dependent on the ability to exploit arbitrage opportunities between off-peak charging and peak discharging. It was found that operation of storage on weekends or public holidays was not economical due to the lack of differential tariff structures during these periods, with a significant cost to the customer during these times.
- Time of use tariffs make a significant impact on the economics of storage units
- Higher consumption customers are more likely to benefit from using customer-based batteries when operating in conjunction with PV generation.
- When distributed storage and generation are used in conjunction it has the potential to minimise customers' energy bills only if a number of conditions and technologies are optimised for individual consumer demand patterns.
- Distributed generation and storage does have a negative impact on the network, if the network distributor does not monitor and adjust the network grid (mainly tap voltage settings would need to be adjusted)
- The combination of distributed generation and storage has been shown to be able to provide sufficient energy for a period of time on a feeder spur. However the current protection regime is not suitable to operate the spur feeder in a safe manner.
- Smart meters can be used to gather data on household energy usage to help assess the suitability for distributed generation and storage systems, and whether these systems can reduce the household electricity bill or maximise returns.
- The cost benefit assessment indicated that at present, commercially mature forms of distributed storage have limited availability and are not financially viable for most Australians. However, the analysis indicated that from the early to mid-2020's, distributed storage could begin to be financially attractive for customers and will grow in installed capacity over the period through to 2034.
- The cost benefit analysis indicated that distributed storage would have positive net present values from 2024 (medium economic scenario) for each of the four network types investigated (CBD, Urban, Short rural and long rural) and also under the three macroeconomic scenarios investigated.
- The cost benefit analysis and modelling showed that despite anticipated price reductions in distributed storage devices, without changes to retail electricity pricing structures there will be no deployment of storage until 2034 in Australia. The modelling showed that existing tariff structures effectively discouraged the uptake of battery storage technologies.
- Modelling estimated the deployment of around 3.5 GW of storage in the NEM by 2034 under the dynamic pricing (network capacity charge in combination with a retail critical peak prices) scenario, in comparison to the BAU scenario.
- The SMSC trials indicated that there is potential for distributed storage to export to the grid during peak events and that exporting during these times could provide a cost effective alternative to centralised generation from peaking plants.
- Currently any exports during peak pricing events are not efficiently valued. Currently the export is valued at the feed-in-tariff rate, rather than the higher value of generation cost at peak times.
- Dynamic feed in tariffs could be used to incentivise exports of power to the grid during periods of peak demand, i.e. rewarding the customer for not just offsetting their own demand but for also achieving negative net demand in peak times.
- The technical compendium [32] recommended that a further area of study should focus on battery systems installed by customers and how networks might obtain enhanced value by incentivising customers through a direct load control incentive or tariff scheme.

Existing Energy Storage Installations in Australia

With regards to current installations of energy storage within Australia, the U.S. DOE Global Energy Storage Database [45] provides a comprehensive list. The projects listed and categorised into distributed, centralised or pumped hydro storage are:

Distributed Storage Systems:

- Smart Grid Smart City project – 40 5KW/10 kWh zinc-bromine redox flow battery storage systems installed in the suburbs of Elmore Vale and South Wallsend in Newcastle, NSW to test the technology in an urban setting.
- Smart Grid Smart City project – 20 5kW/10 kWh zinc-bromine redox flow battery storage systems installed at Upper Gundy and Scone, NSW to test the technology in a rural setting.
- University of Queensland – a 90 kW/240 kWh zinc-bromine redox flow battery storage system connected to one of the University's 340 kW PV systems.
- ZBB Experimental Battery system – The system installed in a building in Mayfield West, NSW, stores solar and wind energy produced by a building PV system and wind turbines. The storage capacity of the zinc-bromide flow battery is 500 kWh with a power rating of 100 kW.
- Global Change Institute – a 120 kW/288 kWh zinc-bromine redox flow battery storage system connected to the building load and 140 KW-peak PV system located at the Global Change Institute building, in the University of Queensland.
- UTS – ZBB energy is providing a 25 kW zinc-bromide flow battery system to provide an integrated micro grid energy management system to the University of Technology Sydney to serve as a permanent power source and demonstration/learning unit.
- GPSS-SWR (grid power support system - single wire earth return) – a 25 kW/100 kWh lithium iron phosphate battery system used for voltage regulation, power factor correction, peak current injection and UPS functionality at Bushland Ridge in Western Australia.

Centralised Storage Systems:

- King Island Renewable Energy Integration project – Hydro Tasmania installed an Ecoult UltraBattery storage system capable of providing 3 MW of power contribution and storing 1.6 MWh of useable energy.
- Hampton Wind Park – 1 MW UltraBattery storage system used to address difficulties associated with the variability and uncertainty of wind power production.
- Cape Barren Island Hybrid system – Cape Barren Island received a major electricity upgrade that involved upgrading of the diesel generator, control systems and the network and the installation of wind turbines, solar panels and a large battery bank.
- Lake Cargelligo Solar Tower – a 3MW thermal storage solar tower in Lake Cargelligo in NSW.
- Coral Bay PowerStore Flywheel project – a PowerStore 500 kW flywheel installed in conjunction with wind power and diesel generators at Coral Bay, Western Australia. The storage system enables the wind turbines to supply up to 95% of Coral Bay's energy supply at times.
- Marble Bar PowerStore Flywheel project – a PowerStore 500kW flywheel installed in conjunction with PV systems and diesel generators at Marble Bar and Nullagine in Western Australia. The store system enables the PV system to supply 60% of the average daytime energy for both towns over the course of a year.
- Leinster Nickel Operation PowerStore Flywheel project – a 1MW PowerStore flywheel installed at BHP Billiton's Leinster nickel mine in Western Australia. The storage system reduced the total demand shift to 6.5 MW from 8.5 MW while adding 1 MW of spinning reserve to the system.
- Kalbarri Wind Farm PowerStore Flywheel project – a 1 MW PowerStore flywheel installed at the Kalbarri wind farm in Western Australia.

Pumped Hydro Storage Systems:

- Tumul Hydroelectric Power Station 3 – a 600 MW open loop pumped hydro storage system located at Talbingo Dam in NSW, integrated with conventional hydroelectricity generation at a facility with 1500 MW capacity [11].
- Wivenhoe Power station – a 500 MW pumped storage hydroelectric plant located in Wivenhoe in Queensland.
- Kangaroo Valley and Bendeela Pumping and Power Stations – 180 MW and 80 MW open loop pumped hydro storage system operated by Eraring Energy. These hydro power stations are known as the Shoalhaven Scheme, which are located in the Southern Highlands of NSW
- Poatina Power Station – a 300 MW open loop pumped hydro storage system in Tasmania. This is Tasmania's second largest power station
- Tods Corner Power Station – a 1.7 MW open loop pumped hydro storage system in Tasmania

In addition, EcoGeneration's guide to Solar Energy Storage [10] list of storage in action included an additional two examples of energy storage within Australia :

- Trials of lead acid battery storage by Ergon Energy on Magnetic Island in Queensland which demonstrated peak load reductions of 40% in comparison to business as usual predictions, network augmentation deferral of eight years, reduced customer bills and greenhouse gas savings.
- A trial of lead acid battery storage at the Bendigo Solar Park illustrating demand shifting

As well, SP AusNet (a Victorian network operator) announced the commissioning of a hybrid grid energy storage and diesel generation system that will include lithium ion batteries (1 MW/1 MWh) and a 1 MW diesel generator [73]. Similarly, Griffith University in conjunction with Energex, Ergon Energy and Elevare Energy are undertaking peak demand energy trials within Queensland [74]. The trials will investigate 1) the benefits of utility side generation and storage on demand reduction and voltage management on the network; 2) The impact of a distributed energy storage system combined with power electronics and solar PV for a commercial building at Griffith University; and 3) the effect of distributed energy storage on a residential home in Brisbane, where modelling suggested that homes on a time of use tariff could install energy storage systems with a 3 to 5 year payback.

With regards to regulation and policies within Australia that influence energy storage, the South Australian distributor, SA Power Networks, has written regarding energy storage and fuel cells in their October 2013 Industry News [75] indicating that such equipment can cause interference on their network which can impact the quality of supply for other users.

Endeavour Energy, the energy retailer for Sydney's Greater West, the Southern Highlands and the Illawarra, has also made reference to the future impacts of battery energy storage systems in their 2013 Distribution Annual Planning Report [76]. The report indicates that Endeavour Energy expects a natural progression for PV customers to consider installing battery energy storage system in the future as feed-in tariffs reduce and the benefits dissipate. They expect there will be a growing incentive for consumers to utilise the generation from PV for internal consumption via battery storage, which from Endeavour Energy's perspective may result in a reduction in voltage complaints as the exportation of energy from PV systems reduces.

Queensland utility Ergon Energy has recently been in the press indicating that it is planning to set energy storage capacity targets out to 2020 in an attempt to shift its business model away from the reliance on poles and wires [77]. The article indicates that Ergon Energy's CEO, Ian McLeod, believes that energy storage would be an obvious option for the augmentation of single line wires that provide power to remote areas in Queensland.

What can the CRC for Low Carbon Living do to enable the short and medium term development and deployment of distributed energy storage within Australia’s energy system with an aim to reduce carbon emissions?

This initial scoping study is being undertaken to investigate the current technical and economic potential for distributed storage. The specific objectives of this initial study are to identify key stakeholders and value propositions of distributed storage and to identify the gaps in the existing knowledge on distributed energy storage with the aim to identify future research projects (and the appropriate CRC participant involvement) that will increase the value proposition and reduce potential barriers for distributed energy storage.

The project commenced, via a stakeholder meeting held on the 18th of December, 2013 at the University of New South Wales, by asking invited participants to answer what they saw as the key elements/questions to investigate with regards to distributed storage. A range of responses, questions and discussions ensued. Generally, the issues/questions raised fell into one of the following 9 categories:

- Barriers to distributed storage
- Economics of distributed storage
- Location and capacity of distributed storage
- Models of distributed storage
- Network issues
- Policy frameworks
- Social perspectives of distributed storage
- Technologies of distributed storage
- Thermal storage

Where possible this issues paper has attempted to address the issues/questions raised from the initial stakeholder meeting which can already be answered. The other issues/questions raised that have not been addressed at this point in time have been included at the end of each respective section of this issues paper.

The CRC requests your feedback on this issues paper. We welcome all comments, questions or further recommendations for research in the field of distributed energy storage. The CRC will aim to develop a series of research projects around distributed energy storage, based on the findings and stakeholder feedback from this initial scoping study. The CRC has the ability to be involved in economic, technical and regulatory studies on distributed storage which can then feed into living lab projects.

Potential Future Projects

This scoping study has currently identified a number of potential future projects that might contribute to the CRC-LCL's objectives and capabilities in the distributed storage space. Refining and expanding this list is a key deliverable for the project, and hence a particular area for stakeholder contributions.

1. Urban (residential and business) distributed renewable energy and storage:

To identify the potential for urban renewable energy and storage systems by investigating:

- Technical performance and costs of commercial and near-commercial systems
- Potential business models of ownership, service and maintenance
- Capacity and installation location (i.e. community precinct systems vs. household based systems)
- Other Issues like barriers to deployment and operation and opportunities for both existing and new commercial and residential developments.

2. Off-grid and Edge of grid solutions:

To identify the potential for photovoltaics, storage and other forms of generation to supply a feasible solution to network issues of reliability for edge of grid communities. The aim will be to identify whether a standard scalable design can be generated. As per the urban PV and storage project, issues of feasibility, costs, business models etc. will be investigated. A key component of such a project is tools to appropriately compare centralised grid versus decentralised energy options within these contexts.

3. RE penetration study:

To identify the current penetration capacity of renewable energy generation on the distribution network and to identify how the penetration capacity can increase with the inclusion of distributed energy storage (electrical and thermal). Such a project would hinge on tool development that effectively integrate renewable and storage models. There are opportunities to link this work with wider international efforts underway in this space and it will be important to link distributed energy storage assessment with other possible measures for managing high PV penetration.

4. Distributed energy markets and broader regulatory and policy frameworks to facilitate distributed energy storage.

Distributed storage falls within the broader context of a growing range of distributed energy opportunities through distributed generation and smart end-use technologies. A key question is what retail market and broader policy and regulatory arrangements might best facilitate appropriate deployment and use of all of these options. Note that some options might establish a greater value proposition for storage such as PV generation, whilst others might potentially represent competition for particular storage deployments, such as low-cost smart controllable loads. Such industry arrangements would certainly include retailer 'energy' network tariffs, broader connection requirements and planning frameworks, as well as the wider policy frameworks and institutional arrangements that are required.

5. Living Laboratories with distributed storage

Whilst there have been a number of trials of residential and network storage options here in Australia, there are still a range of technical, economic and wider uncertainties that will almost certainly require further trials. The living laboratories provide a framework for such trials that includes monitoring and opportunities for wider community engagement. A number of existing and proposed developments exist in this space.

1. Watt, M., et al. *PV in Australia 2013*. 2014 [cited 2014; Available from: http://apvi.org.au/wp-content/uploads/2014/07/PV-in-Australia-Report-2013.pdf.
2. Commonwealth Scientific and Industrial Research Organisation. *Change and choice: The Future Grid Forum's analysis of Australia's potential electricity pathways to 2050, CSIRO*. 2013; Available from: http://www.csiro.au/Organisation-Structure/Flagships/Energy-Flagship/Future-Grid-Forum-brochure.aspx.
3. Clean Energy Council. *Clean Energy Australia Report*. 2013 [cited 2014 18/07/2014]; Available from: http://www.cleanenergycouncil.org.au/policy-advocacy/reports/clean-energy-australia-report.html.
4. Energy Supply Association of Australia. *Electricity Gas Australia 2013*. 2013 [cited 2014 18/07/2014]; Available from: http://www.esaa.com.au/policy/EGA_2013.
5. Energy Users Association of Australia. *Electricity Prices in Australia: An International Comparison*. Prepared by Burce Mountain, Director, CME 2012 [cited 2014 18/07/2014]; Available from: http://www.euaa.com.au/wp-content/uploads/2012/03/INTERNATIONAL-ELECTRICITY-PRICE-COMPARISON-19-MARCH-2012.pdf.
6. Marchment Hill Consulting, *Energy Storage in Australia: Commercial Opportinities, Barriers and Policy Options.* Report for the Clean Energy Council, 2012. **MHC, Melbourne**.
7. James, G. and J. Hayward, *AEMO 100% Renewable Energy Study: Energy Storage.* CSIRO, Prepared for the Australian Energy Market Operator (AEMO), 2012.
8. Szatow, T. and D. Moyse, *What happens when we un-plug: Exploring the consumer and market implications of viable, off-grid energy supply.* Energy for the People, 2014.
9. Grattan Institute, *Energy Futures 2014 Seminar Series: Energy Storage - What Scale? What Cost? What Impact?* Melbourne, 27/02/2014 2014.
10. EcoGeneration. *The Ultimate Guide to Solar Energy Storage*. Available from: http://ecogeneration.com.au/shop/the_ultimate_guide_to_solar_energy_storage/084224/.
11. Hearps, P., et al., *Opportunities for Pumped Hydro Storage in Australia.* Melbourne Energy Institue, Univerisity of Melbourne, Victoria, 2014.
12. Akhil, A.A., et al. *Electricity Storage Handbook in Collaboration with NRECA*. Sandia National Laboratories SAND2013-5131 2013; Available from: http://www.sandia.gov/ess/publications/SAND2013-5131.pdf.
13. US-DOE. *Grid Energy Storage*. 2013; Available from: http://energy.gov/oe/downloads/grid-energy-storage-december-2013.
14. Bronski, P., et al. *The Economics of Grid Defection: When and where distributed solar generation plus storage competes with traditional utility service*. Rocky Mountain Institute; Homer Energy; CohnReznick Think Energy 2014; Available from: http://www.rmi.org/electricity_grid_defection.
15. IEC. *Electrical Energy Storage: White paper*. International Electrotechnical Commission 2011; Available from: http://www.iec.ch/whitepaper/energystorage/.
16. Bhatnagar, D., et al., *Market and Policy Barriers to Energy Storage Deployment: A Study for the Energy Storage Systems Program.* Sandia National Laboratories SAND2013-7606, 2013.
17. Parkinson, G. *Utilities face new challenge in rush for home storage*. Renew Economy 2014 [cited 2014 18/07/2014]; Available from: http://reneweconomy.com.au/2014/utilities-face-new-challenge-in-rush-for-home-storage-73465.
18. Goel, S. and M. Watt. *Evaluating the Benefits of Implementing Existing Storage Technologies with Residential PV Rooftop Systems*. EUPVSEC 2013 2013 [cited 2014 18/07/2014]; Available from: http://ceem.unsw.edu.au/sites/default/files/documents/6CV.5.33.pdf.
19. Oliva H, S. and I. MacGill, *Value of net-FiT PV policies for different electricity industry participants considering demand-side response.* Progress in Photovoltaics: Research and Applications, 2014. **22**(7): p. 838-850.
20. smart grid smart city. *Smart Grid, Smart City Monitoring and Measurement Report IV - Energy Resource Management*. 2013 [cited 2014 15/04/2014]; Available from: http://www.smartgridsmartcity.com.au/About-Smart-Grid-Smart-City/~/media/Microsites/SGSC/Files/PDFs/Monitoring%20and%20Measurement%20Report/MMR4%20ERM%20Energy%20Resource%20Management.pdf.
21. Ergon Energy and Australian Government Department of the Environment. *Townsville Solar City, Queensland*. [cited 2014 18/07/2014]; Available from: http://www.townsvillesolarcity.com.au/.
22. Sparkes, D. *Ergon seals deal for 2MWh of battery storage*. Renew Economy 2014 [cited 2014 18/07/2014]; Available from: http://reneweconomy.com.au/2014/ergon-seals-deal-for-2mwh-of-battery-storage-27606.
23. Geoscience Australia and ABARE, *Australian Energy Resource Assessment*. 2010: Canberra.
24. Australian Bureau of Statistics. *Table 9, 4602.0.55.001 - Environmental Issues: Energy Use and Conservation, Mar 2011*. Australian Bureau of Statistics 2011 03/11/2014]; Available from: http://www.abs.gov.au/AUSSTATS/abs@.nsf/Lookup/4602.0.55.001Main+Features1Mar%202011?OpenDocument.
25. Ethan N. Elkind, Steven Weissman, and Sean Hecht. *The Power of Energy Storage: How to Increase Deployment in California to Reduce Greenhouse Gase Emissions*. 2010; Available from: http://www.law.berkeley.edu/files/Power_of_Energy_Storage_July_2010.pdf.
26. Department of Industry, I., Climate Change, Science, Research and Tertiary Education, *100 per cent renewables study*. 2013, Commonwealth of Australia: Canberra.
27. Denholm, P., et al., *The Role of Energy Storage with Renewable Electricity Generation*, in *NREL/TP-6A2-47187*. 2010, National Renewable Energy Laboratory: Golden, Colorado.

28. The Electricity Advisory Committee, *Bottling Electricity: Storage as a Strategic Tool for Managing Variability and Capacity Concerns in the Modern Grid*. 2008.
29. U.S. Department of Energy, *20% Wind Energy by 2030: Increasing Wind Energy's Contribution to U.S. Electricity Supply*, DOE/GO-102008-2567, Editor. 2008.
30. Sayeef, S., et al., *Solar intermittency: Australia's clean energy challenge.* CSIRO, 2012.
31. vaassa ETT and Marchment Hill Consulting. *Integrating Renewables into the Grid*. ARENA: Stocktake Study 2014 [cited 2014 18/07/2014]; Available from: http://arena.gov.au/files/2014/07/ARENA-Stocktake-Instalment-B-v1-0.pdf.
32. Simpson, R., et al., *Distributed Generation and Distributed Storage - SGSC Technical Compendium.* Ausgrid, smart grid smart city, 2014.
33. Nakatsuji-Mather, M., *Smart Grid, Smart City Trial - RedFlow Final Report.* 2014.
34. Taylor, P., et al. *Pathways for energy storage in the UK*. Centre for Low Carbon Futures 2012 [cited 2014 07/05/2014]; Available from: http://www.lowcarbonfutures.org/sites/default/files/Pathways%20for%20Energy%20Storage%20in%20the%20UK.pdf.
35. Lilley, B., A. Szatow, and T. Jones. *Intelligent Grid: A value proposition for distributed energy in Australia*. CSIRO 2009 [cited 2014 01/05/2014]; Available from: http://www.csiro.au/en/Organisation-Structure/Divisions/Energy-Technology/Intelligent-Grid/Intelligent-Grid-report.aspx.
36. Schoenwald, D.A., et al. *Protocol for Uniformly Measuring and Expressing the Performance of Energy Storage Systems, SAND2013-7084*. 2013 [cited 2014; Available from: http://www.sandia.gov/batterytesting/protocols/ESS_Protocol_SAND.pdf.
37. Conover, D., V. Viswanathan, and A. Crawford. *PNNL-23390 - Determination of Duty Cycle for Energy Storage Systems Integrated with Microgrids*. 2014 03/11/14]; Available from: http://www.sandia.gov/ess/docs/Duty_Cycle_ESS_Integrated_Microgrids.pdf.
38. Moyse, D. *Stand alone power systems as an alternative to grid connection at the fringe of the grid: Summary for policy makers*. Alternative Technology Association, Melbourne, Vic 2012 [cited 2014 01/05/2014]; Available from: http://www.ata.org.au/wp-content/uploads/2013/09/Fringe-of-Grid-SAPS-Research-Summary-for-Policy-Makers-Final-160812-v4.0.pdf.
39. Sue, K., I. MacGill, and K. Hussey, *Distributed energy storage in the Australian National Electricity Market: potential benefits, current barriers and integration challenges.* Forthcoming in Energy Research and Social Science Journal, 2014.
40. Wilson, D. and L. Hughes, *Barriers to the Development of Electrical Energy Storage: A North American Perspective.* The Electricity Journal, 2014. **27**(2): p. 14-22.
41. Hensley, R., J. Newman, and M. Rogers. *Battery technology charges ahead*. McKinsey Quarterly 2012; Available from: http://www.mckinsey.com/insights/energy_resources_materials/battery_technology_charges_ahead.
42. Parkinson, G. *How battery storage costs could plunge below $100/kWh*. RenewEconomy 2014 03/11/2014]; Available from: http://reneweconomy.com.au/2014/battery-storage-costs-plunge-below100kwh-19365.
43. Savvantidou, S., et al. *Energy Darwinism II*. 2014 03/11/2014]; Available from: https://ir.citi.com/UAXL%2F1gNFctVBgY9Y%2BYI2AVo44t83FCcT4CS6TgoRho8dlIkm1tZOw%3D%3D.
44. Government of South Australia. *Solar feed-in scheme*. 2014; Available from: http://www.sa.gov.au/topics/water-energy-and-environment/energy/saving-energy-at-home/assistance-for-organisations-that-work-with-households/further-energy-information-to-help-households/rebates-concessions-and-incentives/solar-photovoltaic-systems/solar-feed-in-scheme#title9.
45. U.S. Department of Energy. *DOE Global Energy Storage Database*. 2012; Available from: http://www.energystorageexchange.org/.
46. IEC. *TC 120 for smart grid integration*. 2012 [cited 2014 20/05/2014]; Available from: http://www.iec.ch/etech/2012/etech_1112/tc-3.htm.
47. Boughen, N., Z.C. Castro, and P. Ashworth, *Understanding the residential customer perspective to emerging electricity technologies: Informing the CSIRO Furutre Grid Forun.* Brisbane, Queensland: CSIRO, 2013.
48. Dickens, A., et al. *Energy Storage - Power to the People*. 2014 03/11/2014]; Available from: http://www.qualenergia.it/sites/default/files/articolo-doc/Energy%20Storage.pdf.
49. IEA. *Technology Roadmap - Energy Storage*. 2014 [cited 2014 01/05/2014]; Available from: http://www.iea.org/publications/freepublications/publication/name,36573,en.html.
50. Ward, A. and S. Wilkinson. *Abstract - The Future of Grid Connected Energy Storage - 2014 Edition*. 2013 [cited 2014 09/05/2014]; Available from: http://technology.ihs.com/436065/grid-connected-energy-storage-report-2014.
51. Kaun, B., *Cost-Effectiveness of Energy Storage in California.* Technical Update, 3002001162, June 2013, 2013.
52. Channell, J. and P. Nguyen. *Battery storage - the next solar boom?* Citi Research 2013 03/11/2014]; Available from: https://ir.citi.com/%2fZwWmt6640nsa0RWIAKfpkh4uhtK0KJgCMucr1xpzykg6XYhf%2fROj1npohAzNq1UE%2bXwozNQSm4%3d.
53. Byrne, R.H., et al., *Methodology to Determine the Technical Performance and Value Proposition for Grid-Scale Energy Storage Systems.* Sandia National Laboratories SAND2012-10639, 2012.
54. Bhatnagar, D. and V. Loose, *Evaluating Utility Procured Electric Energy Storage Resources: A Perspective for State Electric Utility Regulators.* Sandia National Laboratories SAND2012-9422, 2012.
55. Steeley, W., *Substation Energy Storage Product Specification.* Technical Update, 1024282, October 2012, 2012.

56. IEC. *Grid integration of large-capacity Renewable Energy sources and use of large-capacity Electrical Energy Storage: White paper*. International Electrochemical Commission 2012 [cited 2014 07/05/2014]; Available from: http://www.iec.ch/whitepaper/pdf/iecWP-gridintegrationlargecapacity-LR-en.pdf.
57. Ellis, A., et al., *PV Power Output Smoothing using Energy Storage.* Sandia National Laboratories SAND2012-6745, 2012.
58. Smart Grid Insights. *Energy Storage: Asian Systems & Apps*. Zpryme Research & Consulting 2012 [cited 2014 07/05/2014]; Available from: http://smartgridinsights.com/standard/energy-storage-asian-systems-apps/.
59. Kintner-Meyer, M., et al. *National Assessment of Energy Storage for Grid Balancing and Arbitrage: Phase 1, WECC*. U.S. Department of Energy, Office of Electricity Delivery and Energy Reliability 2012 [cited 2014 07/05/2014]; Available from: http://energyenvironment.pnnl.gov/pdf/PNNL-21388_National_Assessment_Storage_Phase_1_final.pdf.
60. Parkinson, G. *Japan launches battery storage subsidy for homes, business*. Reneweconomy 2014 [cited 2014 11/04/2014]; Available from: http://reneweconomy.com.au/2014/japan-launches-battery-storage-subsidy-homes-business-51085.
61. Parkinson, G. *Japanese energy giants rush into storage as solar booms*. Reneweconomy 2013; Available from: http://reneweconomy.com.au/2013/japanese-energy-giants-rush-storage-solar-booms-58508.
62. Parkinson, G. *Germany finances major push into home battery storage for solar*. 2013 [cited 2014 10/04/2014]; Available from: http://reneweconomy.com.au/2013/germany-finances-major-push-into-home-battery-storage-for-solar-58041.
63. Colthorpe, A. *Put up or shut up - Time for storag*. SolarBusinessfocus 2014 [cited 2014 10/04/2014]; Cover Story]. Available from: http://www.solarbusinessfocus.com/articles/put-up-or-shut-up-time-for-storage.
64. Colthorpe, A. *Japan launches subsidies for lithium-ion battery storage*. PVTECH 2014 [cited 2014 10/04/2014]; Available from: http://www.pv-tech.org/news/japan_launches_subsidies_for_lithium_ion_battery_storage.
65. Wilkinson, S. *Japan Energy Storagge Subsidies to Spark Market Growth*. 2014 [cited 2014 09/05/2014]; Available from: http://technology.ihs.com/495095/japan-energy-storage-subsidies-to-spark-market-growth-says-sam-wilkinson-ihs-research-manager-for-energy-storage.
66. Casey, T. *Renewable energy barriers fall with new FERC order*. Clean Technica 2013 [cited 2014 10/04/2014]; Available from: http://cleantechnica.com/2013/11/25/energy-storage-barriers-fall-with-ferc-order-792/.
67. Colthorpe, A. *Puerto Rico introduces mandate for energy storage in new renewable projects*. PVTECH 2013 [cited 2014 10/04/2014]; Available from: http://www.pv-tech.org/news/puerto_rico_introduces_mandate_for_energy_storage_in_new_renewables_project.
68. Wilkinson, S. *Boost for energy storage market as mandatory requirements introduced in Puerto Rico, driving 1.5 GW of energy storage installations with renewable power plants in 2017*. 2013 [cited 2014 09/05/2014]; Available from: http://technology.ihs.com/492074/boost-for-energy-storage-market-as-mandatory-requirements-introduced-in-puerto-rico-driving-15-gw-of-energy-storage-installations-with-renewable-power-plants-in-2017.
69. AEMO. *100% Renewables Study - Modelling Outcomes*. Australian Energy Market Operator 2013; Available from: http://www.climatechange.gov.au/reducing-carbon/australian-energy-market-operator/100-cent-renewables-study-modelling-outcomes.
70. Sue, K., I. MacGill, and K. Hussey, *Distributed energy storage in the Australian National Electricity Market: assessing potential benefits and a framework for integration.* Proceedings of the 50th Annual Conference, Australian Solar Energy Society, Melbourne December 2012, 2012.
71. Arup, et al., *Smart Grid Smart City: Shaping Australia's Energy Future - National Cost Benefit Assessment : Executive Report.* 2014.
72. Arup, et al., *Smart Grid, Smart City: Shaping Australia's Energy Future - National Cost Benefit Assessment.* 2014.
73. Parkinson, G. *Australia networks look to battery storage to cut grid costs*. Reneweconomy 2014; Available from: http://reneweconomy.com.au/2014/australia-networks-look-to-battery-storage-to-cut-grid-costs-47334.
74. Holcombe, B. *Building a grid and commercial distributed energy storage system (Griffith University & Elevare Energy)*. Australian Energy Storage Conference & Exhibition 2014 - Day 2 May 9: Emerging business models, economics and end of life of energy storage session 2014 [cited 2014 15/05/2014]; Available from: http://www.australianenergystorage.com.au/conference/conference-timetable/.
75. SA Power Networks. *Industry News - PV Process Update #2*. 2013 [cited 2014 07/05/2014]; Available from: http://www.sapowernetworks.com.au/public/download.jsp?id=27824.
76. Endeavour Energy. *Distribution Annual Planning Report*. Endeavour Energy, Seven Hills, NSW 2013 [cited 2014 16/05/2014]; Available from: http://www.endeavourenergy.com.au/wps/wcm/connect/1c8a7e00423d5e82bf10bf2b41d2faac/Endeavour+Energy+2013+Distribution+Annual+Planning+Report.pdf?MOD=AJPERES.
77. Parkinson, G. *Ergon to set California-style energy storage target for 2020*. Reneweconomy 2014 [cited 2014 29/04/2014]; Available from: http://reneweconomy.com.au/2014/ergon-to-set-california-style-energy-storage-target-for-2020-79569.