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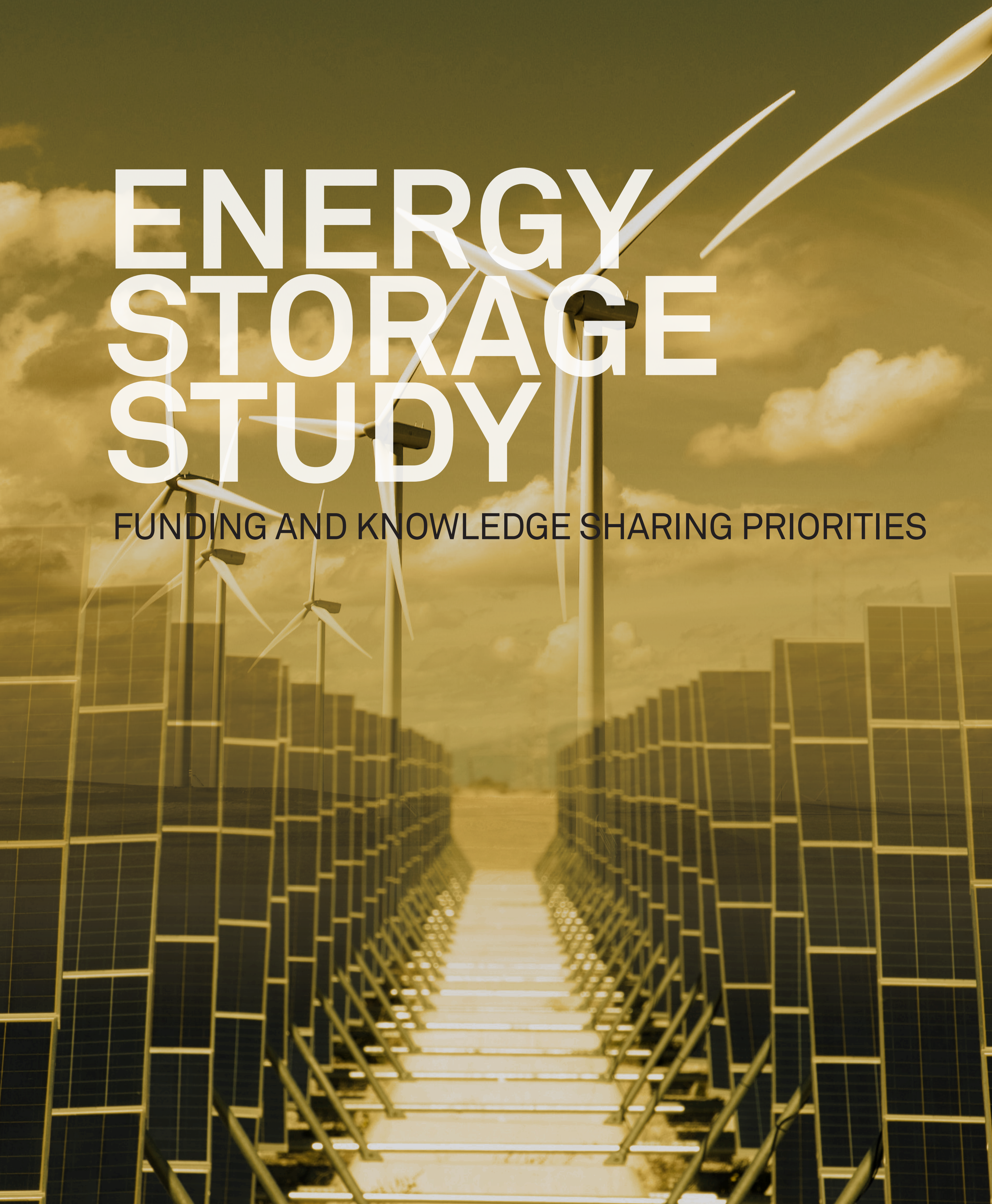
Prepared for Australian Renewable Energy Agency

ENERGY STORAGE STUDY

FUNDING AND KNOWLEDGE SHARING PRIORITIES



Energy Storage Study

A storage market review and recommendations for funding and knowledge sharing priorities

Client: Australian Renewable Energy Agency

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Executive Summary

The role of enabling technologies such as energy storage is becoming more important as Australia moves towards higher penetrations of intermittent renewable generation such as solar and wind power. Some parts of Australia are already experiencing the technical limitations of intermittent renewables, leading to emerging power quality issues or curtailment of renewables. If ARENA is to continue supporting the growth of Australia's renewables market efficiently and at lowest cost, it is important to support the development of new markets for enabling technologies. Energy storage is perhaps the most significant enabling technology, providing the ability to both smooth and shift renewable generation to match demand profiles.

International developments

AECOM has reviewed ten leading international energy storage markets, including the United States (California, Hawaii, Texas and New York), China, Japan, South Korea, Germany, United Kingdom and Italy. To date, California and Germany have setup the most sophisticated programs. Both markets have sought to spread their energy storage investment focus across wholesale, T&D and end-user markets by placing the obligation on utilities to meet the program objectives, while supporting private users with direct rebates.

Noting that many of the international programs are relatively immature and their relative success is yet to be determined, some key preliminary learnings observed were:

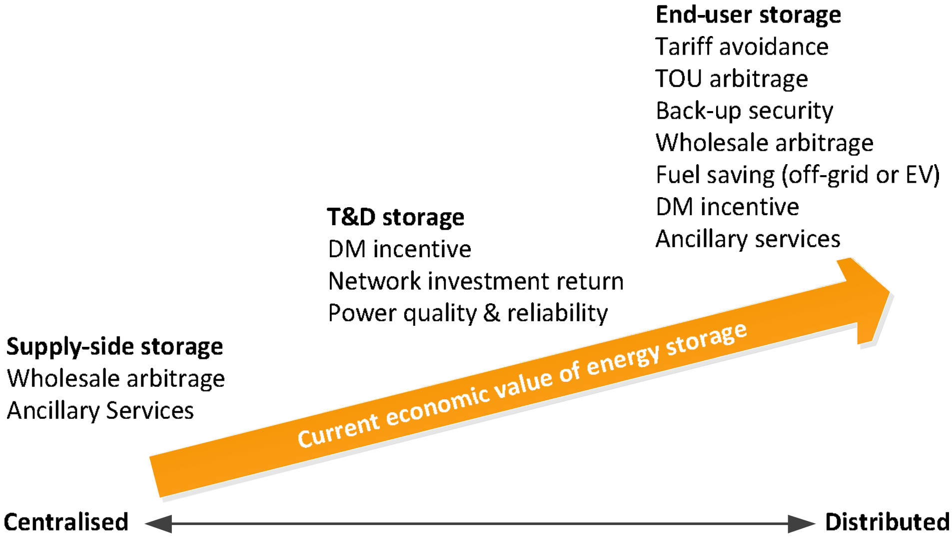
- The importance of **safety** in residential applications; there have been unconfirmed accounts of multiple house fires in Germany caused by batteries installed under the KfW 275 residential storage rebate program. Batteries are high energy sources and it is most important that they are manufactured and installed such that the safety of home-owners is not compromised.
- The focus on providing **network value;** end-user applications have the ability to provide a shared-value to networks by reducing capacity requirements. Germany is attempting to capture this value by requiring that all recipients of household battery rebate allow DNSPs to remotely control the battery system. Distribution network costs are the largest contributor to electricity prices in Australia and battery systems have the ability to simultaneously reduce network investments while supporting distributed renewable installations.
- California's focus on building a **robust network** to facilitate renewables; California is seeking to build a smart and robust electricity network that will be able to cope with the strains of high penetrations of renewables under its 33% by 2020 target. California has commenced a holistic approach to its networks, looking at energy efficiency and demand-side participation as well as energy storage deployed across its network, from the supply side, through the networks to the end user.

Domestic context

Australia's energy market differentiates itself from many international markets with its large fringe-of-grid and off-grid markets, as well as an oversupply of generation capacity and low customer density. While these characteristics present niche market opportunities for energy storage in Australia, the broader electricity market's interest in energy storage is comparable to many international markets, that being overcoming the system integration challenges associated with regional concentrations of rooftop solar PV and utility-scale wind farms.

There is currently higher value for storage at the end-user level than on the supply-side, while the value of T&D applications is highly variable, network specific and often subject to regulatory barriers. This trend is illustrated in Figure 1, which also identifies the value streams for each installation location.

Figure 1 Illustration of the value of energy storage across the electricity value chain



The high-value of the end-user installation is largely due to the ability to increase the behind-the-meter utilisation of solar power, offsetting consumption from the grid. This is the largest and most tangible revenue stream ($/kWh) available to storage projects in the current market as well as in the foreseeable future. Some economic drivers such as wholesale arbitrage and ancillary services are difficult to monetise without an aggregator or retailer. As shown in Table 1, end-user installations are also capable of delivering other economic drivers, whereas T&D and supply-side installations are restricted in their value streams. It is important to note that distributed energy installations are generally smaller than centralised installations. As such, some economies of scale are lost and some technologies (such as solar thermal storage, CAES and PHS) would not be economically feasible due to scale constraints.

Table 1 Summary of value streams available for different energy storage applications

	Current value	Expected future trend	Off-grid	Wholesale	T&D	End user
Tariff avoidance + TOU load shifting	▮▮▮▮	↑				✓
Back-up security	▮▮▯▯	–				✓
Wholesale arbitrage	▮▯▯▯	↑		✓		✓
Fuel saving	▮▮▮▯	–	✓			✓
Ancillary services	▮▯▯▯	↑		✓		✓
DM incentives	▮▯▯▯	↑			✓	✓
Network investment return	▮▮▯▯	–			✓	
Power quality	▮▯▯▯	↑	✓		✓	✓
Shared benefits	▮▯▯▯	↑	✓	✓	✓	✓

Technology status

Current energy storage markets both domestically and internationally are dominated by pumped hydro which is a mature technology with known cost structures. However, further deployment of pumped hydro is severely limited by geographical and environmental site requirements as well as project size requirements to achieve economies of scale. Conversely, many emerging energy storage technologies are immature and the cost structures are not well defined. Battery technologies offer unique advantages in that they can easily be scaled to suit many applications and have high cycle efficiency. The potential for significant cost reduction of some battery technologies provides real opportunity for significant deployment in multiple applications. In particular, Li-ion batteries prices are expected to reduce by over 60 percent and flow battery prices by over 40 percent by 2020 [1]. Nonetheless, technology demonstration is still required to prove the technical performance, understand implementation requirements and build local knowledge and capability in industry.

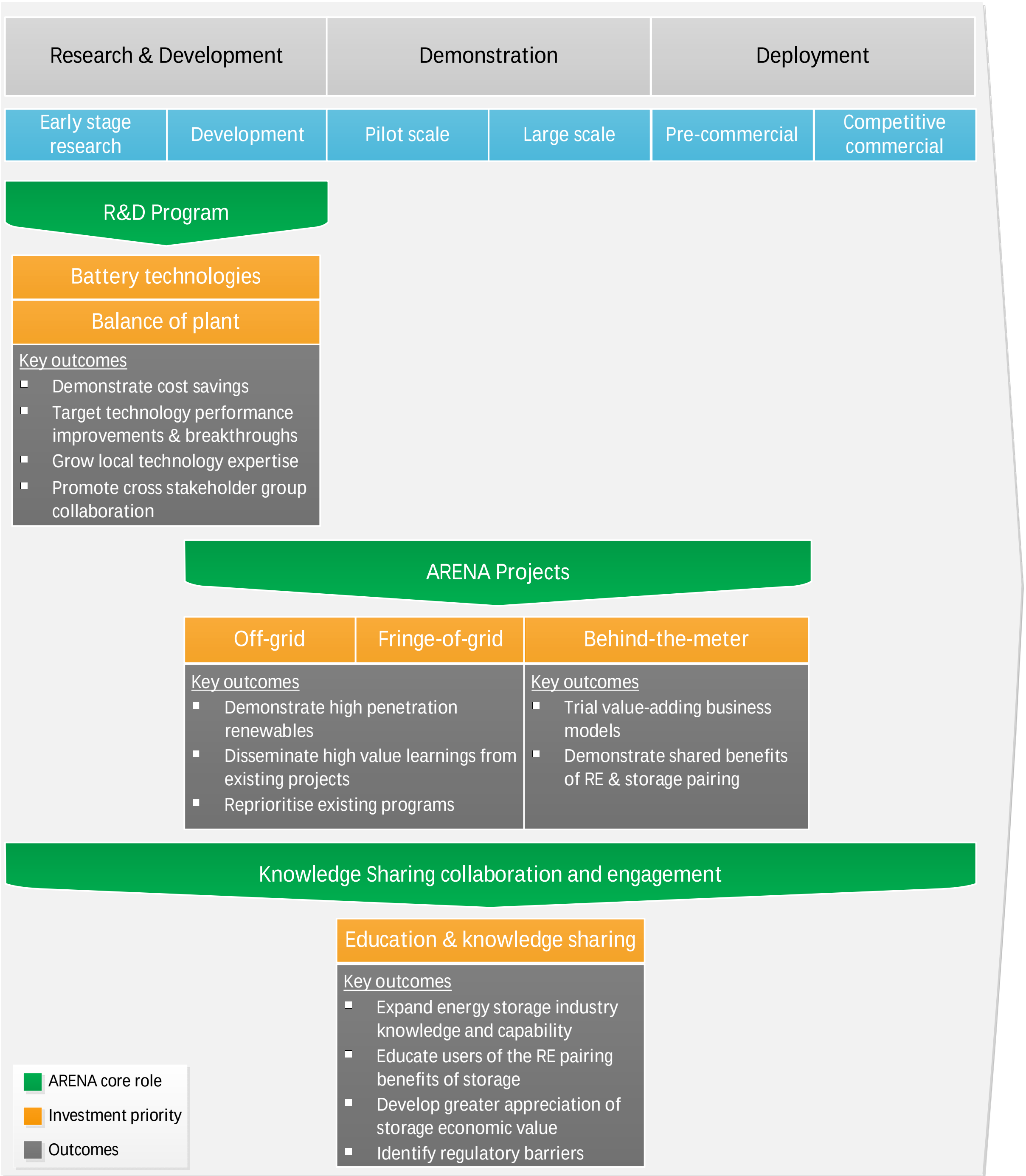
Recommended investment priorities initiatives

AECOM has developed a list of investment options and prioritised them using three evaluation criteria:

1) **Alignment with ARENA's objectives** and mandate
2) **Investment influence**, likely impact of ARENA's investment in improving technical & commercial readiness
3) **Replicability**, likelihood of the investment to facilitate ARENA's objectives through repeated future deployment.

The evaluation assessment was based on the findings from the international and domestic market reviews, the industry survey, stakeholder consultation, as well as AECOM's own knowledge and experience. The evaluation led AECOM to recommend seven investment priorities for ARENA, summarised in the illustration below.

Figure 2 Recommended energy storage initiatives, priorities and outcomes



While ARENA has supported energy storage projects in the past for a variety of reasons, this study seeks to bring together a coordinated and targeted approach for ARENA's consideration. Each of the recommended funding priorities has been selected for different reasons. Education and Knowledge Sharing is the means by which ARENA can help reduce barriers to energy storage, particularly regulatory, technical capacity and awareness. The selection of Demonstration Projects was impacted strongly by the relative impact on the renewable uptake, the potential size of the market and medium term market conditions. Utility scale demonstration projects were not preferred due to forecasted weak financial drivers in the wholesale market for wholesale arbitrage; however this is reflective of current market conditions. Supply-side energy storage could be considered inevitable given current renewable uptake trends, but the financial drivers are significantly weaker than for demand-side applications (which can also participate in wholesale markets). For a more detailed discussion, please refer to Section 5.3.

Based on our assessment, ARENA is recommended to target and coordinate its energy storage funding to maximise its industry development impact, focusing on building the capacity of industry to further appreciate the benefits of adopting energy storage. ARENA should by no means restrict its initiatives to those highlighted above. Rather, this list highlights where ARENA might provide the most value given its overall mandate, particularly as the market continues to evolve in the short to medium term. Given the expected rapid evolution of this market it is recommended that initiatives are reviewed regularly to ensure market relevance.

Concluding Remarks

The rapid uptake of solar PV provides a useful analogy to what could occur in the energy storage market, as technology prices have potential to reduce as technology development simultaneously improves. The behind-the-meter market segment of energy storage is widely expected to undergo a similar boom to the solar PV industry, with a tipping point expected within the next ten years as further cost reductions are achieved. However, the risks and opportunities from an energy storage boom are more complex than for solar PV due to the multitude of applications and value streams relating to storage, greater safety risks, and the cumulative impact on the continued growth of rooftop solar. As such, ARENA should work with industry participants such as technology suppliers, NSPs and retailers to prepare the market for a future boom, supporting the demonstration and establishment of safe standards and sustainable market structures which adequately reward each of the value streams. By supporting the development of an efficient market for energy storage, ARENA will facilitate additional supply of renewable energy by addressing intermittency and power quality challenges that could otherwise stall growth in the market.

Table of Acronyms

Table 2 Table of acronyms

Acronym	Definition
AC	Alternating Current
ACT	Australian Capital Territory
AEMO	Australian Energy Market Operator
AER	Australian Energy Regulator
AESA	Australian Energy Storage Alliance
ARENA	Australian Renewable Energy Agency
CAES	Compressed Air Energy Storage
CAPEX	Capital Expenditure
CEC	Clean Energy Council
CSIRO	Commonwealth Scientific and Industrial Research Organisation
CSP	Concentrated Solar (thermal) Power
DC	Direct Current
DER	Distributed Energy Resources
DM	Demand Management
DMEGCIS	Demand Management and Embedded Generation Connection Incentive Scheme
DMIA	Demand Management Innovation Allowance
DMIS	Demand Management Incentive Scheme
DNSP	Distribution Network Service Provider
DoE	(US) Department of Energy
DSP	Demand Side Participation
EPRI	Electric Power Research Institute
EV	Electric Vehicle
FCAS	Frequency Control Ancillary Services
GJ	Giga-Joule
GUSS	Grid Utility Support Systems
GW	Giga-Watts
HVAC	Heating, Ventilating and Air Conditioning
IP	Intellectual Property
IRENA	International Renewable Energy Agency
ISF	Institute for Sustainable Futures
IT	Information Technology
LCOE	Levelised Cost of Energy
Li-ion	Lithium-ion
LNG	Liquefied Natural Gas
MW	Mega-Watts

Acronym	Definition
MWh	Mega-Watt-hours
NaS	Sodium Sulphur
NCAS	Network Control Ancillary Services
NEM	National Electricity Market
NSP	Network Service Provider
NSW	New South Wales
OPEX	Operating Expense
PHS	Pumped Hydroelectric Storage
PPA	Power Purchase Agreement
PV	Photovoltaic
PWC	Power and Water Corporation
QLD	Queensland
R&D	Research and Development
RAB	Regulated Asset Base
RE	Renewable Energy
RFP	Request For Proposal
RIT-D	Regulatory Investment Test for Distribution
SA	South Australia
SMES	Superconducting Magnetic Energy Storage
SRAS	System Restart Ancillary Services
SWIS	South-West Interconnected System
T&D	Transmission and Distribution
TBA	To Be Announced
TNSP	Transmission Network Service Provider
TOU	Time of Use
UPS	Uninterruptible Power Supply
USD	United States Dollars
VRB	Vanadium Redox Battery
WA	Western Australia
WACC	Weighted Average Capital Cost

1.0 Introduction

1.1 Background

Like the IT and telecommunications industries before it, the electricity industry is experiencing an accelerating trend towards smarter, more disaggregated and more decentralised energy resources. Understanding and anticipating this trend is crucial to prepare for the major opportunities and challenges it will create.

The energy storage industry is evolving rapidly and new technologies could fundamentally shift the way electricity has traditionally been generated and delivered. As was defined in CSIRO's Future Grid Forum analysis, energy storage adoption is likely to occur as a 'megashift' rather than incremental impact on the electricity industry, due to the rapidly changing economic proposition as well as the disruptive influence on the market. As such, these technologies should be reviewed in relation to the other influencing factors impacting their use, as well as their potential to facilitate additional uptake.

Energy storage technology has developed tremendously in recent years and is expected to continue to grow. While the costs are still prohibitively high for mass deployment, the trend of reducing costs for battery technologies such as lithium-ion and flow battery technologies suggests that there will be a dramatic shift towards these technologies in the next one to two decades**.** Before moving to a market-led roll-out, there is a need to develop demonstration project experience in Australia's market. This will help provide industry learnings to inform key stakeholders such as consumers, local communities, technology suppliers, financiers, existing electricity asset owners, regulators, retailers and policymakers.

1.2 Project objectives

Despite recent developments, intermittent renewable energy generators still face technical and economic barriers to deployment. The application of energy storage offers numerous complementary services for intermittent generators and as renewable energy penetration increases over time, it is likely that these services will provide more value to both renewable energy proponents and to network operators. The complementary services include:

- the ability to time-shift energy generation to periods of high value
- the ability to positively impact network congestion during periods of network stress
- the ability to allow higher capacity and penetration of renewable generators on existing infrastructure
- the ability to regulate ramp rates (smoothing)
- ability to supply network ancillary services from energy generated by intermittent renewable generators
- The benefits of energy storage are not restricted to renewable energy and energy storage can also offer broader benefits for the energy sector including:
- deferral of network upgrade costs
- the ability to time-shift low cost or, if required, low emissions generation
- ability to allow generators to operate at high efficiencies – lowering overall cost of generation
- reduced spinning reserve requirements reducing fuel consumption and associated emissions
- assisting demand management

The overall objective of this project was to highlight to ARENA areas where there is potential synergistic opportunity for energy storage to enable increased use of renewable energy in the Australian market. These learnings will be used by ARENA to refine its priorities and inform its investment decisions in this area.

The primary objective is to produce recommended ARENA specific storage funding and knowledge-sharing priorities. The ARENA storage priorities will be developed in the context of ARENA's legislated objectives to increase the supply and improve the competitiveness of renewables.

1.3 Project scope

ARENA has identified that energy storage is an important emerging technology and could become a critical enabling technology to increase penetration of, and maximise the value proposition of, intermittent forms of renewable energy.

Currently, there is an opportunity for ARENA to help shape the introduction of storage technologies in Australia, whilst simultaneously pursuing the ARENA mandate to invest across the innovation chain to improve renewable energy affordability and increase its use. Accordingly, ARENA has commissioned AECOM to perform an up-to-date analysis of the energy storage industry with the aim of assisting ARENA refine its investment priorities. In this report, AECOM investigates:

- various energy storage applications
- status update of energy storage technologies
- discussion regarding the costs, benefits and overall economics of various applications and technologies
- recent relevant international experience and its relevance for Australia

  the status of energy storage in Australia including opportunities and barriers
- timing issues (e.g. projections of cost reductions)
- a stocktake of energy storage projects in Australia
- learnings from targeted industry stakeholder consultations
- learnings from a market survey
- the merits of a variety of potential ARENA initiatives.

Current energy storage markets both domestically and internationally are dominated by Pumped Hydroelectric Storage (PHS) which is a mature technology with known cost structures. Further deployment of PHS is limited by geographical and environmental site requirements as well as project size requirements to achieve economies of scale. Conversely, many emerging energy storage technologies are immature and the cost structures are not well defined. The changing cost structures of some energy storage technologies (particularly battery technologies) provide real opportunity for market development, however technology demonstration and implementation is still required to prove the ability of the technologies, understand implementation requirements, and reduce costs associated with movement along the technology maturity curve. Battery technologies also offer the unique advantage that they can easily be scaled to suit many applications.

Due to the strong domestic and international trends towards battery technologies, this study places a strong emphasis on battery technologies, especially with regard to capability, applicability and cost projections. Nonetheless, other emerging technologies (e.g. thermal and compressed air energy storage) and indeed even well-developed technologies (e.g. PHS) are not excluded from the analysis, findings and recommendations of this study. This is because energy storage technologies are expected to evolve quickly, both in capability and cost-reduction. As such, it is recommended that ARENA remain technology agnostic on energy storage and instead focus its programs on the markets that provide best short to medium term value.

1.4 Study Logic

As illustrated in Figure 3, the study has been split into three distinct phases to enable a logical development of the current understanding of international and local energy storage market and technology developments prior to considering the study objectives. These phases are detailed as:

Phase A - Literature Review, this included using publically available and AECOM international resources, the purpose of this phase it to provide a summary of the energy storage market status. The corresponding literature review sections of the report are described below.

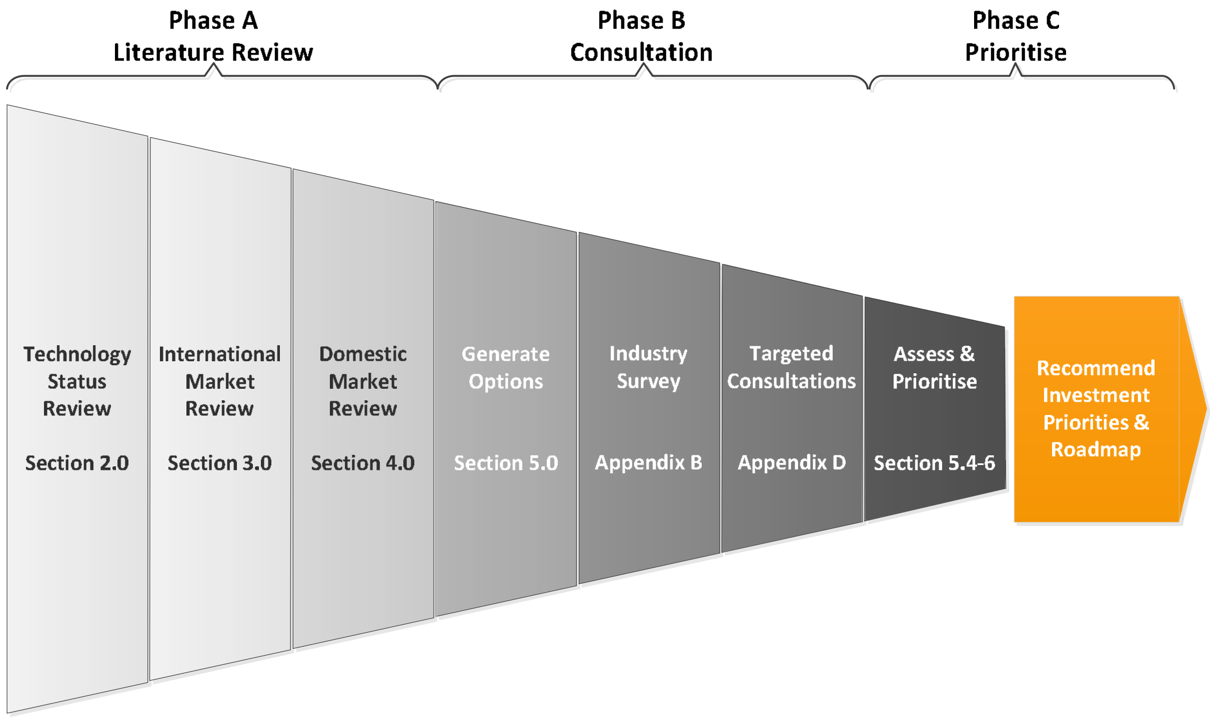
- *Storage Technology Review*, current available energy storage technologies have been described and a discussion regarding the costs, value and overall economic trends of various technologies.
- *International Market Review*, the focus has been on markets with a direct policy focus on supporting energy storage and what the relevant learnings are for Australia.

- *Domestic Market Review*, investigated the key characteristics of the electricity market, what policy and regulations are currently in effect, the status of different market segments within Australia, an energy storage project stocktake and what barriers exist for implementing energy storage.

Phase B - Consultation; industry consultations were carried out with various stakeholders via teleconference and workshops. Additionally an Australian industry wide survey was distributed using a database of relevant AECOM contacts. It was also distributed through the Energy Storage Alliance of Australia and the Australian Energy Storage Council contacts to gain further learnings.

Phase C - Prioritise; the various energy storage technologies were described according to their application, ability to build capacity and the development of new technologies. Furthermore an evaluation of the possible investment options was conducted and a short list of priorities is provided to guide future investment decisions.

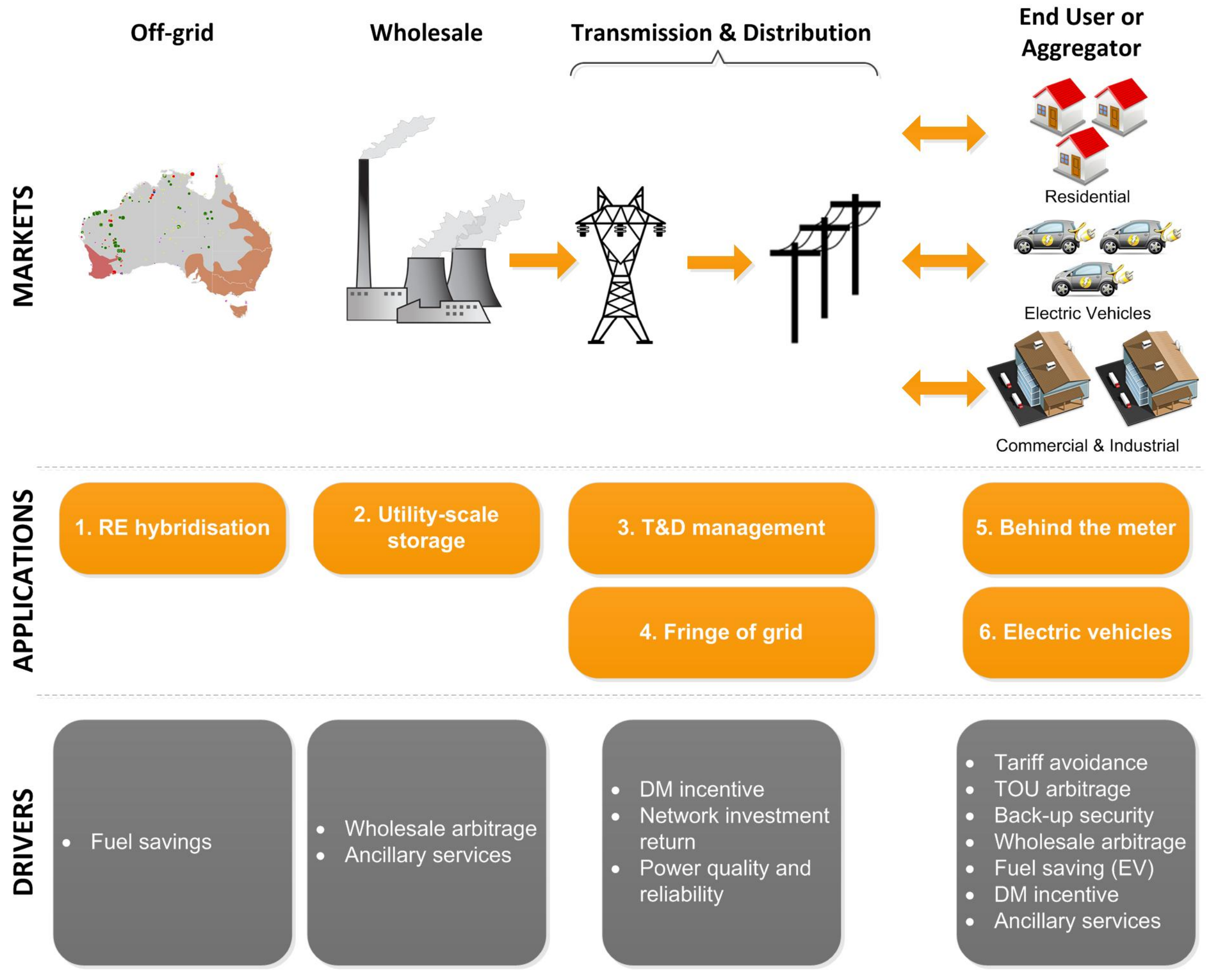
Figure 3 Report logic and phases



1.5 Storage markets, applications and drivers

Energy storage technologies can operate in various markets, applications and provide parts of the value chain. Various economic drivers have been identified and are illustrated in Figure 4 below.

Figure 4 Storage markets, applications and drivers



The four main market segments for energy storage applicable to both the Australian and Global market context are:

Table 3 Definitions of market segments

Market	Definition
Off-grid	Isolated or islanded electricity systems which are not connected to main electricity systems (i.e. NEM or SWIS in Australia) which are generally reliant on diesel generators to supply electricity. AECOM has previously studied this market on behalf of ARENA (http://arena.gov.au/files/2014/12/ARENA_RAR-report-20141201.pdf).
Wholesale	The supply-side of the electricity industry, which encompasses the market where electricity is generated and sold (i.e. NEM or SWIS in Australia). This market also provides frequency ancillary services required for grid stability in Australia.
Transmission and distribution	The distribution of electricity is provided through regulated monopoly markets which obtain economic returns and incentives for the investment or deferral and management of the networks. This market also provides voltage ancillary services required for grid stability in Australia.
End user or aggregator	Includes residential, commercial, industrial and electric vehicle electricity consumers or aggregators such as retailers. It is the only market segment that can obtain economic value created from other market segments, making it the most attractive market for a variety of

Market	Definition
	distributed energy resources such as energy storage.

Within each market, energy storage can be used in a variety of applications. The primary applications in each market segment are defined in Table 4 below. Note that in some cases, the applications may suit a variety of markets.

Table 4 Definitions of applications

Market	Application	Definition
Off-grid	RE hybridisation	Energy storage can provide a useful short term system smoothing function that enables higher penetrations of intermittent renewable energy generation when hybridised into isolated or islanded electricity systems. Essentially the energy storage device provides ‘spinning reserve’ to help manage load or generation variations.
Wholesale	Utility-scale storage	Energy storage can provide power quality, price arbitrage and reliability services to the wholesale electricity market. Technologies such as pumped hydro storage are commonly used to provide a fast response system balancing services to enable less responsive generation sources to operate at their peak performance.
T&D	T&D management	Energy storage can provide network support particularly in constrained or highly concentrated renewable regions. Investment in energy storage can reduce T&D capacity congestion and substation overloading, manage reverse power flow often associated with concentrations of distributed generation and provide power quality stability services.
	Fringe-of-grid	A subset of T&D management, the fringe-of-grid energy storage applications, can provide an alternative to network or micro-grid operators to maintain high quality and reliable electricity supply to the more difficult and costly fringe-of-grid regions of the network.
End users or aggregator	Behind-the-meter	Energy storage can provide load shifting, peak shaving, back-up and renewable pairing services to end users. Coupling solar PV with storage can enable larger PV installations and increase the behind-the-meter use of intermittent renewable generation. The aggregation of energy storage devices can also allow the technology to be applied to other market segments through the provision of demand response, capacity and ancillary services.
	Electric vehicles	As a subset of behind-the-meter, the uptake of EVs enables the use of transportable energy storage devices to provide the same services. It is likely that public fast charge and battery swap stations may also help facilitate the uptake in this market.

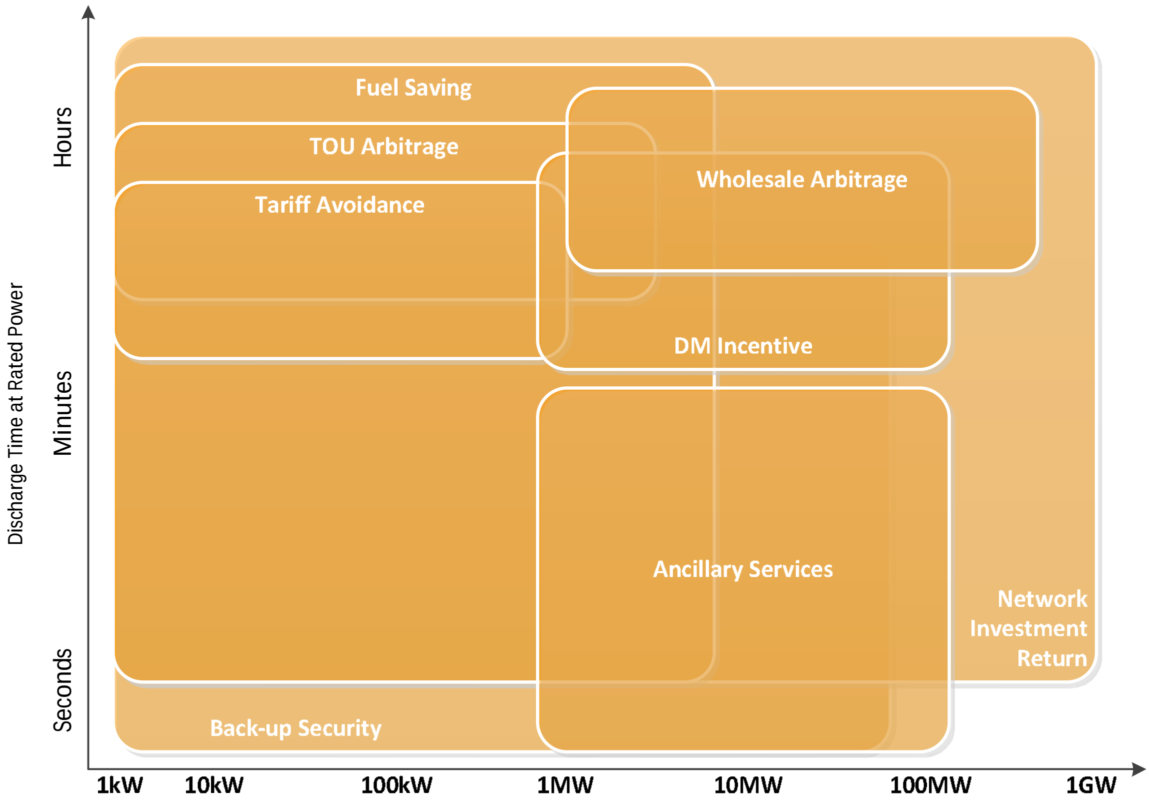
The economic value derived from each application varies across the electricity value chain. Table 5 below provides an overview of the drivers for energy storage.

Table 5 Definitions of drivers

Drivers	Discharge time	Required capacity	Description
Fuel savings	Mins - Hrs	kW - MW	The use of energy storage in the automotive or off-grid sectors, enable avoidance of costly fuel operating costs.
Wholesale arbitrage	Mins - Hrs	MW	The ability to match generation to wholesale market demand. Energy storage can shift energy from off-peak times to when it is needed, thereby providing value from the difference in price. Consequently energy storage can provide additional capacity in certain circumstances reducing the need for fossil fuel peaking power stations.
Ancillary services	Secs - Mins	MW	Electricity networks are a delicate second-to-second balance of generation and load. Energy storage can provide additional services used to maintain key technical characteristics of the system, including standards for frequency, voltage, network loading and system restart services. Within the NEM, AEMO operates 8 separate markets for the delivery of frequency control ancillary services (FCAS) and purchases network control ancillary services (NCAS) and system restart ancillary services (SRAS) under agreements with service providers.
DM incentive	Mins - Hrs	MW	Activities that involve utilising alternative activities and technologies, like storage, instead of upgrading existing networks using traditional means. In the NEM, these are captured in the Demand Management Incentive Scheme. The purpose of this and other schemes adopted around the world are to use energy storage (among other options) to alleviate or avoid the need for infrastructure expenditure required to manage network constraints.
Network investment return	Mins - Hrs	kW - MW	Regulated network businesses in Australia obtain a regulated rate of return which allows the operator to obtain a reasonable return for the cost incurred through efficient investment in, and operation of, electricity network assets. As energy storage becomes more mature and cost competitive it is likely that more network operators will include it as part of their regulated asset base.
Power quality and reliability	Mins - Hrs	kW - MW	Network operators have system reliability and quality standards which must be maintained. Energy storage can be used by NSPs to maintain or improve system performance thus avoiding penalties from regulators.
Tariff avoidance	Mins - Hrs	kW - MW	Pairing energy storage with renewable energy sources such as PV can enable end users to avoid consumption from the mains grid by consuming more of renewable energy generated behind-the-meter.
TOU arbitrage	Mins - Hrs	kW - MW	The ability for consumers to use energy storage to avoid high electricity tariffs by shifting load or shaving peak demand to a cheaper time of use (TOU) charges.
Back-up security	Mins - Hrs	kW - MW	The use of energy storage as a source of back-up power, providing UPS services, is an obvious application of energy storage. The importance for UPS for industry should not be underestimated, with a 2004 study putting the national cost of power outages in the United States at $80 billion annually. [2] These costs and lost productivity have led to a number of end-users who require high reliability to construct backup generators.

Energy storage technologies have a diverse range of applications across each of the different technical and commercial functions of the electricity market, including transmission, distribution, end-user, off-grid, transport and generator market segments. In each of these market segments, storage technologies can simultaneously fulfil multiple roles varying from load shifting, to spinning reserve and power quality. Each of these roles can be linked to challenges imposed by high uptake of renewable technologies and, as such, are aligned with ARENA's mandate.

Figure 5 Energy storage drivers



A further comparison of the discussed energy storage technologies and their applications can be found in Appendix A.

A summary of the common drivers and challenges for energy storage technologies is provided in the table below.

Table 6 Drivers and challenges for energy storage technologies

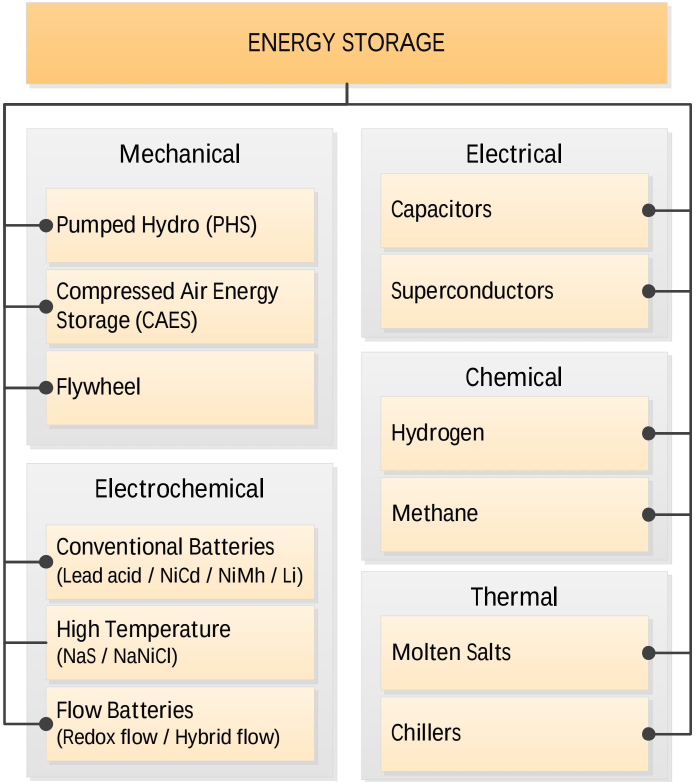
Drivers
Increasing renewable energy aspirations
- Large increases in the uptake of both utility-scale intermittent generation and distributed intermittent generation is growing to such an extent that energy storage is becoming increasingly important to smooth intermittent generation output and help manage the mismatch between supply and demand
Increasing network costs and poor utilisation of assets
- Energy storage has the ability to improve the efficiency of network operation by improving asset utilisation through reducing peak demand
Increasing need for reliable backup power
- Backup power requirements in many market segments, such as telecom and data centres, are becoming more stringent. New energy storage devices, with their improved performance, are becoming the proven solutions in these niche markets.
Electric vehicle uptake
- Although the EV market in Australia is currently very small, uptake outside of Australia is increasing rapidly with some countries having passed 5 percent market share point in 2013 [3]. Large-scale adoption of EVs in Australia is widely considered inevitable, and car manufacturers are continuing to introduce new EV products to the Australian market. - Widespread adoption of EVs will put large energy storage capacity in the homes of many Australians. There is a large opportunity to utilise the storage potential to help facilitate higher uptake of renewables.

Challenges
High initial investments
- The large CAPEX requirement for battery energy storage is currently restricting broad adoption. The main cost components are the raw materials, materials processing, manufacturing costs and balance of plant costs. Material costs account for nearly 75 percent of the total battery pack cost, while manufacturing and other costs represent around 5 and 20 percent respectively.
Lack of common codes and standards
- There are currently no common, industry-wide codes and standards developed for energy storage devices at present. This leads to each manufacturer developing its own internal standards which causes compatibility issues and can create further issues during installation and maintenance. Moreover, the use of unique or custom-made spare parts, deployed in technologies manufactured by different companies, delays the effects of economies of scale for the industry. Lack of standards to compare different product offerings also confuses the potential customers.
Grid interconnection barriers and excess capacity
- Many countries around the world do not have policies, standards, and infrastructure to support grid connectivity of energy storage devices.
Environmental and recycling
- Many battery technologies utilise expensive and rare natural resources. Developing efficient recycling processes will assist the industry to minimise its environmental footprint and recycle valuable materials. - Battery performance typically reduces substantially within a ten year operation life. Despite this, there will be opportunities to reuse batteries in new applications despite reductions in performance e.g. some businesses may choose to specialise in purchasing old EV batteries to use in grid applications or install in households (where the reduced performance of the battery is largely immaterial due to the large oversizing of PV batteries relative to the residential use).

2.0 Storage Technology Review

The broadest definition of energy storage includes any system for absorbing energy in some form at one time and releasing at a later time. Storage technologies can be grouped by the similarities of the storage medium. The figure below shows such a classification scheme. The technologies discussed in this section are grouped according that scheme.

Figure 6 Classification of energy storage technologies



2.1 Electrochemical storage (batteries)

Batteries use chemical reactions with two or more electrochemical cells to enable the flow of electrons. The battery is charged when excess power is available and later discharged as needed. Battery storage is highly versatile and can be used for both short-term and long-term applications. It also benefits from being highly scalable and highly efficient. Furthermore, it can be installed throughout the energy system and has already achieved deployment in both distributed and centralised systems for mobile and stationary applications at varying scales. Widespread deployment, however, is hampered by challenges in energy density, power performance, lifetime, charging capabilities, environmental and safety hazards and costs.

The most prominent battery technologies are described further below.

2.1.1 Lead acid batteries

Lead-acid batteries, invented over 150 years ago, are the oldest and most commonly used type of rechargeable battery. They consist of lead and lead oxide electrodes in an acid electrolyte. There are two types of lead-acid batteries, namely ‘flooded or vented’ and ‘sealed or valve-regulated’. They are low cost and are used in numerous applications including vehicles, off-grid power systems, uninterruptible power supplies and many more. Typical lead-acid batteries have efficiencies of around 70 - 90 percent with an expected lifetime of 5-15 years [4]. They typically have lower cycle lifetimes and depths of discharge than other battery types and contain toxic materials that have negative environmental impacts.

Advanced lead-acid battery technology such as the UltraBattery developed by the CSIRO, combines lead-acid battery technology with ultra-capacitors. These technologies increase efficiencies, lifetimes and improved partial state-of-charge operability. They are an emerging technology with more and larger-scale applications, but at a higher cost than traditional lead-acid batteries.

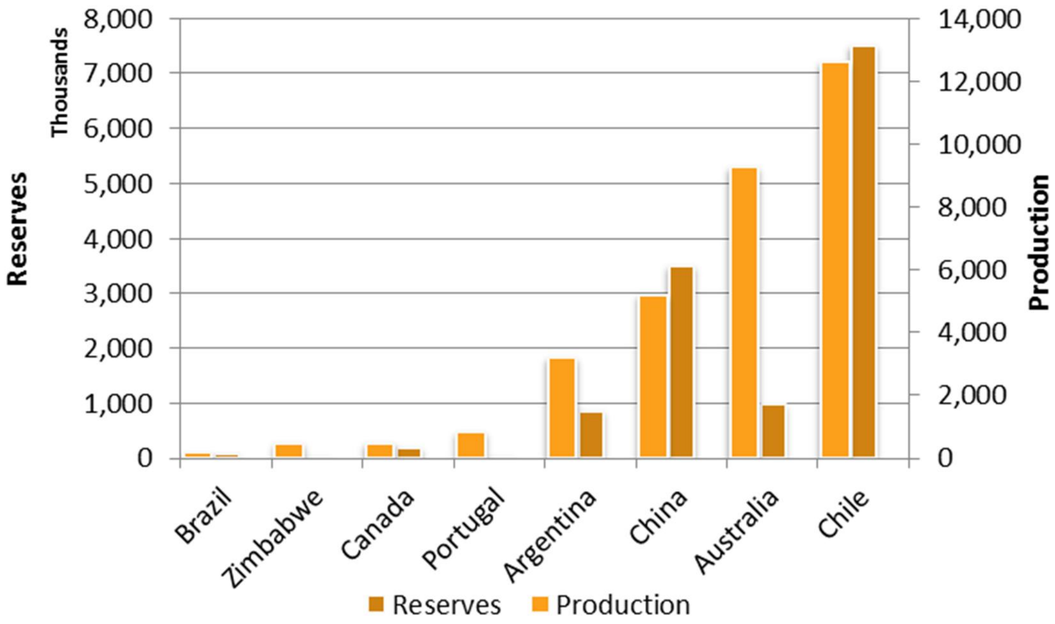
Lead-acid batteries have been coupled with numerous solar, wind and off-grid power systems and have historically been a cheap, reliable source of storage. However we have begun to see a trend towards Lithium-ion batteries replacing many traditional lead-acid applications.

2.1.2 Lithium-ion (Li-ion)

Lithium-ion (Li-ion) battery technology has been in development for around 40 years and has historically been used in the electronics and transportation industries. Li-ion batteries are becoming a common replacement for lead-acid batteries in many applications. They are a rechargeable, versatile battery type with numerous advantages over lead-acid. They have a high energy density, low self-discharge and high charging efficiency. Li-ion batteries are commonly used in small portable electronic devices such as computers and mobile phones, electric vehicles (EVs) and increasingly back-up power supplies and power-grid stability applications.

Efficiencies range from 85-98 percent with lifetimes of 5-15 years [5]. Technological improvements developing rapidly, along with significant cost reductions being seen, make Li-ion batteries one of the most promising emerging battery technologies with abundant applications. Large scale Electric Vehicle (EV) manufacturing and developments (by Tesla in particular) are thought to be driving drastic price reductions in Li-ion batteries, which should have a flow on effect for all their applications.

Figure 7 Global lithium reserve base (tonnes) by country (2011) [6]



With over 39 million tonnes of known reserves of lithium across the world, a challenge for this technology is that just one third of these reserves are currently economically recoverable [7]. The reserves are concentrated in Chile, China and Argentina, although Australia has the second largest annual production. The reserves of key lithium-rich nations are shown in the figure above. While it is difficult to predict whether or not demand for lithium will outstrip supply, there is currently ample supply and concerns of global shortages are speculative [8]. Further research into reserves, increased market size and assistance from government subsidies will help to increase the economic viability of lithium reserves [9]. Lithium can also be 100% recycled, but recycling is often more expensive than mineral extraction [8].

One of the greatest obstacles facing Li-ion is safety. The energy density of cells and combustibility of lithium, mean cells can overheat and catch fire [1].

2.1.3 Sodium sulphur (NaS)

Sodium Sulphur (NaS) batteries are classified as 'high-temperature' and 'liquid-electrolyte-flow' batteries. This technology has a high power and energy density – more than four times that of lead-acid. It consists of molten sulphur at the cathode and sodium at the anode, which are separated by an electrolyte. NaS batteries were demonstrated largely in Japan in the 2000's, by Tokyo Electric Power Company and NGK Insulators. The batteries are maintained at a temperature of 300-350°C. The shortcomings of NaS include the need for an external heat source for its efficient operation, the presence of hot and hazardous materials, and safety issues [4].

Despite the safety risks (c.f. large fire at Tsukuba in Japan in 2011), NaS batteries have been implemented for large-scale grid support, particularly in the USA and Japan.

2.1.4 Flow batteries

Flow batteries have a similar electrochemical process to conventional batteries; however, flow batteries contain two electrolyte solutions in two separate tanks, circulated through two independent loops. The chemical composition of the electrolyte solution defines the sub-categories of batteries, the most important being Vanadium Redox Battery (VRB) and Zinc-Bromine. A cooling system is usually needed, as charging and discharging releases heat. Flow batteries are usually between 65 and 80 percent efficient, allow approximately 10,000 cycles, allow operational flexibility in terms of depth-of-discharge, and have a short response time [10]. Flow batteries are scalable, suitable for large-scale applications and are environmentally friendly, however, are more complex systems.

Table 7 Technical comparison of common battery types* [10], [11], [12]

	Valve-Regulated Lead-Acid	Advanced lead-acid	Lithium-ion	Sodium-sulphur	Flow batteries
Power Range (MW)	1 – 50	1 – 50	< 100	5 – 100	1 – 100
Storage Duration	2 – 4h	1 min – 8h	1 min – 8h	1 min – 8h	1 – 5h
Cycles	1,000 – 5,000	4,500 – 10,000	1,000 – 10,000+	2,500 – 4,500	>10,000
Operating Life (years)	3 – 15	5 – 15	5 – 15	5 – 15	15 – 20
Efficiency (%)	70 – 90	90 – 94	85 – 98	70 – 90	65 – 85
Response Time	< secs	< secs	< secs	< secs	< secs

*Table 7 is for comparative purposes only. Battery storage technologies are improving rapidly and these figures may not be totally reflective of all current applications or future markets. Figures have been sourced from various literature reviews and may not be completely accurate or comprehensive.

For more details on energy storage technologies please see Appendix A.

2.2 Other storage technologies

The focus of this study is on batteries, as they are the most versatile type of storage and have many relevant applications including enabling of renewables. However there are many other types of energy storage technologies worth mentioning, some of which have been widely adopted worldwide.

Table 8 Energy storage technologies [5], [10]

Technology	Description
Mechanical storage technologies	
Flywheels	Flywheels are mechanical devices that spin at high speeds, storing electricity as rotational energy. This energy is later released by slowing down the flywheel's rotor, releasing quick bursts of energy (i.e. releases of high power and short duration). Flywheels have a low energy density, but high power density. They can release large amounts of power over a short period (typically minutes). They require minimal maintenance and typically have a longer lifespan than batteries [12].
Pumped hydro storage (PHS)	Pumped hydro storage makes use of two vertically separated water reservoirs. It uses low cost electricity to pump water from the lower to the higher elevated reservoir using either a pump and turbine or a reversible pump turbine. During periods of high demand, it acts like a conventional hydro power plant, releasing water to drive turbines and thereby generating electricity. Efficiency typically ranges between 70 and 85 percent. In general, pumped hydro storage plants can reach their full power load in a few minutes, with reaction time ranging in the seconds. Pumped hydro is historically the cheapest way to store large quantities of energy with high

Technology	Description
	efficiency over a long time. It is a mature technology that has been implemented all around the world. It does, however, require large reservoir areas, is not suited to distributed generation and there is a lack of suitable new sites, especially in Australia [5].
Compressed air energy storage (CAES)	Compressed Air Energy Storage (CAES) systems use off-peak electricity to compress air, storing it in underground caverns or storage tanks. This air is later released to a combustor in a natural gas turbine to generate electricity during peak periods. Efficiency typically ranges between 45 and 70 percent. Besides PHS, CAES is the only other commercial bulk energy storage plant available today. CAES is a relatively mature and cost effective technology; however it requires suitable large underground caverns for storage and is typically coupled with non-renewable natural gas generators [5] [10].
Electrical storage technologies	
Super-capacitors and Ultra-capacitors	Super-capacitors store energy in large electrostatic fields between two conductive plates, which are separated by a small distance. Electricity can be quickly stored and released using this technology in order to produce short bursts of power. Super-capacitors are high-power, low-energy devices that can react very quickly. Due to the absence of a chemical reaction (unlike batteries), they can withstand a very high number of cycles (up to 100,000). They are highly efficient (80 - 95 percent), but require sophisticated power electronics to ensure steady output. Applications include stabilising voltage and frequency in power systems as well as energy recovery on locomotive breaking systems [5] [12]. This technology was hybridised with lead acid batteries by CSIRO and commercialised by Ecoult, who has used it on a number of projects in the United States as well as a 3 MW / 1.6 MWh installation at King Island in Australia.
Superconducting magnetic energy storage (SMES)	Superconducting magnetic energy storage systems store energy in a magnetic field. This field is created by the flow of direct current (DC) electricity into a super-cooled coil. In low-temperature superconducting materials, electric currents encounter almost no resistance, so they can cycle through the coil of superconducting wire for a long time without losing energy. SMES react almost instantaneously and have a very high cycling life. They require limited maintenance and can achieve high efficiencies, with only between 2 - 3 percent losses resulting from AC/DC converters. However, there are high energy requirements for refrigeration to keep the system at extremely low temperatures, plus the complexity of the system and the high cost of superconductors. SMES are currently at an early demonstration phase and are only suitable for short-term storage [5] [12].
Chemical storage technologies	
Hydrogen fuel cell	Hydrogen energy storage technologies are based on the chemical conversion of electricity into hydrogen. Electrolysis is used to split water (H_2O) into its constituent elements, Hydrogen (H_2) and Oxygen (O_2). Due to its low atomic mass, it has an unrivalled specific energy. The electrolysis process can be reversed (i.e. hydrogen and oxygen generate electricity and water) to feed electricity back into the grid, using a fuel cell. The efficiency of this process is typically 30 to 45 percent [5].
Hydrogen combustion	Hydrogen can be passed through heat engines in a similar way to natural gas, to produce electricity. Some disadvantages include low round-trip efficiencies (20 to 35 percent), high capital cost and safety concerns (as hydrogen is an extremely volatile gas) [5].
Thermal storage technologies	
Molten salt energy storage	Molten salts are solid at room temperature and atmospheric pressure, but undergo a phase change when heated. This liquid salt is frequently used to store heat in concentrating solar (thermal) power (CSP) facilities for subsequent use in generating electricity. Molten salt is capable of storing large amounts of energy for up to 15 hours, and achieving high levels of efficiency. Molten salt storage is limited to CSP technology applications, which is not mature in Australia [5] [12].
Chilled water / ice energy storage	Thermal storage can also be used in low temperature applications such as air-conditioning systems. Water can be chilled or frozen into ice during low tariff off-peak times, then released as a “chilled” load in higher tariff times. The United States and Japan have installed significant

Technology	Description
	amounts of thermal storage that uses ice for cooling applications, reaching efficiencies of 75 to 90 percent [12].

2.3 Storage technology comparison

Figure 8 shows a comparison of different energy storage types, their relative discharge times, MW power scale and efficiencies. For example, PHS has a large power capacity discharged over a long period of time, whereas super capacitors and flywheels are at the lower power capacity end, but operate very quickly over short time periods. Batteries are capable of providing short-to-medium term storage over a wide range of output capacity. Being modular and scalable, batteries can provide any scale of power capacity and improving technologies (e.g. Li-ion) are capable of for both fast and slow discharge rates.

Figure 8 Electricity storage technologies comparison – discharge time vs. power capacity (MW), [5]

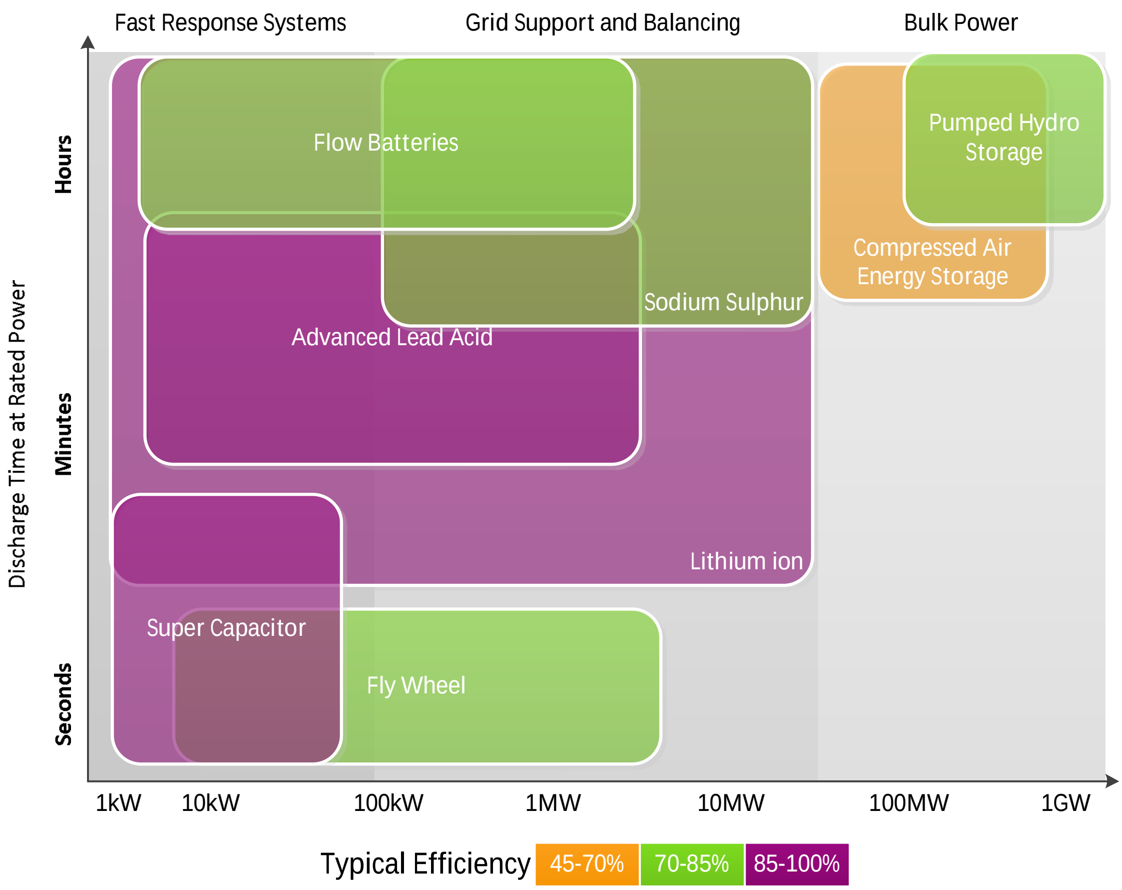
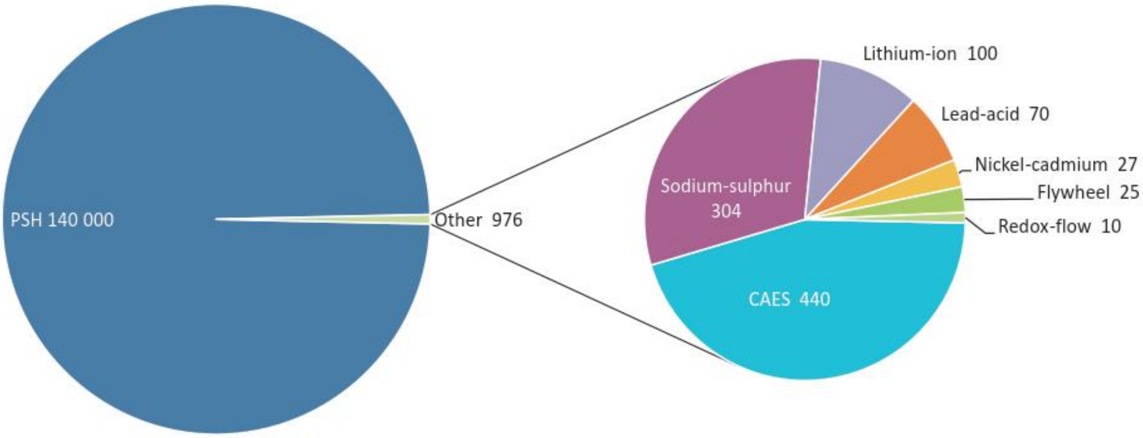


Figure 9 shows a snapshot of global installed grid-connected electricity storage capacity. The vast majority (99 percent) of this capacity is comprised of pumped hydro storage (PHS). PHS was historically the cheapest form of energy storage and has been utilised on a very large scale using large bodies of water. PHS is a mature technology with known costs that needs to be developed on a large scale (100+ MW) to obtain cost efficiencies. In Australia, sites suitable for PHS are limited, project development times are long (>6 years) and obtaining approvals to develop the sites can be extremely challenging.

Figure 9 Global installed grid-connected electricity storage capacity (MW), [12]



Of the other 1 percent of grid-connected storage types, the current biggest players are CAES and sodium-sulphur (NaS) batteries. CAES has again historically been a cheap form of large-scale energy storage. It is usually paired with a natural gas generator and requires large underground caverns or tanks. Similarly, NaS batteries was popular as a large-scale energy storage technology in the USA and Japan; however, several safety and fire incidents as well as emerging alternative technologies has led to a reduction in NaS projects.

While Li-ion does not make up a large share of the existing market, significant progress has been made on regarding performance and manufacturing cost, which has led to it being a highly favoured technology for most applications in today's market.

2.4 Technology cost

The charts below provide indicative Capital Costs and Levelised Cost of Energy (LCOE), respectively, for a variety of energy storage technologies. While considering the costs of each technology it is important to note that battery technologies (excluding NaS) are suitable for (but not limited to) small-scale applications, while NaS batteries, PHS, CAES and CSP are generally suited only to large applications typically megawatt scale or above. Furthermore, prices are highly project specific particularly for CAES and PHS.

As discussed in Section 2.5, substantial cost reductions are forecast for Li-ion and flow battery technologies. For Li-ion batteries, substantial savings have already been observed in the market since the publication of technology costs by IRENA and EPRI. As such, AECOM has also included an indication of current market prices for this technology. AECOM has not provided current market prices for other technologies as they have either not changed sufficiently since release of prior publications, or there is insufficient evidence of price improvements.

Conversely, established technologies such as PHS are unlikely to achieve significant cost reductions in the future. It is also important to note that available costing information is primarily dated 2012, and some battery technologies would currently exhibit lower cost structures.

When comparing storage technology cost it is very important to consider the limitations of each technology and the assumptions behind the costings. In particular, for capital cost (dollars per W), it is very important to compare the storage duration between technologies. Likewise, for LCOE it is very important to consider the impact of operating regime, storage duration and varying project lifetimes, which can have large impacts on the published costs.

Figure 10 Energy storage technologies capital costs (installed) [13], [14], [15], [16], [17], [18]

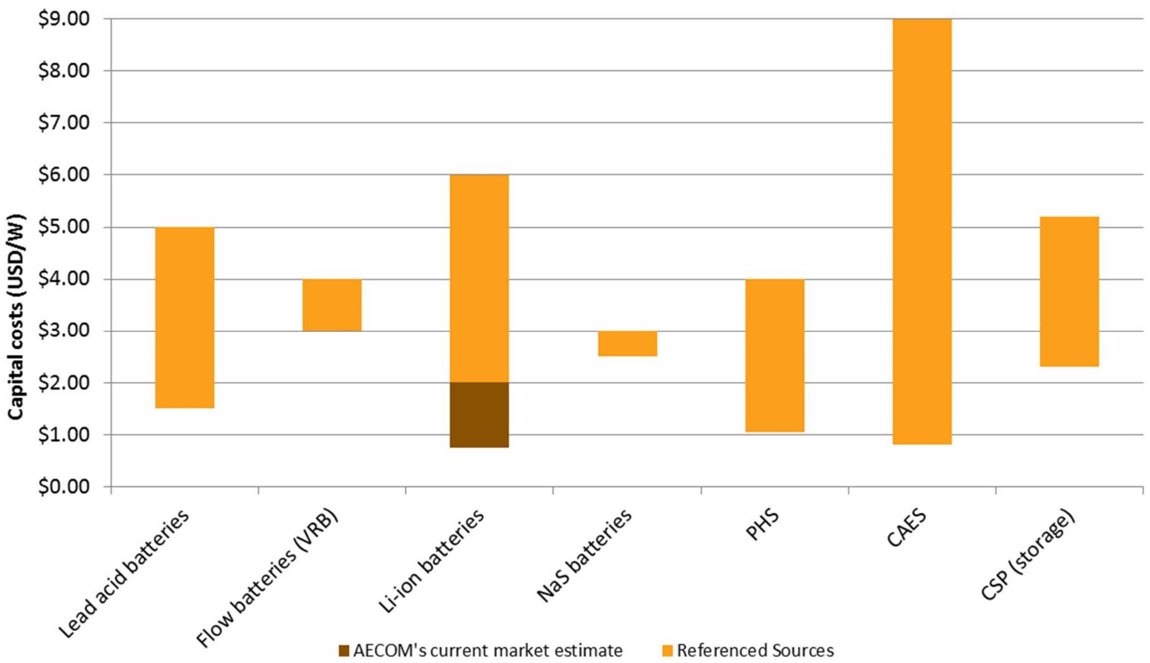


Table 9 Storage technology capital cost source, year and assumptions

Technology	Source/year	USD/W	Assumptions
Lead acid battery	IRENA / 2012	$1.50 - $2.00	3-20MW in size, 10 seconds to 4 hours of storage
Lead acid battery	EPRI / 2012	$2.50 – $5.00	50kW to 10MW in size, total installed cost
Flow batteries (VRB)	IRENA / 2012	$3.00 - $4.00	50kW to 10MW in size, up to 8 hours of storage
Li-ion battery	IRENA / 2012	$2.50 - $3.00	Up to 5MW in size, 15 minutes to 4 hours of storage
	EPRI / 2012	$2.00 - $6.00	50kW – 1MW in size, total installed cost
	AECOM / 2015	~$1.00-1.80	Current market price based on recent tenders MW scale systems (includes balance of plant costs) 15 mins to 1 hour storage
NaS battery	EPRI / 2012	$2.50 - $3.00	1MW – 50MW in size, total installed cost
PHS	IRENA / 2014	$1.05 - $4.00	Average cost of large pumped hydro plants
CAES	IRENA / 2012	$0.80 - $9.00	Large applications using ideal sites (assuming cheap, natural underground caverns) and applications which require ground in-vessel storage.
CSP (storage)	California energy Commission / 2011	$2.30	Solar Power Tower – mid cost case with 11 hours of storage
	IRENA / 2010	$2.50 - $5.20	Parabolic trough, 6 hours of storage (storage cost only, assume existing plant)

Figure 11 Energy storage technologies Levelised Cost of Electricity (LCOE), [13], [15] [16]

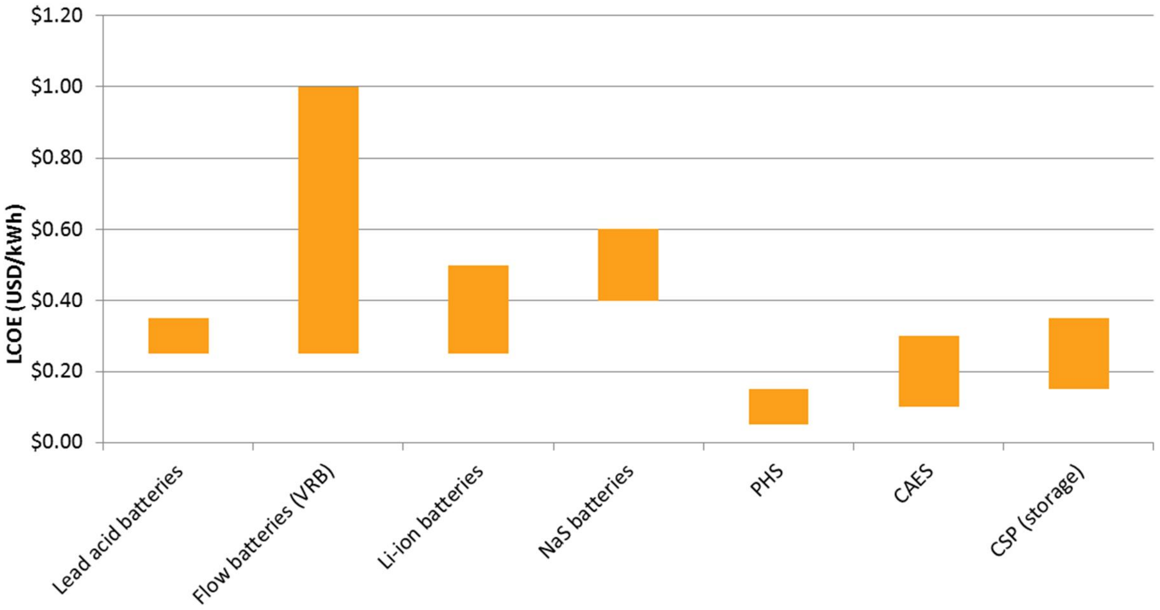


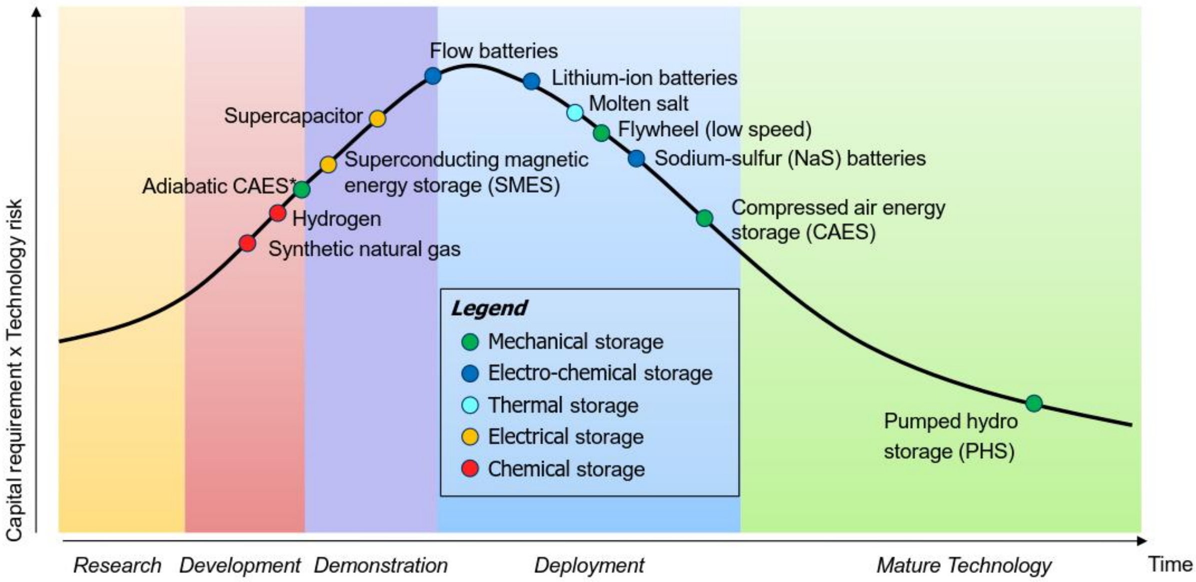
Table 10 Storage technology LCOE source, year and assumptions

Technology	Source/year	USD/kWh	Assumptions
Lead acid batteries	IRENA / 2012	$0.25 - $0.35	Small to medium applications, less than 10MW in size
Flow batteries (VRB)	IRENA / 2012	$ 0.25 - $0.30	50kW to 10MW in size, up to 8 hours of storage
	EPRI / 2012	$0.60 - $1.00	1MW to 50MW in size, total installed cost
Li-ion battery	IRENA / 2012	$0.25 - $0.50	Projected costs up to 5MW in size (for large Li-ion cells), 15 minutes to 4 hours of storage
NaS battery	EPRI / 2012	$0.40 – $0.60	1MW to 200MW in size, total installed cost
PHS	IRENA / 2012	$0.05 - $0.15	Large applications, greater than 200MW in size
CAES	IRENA / 2012	$0.10 - $0.30	Large applications, 50MW to 200MW in size
CSP (storage)	IRENA / 2010	$0.15 - $0.35	Parabolic trough, 6 hours of storage (storage cost only, assume existing plant)

2.5 Technology maturity

There are many different types of energy storage technologies, each at different stages of development and deployment. Figure 12 below compares some of the technologies in terms of their maturity, relative capital costs and risk. The maturity curve closely pairs with the market share seen in Figure 9. It is evident that PHS is the most mature technology, having 99 percent of the energy storage market share, followed by CAES and NaS. Li-ion batteries are in the deployment phase with further cost reductions expected as the technology matures.

Figure 12 Technology maturity curve, [5]



There are many different types of Li-ion batteries deployed and in development, including Lithium Cobalt Oxide, Lithium Nickel Manganese Cobalt, Lithium Manganese Oxide, Lithium Titanate Oxide, Lithium Iron Phosphate, Lithium-polymer plus many others. Different manufacturers offer different technology types with slightly differing performance and technical characteristics. Li-ion batteries and supporting controls systems are now becoming smart, comparable to flywheels in response time, can provide grid stability support as well as longer duration energy supply. The big drive in research and development is to increase the energy density of Li-ion batteries, which will in turn drive down the currently high capital costs.

Some lead-acid battery manufacturers are also improving this technology and developing “advanced lead-acid” batteries by incorporating carbon in the electrodes, combining super-capacitors or other approaches. These advanced lead-acid technologies are being trialled now by some suppliers including Ecoult in Australia.

Other emerging technologies include:

1) Liquid air energy storage systems

2) Non/low fuel CAES

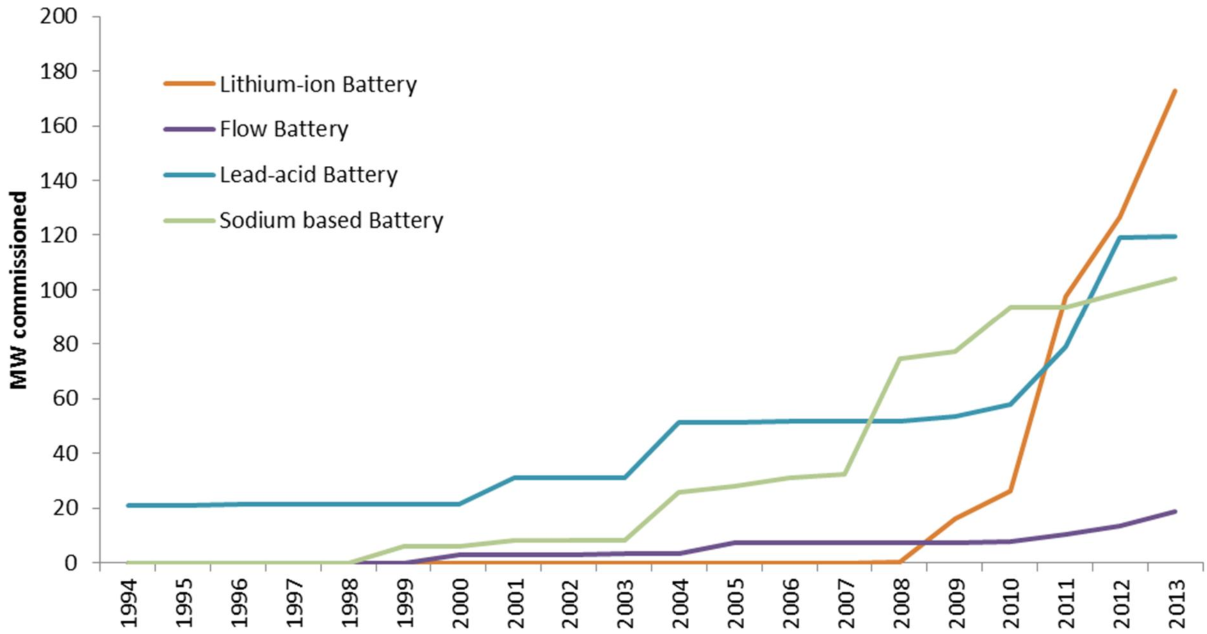
3) Underground PHS

4) Nano-super-capacitors

Those energy storage devices that have the following characteristics will likely be more prevalent as costs fall; quick charge time, high power density, high energy efficiency, high reliability, high cycle times, low carbon footprint and low disposal issues.

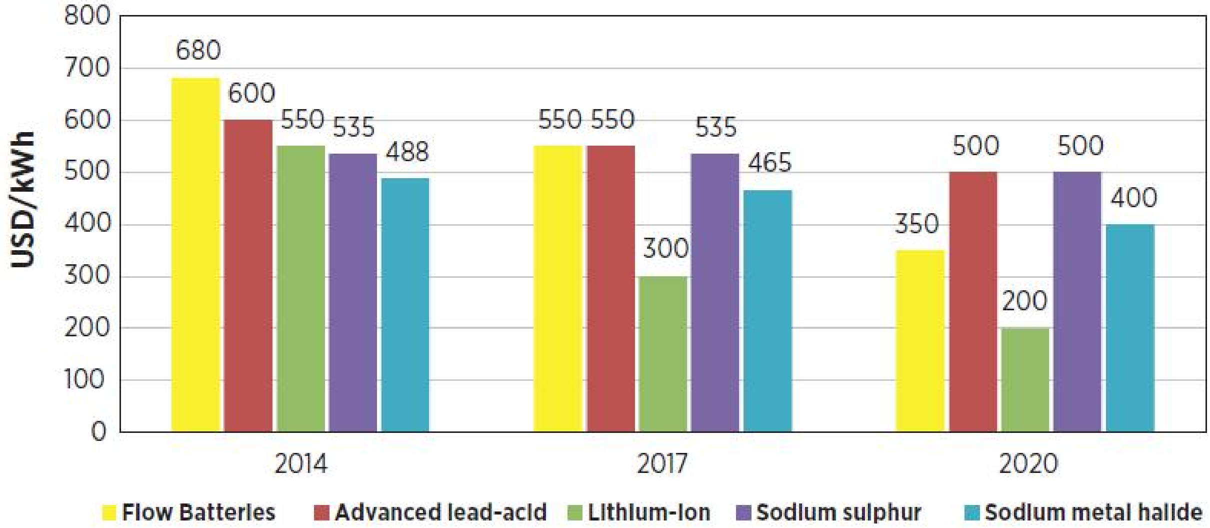
Using data collection from the US Department of Energy (DoE) database [19], across a range of electro-chemical project types, historical trends in project installations can be observed. Until the late 2000’s, lead-acid batteries were the dominant technology. Around 2007, installed capacity of sodium based batteries began to overtake lead-acid. While both sodium and lead-acid batteries continue to rise in uptake, the rapid rise of Li-ion technology is easily visible. A fast reduction in the cost of Li-ion batteries, combined with its superior performance characteristics and its wide variety of applications (i.e. power and energy) has led to the recent growth in Li-ion uptake.

Figure 13 Cumulative global capacity (MW) of battery storage by technology as listed on the US Department of Energy database [19]



As battery prices have fallen, there has been much market speculation that the battery market might “take off” in a similar way to the boom in photovoltaics (PV) over the past five years. There have been great advances in battery chemistry and technology in recent decades, resulting in improved performance and reduced costs. The International Renewable Energy Agency (IRENA) has forecast that prices for various battery technologies will continue to decrease. Figure 14 shows that while all battery technologies are forecast to reduce in price, the largest reductions are forecast to occur with Li-ion and flow-battery technologies, with prices reducing from $550 per kWh in 2014 to $200 per kWh by 2020 for Li-ion, and from $680 per kWh to $350 per kWh for flow batteries [1]. Note that the difference in battery prices between Figure 14 and Figure 10 can be attributed to fully installed system costs being considered in Figure 10.

Figure 14 Lowest current and projected battery cell price by type for utility-scale applications [1]



These technology developments were originally driven by market demand for lighter, smaller and cheaper batteries for mobile phones, laptop computers and personal electronic devices. This trend has accelerated with the rise of the electric vehicle industry. Tesla’s announcement of plans to establish a $5 billion “Gigafactory” which aims to produce 50 GWh per annum of battery capacity, while projected to cut Tesla’s battery prices by one third, is perhaps the most prominent example of this trend.

3.0 International Market Review

3.1 Introduction

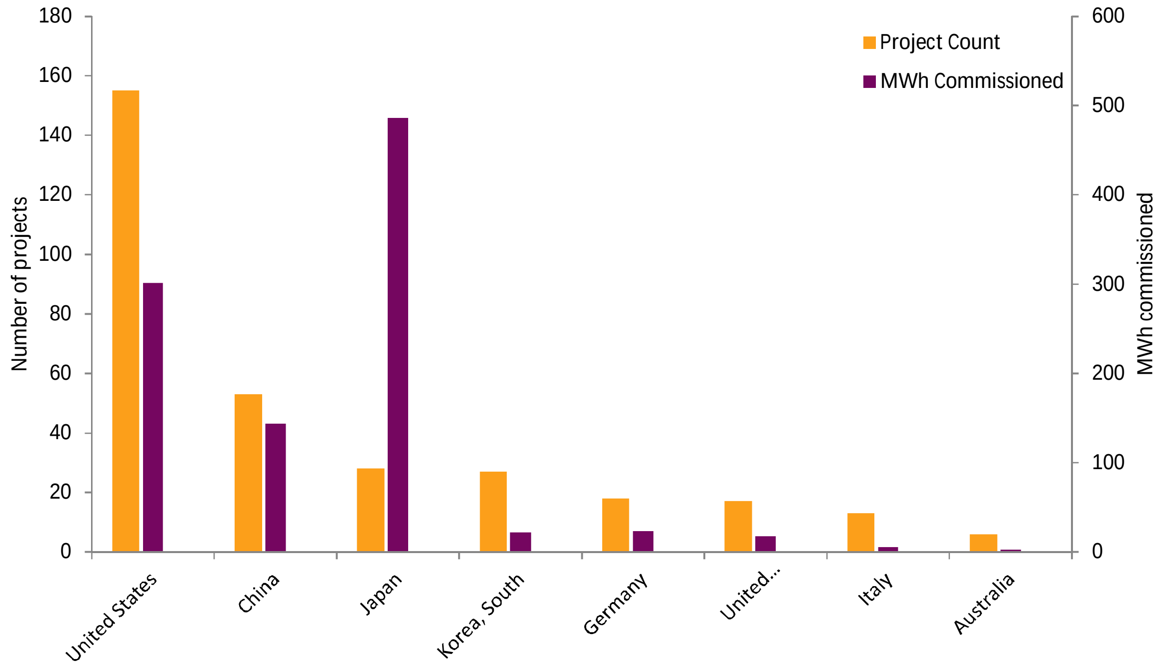
Australia has an opportunity to learn from the approach of international markets when developing energy storage investment priorities. With the growing focus towards increasing the use of clean energy, governments of various countries have introduced policies and incentives to promote the development and implementation of advanced energy storage systems. Countries such as the UK, Germany, Japan, China and USA have all recently announced programs focused on demonstrating and subsidising the uptake of energy storage and electric vehicles. Greater uptake in Australia is widely considered to be inevitable as cost reductions driven by international markets impact our domestic market. Given the nascent state of the energy storage industries (other than pumped storage), it will be important to draw from international trends and experience to inform views the domestic perspective in relation to future commercial models, technical developments and the broader economic and regulatory landscape.

AECOM has focused the International Market Review on ten leading international markets for energy storage. These include:

- United States (California, Hawaii, Texas and New York)
- China
- Japan
- South Korea
- Germany
- United Kingdom
- Italy

These markets been selected as they have the largest number of large-scale battery storage projects as per the US Department of Energy database and because they represent a diverse range of market circumstances and drivers. In addition to the focus on battery storage, many of these markets also support other energy storage technologies as well as alternatives enabling technologies such as demand response technologies. Figure 15 shows the number projects commissioned and the energy capacity of those projects. The United States has the largest project count, while Japan has the largest MWh commissioned as well as a significantly larger average project size than the other markets (indicative of multiple large-scale storage projects).

Figure 15 Total operational battery projects by country as listed on the US Department of Energy database [19]



This chapter seeks to describe the recent developments these leading energy storage markets, describing the respective policies, programs, supporting mechanisms and objectives. Understanding the broad array of approaches utilised internationally, as well as the drivers of those approaches, will assist ARENA to consider its options and help determine its knowledge sharing and investment priorities. In this international review, each international market is qualitatively rated for its investment focus across each of the markets described in Table 3 (Section 1.5).

3.2 California (USA)

3.2.1 Background

California has a strong track record of ambitious environmental programs within the energy sector including the Renewables Portfolio Standard and the Global Warming Solutions Act (2006).

The Renewables Portfolio Standard requires all utilities in the state to source 33 percent of electricity sales from clean renewable resources by 2020. The state currently has 21 GW of installed renewable capacity with utilities serving 20.9 percent of their retail electrical load from renewable energy, as of August 2014. As such, California's penetration of renewables is currently comparable to Australia's 2020 target (20 percent), and California's 33 percent target is similar with the existing renewable penetration in South Australia.

In support of its renewable energy target, California has also introduced energy storage targets and support programs to facilitate the integration of renewables and efficient management of electricity networks.

The California Public Utilities Commission has identified a range of barriers hindering the adoption of storage technologies, described below:

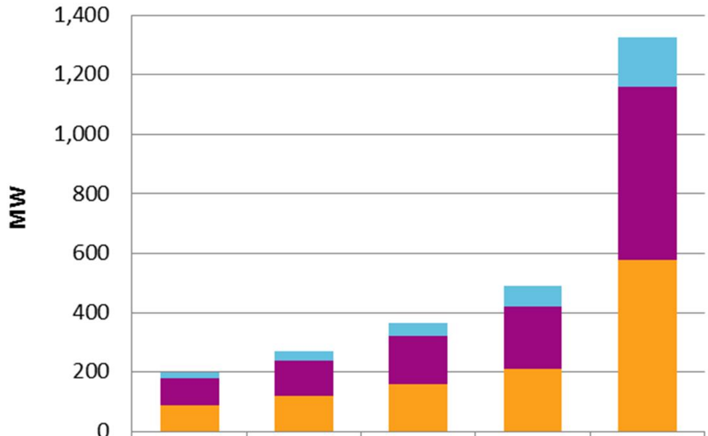
- lack of definitive operational needs
- lack of cohesive regulatory framework
- evolving markets and market product definition
- Resource Adequacy (RA) accounting (tool to monitor loss of load and ensure system reliability, with no value currently assigned to storage-based devices)
- lack of cost-effectiveness evaluation methods
- lack of cost recovery policy
- lack of cost transparency and price signals (wholesale and retail)
- lack of commercial operating experience
- further define the energy storage interconnection process.

3.2.2 Energy Storage Mandate

In order to keep up with California's aggressive renewable energy goals, the California Public Utilities Commission passed a mandate in 2013 that requires the state's three largest investor-owned utilities to install 1.3 GW of storage by 2020. The policy aims to promote efficient investment and operation of the transmission and distribution networks and defer the need for augmentation. An additional goal of the program is to assist the integration of renewable energy and minimise greenhouse gas emissions.

The mandated energy storage targets are shown in Figure 16. Each Network Service Provider (NSP) has a separate target, as well as quotas for each market segment: transmission (which incorporates wholesale market), distribution and end user. The quotas are weighted more towards the transmission category, but there is flexibility to shift up to 80 percent between the distribution and transmission categories of the grid, subject to the economic benefits of identified projects. The scheme has been designed to allow a high level of flexibility for NSPs to determine how they best wish to deploy energy storage projects according to the specific needs of their networks. For example, the scheme targets are defined in megawatts rather than megawatt-hours to give NSPs increased flexibility in how they implement storage systems [20].

Figure 16 Energy storage procurement targets (MW)



	2014	2016	2018	2020	Total
San Diego Gas & Electric	20	30	45	70	165
Pacific Gas & Electric	90	120	160	210	580
Southern California Edison	90	120	160	210	580

Despite opposition from the utilities, the mandate is going ahead but is subject to amendment in the case of unanticipated difficulty or expense of energy storage procurement [21]. Details of the targets are provided in Figure 16 above. The mandate can be serviced through demand management initiatives which are currently making up the majority of each utility's obligation.

3.2.3 Self-Generation Incentive Program

The Self-Generation Incentive Program is one of the longest running distributed generation incentive programs in the United States. It provides rebates for distributed energy systems on the customer side of the utility meter. In 2014, US$77 million was paid to distributed generators, with 75 percent allocated to renewables and emerging technology [22]. The program includes wind turbines, waste heat to power technologies, pressure reduction turbines, internal combustion engines, micro turbines, gas turbines, fuel cells, and has recently been modified to include advanced energy storage systems. The rebate payable to energy storage systems is tiered according to the installed capacity, as shown in Table 11.

Table 11 Rebate available to installers of energy storage systems in California

System size	Rebate
0 MW to 1 MW	$1.62/W
1 MW to 2 MW	$0.72/W
2 MW to 3 MW	$0.36/W

These rebates are subject to a number of eligibility requirements, including at least 2 hours discharge at the rated capacity and the capability to discharge fully at least once per day (or hundreds of partial discharge cycles per day if paired with wind generation). Other requirements relate to minimum technical performance and system sizing restrictions.

3.2.4 Incentives to compensate fast response for frequency regulation (US Federal Government policy)

Frequency regulation services have traditionally been provided by slow-responding fossil fuelled generators like gas turbines and coal-powered generators. However, battery technologies have faster response times for providing frequency regulation services and can provide more accurate dispatch levels than traditional frequency regulation services. As the penetration of renewables increases, there is expected to be a growing demand for frequency control ancillary services.

The Federal Energy Regulatory Commission has introduced new requirements to financially compensate superior delivery of frequency regulation services (whether through more accurate dispatch, or more timely dispatch). These changes will make some energy storage technologies more competitive in the frequency regulation market.

Southern California Edison 250 MW energy storage procurement – successful tenderers

Southern California Edison recently announced winners of its 250 MW energy storage procurement. Winners included a range of storage technologies including grid-scale, behind-the-meter, thermal storage technologies. Some of the winning projects are described below.

AES Corporation 100 MW / 400 MWh Li-ion battery

AES Corporation is building a 100 MW Li-ion battery able to provide 4 hours of energy storage as an alternative to gas peaking plants. With the project set for completion by early 2021, it is currently the world's largest electrochemical battery under development. The contract involves a twenty-year power-purchase-agreement underpinning a guaranteed revenue stream. The long duration and daily cycling requirements of the battery will test the technical limits of Li-ion technology, which have so far been mostly used for up to two-hours of duration [23].

Stem 85 MW Li-ion battery

Stem has been awarded 85MW of behind-the-meter energy storage to be deployed at multiple customer locations in the Western Los Angeles Basin. Stem must deploy the full 85MW of storage by 2021. This energy storage will act as dispatchable capacity to enhance the local reliability of the region [24]. Stem designs its Li-ion batteries and control systems in scales of 18-54kW and is currently installing these systems in 68 Extended Stay America hotels [25].

Advanced Microgrid Solutions: 50 MW hybrid-electric buildings

Advanced Microgrid Solutions is developing 50 MW of "hybrid-electric buildings" throughout its West Los Angeles service territory. Advanced Microgrid Solutions' initiative is to install advanced storage systems in commercial and industrial buildings to provide large-scale grid support by creating "fleets" of energy storage that operate as a single resource. This allows Southern California Edison to shift the entire fleet of buildings to stored energy when grid resources become strained. Advanced Microgrid Solutions are technology agnostic, they find the best batteries, software and technicians available for what local utilities need for grid support [26] [27]

26M W cold storage by Ice Energy

Ice Energy has announced that it has won 26 MW of energy storage capacity throughout Orange County, California, to be deployed over the next six years (2021). Ice Energy utilises rooftop air conditioning units to use cheaper night time power to turn water into ice, this ice is then used to reduce how much electricity is needed to operate the air conditioning units during the heat of the next day. The company's product, Ice Bear, is able to defer about 10kW of power during the day in medium sized commercial buildings, which amounts to deploying around 2,500 of these units for a total capacity of 26 MW [28] [29].

3.2.5 Key observations and learnings for Australia

It is interesting to note that California has placed the largest targets on the transmission sector (more than 50 percent). The reasons behind this focus have not been widely promoted. Nonetheless, this emphasis on the transmission sector has received some criticism from commentators who claim that investment in storage has more value closer to the source of load variability (such as households) and that there is minimal demand for supply market style storage at a utility scale. In addition, electricity has more value at the retail level than the transmission level. [30]

The Self-Generation Incentive Program is extremely generous particularly at the <1 MW scale, compared to rebates offered in other countries (e.g. China, Germany etc.). It is noted that overly-generous rebates can lead to boom-bust cycles and funding organisations should be cautious to ensure the rate of uptake of technologies under such programs does not exceed budgeted funding.

An additional learning is that existing markets for frequency regulation may not recognise the technical proficiency of some energy storage technologies in providing frequency regulation. The US has made changes to place higher value on frequency control services that have a superior /faster response than traditional service providers.

Table 12 Investment focus for California

Market segment	Investment focus
Wholesale	Very high
Transmission and distribution	
End user	High
Off-grid	Low

3.3 Hawaii (USA)

3.3.1 Background

Hawaii is characterised by very high electricity prices, abundant natural resources and ambitious clean energy goals, resulting in high penetrations of wind and solar generation. However, the unpredictable and diverse nature of weather patterns in Hawaii makes renewable energy generation distinctly more intermittent than in other regions in the world [31]. Electricity prices are around twice that of any other US state (around AU$0.45/kWh) due to the heavy reliance on fossil fuel imports for electricity generation [32]. Renewable energy currently supplies nearly 21 percent of the total generation in Hawaii, and this is set to grow further with the Hawaiian Electric Company recently submitting Power Supply Improvement Plans to the Hawaii Public Utilities Commission to increase the renewable energy target from 40 to 65 percent by 2030 to help reduce electricity costs to consumers [33].

Each Hawaiian island has a separate stand-alone grid, and although there are plans to connect the islands through integrated modernised grids in the future, they are currently not connected. With such intermittent natural resources, energy storage has the potential to play an enabling role in achieving Hawaii's ambitious energy goals.

3.3.2 Oahu energy storage proposal

Oahu is the most populated island in Hawaii and has the highest electricity demand. The large deployment of wind and solar on the island has challenged Hawaiian Electric Company to maintain a reliable grid at an affordable price. Recently, the Hawaii Public Utilities Commission requested Hawaiian Electric Company to improve its approach to solar PV integration, develop a demand response plan, and improve grid reliability. High penetration of solar PV has led to challenges associated with voltage and frequency regulation as well as inefficient utilisation of the existing thermal generation fleet (due to high spinning reserve requirements). In response, Hawaiian Electric Company has issued a request for proposals for 60 MW to 200 MW of energy storage systems (minimum 30 minutes storage) [34]. Hawaiian Electric Company anticipates that the storage facilities will help achieve cost-effective sub-second frequency response and minute-to-minute load following. Proposals for the project were due July 2014 and Hawaiian Electric Company is currently negotiating with three battery storage developers with hopes to sign with all three and have systems in service by early 2017 [35].

3.3.3 Kauai Island Utility Cooperative energy storage RFP

Kauai Island Utility Cooperative's grid is an islanded system with increasing solar penetration under programs enabling residential and commercial customers to install solar systems. Currently, up to 95 percent of daytime demand is provided by solar power. In order to solve challenges associated with intermittency and over-generation, the Kauai Island Utility Cooperative has issued a Request for Proposals for a 20 MWh to 40 MWh energy storage system [36].

Case Study: Wind-firming project in Kahaku
The 30MW First Wind generation plant was paired with a 15 MW battery system to smooth generation variability to +/-1MW per minute. The project received a $117 million loan guarantee from the Department of Energy for the project (including wind turbines plus storage). However the battery storage system was destroyed in 2012 after a second fire (following a previous fire in 2011). Honolulu's fire captain described the fire as difficult to control and dangerous, illustrating the potential safety hazards broadly associated with storage. Investigations into the cause of the fires indicated that the Dynapower inverters were not sufficiently robust. Battery provider Xtreme Power filed for bankruptcy in 2014 [37]

3.3.4 Key observations and learnings for Australia

Hawaii is a valuable case study for Australia's large off-grid sector. Hawaii's high cost of electricity has made renewables more competitive, achieving high levels of penetration with even larger targets proposed. Storage technologies are poised to facilitate additional uptake of renewables, reduce electricity cost and provide improved power quality. ARENA and interested off-grid electricity operators may obtain significant learnings from the Hawaii experience including sizing, design, technology performance, project delivery and replication.

Table 13 Investment focus for Hawaii

Market segment	Investment focus
Wholesale	High
Transmission and distribution	Medium
End user	Unknown
Off-grid	High

3.4 New York (USA)

3.4.1 Background

New York's Renewable Portfolio Standard requires that 30 percent of state electricity generation comes from renewable energy by 2015. The current penetration of renewables is approximately 21 percent with the majority coming from hydropower [38], but intermittent generation sources such as wind and solar have been growing rapidly in recent years and are expected to make up much of the remaining target.

3.4.2 Enhanced load reduction program (proposed)

In response to the potential closure of the 2 GW Indian Point nuclear reactor, electricity supply company Con Edison has joined the New York State Energy Research and Development Authority to propose an enhanced load reduction program to accelerate the implementation of technologies that reduce peak energy demand. Rebates for battery storage systems have recently increased four-fold from $600/kW, with current rebate rates given below in Table 20.

Table 14 Incentives for battery storage systems [39], capped at US$10 million

System size	Incentive
50 kW – 500kW	$2,100/kW
500kW – 1MW	$2,310/kW
1 MW or greater	$2,415/kW

The program is similar to California's Self-Generation Incentive Program, although it differs in that the rebates are more generous and that they increase with increasing system size. Incentives are capped at 50 percent of total project cost and must be installed by June 1, 2016. A number of other technologies are also eligible (at different rebate rates) including thermal storage, and various demand management and energy efficiency technologies.

3.4.3 Reforming Energy Vision (REV) Initiative

New York Governor Cuomo announced plans in April, 2014 for a “fundamental shift in utility regulation” in order to modernise an aging and outdated electricity grid. On February 26, 2015, the New York State Public Service Commission issued an order adopting the regulatory policy framework and implementation plan for Reforming the Energy Vision (REV). The REV is aiming to encourage and reward utilities, energy service companies, and customers for activities that contribute to grid efficiency, making the state more attractive for DER as an integral part of the future of the electric distribution system. It will engage consumers through expanded demand management, energy efficiency, clean distributed generation, and energy storage to reduce peak demand and capital investment in network infrastructure (currently estimated at $30 billion in the next 10 years) [40]. There is a strong focus on consumer engagement to reduce peak demand. Part of the demand management strategy involves the use of batteries behind-the-meter that could be charged by excess power from solar, and discharged during times of high demand.

The new REV framework calls for the creation of a marketplace for distributed energy, known as the Distributed System Platform (DSP). The DSP will function similarly to the New York Independent System Operator (NYISO), only for distributed generation. It will fulfil dual functions as both a market maker and system coordinator. Within these functions, the DSP will offer products and services to users of the platform, which may include platform access, analytics, interconnection services, etc. [41]

By May 15, utilities must identify non-wire alternatives for their systems; by July 15 they must begin soliciting and developing demonstration projects that are aligned with the REV framework; and by December 15 they must file Distribution System Platform (DSP) implementation plans.

3.4.4 Key observations and learnings for Australia

With a relatively low proportion of utility scale intermittent generation, renewable generation applications are likely to be limited to pairing with residential solar PV systems. Other key drivers will include demand response, frequency regulation and smart network operation.

The rebates offered to energy storage projects within New York appear very generous, and could possibly lead to a boom-bust cycle. Close monitoring of uptake rates and market prices, along with fast adjustments to the size of the rebate will be necessary for the scheme to be a success. It is also unclear why the incentives are higher for larger systems.

Despite positive rhetoric to support energy storage applications within electricity networks, there is not yet any clear program to support its uptake. Nonetheless, New York appears to be a key market with political will to modernise grid operations.

Table 15 Investment focus for New York

Market segment	Investment focus
Wholesale	Medium
Transmission and distribution	Medium
End user	Medium
Off-grid	Low

3.5 Texas (USA)

3.5.1 Background

Despite being an international leader in the oil and gas industry, Texas has introduced a Renewable Portfolio Standard which has led to a rapid increase in renewable energy penetration in the state. In 2005 the Renewable Portfolio Standard was expanded to increase the state target to 10,000 MW of installed renewable energy capacity by 2025, which was reached in 2010, 15 years ahead of schedule. Texas has the most abundant wind resource in the United States, which accounted for 76 percent of the total renewable energy generation in 2011 [42]. Renewable energy currently accounts for 10 percent of total electricity generation in Texas [43].

While wind resources are greatest in West Texas, most of the population and power demand lies in the eastern part of the state. Therefore, the Public Utilities Commission collaborated with the Electricity Reliability Council of Texas to establish a transmission project to bring the wind generation from the west into the electricity market in the east. The project involved 5,800 km of transmission lines and was completed by the end of 2013. Texas is the only mainland state with its own grid, so Electricity Reliability Council of Texas works outside of strict Federal jurisdiction and does not import electricity from any of the other states [44].

Texas is now adapting utility-scale energy storage technology to mitigate short-term fluctuations in renewable output, as well as to shift the load of wind generators which generate most during the night to times when demand is higher.

3.5.2 Oncor battery storage proposal

One of Texas's transmission and distribution utilities, Oncor, is seeking approval to spend $5.2 billion on distribution-grid-connected batteries. The plan calls for deployment of up to 5GW of energy storage, starting in 2018 when the cost of batteries is expected to be significantly lower.

Oncor claims that the batteries will give Texas's grid operator the capability to instantaneously increase or decrease total electricity generation by at least 7 percent to keep the grid balanced [45].

As in Australia, NSPs in Texas cannot participate in the wholesale electricity market, which restricts Oncor from capturing all the economic benefits from adding battery storage. Instead, Oncor is proposing to use the batteries for ancillary services and then auction any additional unused storage to other generators who are legally able to offer it to the wholesale electricity market [45]. It is expected that Oncor may encounter opposition from state legislators and energy regulators with its current proposition. However, if progressed, it will be one of the largest energy storage procurement programs globally [45].

Case Study: 36MW wind-firming battery pilot

In 2012, Xtreme Power finished construction of a 36MW battery pack, located at the 153MW Notrees Wind Farm in West Texas for energy generator Duke Energy. Duke Energy agreed to match $22 million funding from the Department of Energy. Electricity Reliability Council of Texas will also be able to direct the facility to operate to meet the immediate power needs of the network. The driver for the project is to demonstrate the capability of energy storage to mitigate the intermittency of wind power. [46]

3.5.3 Texas Emerging Technology Fund

The Texas Emerging Technology Fund was created by the Texas Legislature in 2005 to provide Texas with an advantage in the research, development, and commercialisation of emerging technologies. To date, the Texas Emerging Technology Fund has awarded over $46 million to renewable energy-related projects, including technologies such as solar cells, algae biofuels, and advanced batteries.

Some start-up companies involved with energy storage that have been funded by the Texas Emerging Technology Fund include:

ActaCell (2009), an innovator in next generation high power Li-ion batteries ($1 million funding) [47]

BetaBatt (2008), working on commercializing a long-life, self-recharging battery ($500,000 funding) [48]

LynnTech (2007), Developing high power hydrogen/air fuel cell technology ($600,000 funding) [49]

3.5.4 Key observations and learnings for Australia

The deployment of storage technologies in Texas is being led by the state's largest NSP, Oncor, which is seeking to incorporate storage into its asset base. Oncor is focusing on the supply market (including integration of renewables), and transmission and distribution applications (including power quality). This is driven by a need to manage the quickly increasing wind penetration expected in West Texas.

One unique aspect of Oncor's model is that it has addressed a common barrier associated with the many roles of energy storage. Most large energy markets like Australia are structured to separate the transmission and distribution roles from the wholesale generation market. In this structure, transmission and distribution companies are typically not allowed to work in the wholesale market due to market rule restrictions. This can limit the revenue streams of energy storage systems, which provide value to the grid as well as to the wholesale market. It appears that Oncor intends to work around this issue by auctioning the wholesale energy component of its battery to market participants, thus not directly participating in the wholesale market. Similar work-arounds may be possible within the National Energy Rules.

Texas has an ambitious program for deployment of 5 GW of energy storage and has delayed the investment to 2018 to obtain better value in the anticipated price decline of the battery market.

Table 16 Investment focus for Texas

Market segment	Investment focus
Wholesale	Med-high
Transmission and distribution	Low
End user	Low
Off-grid	

3.6 China

3.6.1 Background

The Central Government has stated that it will pursue energy storage as part of the same policy platform that has driven growth in the renewable energy sector. This will likely commence with a series of demonstration projects. [50]

In its latest 5 year plan (2011-2015), both the Central government and the provincial and local government have issued as many as 25 documents regarding energy storage, including the State Plan, regulations, standards, white papers and subsidizing guideline to support achieving the Central Government's ambitious renewable targets.

In the 5 year plan, renewable generation targets include (for 2015):

- wind generation will reach 100GW and annually output to reach 190 TWh
- solar PV generation will reach 35GW, approximately 40 percent centralised and 60 percent as distributed
- hybrid electric vehicles and plug-in electric vehicles to grow to up to 5 million vehicles by 2020.

China already has the world's two largest pumped hydro plants, including 2,400MW in the Southern Grid near Hong Kong, and 1,800MW near Shanghai in the Eastern Grid. Nonetheless, China is still looking to invest large amounts in battery storage. By 2013, China had installed 57 MW of demonstration battery projects; however, significantly larger projects are now underway.

3.6.2 Pairing generation with storage

China currently experiences very high levels of curtailment of wind generation due to network constraints, with some wind farms losing up to 40 percent of their expected generation.

A new policy directive requires intermittent generators to pair their generator with energy storage as a grid-connection requirement. This policy applies across all levels, including rooftop solar through to utility scale plants. As such, the potential impact of this policy is staggering, given the growth in the wind and solar generation. State Grid, the Government-owned transmission and distribution company, has recommended that storage systems are sized at 14 percent of the installed generation capacity.

3.6.3 Battery manufacturing plants

Up Energy Development Group has commenced construction of a Vanadium Redox Battery (VRB) manufacturing plant in Inner Mongolia with an annual output of 2GW/10GWh of batteries per year. The plant will be powered by a wind-solar-storage renewable precinct by Up Energy Development Group Limited comprises of 150MW wind, 30MW solar and 30MW/300MWh VRB battery storage.

An additional VRB manufacturing plant in northern China by Golden Energy Century Ltd aims to produce an annual output of 1GW / 6GWh.

These are just two examples of a large trend towards increasing battery manufacturing capability in China. Large growth in demand is forecast across a number of applications, including transport (trains, electric vehicles and electric bicycles), military applications and energy market applications.

3.6.4 Transportation

China has the world's longest high-speed rail operation and is also trending towards electric vehicles (particularly electric bicycles) for private transport. Both these markets will play a large role in growing demand for advanced battery systems, supporting the development of new large manufacturing facilities.

Case study: Demonstration projects in China

Other than the mandated pairing of energy storage with renewable projects, the immediate future of the energy storage market in China will be entirely reliant on demonstration projects. Projects are expected to be focused on microgrid, distributed generations, industrial solar and even end user demand management applications. In addition, the Central government is promoting up to 100 “Smart-Cities” to be set up where they believe solar-storage modular packages are to be used in large numbers in the power distribution network.

An example demonstration project is the Zhangbei wind-solar-storage project by State Grid in Northern China, which is currently in operation (first stage only). It comprises of 100MW of wind, 40MW of solar and 14MW storage (an additional 6MW is planned). It is interesting to note that the 14MW storage already installed uses Li-ion batteries, however the additional 6MW may not utilise Li-ion technology, with VRB and even Lead-Carbon (PbC technology) also under consideration.

3.6.5 Key observations and learnings for Australia

The policy of mandatory pairing of generation systems with storage appears ambitious, expensive and potentially inefficient due to the untargeted nature of the rollout and a risk of unutilised storage capacity. It is noted that for most systems, the installation of storage will deliver very poor economic returns as the storage system may not provide additional revenue for the generator. This is very different to other international markets that attempt to target projects where storage can add the most value.

The demonstration project model appears to be effective in slowly building an energy storage market, leading to commercialisation of the product. This gives China time to create the market structures, technical learnings and design standards to support commercialisation of the energy storage market.

While the general technology preference in China has been Li-ion technologies, it is still very interesting to note the very large investments being made in VRB technology. It is possible that this is a reaction to instances where overheating and fires occurred on Li-ion demonstration projects.

Table 17 Investment focus for China

Market segment	Investment focus
Supply-side	Low
Transmission and distribution	Medium
End user	Medium
Off-grid	Unknown

3.7 Japan

3.7.1 Background

Japan is Asia’s 2nd largest consumer of electricity, yet it is highly dependent on foreign fossil fuel reserves for electricity generation. Japan is the world’s largest importer of liquefied natural gas, the second largest importer of coal and third largest importer of oil [51].

Historically, Japan has a strong history of utilising energy storage technologies to reduce demand variability from its nuclear generators. This included the development of 25 GW of pumped hydro storage, followed by 74 MW of sodium-sulfur batteries [19]. Japanese company Nippon Gaishi Kaisha is the world leader in sodium-sulfur batteries, although demand for this technology is growing at a much slower rate than Li-ion technology. Japan has the only operating sea-water pumped hydro storage facility in the world.

Prior to the Fukushima earthquake in 2011, Japan was the world’s third largest producer of nuclear power, accounting for 26 percent of the country’s electricity supply. Since then, regulations on seismic resilience have become so stringent that two thirds of the country’s reactors are likely to never resume operation [51].

Having lost over 60GW of nuclear capacity, Japan is in a vulnerable position and is looking to utilise renewable energy to reduce its dependence on foreign fossil fuel imports. This commenced with the introduction of feed-in tariffs to promote investment in a variety of renewable technologies (both residential and utility scale). Japan currently has a relatively low penetration (approximately 8 percent hydro, 2 percent wind and solar) of renewables [52], and while Japan doesn’t have a mandated target, the environment minister has been quoted saying 30 percent of Japan's energy should come from renewables by 2030 [53]. With such ambitious renewable energy targets, Japan has recognised the role of energy storage in facilitating large penetration of intermittent generation.

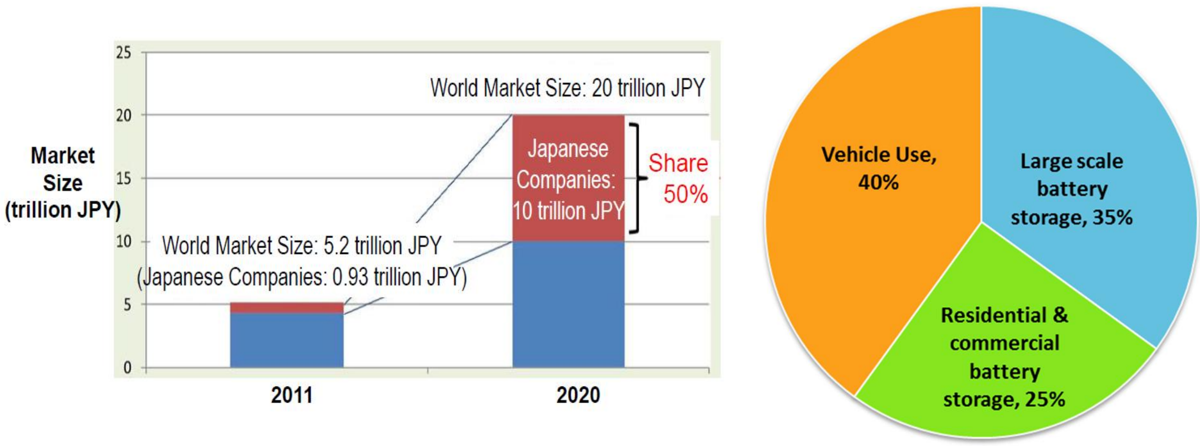
Currently the Japanese government subsidises individuals and businesses up to two-thirds of the purchase price for Li-ion storage solutions as discussed in 3.7.3 [54].

3.7.2 Storage Battery Strategy Project

In 2012, the Ministry of Economy, Trade and Industry set up the storage battery project team which is responsible for battery industry and information policies, overseeing energy policies and supervising industrial policies for the application of storage batteries. The goal of the team is to "formulate and implement integrated strategic policies for storage batteries, including creation of future storage battery markets, industrial competitiveness enhancement, and international standardization of relevant technologies" [55].

The government is aiming for Japanese companies to achieve around half of the world's battery storage market share by 2020 in order to see how mass production will reduce battery prices and aid in energy self-sufficiency for the country.

Figure 17 Forecasted installation growth in the battery market (trillion Japanese Yen), including target market share/segments for Japanese battery companies [56]



3.7.3 Battery storage subsidy

Japan has a new subsidy program to support the installation of stationary Li-ion batteries by individuals and businesses. The subsidy is set to cover up to two thirds of the cost of the storage system, paid by Ministry of Economy, Trade and Industry with a budget of $US98.3 million. Payments will be capped at US$9,846 for individuals and US$982,000 for businesses installing battery systems with a capacity of 1kWh or more. [57]

Case Study: Microgrid demonstration project

The Ministry of Environment has a budget of US$7 million per year for three years to fund low-carbon microgrid demonstration projects that incorporate renewable energy production and energy storage systems. The Ministry of Environment will fund up to 75 percent of the project costs with an aim to facilitate the development of self-sufficient, disaster-resistant community microgrids. The program is open to municipalities as well as private firms. [58]

3.7.4 Key observations and learnings for Australia

Japan has a strong history promoting energy storage (i.e. pumped hydro and sodium sulphur rollout) as a means of balancing supply and demand. Historically, Japan has not favoured any single application of energy storage, with broad support across the electricity system. However, the current battery storage subsidy provides funding for only the Li- ion technology.

Table 18 Investment focus for Japan

Market segment	Investment focus
Wholesale	Medium
Transmission and distribution	
End user	
Off-grid	

3.8 South Korea

3.8.1 Background

Over 90 percent of South Korea's electricity is provided by the vertically integrated company KEPCO, which is 51 percent government-owned [59]. South Korea is heavily reliant on non-renewable sources such as coal (45 percent), gas (21 percent), and nuclear (29 percent), while non-hydro renewables comprises less than 1 percent of total energy sources. In addition, South Korea is heavily dependent on global markets as over 96 percent of total energy is imported [60], and is vulnerable to supply shortages [61].

South Korea is home to several leading battery manufacturers including Samsung, Kokam and LG, and is moving towards incorporating smart grid technologies such as the use of energy storage for demand management [60].

In 2011, South Korea announced that it would invest US$5.94 billion by 2020 in developing the energy-storage industry - one third on R&D and the rest on building infrastructure. The government will participate along with private companies.

3.8.2 KEPCO energy storage drive

KEPCO is purchasing 52MW of Li-ion batteries for frequency regulation in a market estimated to be 1.1GW. The 52MW is split across two plants and attached to substations. KEPCO estimates it can purchase an additional 500MW for the same task out to 2017. The project is driven by a number of motives: first, it is expected that the storage facility will be cost competitive with existing frequency regulation providers, while providing a higher level of service (i.e. faster response). This will also release additional thermal generation capacity (currently reserved for frequency regulation) and put downward pressure on wholesale costs. [62]

In addition, metro rail providers are installing and operating over 20 MW of ultra-capacitors in order to save energy through regenerative breaking and provide voltage stabilisation to the grid [63].

South Korea is pushing towards development and demonstration of smart grids with the establishment of policies and trial programs across the whole of Jeju and Gapado islands [64]. Their smart grid development is largely focused on developing software and IT systems to better utilise and connect existing grid infrastructure. The smart grid initiative is expected to utilise 7MW of Li-ion storage, with 3MW dedicated directly to supporting renewables penetration, through time shifting and capacity firming [19].

3.8.3 Key observations and learnings for Australia

South Korea is focusing its research on the communications element of the storage system. This is reflective of a proactive decision to focus on its relative research strengths, where it can achieve technological breakthroughs.

Energy storage integration into railway systems is an additional valuable application for storage. By harnessing kinetic energy that would otherwise be lost, it provides the opportunity to provide grid support services, market arbitrage and power quality services. One drawback is that this application has no direct link to renewable energy.

Table 19 Investment focus for South Korea

Market segment	Investment focus
Wholesale	Low
Transmission and distribution	
End user	Medium
Off-grid	N/A

3.9 Germany

3.9.1 Background

Germany has a history of strong leadership in energy technology and policy, including innovative and ambitious support programs such as their feed-in tariffs to support renewable energy generation. German policy example and experience is often considered by countries seeking to follow Germany's lead when designing energy policy and programs. Like Australia, Germany has a high proportion of PV installations as residential systems.

Germany has a lower quality of renewable resources compared to Australia, however, the favourable policy and investment environment has resulted in Germany quickly moving to nearly 30 percent renewable energy, with wind contributing 10 percent, biomass 8 percent and solar 7 percent making the largest contributions [65].

Energy storage is viewed as an essential enabling technology required to facilitate Germany's 50 percent renewable electricity target for 2030.

3.9.2 Programs

Storage initiatives in Germany take several forms. While there are no direct storage targets, the German Federal Environment Ministry (BMU) has introduced a number of incentives, each initiative targeting different market segments. These include combinations of grants and low interest loans financed through KfW (a German government-owned development bank). In addition, electricity storage facilities are exempt from many fees and charges, such as renewable energy levies and grid tariffs [66].

The programs listed below are technology agnostic, and do not specify batteries in particular. Only the storage components of the programs have been listed – other infrastructures may be eligible for the programs in question.

Table 20 Programs in Germany for storage support. [67]

Program	Description	Target group	Specified storage purpose(s)	Support mechanism	Other
KfW 203	Financing for **energy efficiency** projects (energy storage projects included)	Local authorities and community organisations	None	Low interest finance	Interest rate: 0.6-1.3 percent up to 30 yrs
KfW 204	Financing for energy supply projects (**thermal** storage projects included)	Companies with less than 5 percent market share (generation) and PPPs	None	Low interest finance	Up to €50 million per project. Negotiated interest rate. 1-5 year period of no repayment.
KfW 274	Energy Storage in **combination** with PV	Households and private companies	Load management	Low interest finance	Up to €25 million per project. 1-3 year period of no

Program	Description	Target group	Specified storage purpose(s)	Support mechanism	Other
					repayment
KfW 275	Energy Storage in **combination** with PV (Max 30kW). Must allow NSP control and must reduce PV peak by 40 percent of rated capacity.	Private Consumers	Peak shaving	Grants, low interest finance	Grant up to 30 percent of investment.
KfW 291	*Energiewende* – energy supply, efficiency, storage and **transmission**	Companies	Storage for energy efficiency or load management, or R&D for general storage	Low interest finance	Loans from €25 to €50 million. Fixed interest rate for 10 years
KfW 230	Environmental **Innovation** Program	Companies	None	Grants, Low interest finance	Grant up to 30 percent of investment. 5 year minimum

Of these programs, KfW 275 (Peak shaving for private PV and storage systems) is expected to be the most relevant for promoting energy storage due to its generous grant, economic application (behind-the-meter storage) and large market size. In addition, many commentators such as EuPD estimate that market growth in storage will be driven primarily by the residential sector, as there are a high proportion of residential PV installations receiving low feed-in tariffs exposed to high residential electricity prices [68]. More than two-thirds of German PV installers are now offering storage options to their customers, and 90 percent of installers have expressed a desire to do so. Currently, nearly 2 percent of PV households have installed battery storage. High upfront costs are considered to be the major obstacle to purchase. As such, the grant component KfW 275 is considered by the EuPD to have driven the uptake in storage solutions relative to other European countries [69]. As of late 2013, the German government had provided over €32 million in loans and €5 million in grants [70].

In addition it is worth noting that utility-scale battery projects are also being built to support network operation. The Schwerin battery (5 MWh) is owned by the WEMAG AG utility, which received over 80 percent of its energy from wind power in 2013. The storage facility was designed to even-out short term fluctuations across their network [71]. Utility-scale batteries are also being installed alongside generation plants, such as the 1.6 MW battery paired with the 67.8MW Alt Daber solar plant, which allows for the plant to provide ancillary services by feeding primary operating reserve power directly into the 110 kV distribution network. This project required government funds to be economical [72].

Case Study: 5 MW / 5 MWh commercial battery
Europe's largest commercial battery power plant was connected to the grid in Germany in September 2014. The 5 MW / 5 MWh Li-ion battery was installed to support a regional distribution grid with 80% renewable penetration, expected to approach 100% during 2015. The battery is owned and operated by WEMAG AG, a German green energy and natural gas utility that also operates the grid. With a response time measured in milliseconds, it is expected to help stabilise frequency, balance unpredictable renewable output, control voltage , provide black-start capability, and offer short-circuit protection for the grid. The project was given a €1.3 million grant from the Federal Environment Ministry's Environmental Innovation Programme to cover first-of-a-kind technology risk, with the rest of the costs expected to be recovered through competing in the primary frequency regulation market [73].

3.9.3 Key observations and learnings for Australia

Germany is allocating its funding for energy storage across each of the markets segments and applications with a slight preference towards the residential market. The driver for supporting energy storage is often linked directly with renewable energy, particularly in areas of the grid with high penetrations of renewable generation (larger than 50 percent). Storage can reduce curtailing of renewable generation and reduce the requirement for networks to be upgraded to better host large amounts of renewable generation.

A standout feature of the German programs is the requirement for grant recipients in the KfW program to allow the utility to control the operation of installed household energy storage. This feature is designed to ensure that benefits from efficient network operation can be achieved and benefit the broader population. It also allows the network to compile a registry of battery storage systems, providing insight into the impact of their use.

Table 21 Investment focus for Germany

Market segment	Investment focus
Wholesale	Medium
Transmission and distribution	
End user	High
Off-grid	Not applicable

3.10 United Kingdom

3.10.1 Background

The United Kingdom has a target of 15 percent of total energy from renewable sources by 2020. In the electricity sector, wind and solar already make up 15 percent of electricity generation due to incentive schemes such as feed-in tariffs and the renewables obligation for utilities.

The electricity sector is currently undergoing reforms, including the addition of a UK wide electricity capacity market to complement the energy market, and feed-in tariffs to replace the renewable purchase obligations. The Secretary of State for Energy and Climate Change claimed that the capacity market would help facilitate the introduction of energy storage technologies [74]. However, the changes have proven to be more supportive of existing thermal generation facilities (who have received windfall profits) and provide little competitive incentive for the development of storage facilities [75].

According to the Energy Storage Operators Forum [76], there is a range of storage applications proposed and deployed across the electricity system. The projects proposed and deployed by the Department of Energy and Climate Change and by DNSPs as of December 2014 are shown in Figure 18 and Figure 19.

Figure 18 Location of proposed and deployed storage by DNSPs and Department of Energy and Climate Change as of 1 Dec 2014 [76]

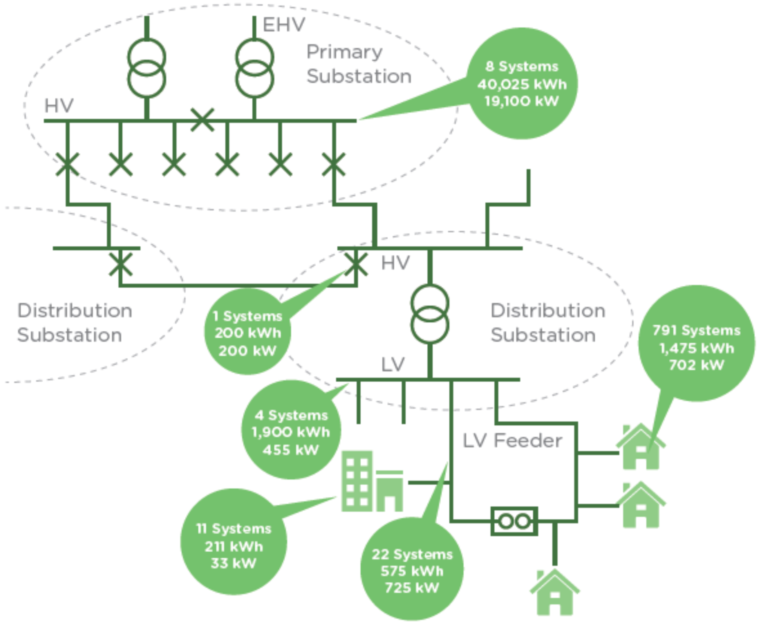
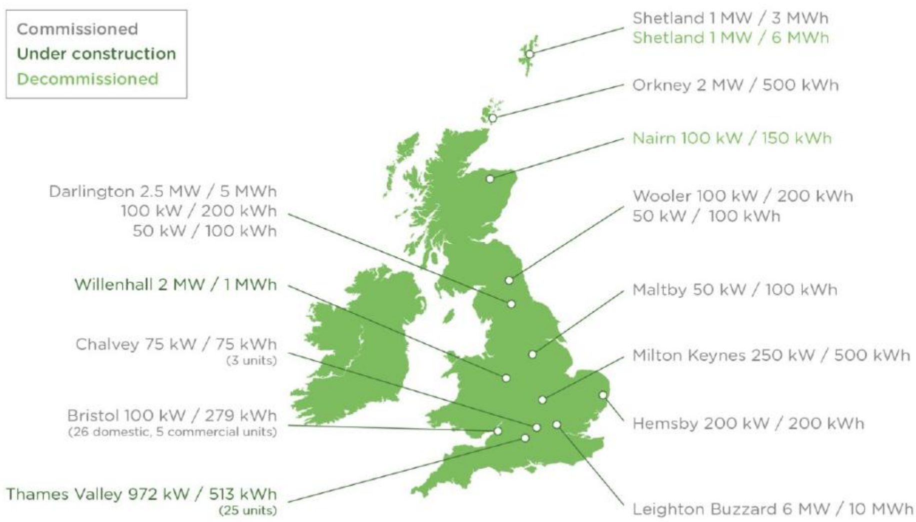


Figure 19 Geographic distribution of proposed and deployed storage by DNSPs and Department of Energy and Climate Change as of 1 Dec 2014 [76]



While learnings are being supported across the electricity system, it is clear that the primary focus is currently at the primary substation level.

3.10.2 Energy Storage Technology Demonstration program

Since 2010, the public sector has provided more than £50 million for research, development and demonstration of energy storage [77]. The Department of Energy and Climate Change has allocated a £17m fund for Energy Storage Technology Demonstration. Recently, this program awarded £8m to the below four projects [78]:

A 5 MW / 15 MWh Liquid Air Energy Storage system using waste heat from landfill gas to balance supply and demand

0.5 MW demand response batteries installed across 300 households

1.26 MWh Vanadium Redox flow system in the Isle of Gigha (Scotland), primarily to support the high amounts of wind penetration. This occurs through removing constraints on generation time, allowing sale of wind energy at peak times, and also grid support through voltage control, frequency control and short-term operating reserve.

The development of a potential solution to use recycled EV batteries for network reinforcement and support intermittent renewable integration

3.10.3 Low Carbon Networks fund

The British Office of Gas and Electricity Markets (OfGem) has established a Low Carbon Networks fund, which allows up to £500 million facilitating the take up of low carbon and energy saving initiatives by NSPs. Eligible projects include electric vehicles, heat pumps, micro and local generation, smart meter rollout and demand side management. The fund is split into two separate tiers: the first targets small-scale projects while the second tier targets a small number of flagship projects (up to £64 million allocated annually).

Case Study: 6 MW /10 MWh Li-ion battery at a primary substation in Bedfordshire

In this project, S&C Electric, Samsung SDI, and Younicos collaborated to construct a 6 MW /10 MWh Li-ion battery at a primary substation in Bedfordshire. The project aims to assess the cost effectiveness of energy storage as a tool to reduce capacity constraints and balance intermittent generation from solar PV and wind.

The £18.7 million project is funded by £13.2 million from the Low Carbon Networks Fund, £4 million from UK Power Networks, and £1.2 million from other sources. Operation commenced on December 15 2014. [79]

Case Study: 1 MW battery on Shetland Islands

As a part of the Northern Isles New Energy Solutions Project, OfGem funded £1million to a 1 MW, 6 MWh NaS battery on Shetland Islands (Scotland) to reduce peak demand on diesel generation and to increase the knowledge and understanding of battery operation within a network environment. Building commenced in February, 2011, but 2 weeks prior to the scheduled date of operation in 2012, there was a fire at a NaS installation in Japan. NGK (battery manufacturer in Japan) recommended that all NaS battery installations worldwide shut down until the root cause of the fire was determined. Although safety modifications were determined to substantially reduce the risk of fire, the associated consequences involved switching off the power supply to all of Shetland Island. Since there was no suitable solution to extinguishing the fire within a reasonable timeframe, it was decided that NaS batteries were no longer safe enough for the project. A 1 MW, 3MWh valve regulated lead-acid battery was selected as an alternative to complete the project. It was installed in 2014 and was operational for 4 months, proving successful in reducing peak summer demand, and cycling efficiently to serve the needs of the islands' generation and load profile. The project also provided learning in areas of procurement, design, construction, installation, commissioning and safety for both NaS and lead acid batteries. The second phase of the project will aim to avoid renewable generation constraints, optimise power station operation, as well as improve stability control and ancillary services [80]

3.10.4 Scotland

Scotland has an ambitious renewable energy target of 100 percent by 2020 as well as public support for higher energy independence from the UK. There are several islands in Scotland where energy storage is used to facilitate renewables, including Orkney (Li-ion, 2 MW, operational 2013 [81]), Isle of Eigg (lead acid, 212 kWh, operational 2008 [82] & flywheels, 200kW, operational 2014 [83]), Isle of Gigha (vanadium, 1.25 MWh, est. operational mid 2015 [84]), and Unst (hydrogen fuel cell [85]). In 2011, the route map towards 2020 described the energy storage priorities for the Scottish Government as per below [86]:

- encouraging the UK government to incentivise storage technologies in the capacity market
- undertaking modelling and analysis for characteristics of peak flows
- exploration of the potential for heat storages
- exploration of the support needs for small decentralised storage
- exploration of funding options for energy demonstration projects.

Case Study: 100MW AES Corporation Kilroot Li-ion battery (Northern Ireland)
Currently under construction, the AES Corporation Kilroot Li-ion battery array in Northern Ireland is possibly the largest electro-chemical storage project in the United Kingdom. The100 MW energy storage plant will facilitate higher wind penetrations by reducing wind curtailment, whilst also provide ancillary services, such as frequency control. Currently over 2 percent of wind generation is curtailed in Northern Ireland due to a mismatch between demand and supply. AES Corporation selected Li-ion batteries due to their high efficiency and scalability [87].

3.10.5 Key observations and learnings for Australia

There is a focus on both demonstration and utility scale energy storage projects. This is typically in areas of high renewable energy penetration, for both DNSPs and third parties. The financial support for these storage projects come from grants for network innovation or low carbon networks from a range of sources (Low Carbon Networks Fund, UK Power Networks and OfGem), which allows for a variety of different approaches rather than requiring Department of Energy and Climate Change or OfGem to pre-empt the best outcome. A framework for adaptive learning is created by maintaining an emphasis on synthesising and sharing knowledge on a variety of storage projects.

The Kilroot Li-ion battery project has the potential to demonstrate the effectiveness of energy storage to reduce wind energy curtailment and the provision of FCAS. Whilst Scotland's broader approach to electrification on its many islands could be an approach for Australia's fringe-of-grid areas, by increasing the amount of storage to provide self-reliance from the grid.

Table 22 Investment focus for UK

Market segment	Investment focus
Wholesale	Medium
Transmission and distribution	
End user	Low
Off-grid	Medium

3.11 Italy

3.11.1 Background

Italy's economy has been strongly impacted by the global financial crisis which has also contributed to high electricity prices, as well as financial hardship for a number of participants in the energy sector. The country has a high dependence on fossil fuel imports and a shortage of supply during peak demand periods. In an effort to achieve competitive and sustainable growth, the Ministry of Economic Development (MiSE) has developed a National Energy Strategy which focuses on providing affordable, high quality energy with limited environmental impact. With renewable energy becoming increasingly recognised as an opportunity for economic recovery, the strategy seeks to increase the renewable energy target of 20 percent by 2020 (which was exceeded nearly 8 years ahead schedule thanks to very generous incentives, which focused on rooftop solar) [88].

Nonetheless, the very high penetration of rooftop solar has caused challenges and additional costs within distribution networks. This has led to interest in energy storage to address peak demand and reduce reverse flow.

Case Study: Terna energy storage projects
Terna is a leading Transmission Network Service Provider (TNSP) in Italy and has invested €31 million in energy storage projects [89]. In an attempt to ensure reliable and cost-effective integration of renewables to the grid, Terna has launched a program through its subsidiary Terna Storage that focuses on development and implementation of energy storage projects for the transmission network. The program consists of an energy-focused project and a power-focused project, see details below [90].
Energy-intensive project
This project consists of three storage systems in southern Italy, totalling 34.8MW, aiming to ensure flexibility in the management of renewable power plants and improve the capacity of the transmission grid to carry renewable power. The program will allow for load shifting of wind farm output to recover hundreds of GWh that is currently being curtailed. This project will increase the efficiency of the network and reduce the cost of energy [90].
Power-intensive project
Approved in 2012, this project will install 40MW of energy storage capacity to increase security of electricity networks and develop smart grid applications. The first phase of the project comprises of 10MW Li-ion and 6MW of various other battery technologies for comparison purposes [89]. Following positive initial results, phase 2 was announced, consisting of 20MW Li-ion battery and a 4MW sodium-nickel-chloride battery [19].

3.11.2 Domestic energy storage regulations

While the investment focus on storage projects has predominantly been at the utility level, some commentators suggest that new regulations may enable faster uptake of storage systems at the household level. The Regulatory Authority of Electricity and Gas set new rules stating that batteries must be considered as production facilities and will be incentivised accordingly [91]. Italian battery and battery-inverter manufacturers are currently producing household storage systems for the German market. This experience is expected to lead to improved accessibility for the Italian household market as costs decline [92].

3.11.3 Key observations and learnings for Australia

While there is no clear long term strategy for investment in energy storage, Italy has implemented some impressive large-scale demonstration projects, covering applications for renewable integration (wind firming / generation shifting), power quality and efficient network operation.

While the residential storage incentives are not yet in place, there is clearly a large opportunity within the residential market for combining energy storage with rooftop solar, especially given the participation of Italian companies in the German residential market.

It is also interesting to note the preference for Li-ion technology in the utility scale projects.

Table 23 Investment focus for Italy

Market segment	Investment focus
Wholesale	Low
Transmission and distribution	Medium
End user	Medium
Off-grid	Low

3.12 Other markets

Brief descriptions of the status of the energy storage markets in some other international markets are provided in the table below:

Table 24 Overview of government actions supporting energy storage deployment [12]

Market	Organisation and overview	Installed battery capacity (MW) [19]
Canada	Ontario Ministry of Energy - As a part of the long-term energy plan, the Ontario government will	7.9 MW 6 Projects

Market	Organisation and overview	Installed battery capacity (MW) [19]
	include storage technologies in its competitive procurement model for renewable energy. Initially, 50 MW of storage technologies will be installed to assist with the integration of intermittent renewable generation, optimise electric grid operation, and support innovation in energy storage technologies [12]. - Of the 50 MW of storage to be installed, 35 MW is to be procured by the Independent Electricity System Operators who have contracted 5 companies that offer ancillary services to support increased reliability and efficiency of the grid [93]. The cost of these contracts is expected to be approximately $14 million per year for three years. - The remainder of the target is to be procured by Ontario Power Authority who is aiming to use energy storage for time-shifting of energy production and consumption. For each project the Contract Power Capacity must be between 500-2,000 kW and to be able to fully charge/discharge (cycle) from/to the Transmission System or a Distribution System within a 24-hour period delivering the Contract Power Capacity over a minimum of four hours [94].	
European Union	European Commission – Framework Research Programme (FP7) - Co-funding (with the Intelligent Energy Europe Programme) of the stoRE project, with the goal of creating a framework that will allow energy storage infrastructure to be developed in support of higher variable renewable energy resource penetrations. Target countries include Spain, Germany, Denmark, Austria, and Ireland.	N/A
Puerto Rico [95], [96]	- The Puerto Rico Electric Power Authority Requires all new solar and wind to add 30 percent nameplate capacity to intermittent generation facilities for FCAS, and maintain 45 percent of the capacity in reserve for at least 1 minute for ramping control.	Not available
India	- India is pursuing renewable energy and energy storage as a secure power resource for more than 300,000 telecom towers, and announced a $40 million contract in July 2013 for Li--ion battery energy storage systems to meet that need. It is estimated that 100,000 towers are already using storage [97] - As a high proportion of rural communities remain un-electrified, micro or minigrids are often touted as a method of delivery. Companies such as ABB see this as a large potential market [98], and India Electronics and Semiconductor Association consider this the largest portion of a 15 - 20 GW market [99]. - While there is little physical development of utility scale storage, there has been in recent times the development of a storage ecosystem including R&D, identifying opportunities for storage, facilitating stakeholder meetings, and building an ancillary market [100] - In addition, there are also many household storage battery systems typically used for UPS due to poor electricity reliability. As such, limited renewable facilitation and network benefits were not drivers for the installation of these batteries.	100,000 projects 85kW 2 Projects
New Zealand [101] [102]	Vector - As a solution to reduce demand from households on the grid, especially in the evenings, New Zealand's largest Distribution Network Service Provider (DNSP), Vector ran a trial of leases to its customers to install rooftop solar with Li-ion battery storage for around the same price as electricity. Vector installs smart meters and monitors the performance remotely. - The trial started in 2013 and has reached over 300 rooftops in 10 months. The offer included a 3kW PV array, an inverter and 10.7kWh battery, with	~3000 kWh 8kW 2 Projects

Market	Organisation and overview	Installed battery capacity (MW) [19]
	the array expected to produce 12kWh a day. - The most attractive leasing option appears to offer a system with a down payment of NZ$1,999 followed by monthly payments of NZ$70 over the course of the 12.5 year lease. Vector has ownership of system and is responsible for maintenance and repair.	
France	NOME Act - France is moving towards a regulatory framework that supports energy storage. The NOME Act will give competitive value to the power capacity made available to the grid. Energy storage will gain value through capacity certificates and according to the proposed market design, energy storage systems will be financially reimbursed for both charging and discharging, relative to other forms of capacity. The capacity market isn't expected to appear until 2017 [103]. French Islands - With many French Islands reaching 30 percent renewable penetration, the France energy regulating body CRE now requires all new renewable energy projects in these areas to include energy storage to facilitate grid integration. Energy storage is seen as an area of opportunity for technology testing in an emerging field for French companies. A €34 million solar and storage project on Réunion Island has received funding under arrangement where the system operator must predict how much electricity will be fed into the grid a day in advance and is penalised if the actual output doesn't meet predictions. The project will consist of a 9MW PV array with 9 MW li-ion batteries [104].	5.4 MW 6 Projects
Belgium	- As Belgium plans to move away from nuclear power, they are planning to construct a 2 GWh ring island with the purpose of storing off-shore wind energy. This will support an eventual 2300 MW of off-shore wind. During times of excess wind, the turbines will pump water out of the reservoir, reminiscent of pumped hydro [105].	N/A
Spain	- According to the DoE database, 7.9 MW of storage exists or is planned in Spain, 80 percent of which is utility owned [19]. - Across the Canary Islands, there are a few energy storage programs of different technologies built to firm renewables development. These are a 4 MW ultra-capacitor, a 1 MW Li-ion system and a 0.5MW flywheel. These are partially financed by the Centre for Industrial Technological Development and the EU [19]. - Iceland, Liechtenstein and Norway are providing a portion of an €18 million grant for energy storage projects in Spain [106]	7.9 MW 13 projects
Singapore [107]	Energy Market Authority - Singapore is launching a SG$25m fund for storage and related technologies to support grid stability at the same time as it plans a ramp up in installed solar installations. It will be focused on development and installation of large scale grid-level systems. Focus may include peak shifting, FCAS and renewable energy support. Further details will be available later in 2015.	N/A

3.13 International market summary

Given the various applications of energy storage, it is not surprising to observe that international markets are customising their investment in energy storage according to the unique characteristics of their own energy markets. Key characteristics that influence the investment response in international markets include:

- high penetrations of distributed rooftop solar

- technical issues such as reverse power flow and voltage rise

- high penetrations of utility-scale wind and solar
  - network constraints
  - propensity for excess night time wind generation to exceed demand
  - intermittency creating a requirement for FCAS
- network planning methodologies and drivers
  - existing capacity issues caused by a poor planning
- regulatory restrictions
  - project developers ability to monetise all services provided by project
  - whether NSPs can get regulatory approval to proceed with energy storage projects

All of the markets considered in this report utilised a NSP-led program, with methodologies ranging from demonstration projects and incentive programs to mandated targets.

It is clear that California and Germany have setup the most thorough energy storage programs. Each of these programs spread the investment focus across all applications, putting the onus on utilities to meet the program objectives, while supporting private users with direct rebates.

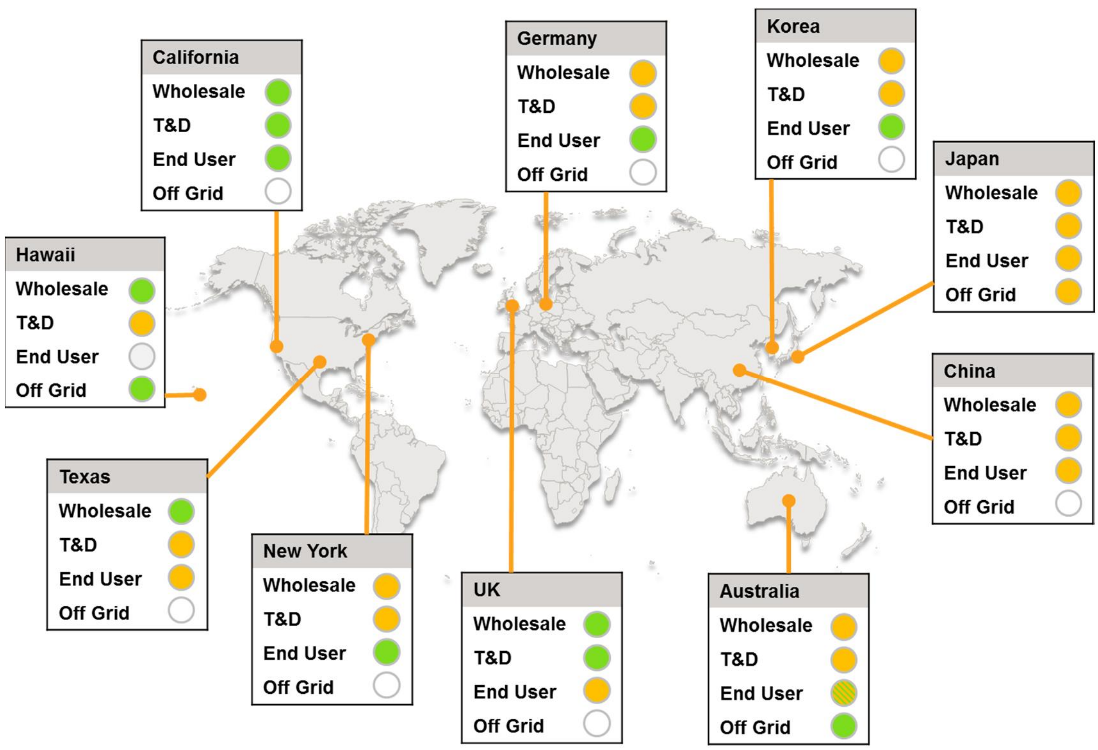
Some other notable observations include:

- Most countries are supporting R&D and targeted demonstration projects for promising storage technologies.
- Utility scale storage is a common demonstration projects, often combining applications such as meeting peak demand, shifting and smoothing renewable generation and frequency regulation. These projects can also offset network augmentation, however, this was rarely stated as a project driver.
- Li-ion is currently the technology of choice in most markets due to factors such as high efficiency, long lifecycle, cost-competitiveness and perceived safety.
- While not making up a large proportion of the investments, microgrids (including island grids) are a key application for facilitating very high penetrations of renewables.
- Information systems are key – either development of the correct markets or the development of communication overlay systems.
- While many countries discuss the benefits of energy storage and have completed demonstration projects, very few have implemented policies to help create a self-sustaining market.

Figure 20 Summary of energy storage market activities [19]

	No.	MW	Wholesale	T & D	End user	Off-grid	Support Method			
Region	**Installed pilots** (utility scale battery only)		**Market focus**				**Storage target / mandate**	**Utility-led rollout**	**Direct funding**	**Finance**
California (USA)	50	32	✓	✓	✓		✓	✓	✓	
Hawaii (USA)	13	29		✓	✓	✓		✓		
New York (USA)	10	11		✓	✓			✓	✓	
Texas (USA)	5	42	✓					✓		
China	53	48	✓	✓	✓	✓		✓	✓	
Japan	28	94		✓	✓	✓		✓	✓	
South Korea	27	32		✓	✓			✓		
Germany	18	12	✓	✓	✓			✓	✓	✓
United Kingdom	17	12	✓	✓	✓	✓		✓	✓	
Italy	13	6		✓				✓	✓	
Australia	8	4.4				✓			✓	✓

Figure 21 Illustration of international storage markets



4.0 Domestic Market Review

While Australia has over 1.5 GW of pumped hydro storage operating in the National Electricity Market, few grid-connected battery, thermal or mechanical energy storage systems have been constructed. In addition, there are no examples of CAES, NaS or liquid metal technology installations and no large-scale pumped hydro facilities have been built in Australia within the last 30 years [108]. Most of Australia's battery storage systems have been installed by off-grid customers using a combination of batteries, PV and/or wind supported by diesel fuel generation. The uptake of energy storage technologies (other than pumped hydro) has been largely restricted by price barriers, but falling battery prices over the next ten years is expected to lead to strong growth in this sector.

Additional barriers that are expected to slow the uptake of storage technologies include:

- insufficient demand-side incentives such as cost-reflective tariffs (further hindered by lack of smart meter infrastructure to facilitate cost reflective tariffs) and demand management incentives
- absence of well progressed design standards and codes
- insufficient provision for the use of storage technologies under the current National Electricity Rules.

Currently, the most relevant cost-effective applications for storage technologies include facilitating renewables in off-grid, fringe-of-grid markets, and behind-the-meter applications, which can capture a range of energy storage benefits. Other applications, including demand management, power quality, reliability, and deferring network augmentation also have potential; however these functions can be delivered using demand management practices such as load curtailment or embedded generation. If these competing technologies can deliver more cost effective solutions to reducing network augmentation, energy storage may only have an indirect role in this space where energy storage installations have a different primary application (e.g. behind-the-meter tariff arbitrage) but also provide value for network management (whether it was intended or not). The key drivers for future uptake of storage technologies include continued price reductions (or incentive programs), the rollout of interval/smart meters, cost-reflective network pricing structures and increasing levels of rooftop PV.

4.1 Key characterisation of the Australian electricity market

The role of energy storage as a means for enabling further deployment of renewable generation must be shaped by the characteristics of Australia's electricity market. This includes consideration for localised high concentrations of intermittent generation (both embedded in distribution networks and at a utility scale), Australia's relatively large fringe-of-grid and off-grid sectors, power quality requirements and value, and the potential role of electric vehicles to provide large-scale rollout of storage capability. A brief context of these factors is provided below.

The Renewable Energy Target (RET)

The RET scheme is designed to ensure that 20 percent of Australia's electricity comes from renewable sources by 2020. It is composed of a Large-scale Renewable Energy Target, which focuses on the establishment of utility-scale renewable energy power stations, typically wind and solar farms; and a Small-scale Renewable Energy Scheme which provides incentives for households, small businesses and community groups to install eligible small-scale renewable energy systems, typically rooftop solar PV systems but also solar water heaters, heat pumps, small-scale wind systems or small-scale hydro systems [109]. The RET has driven the uptake of large-scale wind, rooftop PV and off-grid hybrid renewable projects. Including hydro generation, renewable energy accounted for almost 15 percent of Australia's total electricity generation during 2013 [110].

High penetrations of wind generation in localised areas - South Australia

A disproportionate amount of utility-scale wind farms developed under the RET have been developed in South Australia, due to the abundant wind resource and favourable planning and approvals conditions. In 2013-14, wind generation provided 31 percent of South Australia's total energy demand, giving it the highest penetration of wind in the country. With installed capacity exceeding maximum instantaneous demand, South Australia delivered 100 percent of its electricity demand with wind for the first time on 28 June 2014 between 4:10 am and 4:35am. See Table 25 for the penetration of wind generation using four different measurement indices.

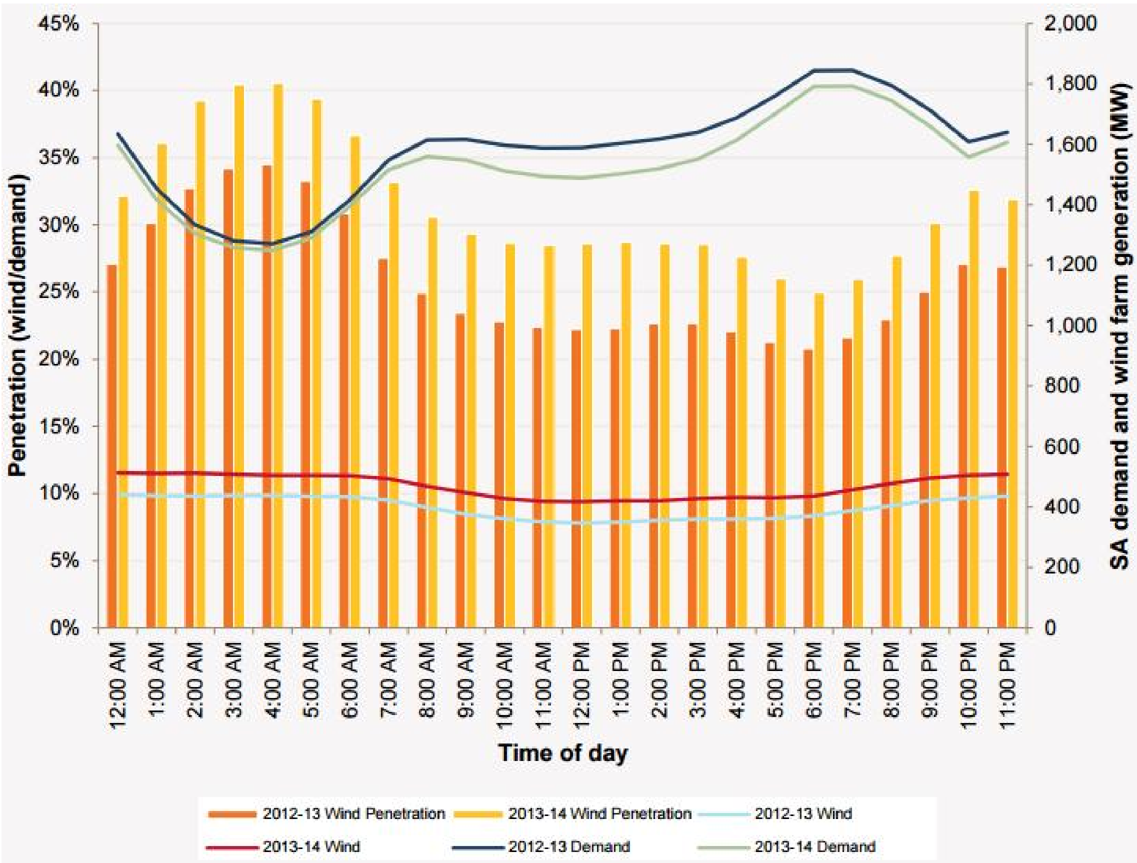
Table 25 Penetration of wind generation in South Australia [111]

Description	2012-13	2013-14
Capacity penetration: installed capacity as a percentage of total installed generation	27%	31%
Energy penetration: ratio of annual wind energy to annual total energy demand	25%	31%
Maximum instantaneous penetration (excluding exports): maximum observed ratio of wind energy to demand over a defined period (typically one year) at any instant in time	88%	100%
Maximum possible instantaneous penetration: the ratio of installed capacity to minimum demand	116%	154%

Due to the intermittency of wind generation, high levels of generation have led to a challenging environment for the South Australian network providers. Notably for 10 percent of the time, absolute wind variation in the south-east and coastal regions can fluctuate by more than 6 percent in a 10 minute period. This variation in generation requires faster and more responsive units than less intermittent generation sources. High variations of wind generation is particularly challenging when the South Australia-to-Victoria interconnector is constrained. Energy storage could help address this challenge by providing load shifting and load smoothing capability.

Wind generation in South Australia typically peaks overnight from around 10:00pm through to 7:00am the next day, which coincides with low electricity demand. Electricity demand is highest between 7:00am through to 8:00pm. This creates an opportunity for bulk energy storage to shift the overnight high generation period into the day to address the discrepancy between wind generation and daily demand. This effect can be seen in Figure 22, which shows average wind penetration in 2013-14 peaking at 4:00am at 40% before falling to 25% at 6:00pm.

Figure 22 South Australia's average daily demand, wind generation and penetration profile [111].



In South Australia, either surplus wind generation or network constraints can lead to curtailment of generation. Energy storage can help reduce curtailment by shifting excess output from wind generators to times when it is needed [111].

Rooftop solar

One of the largest markets for energy storage systems will be the end-user market, which looks to pair storage systems with rooftop solar PV. Australia has experienced rapid uptake of rooftop PV, with total estimated installed capacity rising from 39 MW at the end of 2008 to 4 GW by the end of November 2014 [112]. Rooftop PV has been installed in 13 percent of dwellings across Australia, with the highest penetrations in South Australia and Queensland (22 percent and 20 percent of dwellings respectively) [113]. The concentration of rooftop PV systems is higher in rural and regional area. The top five regions in Australia are shown in Table 26 below.

Table 26 Australian suburbs with the highest concentration of solar PV [113].

Area/region	% of dwellings with solar PV
Hallet Cove, SA	35%
Victor Harbour, SA	32%
Aberfoyle, SA	31%
Canning Vale, WA	29%
Caloundra, QLD	28%

High penetration of embedded solar PV can be problematic for network providers, potentially causing to reverse-flow and localised voltage issues. Solar PV also typically reduces total energy throughput without proportionally impacting peak load. This leads to lower utilisation of network assets.

PV can be coupled with storage to maximise usage behind-the-meter and ensure that PV generated during the day can be stored and used during the peak periods. This model is currently valuable for consumers because it reduces export of excess solar to the grid. Instead, the locally generated electricity can be used behind-the-meter, offsetting electricity purchased from the grid (which can be three to five times more expensive than standard export tariffs).

Off-grid

While only 2% of Australia's population live in off-grid areas, over 6% of the country's total electricity is consumed in off-grid areas. Around 74% of that electricity is generated from natural gas and the remainder is mostly from diesel fuel [114]. The off-grid electricity market has grown in recent years largely associated with expansion in the mining industry. Off-grid electricity is Australia's most expensive electricity due to the underlying high gas and diesel prices in remote areas. As such, the business case for renewables as a means to offset fuel use is strong. Similarly, in order to enable higher penetrations of renewables, energy storage can be utilised to manage the intermittent nature of wind or solar generation. AECOM has previously forecast that the renewable off-grid market potential could grow to over 200 MW in the short to medium term and over 1 GW in the longer term. [114]

ARENA has previously identified the opportunity for renewables and storage in regional areas, and has initiated the Regional Australia Renewables and Community and Regional Renewable Energy programs to support the growth of renewables in this market.

Frequency Control Ancillary Services (FCAS)

Ancillary services help maintain key technical characteristics of the power system, including standards for frequency, voltage, network loading and system restart processes. In the National Electricity Market (NEM), the Australian Energy Market Operator (AEMO) operates eight separate markets for the delivery of Frequency Control Ancillary Services (FCAS) and purchases Network Control Ancillary Services (voltage control) and System Restart Ancillary Services under agreements with service providers.

FCAS markets exist for either raising or lowering frequency for 3 different interval periods: 6 second response, 60 second response and 5 minute response. FCAS providers bid their services into the FCAS markets in a similar way to how generators bid into the energy market. Payments for ancillary services include payments for availability as well as payment for the delivery of the services. Ancillary service costs are dependent upon the amount of service required at any particular time and, as these amounts can vary significantly from period to period, costs will also vary.

FCAS is currently provided by existing thermal and hydro/ PHS generators, with service providers required to provide more than 1MW capacity. While battery technologies can provide faster response times (i.e. near instantaneous) for frequency regulation than thermal and hydro generators, the additional value of improved response times is difficult to measure. The current market frequency regulation market mechanism does not provide financial reward for response faster than required under the 6 second market.

For energy storage, FCAS is currently considered to be a small, secondary revenue stream with energy storage competing against the incumbent providers of FCAS. Future markets may raise the value of FCAS services as the uptake of intermittent generation increases, leading to larger fluctuations in the supply-demand balance, FCAS markets in South Australia are currently considered to be the most attractive, due to its large penetration of wind generation.

Transmission and distribution networks

Australia's transmission and distribution networks are highly varied across the different NSPs as well as within each NSP. As a whole, Australia's electricity networks serve a very low density population across a very large geography. NSPs often utilise very long lines to deliver power to connect remote communities to the main electricity grid.

Large capital investment programs combined with an unexpected decline in demand has led to lower utilisation of assets and large rises in network prices, which has contributed to an increased awareness of electricity prices and alternative supply options such as rooftop solar.

Wholesale market

Much of Australia's electricity market has experienced falling electricity demand over the last 5 years due to energy efficiency, uptake of solar PV, closure of some large industrial loads and changing behaviour. At the same time, a number of large wind farms have been constructed which have contributed additional competition between generators for the meeting demand. Currently, the market has a surplus of generation assets leading to low wholesale prices with limited volatility. This market environment (among other factors) has contributed to the closure of Playford B, Munmorah and Collinsville power stations, as well as the mothballing of two units at Tarong, Swanbank E, Wallerawang power stations. This environment also reduces the potential wholesale market revenue streams for energy storage, with limited potential for market arbitrage as well as significant competition of the provision of FCAS.

4.2 Policy and regulations

There are currently a number of new changes and proposed changes being introduced to Australia's regulatory framework that will impact the treatment of energy storage technologies (and battery technologies in particular). These changes include recommendations from the AEMC's Power of Choice review, changes to tariff structures, competition in metering and improved incentives for demand management. The changes typically relate to demand management and consumer engagement rather than directly impacting energy storage. As such, within the constraints of the regulatory framework, energy storage is effectively in competition with other mechanisms for demand management such as load curtailment, intelligent control systems and other forms of embedded generation.

4.2.1 Power of Choice

One of the key recent reviews in the area of demand side participation is the AEMC's 'Power of Choice' review. The objective of this review was to:

> *'ensure that the community's demand for electricity services is met by the lowest cost combination of demand and supply side options. This objective is best met when consumers are using electricity at the times when the value to them is greater than the cost of supplying that electricity (i.e. the cost of generation and poles and wires).' [115]*

The final report, published on the 30th November 2012 set out a reform package that was to support customer needs in the electricity market over the next 15 to 20 years. The recommended key reforms were as follows:

- To reform the network pricing principles of DNSPs to implement cost reflective network tariffs through engagement with both consumers and retailers to give people the opportunity to be rewarded for changing their consumption patterns
- To expand the levels of competition in metering services to all consumers, not just larger customers as is currently the case
- To clarify provisions giving AEMO the ability to collect information on demand side participation from participants in the market
- Give consumers better access to their electricity usage data so they can better engage in understanding their demand
- Establish a framework to support contestability in demand side participation services which will be enabled using smart meters
- To provide a category of market participant for non-energy services in the National Electricity Rules that will allow the entry of innovative energy products into the NEM
- Reform the demand management and embedded generation connection incentive scheme
- To establish a new demand response mechanism in the NEM

As such, implementation of these recommendations could facilitate a number of energy storage technologies for various forms of demand management, including capacity management, critical peak pricing, load curtailment / generation and tariff arbitrage. While these functions do not directly relate to renewable energy generation, they facilitate new revenue streams for battery storage behind-the-meter, which improves the economics of pairing battery systems with rooftop solar.

The current status of the relevant reform rule changes is outlined in Section 4.2.2.

4.2.2 Current Australian Energy Market Commission rule changes

It is clear that the Council of Australian Governments Energy Council and the Australian Energy Market Commission (AEMC) are moving towards making the overall National Electricity Rules framework more robust to manage the upcoming industry changes. This was commenced with the Power of Choice review outlined above and continues to develop. Key current rule changes are outlined further below, some of which align with recommendations from the Power of Choice review.

Table 27 Relevant AEMC rule changes

Rule Change	Description of impact	Current status
Competition in metering	See Section 4.2.3 below	Consultation commenced, proposed July 2015 completion
Distribution network pricing	See Section 4.2.4 below	Delivered 27th November 2014
Demand Management Incentive Scheme	See Section 4.2.5 below	Consultation commenced, proposed Mid 2015 completion
Improving demand-side participation (DSP) information provided to AEMO	Currently AEMO has little ability to understand actual DSP uptake in the market. The aim of this rule change is for proponents to provide this information to AEMO to ensure it is included in demand forecasts. This should drive better demand forecasting and understanding of the uptake of DSP.	Consultation commenced, completion date to be confirmed

4.2.3 Competition in metering

As part of the Power of Choice review the AEMC highlighted that there is limited competition in the provision of metering services to small consumers. This was considered to be inhibiting investment in metering technologies, predominantly interval meters, which could assist in the development of the battery energy storage market. The proposed change also considers that these metering technologies would facilitate the benefits of storage technologies to be better captured across the energy supply chain.

Within the current framework the metering process and data is controlled by the DNSPs and there is little, if any, incentive to upgrade existing metering equipment. Interval meters would allow consumers to take better control of their electricity consumption and help to realise the benefits coupling rooftop PV with battery storage by allowing for new tariff options (e.g. time of use tariffs).

4.2.4 Tariffs

In the past, NSPs have been free to design tariff structures as they like, which generally responds to consumer preferences. With the implementation of a rule change from 1 December 2014, NSPs will need to determine ways of recovering revenue from each network tariff that reflects the NSP's total efficient costs of providing those services to consumers who pay that relevant tariff, on a long run marginal cost basis. These structures will need to be approved by the AER as part of the regulatory cycle through the development of a tariff structure statement.

As part of the development of new tariff structures the DNSPs will need to demonstrate to the AER how they consulted with both consumers and retailers in setting the new structures. Tariff structures will also need to be transparent enough for consumers to reasonably understand and rationally respond to price signals. Once a tariff structure has been set, NSPs are required to minimise changes to allow consumers time to make informed consumption decisions over a reasonable period of time. It is anticipated that retailers will modify the tariffs provided to consumers to align with the updated DNSP tariff structures.

If combined with a roll-out of interval metering, cost reflective tariff structures will help monetise the system value of installing behind-the-meter battery storage to shift rooftop PV generation from the middle of the day to the evening peak.

4.2.5 Incentive schemes

Demand Management and Embedded Generation Connection Incentive Scheme (DMEGCIS)

The DMEGCIS was a scheme designed to incentivise NSPs to pursue non-network solutions to network planning. Non-network solutions are alternatives to building expensive network infrastructure by reducing or limiting the growth in demand, which would otherwise require network augmentation. This typically includes energy efficiency or demand management such as load curtailment, embedded generation or possibly the use of storage.

According to the AER and DNSPs, the DMEGCIS has not effectively met its goals to incentivise NSPs to implement demand side management solutions as it is an administratively heavy and costly scheme. Two rule change requests have been made to the AEMC and are in the pending stage to reform the DMEGCIS. Both requests call for increased non-distribution network related benefits to NSPs for implementing demand-side management projects that generate net benefits. It will change the focus of the scheme from cost recovery to both cost recovery and profiting from demand-side management projects.

Demand Management Incentive Scheme (DMIS)

To incentivise DNSPs to consider economically efficient alternatives to augmenting network assets, the DMIS was applied to NSW DNSPs for the 2009-14 regulatory control period. It consisted of the Demand Management Innovation Allowance (DMIA) and the "D-factor". The DMIA encourages DNSPs to investigate and conduct broad-based and/or peak demand management projects under a capped allowance. It consists of two parts:

- Part A is an innovation allowance that is part of the DNSP's revenue allowance for OPEX each year of the regulatory control period.
- Part B compensates DNSPs for any foregone revenue demonstrated to have resulted from initiatives approved under Part A (the "D-factor").

The most recent NSW DNSP draft determination will applies Part A of the DMIA under a revenue cap. DMIA Part B or the D-factor will not be applied as the AER expects the revenue cap to replace the function of compensating for any foregone revenue. Draft determination DMIA values for NSW DNSPs are provided in Table 28 below.

Table 28 DMIS draft determination values

NSP	Incentive scheme applied	Detail	Allowance over regulatory period
AusGrid	DMIS	Part A of DMIA	$1 million ($2014-15) per annum over 2015-19
Essential Energy	DMIS	Part A of DMIA	$0.6 million ($2014-15) per annum over 2015-19
Endeavour Energy	DMIS	Part A of DMIA	$0.6 million ($2014-15) per annum over 2015-19

4.2.6 Energy storage standards

Currently, Australia is at the early stage of standards or code development for energy storage systems with the current focus on grid connection (AS4777) but with lesser focus on the design, installation, testing, maintenance or safe housing of battery systems. This represents a significant barrier for the safe, reliable and repeatable installation of battery systems which are currently entering the market.

Establishment of installation and battery housing standards is a very important precursor to the widespread uptake of battery energy storage systems by end-users. It is required to ensure that minimum safety requirements are established prior to any large-scale rollout of battery systems however it is also important to ensure standards are well thought through so they do not impede innovation.

Recently, the Clean Energy Council has received funding from ARENA to investigate and develop battery storage installation safety guidelines with Standards Australia. The aim is to assist in delivery of clear and well designed installation standards which when combined with effective training and accreditation of battery installers is essential for maintaining safety, consumer confidence and the integrity of the industry. The Clean Energy Council (CEC) also has scope to focus on battery materials, system design, installation procedures, operation and maintenance, disposal and recycling. The CEC intends to produce a Consumer Guide to educate and inform about the costs and benefits of different battery storage technologies.

Standards Australia is the Australian member of the International Electrotechnical Commission (IEC) and is a participating member of IEC TC 120 Electrical Energy Storage Systems. The Australian mirror committee to IEC TC 120 is EL-061 Electrical Energy Storage. EL-061 is not currently undertaking to develop any Australian Standards, however, a safe installation standard for batteries has recently been announced as a priority for development by Standards Australia (proposal titled "*Electrical installations – safety of battery systems for use in inverter energy systems*"). Standards Australia members are invited to comment on the development of international standards by IEC TC 120. The list of current projects that make up the work program for IEC TC 120 includes terminology, testing methods, planning and installation, environmental issues and safety consideration. [116]

In addition an E-Waste standard currently exists (AS5377) which partly deals with battery recovery and processing at end of life.

In terms of regulation, battery systems are not well catered for in the National Electricity Rules in terms of their application (potential to operate as both a load and a generator) and the connection requirements which are also influenced by the rules of the local NSP at the proposed connection location. Currently there is also inability of NSP's to participate in the market, to include behind-the-meter storage in their RAB and to monetise the wholesale energy supplied by energy storage systems. DNSPs have also advised that under existing regulations, there is no incentive to propose islanding solutions to consumers which are located at the end of long fringe-of-grid lines.

4.2.7 Summary – policy and regulations

There are many initiatives within the regulatory landscape that are seeking to reduce the cost of providing distribution and transmission network services. These initiatives seek to increase market efficiency and reduce augmentation of network assets through smarter management of infrastructure and technology. Some of the proposed rule changes are likely to enable further uptake of distributed generation and energy storage technologies, either through reducing barriers to private uptake or by creating incentives for demand management practices.

Some regulatory barriers that remain to be addressed include:

- the lack of installation and housing standards for batteries which creates safety and public acceptance issues

- the inability of NSPs to use monetise the wholesale energy component of battery installations
- there is no mechanism for NSPs to propose islanding/microgrid solutions to service isolated consumers which are currently fringe-of grid
- NSPs are not able to include behind-the-meter energy storage in their RAB
- energy storage providers currently require an exemption to the requirement for a retail licence
- energy storage connections may require a separate NEM registration classification (i.e. not load or generator)

4.3 Status of Australian storage markets

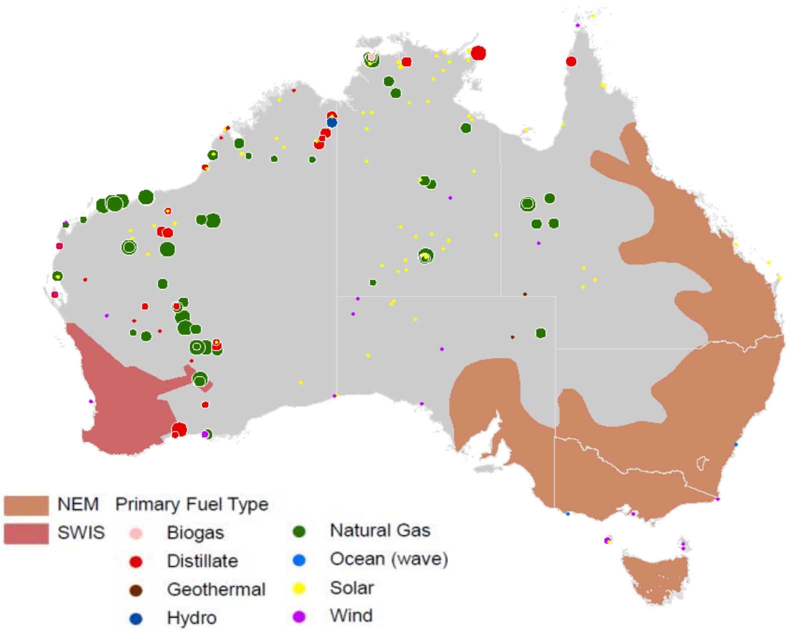
4.3.1 Off-grid

Australia has a relatively large off-grid market for electricity, with off-grid consumers accounting for 6 percent of Australia's total electricity market. The off-grid market is characterised by high electricity prices, due to the high cost of transporting fuels to remote locations and less economies of scale on microgrids. In addition, off-grid electricity markets are typically powered by gas or diesel fuel. Diesel fuel is a relatively expensive source of electricity and many analysts have made predictions of a steep rise in gas prices over the coming years as new LNG export terminals in Queensland become operational. The high cost of electricity opens up a favourable value proposition for renewables such as wind and solar PV. However, solar PV and wind power are intermittent in nature, which can lead to power quality and reliability issues where renewable penetration is high.

Energy storage technologies (particularly batteries) are an enabling technology which helps facilitate higher penetrations of renewable energy. Batteries can provide a "spinning reserve", usually provided by diesel engines as a contingency for fluctuations in the supply-demand balance. The instantaneous response of batteries gives a smoothing effect on the renewable energy output, meaning that higher penetrations are possible.

A summary of the location and technology type of existing off-grid generators is shown in the figure below. It highlights the strength of the off-grid market in Western Australia in particular, which is predominantly fuelled by natural gas and diesel (distillate).

Figure 23 Existing off-grid generation in Australia



Source: AECOM, based on Geoscience Australia 2006 and 2012 power generation database

AECOM has previously forecast that the renewable energy off-grid market potential could grow to over 200 MW in the short to medium term and over 1 GW in the longer term [114].

ARENA has identified the opportunity for renewables and storage in regional areas, and has initiated the Regional Australia Renewables (RAR) and Community and Regional Renewable Energy (CARRE) programs to support the growth of renewables in this market. These programs will help facilitate some demonstration projects with supply-side applications of storage in off-grid markets, as well as transmission and distribution and behind-the-meter applications. Example projects they are supporting are summarised below.

Off-grid case study: King Island Renewable Energy Integration Project (KIREIP)
King Island is located in the Bass Strait and is self-sufficient for its electricity supply. The KIREIP is an initiative of Hydro Tasmania to increase renewable energy generation and reduce the Island's dependence on diesel fuel. ARENA provided $6 million of the total cost ($18 million) of the project [117]. Until recently, King Island relied solely on diesel generation for electricity. Now wind turbines supply up to 70% of instantaneous demand and have helped reduce diesel consumption from 4.5 to 2.6 million litres per annum. With a goal of 65% annual renewable penetration, the project has included the installation of the largest battery based energy storage system in Australia [118]. The 3 MW / 1.6 MWh Ultrabattery (advanced lead acid technology) was provided by Ecoult to further reduce diesel consumption, help maintain stability of the grid and increase the time that the network can operate on 100% renewable energy [119]. KIREIP is using Hydro Tasmania's own advanced automated control systems and dynamic resistor technology, coupled with a flywheel UPS system, ensuring that the island's energy needs are met while utilising all the renewable energy resources available at all times. [120].

Off-grid case study: Lord Howe Island hybrid renewable energy project (*design phase*)
Lorde Howe Island is small and remote, located 600km from the mainland of Australia and relies heavily on expensive diesel generation. The Lord Howe Island Board is seeking to meet a target of 75% renewable energy by 2025, starting with a $11.6 million hybrid renewable energy project that has been partially funded by ARENA ($4.5 million) under the Regional Australia's Renewables – Industry Program [121]. The project consists of 450 kW of solar PV, 550 kW of wind and 400 kW /400 kWh of battery storage, along with stabilisation and demand response technology, which is expected to reduce diesel consumption by up to 70% and completely offset diesel when renewable generation is high. The project will help off-grid communities and businesses to take control of their energy generation as well as help other remote communities find smarter alternatives to generate electricity [121].

4.3.2 Wholesale market

Energy storage applications in Australia's wholesale market include load shifting, renewable firming and frequency regulation. This equates to two revenue streams: the wholesale energy market and FCAS markets. The strength of each revenue stream is largely speculative as it is a function of market conditions such as the supply-demand balance and the reliability of generators and load within the region.

Nonetheless, some load shifting projects may exhibit more reliable trends. For example, some wind farms generate more electricity at night time, when spot prices may be lower as a result of reduced demand. Energy storage could help such wind farms receive higher spot prices by shifting generation to periods of higher demand. However, it is noted that the price differential between day and night is not typically large. Additionally, there has been a NEM-wide trend towards a reduction in spot-market volatility, partly due to declining demand and an oversupply of generation capacity. Therefore, wholesale market trading is not widely viewed as a substantial revenue stream for energy storage systems in the current market conditions.

The FCAS market is similarly oversupplied and is generally considered a supplementary revenue stream rather than a primary revenue stream, although large penetrations of wind generation in South Australia have led to higher FCAS prices in this region.

While it is noted that battery technologies can provide faster (almost instantaneous) frequency support than thermal generation, the existing FCAS fastest response market is 6-seconds. Currently, this capability is providing sufficient power quality to our networks although it is foreseeable that faster response times could be valuable in the future as more intermittent generators are connected.

Supply market storage will also be able to provide value to network service providers in some instances. However it is expected that it will be difficult to secure substantial revenue from NSPs due to the regulatory hurdles necessary for NSPs to gain approval for projects under the Demand Management Incentive Scheme.

Case Study: Hampton wind firming – 1MW/1.8MWh

Hampton Wind Park is a 1.32 MW wind farm owned and operated by Wind Corporation Australia and was supported by grants from two separate Australian governments. In order to achieve higher penetration of renewable energy in the local network, Ecoult provided and implemented a 1 MW / 1.8 MWh Ultrabattery to reduce mismatch between wind availability and demand. The UltraBattery cells were installed to control the ramp rate of the wind turbines to provide a smooth output [122].

The batteries have now been moved to a site in WA and are the property of CSIRO.

Case Study: CSIRO advanced solar thermal energy storage

CSIRO received $3.5 million of funding from ARENA to develop a proof-of-concept solar thermal energy storage facility. The 750kWh thermal storage was connected to a solar concentrator, which generated high pressure superheated steam.

The study concluded that similar projects would have to be in excess of 100 MW_e (250 MW_t) to be viable, estimating that projects of this scale placed in areas with high solar resources could achieve a levelised cost of electricity at $175 / MWh and heat production at $14 / GJ [123].

Case Study: AGL Wind Firming (Feasibility Stage)

This feasibility study proposes to integrate battery storage with a wind farm in South Australia, examining how a medium to large scale (5-30MW) energy storage system can assist the integration of wind energy to the SA electricity network. The project will consider the technical, commercial and regulatory issues associated with energy storage. It also aims to examine the potential for NEM support through FCAS services as well as provide value to ElectraNet's transmission network through peak load management and/or deferral of potential network upgrades. Project proponent AGL is receiving $445,000 in funding from ARENA. [124]

4.3.3 Transmission and distribution networks (includes fringe-of-grid)

Battery storage systems are now being proposed as an alternative to traditional network augmentation. Given that the technology and application is still considered relatively unproven, network businesses are currently investigating the performance and impact of utilising energy storage within their networks through performing trials (see case studies below).

The key challenge within the transmission and distribution market segment is the regulatory hurdles. However recent changes have been made to the Demand Management Incentive Scheme to enable NSPs to be incentivised to deliver non-network solutions. Despite these regulatory incentives further work is underway by Government and regulators to counterweight the selection incentives toward non-traditional options such as energy storage. ARENA can certainly play a pivotal role in assisting NSPs to further demonstrate the benefits of distributed generation such as solar PV, which has the potential to reduce network augmentation, particularly when it is paired with battery storage.

Transmission and distribution applications can broadly be grouped into two categories: main grid applications and fringe-of-grid applications.

Main grid investment deferral

The use of energy storage by NSPs in main grid applications may be driven by capital and operational efficiency objectives rather than renewable generation objectives. An exception to this could be that localised areas with high penetrations of rooftop PV may lead to reverse flows in networks that are not designed to for such operation (typically a limitation of the protection systems). In some cases it may be more efficient to install storage rather than upgrade the substation to bidirectional operation.

Due to the multi-application capability of energy storage systems, NSPs have struggled to define the potential role of batteries in transmission and distribution networks. As such, some NSPs have completed trials to investigate where and how the most value might be obtained. Some of these trials are described below in the case study text box.

T&D case study: AusNet Services Grid Energy Storage System (GESS) trial

AusNet Services is completing a 2 year trial of Australia's first grid-integrated network battery. The trial aims to determine whether or not battery systems can be used as a suitable and cost-effective, non-network solution to peak demand [125]. AusNet Services has received funding for the project under the Demand Management Innovation Allowance.

The 1 MW / 1 MWh Li-ion battery system has been designed and constructed by ABB and Samsung with the purpose of educating AusNet services how battery systems can provide various kinds of support. This could include managing peak summer demand, improving power quality and delaying investment in network upgrades. The system also includes a diesel generator, which reduces the necessary energy storage capacity of the battery.

While the trial is conducted at a non-critical network location, it is expected to be moved to a more critical location in the future.

T&D case study: Smart Grid, Smart City

Smart Grid, Smart City was a $100 million Australian government funded project led by Ausgrid and Energy Australia. The project spanned across 5 sites in Newcastle, Sydney and the Upper Hunter Valley to determine how distributed generation with battery storage can be used with other smart grid technologies to reduce peak demand and improve reliability [126].

The program consisted of field trials of 5kW/10kWh zinc-bromide 'flow' batteries with a remotely controllable battery management system installed in volunteer households across Newcastle and Scone [127]. These trials showed that battery storage systems had a significant impact on peak demand during the typical evening peak periods. However, many households had automatic off-peak hot water systems that turned on very late at night, causing a more severe peak that was not reduced by the batteries [128].

A field trial in Newington was planned to take place using batteries attached to the network, however, these trials did not go ahead due to a number of challenges. As a result, modelling using lead acid batteries took place instead, indicating that under the current tariff structures, energy storage will not be economically viable through to 2034, despite anticipated price reductions in storage technology [127].

Fringe-of-grid support

Fringe-of-grid networks also exhibit an opportunity to utilise storage to defer investment in networks. In particular, an opportunity exists for fringe-of-grid areas that utilise Single Wire Earth Return (SWER) lines. SWER lines exhibit poor reliability and often lead to large distribution line losses. They are typically long and can be expensive to maintain or upgrade. Energy storage has the potential to delay upgrades by load shifting and reducing peak demand. Energy storage solutions in these applications can often by aided by the use of embedded generation within the fringe-of-grid area which, when combined with energy storage can reduce the dependence on the SWER line.

Fringe-of-grid areas are often characterised by power quality and reliability issues, and can exhibit higher penetrations of embedded renewable generation. This combination of factors results in the fringe-of-grid market presenting a significant opportunity for energy storage, which can facilitate higher penetrations of renewables and simultaneously ameliorate power quality and reliability concerns.

Having experienced positive results from its initial trials, Ergon Energy has publically discussed plans to set energy storage rollout targets similar to that in California. The target would be in the order of "tens of megawatts but would require regulatory change to facilitate its delivery [129].

Fringe-of-grid locations could also provide opportunities to reduce network costs by islanding customer groups who are currently supported by long, stringy networks that show low reliability and high maintenance costs. The implementation of energy storage to support islanding of these groups could also enable increased intermittent renewable penetration in the islanded network.

Fringe of grid case study: Ergon Grid Utility Support Systems (GUSS)

Ergon Energy's constrained rural electricity network is being supported by the rollout of 25 kVA / 100 kWh Grid Utility Support Systems (GUSS) providing electricity during peak periods on the Atherton Tablelands in Far North Queensland. The technology proved cost effective in providing reliable electricity to rural customers on constrained single wire high voltage distribution voltage lines, known as SWER [130].

SWER networks cover 65,000km in Queensland, servicing more than 26,000 customers. Traditional augmentation solutions to these networks required to meet increasing demand can cost more than $2 million. GUSS systems are not only a faster solution, but are more cost effective, reducing costs of electricity to consumers by up to 35% [130].

In 2013 Ergon Energy called for tenders to build 25 more GUSS units over 5 years, which consists of 56 Li-ion batteries, a power conversion unit, communications and an enclosure. S&C Electric Company has recently won tenders to install 20 of these units within 12 SWER networks by mid-2015. [130]

Figure 24 SWER networks to have GUSS systems installed [130]

Fringe of grid case study: Horizon Power energy storage requirements

Horizon Power serves customers in regional and remote parts of north western WA but only allows connection to a fixed number of distributed renewable energy sources on its low voltage network. This is known as hosting capacity which varies from town to town depending on the level of spinning reserve at the power stations supplying the area. High penetrations of distributed PV can put a lot of strain on generators when PV generation suddenly drops due to changing weather conditions, requiring high ramp-up from thermal generators. In order to increase hosting capacity, Horizon Power has introduced two methods of generation management: renewable energy smoothing and feed-in management. The method used depends on the size of the generation system installed [131].

Figure 25 Horizon Power distributed generation system size classification [132]

Class	System size
Class 1	$\leq 5\ kW$
Class 2	$\leq 50\ kW$
Class 3	$\leq 1 MW$

Renewable energy smoothing management requires all Class 2 and 3 customers, as well as all customers with Class 1 systems where the towns hosting capacity has been reached, to install energy storage that provides backup power to the grid. In order to ensure that the storage devices continue to work effectively, regular testing of the installation must take place.

Feed-in management is more complex and doesn't involve the use of storage systems. It enables Horizon energy to limit renewable energy generation output for some class 2 system sizes and all class 3 system sizes to ensure grid stability [132].

4.3.4 End users

Energy storage for end-users includes battery and thermal storage technologies. For end-users, thermal storage is typically used for load shifting and demand management applications. As such, it typically has no direct relationship to renewable generation. On the other hand, battery storage is ideal for pairing with solar PV in behind-the-meter applications.

As outlined in Section 4.1, the end-user market is widely considered to present the best value proposition for energy storage by pairing battery storage with rooftop solar PV. Coupling solar PV with battery storage can increase the utilisation of on-site generation behind-the-meter, which in turn reduces the import of grid-electricity.

In addition, the solar electricity generated during the day can be stored and used during the peak periods (typically 6:00pm to 9:00pm), where it is most valuable. This model reduces electricity purchased from the grid which can be three to five times more expensive than standard export tariffs.

A key moment for Australia's energy storage market will be when the NSW Solar Bonus Scheme ends. Under the scheme, over 146,000 customers installed 342 MW of solar PV with gross metering arrangements [133]. These customers will simultaneously stop receiving premium tariffs for electricity exports on 1 January 2017, creating a sudden awareness of the reduced value of end-users' electricity exports. It is expected that customers will switch to net-metering and battery storage to seek more value in their existing solar PV installations.

As such, many solar suppliers are beginning to offer battery products with their solar installations. Similarly, battery manufacturers are looking to release residential products in the near future. Bosch has a residential product already available, while RedFlow and SunPower (through its partnership with Sunverge) have announced plans to release residential energy storage products. SunPower has been conducting pilot programs of its technology in Australia and its technology is designed to facilitate aggregation of many products.

In addition, Tesla, AGL and Origin have all announced intent to enter the stationary residential energy storage market, with AGL and Origin looking to grow their existing PV business by pairing their offering with a battery product.

Bosch household product

The BPT-S 5 Hyrbid consists of a transformerless 5kW inverter, a Li-ion battery with capacity ranging from 4.4kWh to 13.2kWh and an intelligent management system with a touch screen display [134]. It has a round-trip efficiency of 97%.

RedFlow household product

Redflow is looking to release a new household version of it zinc bromide flow battery in April 2015. The ZBM2 is a 48V 5kW/10kWh battery suitable for residential and commercial applications. RedFlow is seeking to differentiate their product by offering a warranty for 200MWh lifecycle output (independent of charging patterns), equivalent to one full discharge per day for 5.5 years. With a base price of US$9,500 each (nominally US$0.48/kWh), the product is not commercial in Australian residential and commercial markets without subsidy [135].

The aggregation business model is becoming more common, as participants attempt to monetise each of the value streams of storage systems. Similar to Sunverge, Reposit Power is developing a platform to open the wholesale and FCAS markets to residential energy consumers with battery storage by aggregating the storage capability across of many residential customers (e.g. FCAS markets require at least 1MW capability). Reposit Power has recently secured $445,000 of funding from ARENA for their GridCredits project, which will be run as a pilot to trial an on-grid PV energy storage and trading system. Additionally, this system will allow energy to be sold back into the grid by placing bids into the market, effectively turning residential properties into peaking power plants [136]. The trial utilised Magellan Power assembled energy storage system including Lithium Iron Phosphate batteries ($LiFePO_4$) [137].

End user case study: TransGrid iDemand

iDemand is a demonstration of a commercial-scale demand management system which includes solar panels, a battery and energy efficient lighting in TransGrid's office in Sydney West. The system includes a 400 kWh lithium polymer battery, which along with the other components is capable of reducing electricity usage at the Sydney West site by up to 50 percent and is equivalent of 40 households' load at times of peak demand [138].

The demonstration was designed and implemented using part of TransGrid's Demand Management Innovation Allowance, aiming to develop methods of managing peak demand and defer or avoid investment in network upgrades. TransGrid launched a research tour and interactive web portal late last year to draw interest from academics and industry members and improve the market for demand management solutions [139].

4.3.5 Electric vehicles

Although the EV market in Australia is currently very small, uptake outside of Australia is increasing rapidly with some countries having passed 5 percent market share point in 2013 [3]. Large-scale adoption of EVs in Australia is widely considered inevitable, and car manufacturers are continuing to introduce new EV products to the Australian market. The recent launch of Tesla Motors, the release of the BMW i3 and the rollout of ChargePoint charging stations in Australia has significantly raised the profile of EVs and will likely lead to higher sales. Tesla has already constructed two charging stations in Australia, and plans to connect all major cities along Australia's east coast with stations located approximately 200 km apart. These stations may allow direct participation in the wholesale and FCAS markets by utilising the battery capacity of any connected vehicles.

In addition, Tesla is also planning to release a home battery storage product to participate directly in the end-user behind-the-meter storage market. This step into the household battery market could be viewed as a step towards vehicle-to-grid operation of EVs, where any person with an EV would also have access to its large storage capability in their house, facilitating more behind-the-meter solar PV use as well as demand-side participation.

The fuel cost of EVs is significantly less than for internal combustion engine cars using petrol and diesel. Origin Energy's EV calculator estimates that the cost of charging an EV during peak times with 100 percent GreenPower is less than half of an equivalent petrol car [140]. With this large price differential, the additional cost of purchasing GreenPower to charge EVs is not considered large and EV companies (including Tesla) are looking at exclusively utilising renewable energy to charge EVs in their business models for public charging stations. As such, the EV market could potentially help ARENA meet its renewable energy objectives through additional development of renewable generation to power charging stations as well as future potential to facilitate renewables-enabling applications such as demand-side participation and pairing with roof-top solar.

Some key challenges that may need to be addressed include barriers for vehicle-to-grid connection (limiting demand-side participation) and standardisation of charging infrastructure, as some EV companies have indicated that they wish to pursue brand-specific charging infrastructure.

4.4 Economic drivers in Australian market segments

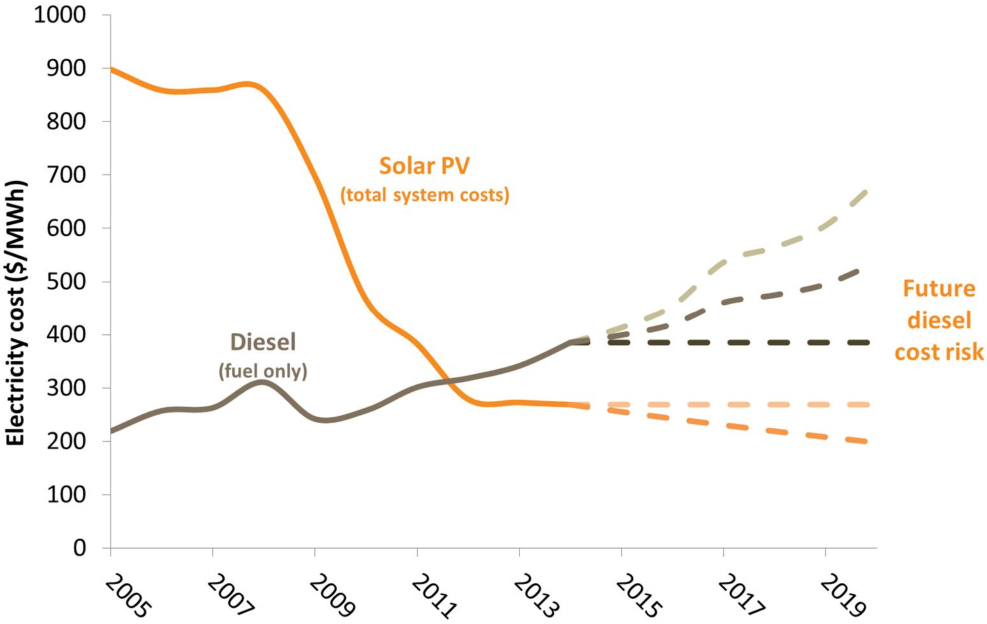
This section seeks to provide an indication of the size of the revenue streams available to energy storage projects in each of Australia's market segments. This is provided for illustrative purposes, such that high level comparisons between the various storage markets can be made. The indicative revenues are provided based on current market conditions and regulatory restrictions.

4.4.1 Off-grid market value

The value of off-grid storage used for hybridisation of renewables can be estimated by considering the cost differential between the levelised cost of renewables and the short-run marginal cost of generation of thermal generation. For example, the levelised cost of electricity for a medium size solar PV plant in remote locations such as the Pilbara is approximately $196/MWh (including a $30/MWh LGC rebate) [141]. However, the short-run marginal cost of diesel generation is $346/MWh (assuming diesel cost of $1.30 per litre) [114]. Therefore, every additional megawatt-hour of solar that can be utilised to offset diesel generation can save $150/MWh (plus the value of renewable energy certificates). Given that energy storage can help fulfil this role by facilitating higher penetrations of solar PV, $120/MWh is a good estimate of the value of energy storage in this application.

Figure 26 demonstrates this price differential and its potential to grow under scenarios where the cost of PV reduces or diesel prices increase.

Figure 26 Solar PV cost comparison with diesel genset fuel-only costs (includes Fuel Tax Credit) [114]

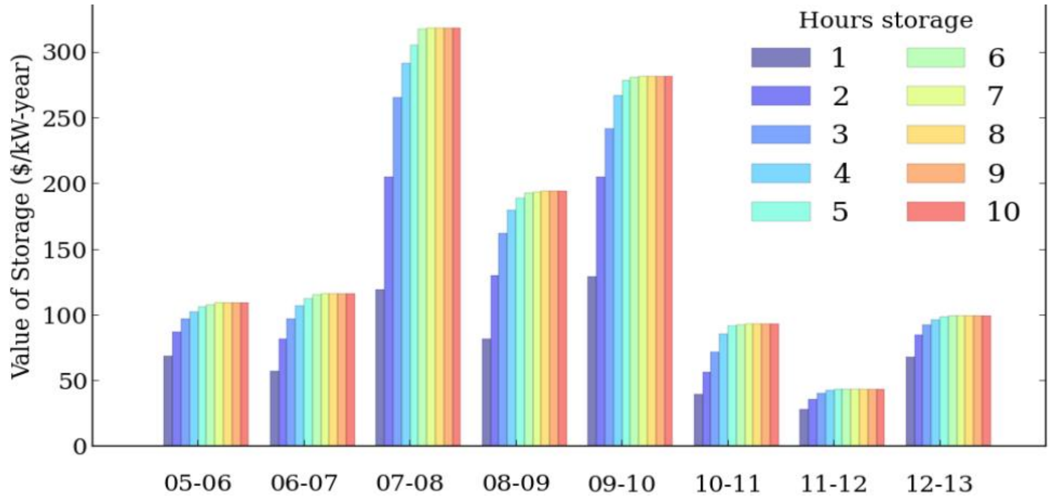


4.4.2 Wholesale market value

AECOM has quantified the potential revenue available to wholesale energy storage facilities using wholesale market arbitrage, using analysis completed by the Melbourne Energy Institute. The analysis looked at the value of pumped storage in each NEM market for the period of 2005 to 2013 based on value that could be extracted from wholesale market arbitrage (which is the largest revenue source available to supply-side energy storage applications). The results are particularly transferable to other bulk storage technologies operating in the wholesale market such as CAES and solar thermal storage, although it is important to note that all technologies have technology-specific limitations that may influence dispatchability and hence ability to capture the full value of wholesale market arbitrage.

As seen in Figure 27, the potential revenue from wholesale energy storage varies drastically from year to year based on wholesale market volatility and the energy system's storage capacity. Since 2005, South Australia has offered the highest value for energy storage (compared to other markets in the NEM) with storage value varying from \$50/kW$_{installed}$ to \$300/kW$_{installed}$ annually (averaging approximately \$150/kW). South Australia's high volatility can be attributed to a number of factors including high temperature variability, limited peaking generation capacity, growing wind generation and a high dependency on interstate generation (which is limited by state interconnectors). Queensland is the next most lucrative market averaging close to \$100/kW$_{installed}$, while other markets offering closer to \$50/kW$_{installed}$ to \$100/kW$_{installed}$ annually. All markets have provided low value in recent years, broadly due to reduction in demand, excess capacity and stable wholesale markets. [142]

Figure 27 Potential annual revenue from pumped storage installations in South Australia [142]



With annual average revenue varying from $50/kW to $150/kW, an example bulk storage system with 6 hour storage could earn from $23/MWh up to $68/MWh for its output (assuming a daily charge/discharge cycle). These generation prices can act as a rough guide for the target levelised cost of energy for bulk storage technologies to become commercially viable.

4.4.3 Transmission and distribution networks market value

Revenue from energy storage applications from the T&D sector is earned for offering capacity rather than energy. Nonetheless, the financial return available for a transmission and distribution energy storage project is very difficult to define. This is because of a number of project specific variables such as network location as well as a changing regulatory environment. In order to better quantify this revenue stream, AECOM has sought comparison with existing peak demand reduction services.

A network planner will seek to utilise the lowest cost option to reduce demand in constrained areas of the network and a number of non-network options are already available to NSPs to reduce demand, including power factor correction, standby generation, load curtailment, temporary generator installation, hot water system and air conditioner cycling and energy efficient lighting. Therefore, through competition from other technologies, the market value of energy storage is limited to the market value of competing demand management technologies. Given that the demand management market is currently not mature, public sources of market prices are difficult to obtain. AECOM has estimated the market value at $45-$120/kW annual revenue (confidential source). The high variance is a reflection on the highly varying technological solutions that might be available for a given network constraint. This estimate is supported by analysis by AEMO on alternatives to upgrading the Ballarat-Bendigo 200kV line. The RIT-T study showed that a non-network alternative (local generation support) was feasible costing $76/kW [143].

While demand management is valued in capacity, it can be converted to energy output (i.e. generation revenue) for comparison with other markets. This is done by assuming 4 hours storage (to cover a peak demand period), and daily cycling (to mimic the output of other markets; i.e. 4 hours x 365 days = 1,460 hours per year), this can be converted to $30-$62/kWh$_{output.}$

The transmission and distribution market is highly challenging for energy storage, with many other competing technologies (e.g. energy efficiency, curtailment) and limited market opportunities being provided by NSPs. In addition, the commercial terms of an agreement with an NSP are challenging to ensure the storage facility can meet the NSP’s technical requirements (e.g. availability, 4 hour peak etc.) and NSP’s may be reluctant to offer long term contracts.

4.4.4 End-user market value

Like the off-grid market, energy storage projects in the end-user market are easily defined. The most promising application of energy storage in the end-user market is pairing with solar PV. In this scenario, an end user with a rooftop solar PV system who is not receiving a feed-in tariff (other than market value provided by a retailer) values self-consumption of solar PV at the retail price of energy. In contrast, exported PV generation may only receive the wholesale market rate as granted by an electricity retailer (e.g. 8 cents per kWh).

Average retail prices in Australia vary greatly in different regions (including states, NSPs and for different tariff structures). For illustrative purposes, AECOM has assumed a $0.29/kWh tariff as per the average NSW residential electricity prices published by AEMC [144]. For houses that already have solar PV installed, energy storage can utilise excess PV generation (that would normally be exported) for self-consumption, effectively providing the user with $0.21/kWh revenue for energy stored. This value is sensitive to tariff rates and structures. In particular, if a customer can offset electricity time-of-use tariffs, there is higher self-consumption value. For example, AGL quotes $0.47/kWh during peak periods in AusGrid's network, which lasts until 8:00pm on weeknights [145].

For houses without PV installed, the value is reduced by factoring in the levelised cost of solar at $0.12/kWh (including STC rebate) [146].

In addition, aggregator business models could open up additional revenue streams to the end-user, including wholesale and transmission and distribution.

4.4.5 Market segment summary

An indication of the relative size of the revenue streams available to energy storage projects in each of Australia's market segments is provided in Table 29. Direct comparison of markets is difficult due to the different manners energy storage is valued and used in each market. As such, each market segment was compared in terms of the "generation revenue", which is defined as the revenue obtained per unit of energy exported during typical operation patterns (with the exception of T&D, where a daily cycle is fabricated to allow comparison). While this metric is suitable for the off-grid and end-user markets, reasonable assumptions were made for the T&D and wholesale market segments to allow direct comparisons. The "generation revenue" metric also provides a useful comparison point with LCOE figures, discussed in Section 2.4.

The comparison shows that the highest financial value is available in the end-user market segment followed by off-grid, wholesale and T&D. It should be noted that these figures are meant for illustrative purposes and are subject to variability and should be reconsidered on a case-by-case basis. The bold text indicates the origin of the revenue. For T&D markets, the revenue is paid periodically (e.g. annually) for capacity. For other markets, the revenue is earned for generation.

Table 29 Summary of potential revenue available for energy storage in each market segment (Source: AECOM)

	Annual revenue (function of system size)			
Market	**$/kW$_{installed}$**	**$/kWh$_{installed}$**	**Generation revenue ($/MWh)* (function of system output)**	**Comments**
Off-grid	N/A	N/A	**$150/MWh (diesel @ $1.30/L)** **$230/MWh (diesel @ $1.60/L)**	- Easily defined - Highly predictable
Wholesale	$50-150/kW	$8-25/kWh	**$20/MWh (mild markets)** **$70/MWh (volatile years)**	- Highly volatile revenue - Market specific - Speculative future value
T&D	**$45-120/kW**	$11-30/kWh	$30-$80/MWh**	- Revenue may only be available for a short period - Only available on constrained areas of the network - Subject to competition from other technologies and DM activities
End-user	N/A	N/A	**$200-260/MWh (existing PV)** **$80-140/MWh (new-install PV)**	- Easily defined - Highly predictable - Dependent on tariff structures
Shared value (i.e. Wholesale + T&D + End-user)			$130-$410/MWh	- Retailer/aggregator facilitation required - Difficult to achieve wholesale value and T&D value for end user

Annual revenue ($/kW): annual revenue defined relative to the size (kW) of the energy storage system

Annual revenue ($/kWh): annual revenue defined relative to the size (kWh) of the energy storage system

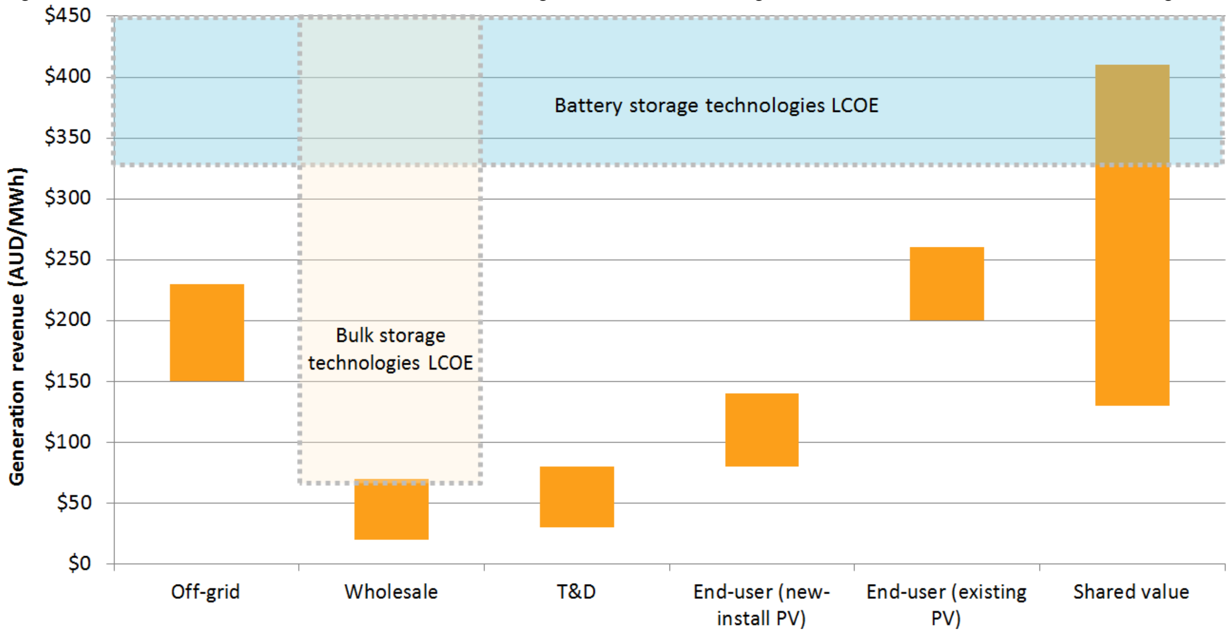
Generation revenue ($/MWh)*: average revenue derived from each MWh the energy storage system outputs – whether behind the meter or exported (assumes daily cycling)

*Generation revenue is a function of how much the system is used. Off-grid and retail are calculated directly from the value of offset costs (fuel, retail costs respectively). Wholesale assumes 6 hour discharging per day, T&D assumes 4 hours discharge per day to cover the peak period.

** The $/MWh value has been fabricated from the capex figure to permit comparison with other markets. The other markets typically operate on a daily cycle; however this would not be appropriate for a demand management storage system. Nonetheless, daily cycling has been assumed to allow comparison.

Figure 28 directly compares the different generation revenue in each market segment, and also highlights indicative LCOE figures for battery technology (all markets) and bulk storage technologies (wholesale market only). Whilst the figure indicates that there is some overlap between LCOE and revenue opportunities, AECOM would highlight that this is only the case in idealised scenarios. For example, the cheapest technologies may not be available (e.g. suitable site for PHS or CAES) concurrently with the most favourable market conditions. It does, however, show a strongly improved business case for "Shared Value", which highlights the importance of trying to aggregate the multiple revenue streams at end-user installations.

Figure 28 Generation revenue available to each market segment cross-reference against the LCOE for Li-ion and CAES technologies[1]



[1] N.B. **Shared value revenue includes simultaneously revenue streams available through retail tariff arbitrage, wholesale market arbitrage and from T&D demand management (idealised scenario)**

4.5 Project Stocktake

The following table shows active energy storage projects in Australian known to AECOM at the time of publishing.

Table 30 Australian energy storage project stocktake [19]

Year	Project	Location	Technology	Owner	Power (kW)	Energy (kWh)	Application	Announced ARENA involvement
Project in operation								
1973	Tumut Hydroelectric Power Station 3	Snowy Mountains, NSW	Pumped hydro	Snowy Hydro Limited	600,000	N/A	Wholesale market arbitrage, FCAS	x
1984	Wivenhoe Power Station	Wivenhoe Pocket, South East Qld	Pumped hydro	CS Energy	500,000	5,000,000	Wholesale market arbitrage, FCAS	x
1977	Kangaroo Valley Pumping and Power Station	Southern Highlands, NSW	Pumped hydro	Origin	160,000	N/A	Wholesale market arbitrage, FCAS	x
1977	Bendeela Pumping and Power Station	Southern Highlands, NSW	Pumped hydro	Origin	80,000	N/A	Wholesale market arbitrage, FCAS	x
2014	King Island Renewable Energy Integration Project	King Island, Tas	Ultrabattery (advanced lead-acid)	Hydro Tasmania	3,000	1,600	Island grid renewable-diesel-storage hybridisation	✓
2011	Lake Cargelligo Solar Tower	Central West NSW	Heat thermal storage	Graphite Energy	3,000	3,000	Renewable capacity firming	x
1966	Tods Corner Power Station	Central Tas	Pumped hydro	Hydro Tasmania	1,700	N/A	Wholesale market arbitrage, FCAS	x
2011	Hampton Wind Park (Moved to an undisclosed site, WA)	Hampton, NSW (moved to WA)	Ultrabattery (advanced lead-acid)	Ecoult	1,000	500	Ramping, voltage support	x
2007	Coral Bay PowerStore Flywheel Project	Coral Bay, NSW	Flywheel	Verve Energy	500	8.3	FCAS	x
2010	Nullagine PowerStore Flywheel Project	Marble Bar, WA	Flywheel	Horizon Power	500	8.3	FCAS	x

Year	Project	Location	Technology	Owner	Power (kW)	Energy (kWh)	Application	Announced ARENA involvement
2010	Marble Bar PowerStore Flywheel Project	Marble Bar, WA	Flywheel	Horizon Power	500	8.3	FCAS	x
2005	Leinister Mine	WA	Flywheel	BHP Billiton	1,000		Reduction of peak demand and spinning reserve	x
2009	Cape Barren Island Hybrid System	Cape Barren Island, Tas	Electro-chemical	Hydro Tasmania	163	163	Island grid renewable-diesel-storage hybridisation	x
2013	Global Change Institute M120	Brisbane, Qld	Zinc Bromine flow battery	University of Queenslan d	120	300	Onsite renewable generation shifting, load following	x
2015	Ergon Energy GUSS	Far North Qld	Lithium-ion battery	Ergon Energy	25	100	Load shifting, voltage support	x
2013	Ergon Energy	Magnetic Island	Batteries	Ergon Energy	5		FCAS	x
2009	Bendigo Solar Park	Bendigo, Vic	Lead-acid battery	Origin Energy	N/A	60	Load shifting	x
2014	TransGrid iDemand	Horsely park, NSW	Lithium polymer battery	TransGrid	100	400	Electric energy time shift, onsite renewable energy time shift	x
Project in planning/construction								
	UTS (University of Technology) Sydney	Sydney, NSW	Zinc Bromine flow battery	UTS	25	50	Behind-the-meter	x
	AusNet Services GESS Trial	Melbourne, Vic	Lithium-ion	AusNet Services	1,000	1,000	Electric energy time shift, grid support	x
	Jemalong Solar Thermal Station	Central NSW	Heat thermal storage	Vast Solar	6000	18,000	Electric energy time shift, renewable time shift	✓
	Lord Howe Island Hybrid RE Project	Lord Howe Island, NSW	Lithium-ion	Lord Howe Island Board	400	400	Solar-wind-diesel-storage hybrid	✓

Year	Project	Location	Technology	Owner	Power (kW)	Energy (kWh)	Application	Announced ARENA involvement
	Smart Grid, Smart City	Newcastle, NSW	Redflow zinc bromide flow batteries	AusGrid	40 x 5kW	N/A	Behind-the-meter	x
	Smart Grid, Smart City	Scone, NSW	Redflow zinc bromide flow batteries	AusGrid	20 x 5kW	N/A	Behind-the-meter	x
	Smart Grid, Smart City	Newington, NSW	Redflow zinc bromide flow batteries	AusGrid	50 x 5kW	N/A	Behind-the-meter	x
	Phase 2 – 4MWh storage for 100% renewables	Weipa, Qld	TBA	Rio Tinto		4000	Renewable capacity firming	✓
	Legion House, Biogas / battery system	Sydney, NSW	Lead-acid battery	Grocon	80		Islanded building, storage coupled with renewable biogas	x
	Degrussa Mine Hybrid Solar / Storage Project	WA	Lithium-ion	Sandfire Resources	6,000	1,500	Hybrid solar-storage system for mine diesel grid	x
	Daly River Hybrid Solar / Storage Project	Daly River, NT	Lithium-ion	Power Water Corporatio n	~1,000	750	Hybrid solar-storage system for remote diesel grid	✓

Note: ARENA has completed the “ARENA involvement column”.

4.6 Barriers for energy storage in the Australian market

A summary of some of the most significant barriers for energy storage in Australia is provided in Table 31 below.

Table 31 Barriers to the uptake of energy storage in Australia

Financial	Market
- Storage projects are highly capital intensive - There is a high cost uncertainty within the battery market as suppliers attempt to establish themselves in a new market, while simultaneously experiencing large reductions in their own product costs - Revenue streams are often difficult to define and secure in long term agreements	- Recent uncertainty for the future of the RET and carbon policies in Australia has stalled investment in renewables that would otherwise increase the drivers for storage - Local experience and case studies are limited - An oversupply of generation capacity has depressed wholesale energy prices and led to limited volatility, significantly reducing value in wholesale energy market arbitrage
Technical	**Regulatory**
- Locally there are limited suppliers of storage technologies, creating concerns over technology support required to meet local demand - Many storage technologies are commercially available; however there are still concerns about longevity and long-term performance - Control systems can be complex and expensive and often need to be tailored to individual projects - There is a lack of Australian and international standards for modern energy storage technologies (particularly batteries), particularly for manufacturing, installation, housing, testing and maintenance	- It can be difficult to monetise the full value of energy storage systems - The regulatory framework currently lacks focus and does not provide guidance for the implementation of energy storage (refer to Section 4.2 *Policy and regulations* for detail) - It is challenging for NSPs to incorporate energy storage projects into their Regulated Asset Base - The grid connection process can be slow and expensive for end users. This is being addressed by updates to AS4777, which are currently underway - NSP-owned storage may need to be differentiated in market registration to prevent NSPs from participating in the market. Another solution may be to allow a separate entity to own the market output (i.e. the financially responsible market participant) - There is currently no subsidy or incentives for widespread deployment

4.7 Australian market summary

The Renewable Energy Target, combined with falling solar panels prices and increasing electricity prices has driven uptake in renewables in Australia. The majority of new renewable deployment (i.e. many hydroelectric generators were built prior to the Renewable Energy Target) can be categorised either as utility scale wind generation or rooftop solar (with a recent trend towards utility scale solar commencing).

The uptake of renewables is now leading to growing interest in energy storage technologies. Demand for energy storage can be considered from two perspectives:

User driven demand; end-users are seeking to lower their energy bills and reduce their dependence on grid-supplied electricity by increasing self-consumption of electricity from their rooftop solar PV. Forecast price reductions for battery technologies will enable this.

Technical requirement; as higher penetrations of intermittent renewables are deployed, a number of technical challenges can arise, such as reverse flow, frequency and voltage control challenges, and reduced network asset utilisation due to rooftop . Energy storage provides a technical solution to this challenge, either by pairing generators with storage to smooth their output, or by utilising energy storage (or alternatives) within T&D networks to make them more robust against the challenges of intermittent generation, and allow more efficient operation of networks.

As drivers for energy storage in Australia's electricity market become stronger (particularly as the price of new technologies comes down), trial projects are becoming more frequent. To date the project proponents include NSPs, generators, retailers and off-grid power system operators.

Four broad energy storage markets have been identified, including:

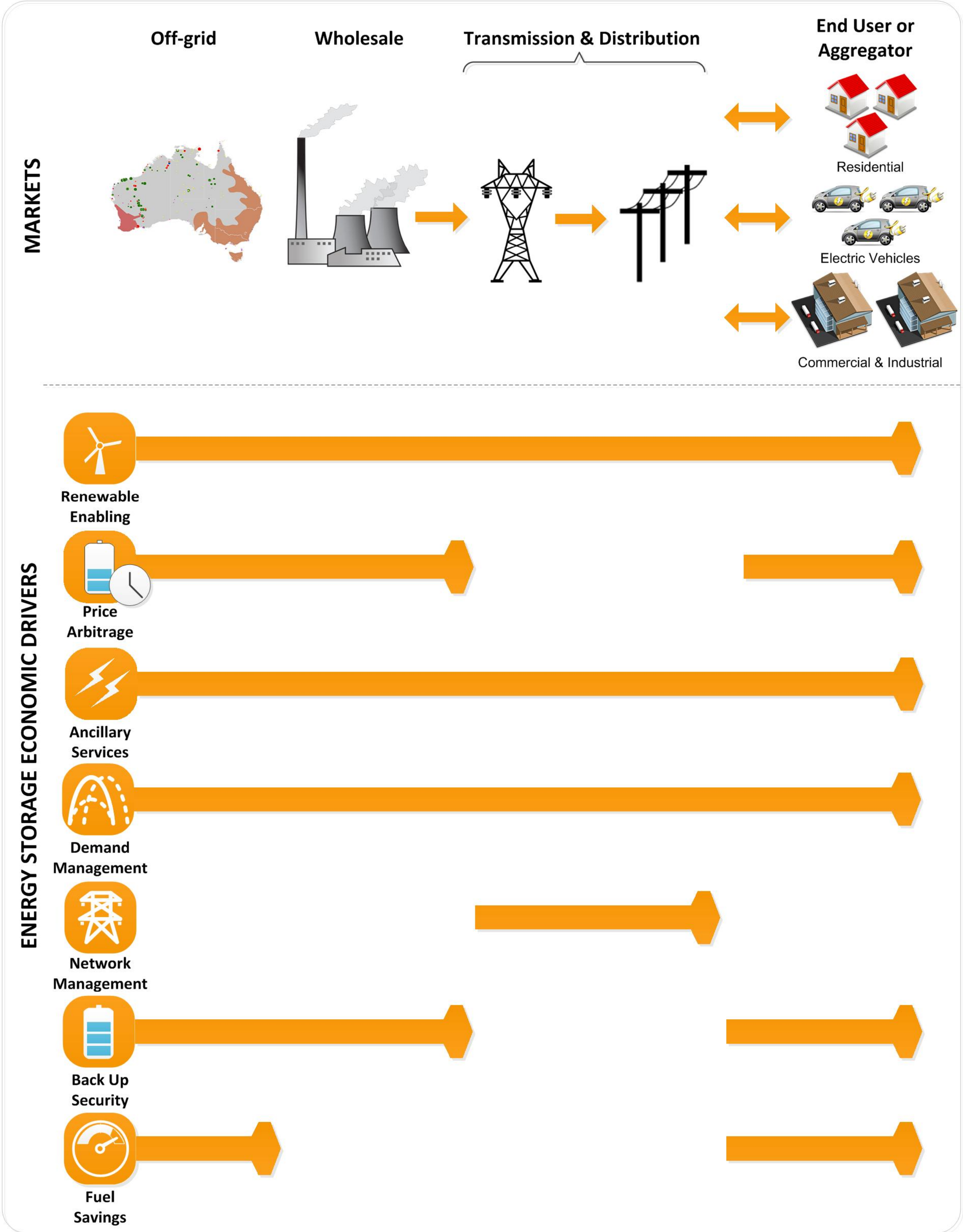
1) Wholesale market
2) T&D networks
3) End users (includes EVs)
4) Off-grid

Analysis of the current market conditions suggests that the off-grid and end-user markets are currently the most commercially attractive propositions, with clearly defined revenue streams and a promising value proposition. Conversely, the wholesale market offers small and highly unreliable revenue to a project proponent in current market conditions (although future market conditions may be more conducive to this market). Similarly, the T&D market is restricted by poorly defined revenue streams, regulatory uncertainty, competition from other technologies, and the absence of a direct link to renewables.

While the cost of energy storage is reducing, a number of technical and regulatory and market barriers remain. These barriers affect some storage applications more than others. For example, the oversupply of generation capacity will not only impact the wholesale market arbitrage revenue stream. Similarly, the rollout of behind-the-meter applications will not be stopped by NSP. It is not believed that the barriers identified in this chapter will prevent commercial uptake of storage if sufficient cost reductions are obtained.

In particular, technical barriers regarding uncertainty of performance, reliability and safety can be addressed by demonstration projects to the benefit of all energy storage markets and applications.

Figure 29 Summary of energy storage benefits across the electricity value chain



5.0 Recommended Investment Priorities

5.1 Overview of learnings

The role of enabling technologies such as energy storage is becoming more important as Australia moves towards higher penetrations of intermittent renewable generation such as solar and wind power. Some parts of Australia (particularly off-grid areas) have already experienced the technical limitations of intermittent renewables, leading to emerging power quality issues or curtailment of renewables (e.g. rooftop solar in Horizon Power's networks, wind generation in South Australia and Western Australia). To continue growing Australia's renewables market efficiently, it is important to support the development of enabling technologies. Energy storage is perhaps the most significant enabling technology, proving the ability to both smooth and shift renewable generation to match demand profiles. Australia has a particularly good solar resource, yet peak demand typically occurs in the evening when solar generation is minimal. Similarly, the wind penetration is much higher in the early hours of the morning due to lower demand occurring while wind generator output remains relatively constant (or increases in many instances). Energy storage is a technology that can help meet the challenge of matching energy demand with renewable generation.

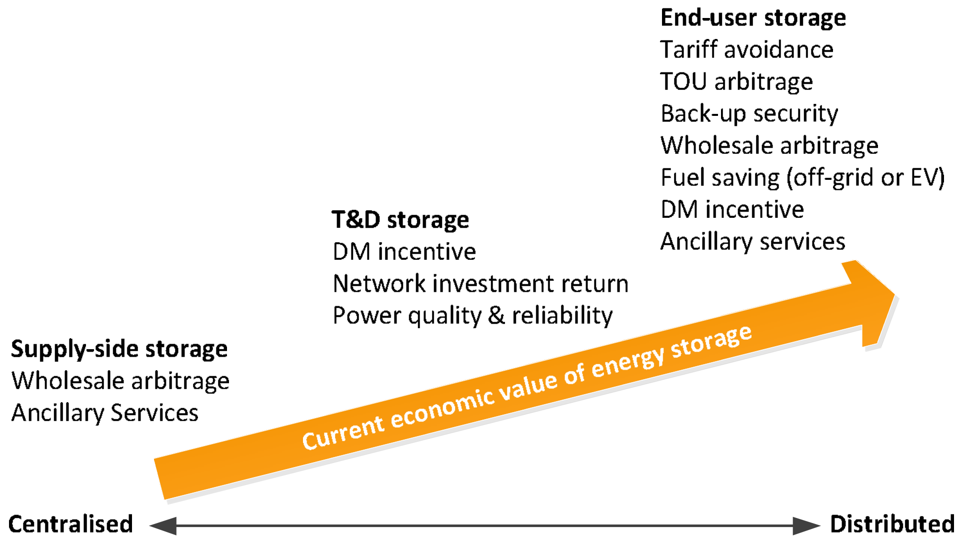
Australia has an opportunity to learn from the approach of international markets when developing energy storage investment priorities. Noting that many of the international programs are relatively immature and their relative success is yet to be determined, some key preliminary learnings include:

- The importance of **safety** in residential applications; there have been unconfirmed accounts of multiple house fires in Germany caused by batteries installed under the KfW 275 residential storage rebate program. Batteries can be dangerous and it is most important that they are manufactured and installed such that the safety of home-owners is not compromised.
- The focus on providing **network value;** distribution network costs are the largest contributor to electricity prices in Australia. International energy storage policy has a focus on using storage to provide network value, in addition to facilitating renewables. Most notably, Germany required that recipients of a capital rebate for household installations allow DNSPs to remotely control the battery system.
- California's focus on building a **robust network** to facilitate renewables; California is seeking to build a smart and robust electricity network that will be able to cope with the strains of high penetrations of renewables under its 33% by 2020 target. California has commenced a holistic approach to its networks, looking at energy efficiency and demand-side participation as well as energy storage deployed across its network, from the supply side, through the networks to the end user.

Australia's energy market differentiates itself from many international markets with its large fringe-of-grid and off-grid markets, as well as an oversupply of generation capacity and low customer density. While these characteristics present niche market opportunities for energy storage, the broader electricity market's interest in energy storage is relatively comparable to many international markets with challenges including high penetrations of rooftop solar PV and utility-scale wind farms.

There is currently higher value for storage at the end-user level than on the supply-side, while the value of T&D applications is highly variable, project specific and often subject to regulatory barriers. This trend is illustrated in Figure 30, which also identifies the value streams for each installation location.

Figure 30 Illustration of the current value of energy storage across the electricity value chain



The high-value of the end-user market is largely due to its ability to increase the behind-the-meter self-consumption of solar power, thus reducing consumption from the grid. This is the largest and most tangible revenue stream available to storage projects in the current market as well as in the foreseeable future. However, as shown in Table 32, end-user installations are also capable of delivering other economic value, whereas T&D and supply-side installations are restricted in their economic value. It is important to note that distributed installations are generally smaller than centralised installations. As such, some economies of scale are lost and some technologies (such as solar thermal storage, CAES and PHS) would not be technically feasible due to scale constraints.

Table 32 Summary of economic drivers available for different energy storage applications

Economic driver	Current value	Expected future trend	Off-grid	Wholesale	T&D	End user
Tariff avoidance	Large	Growing				✓
TOU arbitrage	Small	Growing				✓
Back-up security	Small-medium	Steady				✓
Wholesale arbitrage	Small	Growing		✓		✓
Fuel saving	Large	Steady	✓			✓
Ancillary services	Small	Growing	✓	✓		✓
DM incentives	Small	Growing			✓	✓
Network investment return	Small	Steady			✓	
Power quality	Small	Steady -growing	✓		✓	

The rapid uptake of solar PV provides a useful analogy to what might occur in the energy storage market. The behind-the-meter market segment of energy storage is widely expected to undergo a similar boom to the solar PV industry, with a potential tipping point within the coming ten years as battery prices fall (see Section2.5). However, the risks and opportunities from an energy storage boom are more complex than for solar PV due to the multitude of applications and value streams relating to storage, greater safety risks, and their cumulative impact on the continued growth of rooftop solar. As such, ARENA should work with industry participants such as DNSPs and retailers to prepare the market for a future boom, establishing safe installation standards and sustainable market structures which reward each of the value streams.

While ARENA has supported energy storage projects in the past with a focus on supply stability in remote applications, this study seeks to bring together a coordinated and targeted approach for ARENA to use going forward. AECOM has identified and ranked a number of investment priorities for ARENA to focus on, which can be grouped into three categories: Capacity building, Demonstration projects, and Technology development. The shortlist of investment options are summarised in Table 33.

5.2 ARENA's objectives

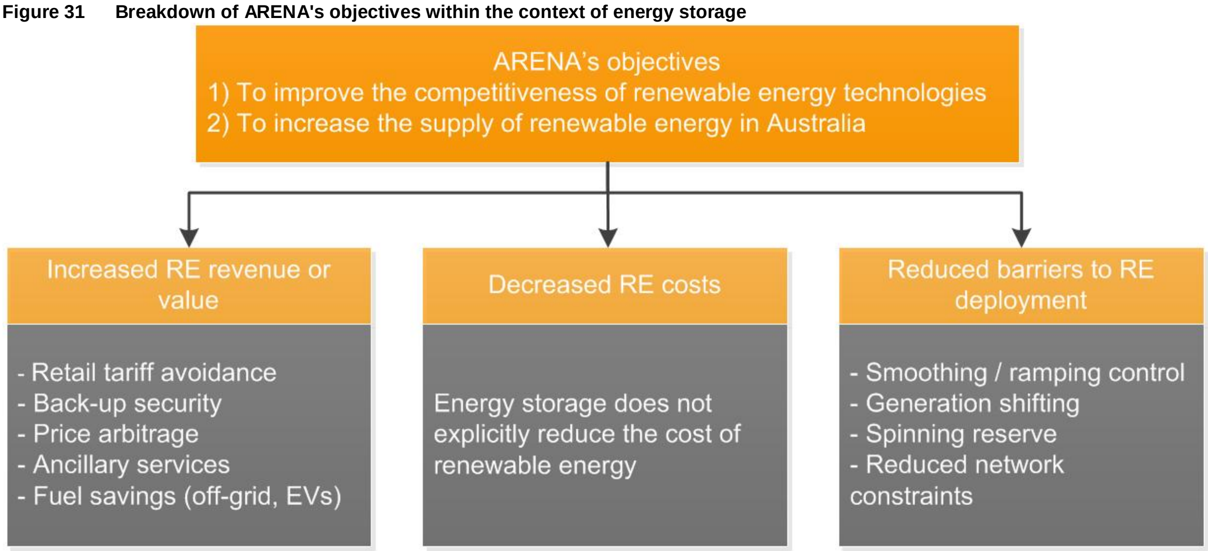
ARENA's objective is to improve the competitiveness of renewable energy technologies, and to increase the supply of renewable energy in Australia. ARENA's Board has identified energy storage as an important enabling technology that is critical to the way that intermittent renewable energy integrates into the energy system.

At a high level, there are three ways energy storage might deliver ARENA's objectives. These include:

1) Enabling increase revenue for renewable energy projects
2) Decreasing renewable energy project costs
3) Reducing barriers to renewable energy deployment

Given the nature of energy storage, it cannot be used to decrease a renewable project's costs. Energy storage can provide value either by increasing revenue or reducing barriers to deployment. This idea is further explored in Figure 31, which outlines the different roles energy storage can have in meeting ARENA's objectives.

Figure 31 Breakdown of ARENA's objectives within the context of energy storage



AECOM has sought to develop investment options and evaluation criteria that align with ARENA's objectives by considering which initiatives can either increase the revenue/value of renewable generation or reduce barriers to its deployment. This is important because some energy storage applications can have limited relevance to renewables (e.g. UPS).

5.3 Investment options

AECOM has developed a list of potential ARENA investment options based on the findings from the international review, the domestic market review, industry consultation (described in Appendix B) and our own professional opinion. These investment options have been designed as a shortlist of options that meet ARENA's objectives (described in Section 5.2) across a wide breadth of markets, applications and stages across the energy storage innovation chain.

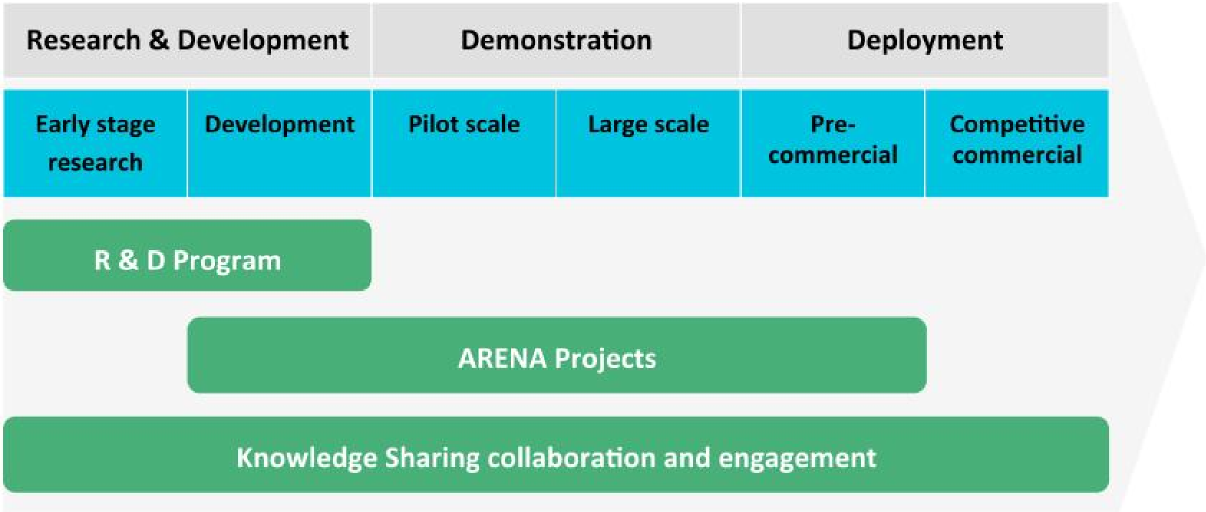
The investment options can be categorised into three types of initiatives:

1) *Demonstration projects*; funding for demonstration of a technology, application and project value, whilst seeking to identify barriers to future market-led deployment.
2) *Capacity building*; measures that enable the market to develop in a safe, educated and productive manner (e.g. education, installations standards).
3) *Technology development*; funding the development of new technologies that could lead to step-changes in efficiency, cost or applications in energy storage technologies.

It is noted that there is considerable overlap of these three categories. For example, *capacity building* is relevant for all initiatives. Similarly, *technology research and development* will often overlap with demonstration projects.

As shown in Figure 32, ARENA's role spans the whole innovation chain, from research and development, through to demonstration and deployment. This is mirrored in the three categories of investment options, where *technology research and development* aligns with ARENA's R&D program, *demonstration projects* aligns with ARENA Projects, and *capacity building* covers Knowledge sharing collaboration and engagement.

Figure 32 Summary of ARENA's role across the innovation chain, which spans R&D, demonstration and deployment [147]



The shortlist of investment options is provided in Table 33. AECOM has also highlighted a number of implementation suggestions and considerations, including areas of focus, limitations, and relationships with ARENA's existing portfolio of programs and projects.

The investment options are intended to be technology agnostic. While some technologies are currently outperforming others in terms of commercial and technical readiness, the fast-evolving nature of energy storage technologies and the project-specific nature of energy storage economics should encourage ARENA to refrain from "picking winners". Instead, ARENA should seek to support technologies that are either the most cost efficient (to reduce funding requirements), or technologies that ARENA sees potential for its funding to contribute towards a step-change in the technology's technical and/or commercial readiness.

Table 33 below defines and discusses a number of investment priority options considered. AECOM has also highlighted a number of implementation suggestions, areas of focus, limitations, and considerations for ARENA's existing/future programs and funding priorities.

Table 33 Description of investment options

Investment priority	Context and drivers	Recommended focus for ARENA	Implementation considerations	Consultation references
Demonstration Applications				
Off-grid hybridisation	The high cost of electricity supply in the off-grid market makes renewables a relatively competitive alternative power supply. Energy storage enables higher penetrations of renewable energy when coupled particularly with diesel power stations in remote energy applications. In particular, battery storage can enable off-grid systems to react to the intermittent nature of renewable energy supply and provide additional power quality and reliability benefits. The performance of energy storage devices in remote applications is relatively unproven and despite a number of demonstrations in various stages of implementation, the remote energy market is still some years from defaulting to implementing hybrid renewables in all remote applications.	ARENA's Regional Australia Renewable (RAR) program will gain traction with project implementation, which will create significant industry learnings and help to catalyse future projects. Since ARENA has already funded numerous projects under RAR & CARRE programs, it is expected that the learnings from these project will likely bring future project benefits. The embryonic nature of the off-grid market means that in the short term the continuation of direct grant funding programs, with refined focus would likely provide additional benefits. AECOM recommend ARENA focus funding specifically toward applications and/or learnings in remote mining, irrigation and communities application where energy storage and renewable energy have high future potential. Focusing on a variety of technologies, locations and innovative ways for reducing system costs will likely create the most future benefit. We suggest ARENA focus on installation of larger scale (>1MW per installation or program of works) and preference projects which focus on a high level of renewable penetration. Particular attention should be given to the integration of enabling technologies which can support greater use of renewable generation whilst maintaining system reliability and stability (i.e. control systems, energy storage, renewable forecasting tools, low load diesel integration, etc.) and developing pathways to replication without further ARENA subsidies.	Some higher value areas for further consideration are: - **Target** hybrid technical developments and breakthroughs which have widespread application, such as communications & control system learnings when integrating energy storage - **Target** larger storage applications on larger loads such as mine sites, irrigators and remote community storage use which supports current and future renewable integration - **Prioritise** the use of renewable resource forecasting tools which optimise the use of off-grid hybrid plant and improve financial returns - **Share** funded project learnings i.e. plant optimisation design learnings, lessons learned, capital and economic performance data	Survey S5 Interviews C2, C4, C12, C13
Utility-scale storage	Pumped storage is already being used in most of Australia's electricity markets to provide both reserve capacity and ancillary services. Despite localised constraints, the existing over-supply of power generation in most of Australia's energy markets means the opportunities for wholesale arbitrage are limited. Current market conditions are not conducive to new energy storage projects providing market arbitrage or FCAS services due to stable wholesale prices and low values of FCAS services. However in the longer term as more traditional thermal plants are retired and more intermittent renewable generation is installed, spot markets will likely experience more price volatility and FCAS price will grow. Currently, wholesale arbitrage and FCAS should be seen as secondary revenue streams to energy storage projects that require a separate, stronger financial driver. The Australian electricity systems were all originally designed to connect centralised conventional power stations to high demand areas. The future electricity system will need to support large variations in power flow as a result of more distributed and intermittent generation. As a result, the demand for ramping control, power quality and matching the variable supply with demand will increase. Energy storage could again play a pivotal role by providing smoothing, load shifting, dispatching and ancillary services associated with higher concentrations of renewable energy.	Utility-scale wind and solar farms are typically located in rural areas where the solar/wind resource is plentiful and large scale developments are possible; however the closest transmission/distribution lines are often constrained meaning that renewable generation could be curtailed. ARENA could consider supporting the use of energy storage to support industry in overcoming some of these challenges through the use of energy storage to enable greater use of highly abundant renewable resources. ARENA support should be directed toward knowledge sharing and demonstration in highly concentrated renewable regions (i.e. South Australia where high penetrations of wind power exist, or Queensland where there is significant solar electricity potential) which provide insight into the future effect of renewables on markets and how energy storage can play a pivotal role. Key knowledge outcomes should include identifying regulatory barriers, quantifying the value streams and forecasting future trends in the value streams. ARENA is currently funding an AGL business case for supply-side integration of storage to complement wind generation in South Australia.	Some higher value areas for further consideration are: - **Target** projects that combine utility scale storage with RE generation that overcomes network constraints and can seek to obtain additional value from market arbitrage and FCAS. Currently, network directed renewable plant curtailment is experienced in South Australia and Western Australia. - **Consider** geographical location of energy storage relative to RE 'hubs' to provide clear linkage with RE and demonstrate complementary advantages. - **Target** projects which provide shared economic benefits to consumers and networks. - **Consider** supply-side value (wholesale arbitrage and FCAS) that can be supplied by all energy storage projects as a secondary revenue stream (i.e. not only on the supply side) - **Target** project demonstrations or studies at locations where there is both network constraint value and future spot price volatility.	Survey S5, S2, S6 Interviews C2, C40, C27, C28, C34
T&D network management	There are three main factors that will drive the investigation of energy storage by NSPs: - Consumer pressure, motivated by significant increases in	Despite T&D applications being one of the higher value creating options for the use of energy storage in both international and domestic markets, there isn't always a direct linkage to ARENA's mandate of	Some higher value areas for further consideration are: - *See fringe-of-grid points below also.* - **Explore** energy storage projects which can reduce network impacts or	Survey S5

Investment priority	Context and drivers	Recommended focus for ARENA	Implementation considerations	Consultation references
	network prices, has forced regulators to assist in easing network price increases. This has resulted in the Australian Energy Regulator (AER) more vigorously challenging network owners' capital investment and operational costs proposals as well as directing a reduction on return on investment (reduction of WACC). Therefore NSPs must consider more innovative technical solutions, particularly if they are more cost effective. - High regional concentrations of distributed solar PV are already causing issues with reverse power flow. Energy storage at the substation could help defer the need upgrade substations for reverse flow operation. Furthermore, installation at the substation level could have improved economies of scale relative to behind-the-meter installations. Despite this application being only applicable in a limited number of locations, as the uptake of distributed generation continues, it is expected that these issues will become more prevalent. - Despite the current uncertainty caused by the proposed changes to the RET, it is expected that a large amount of renewable energy will be installed in a relatively short timeframe. Energy storage could play a pivotal role in its integration.	facilitating renewables and reducing costs. Internationally, much focus is being directed towards demand-response and energy efficiency to improve the utilisation of network assets and reduce spending requirements. This can be achieved through a wide range of technologies, including thermal storage, batteries and smart control systems. Nonetheless, renewables require a robust grid to reach high penetrations. ARENA could provide funding support to NSPs who are motivated to adopt innovative technical solutions with the aim of bolstering the future business case for the use of renewables and/or energy storage as part of their future grid management. For distributed renewable resources, such as solar PV, utilities have developed standards to minimise the safety and stability issues associated with bi-directional flow of exported electricity consequently limiting its use. ARENA should thereby support projects which seek to overcome this challenge for both network businesses and consumers. Similarly support may be required to assist network businesses to better understand the use of distributed renewable assets in their system planning and management. Energy storage and other demand management technologies provide a means for network operators to manage this challenge. Additionally, ARENA should seek to link T&D benefits to behind-the-meter storage systems (see also *behind-the-meter*), such that DNSPs can utilise installed storage capacity to reduce requirements for network augmentation.	costs or deliver benefits associated with high concentrations of renewables. - **Target** projects which underpin the business case for the use of energy storage as an alternative to traditional technology options to manage high concentrations of renewable energy where an end-user and NSP shared benefit can be obtained. - **Consult** with the AER, AEMC and Dept. of Industry, COAG Energy Council further about their focus on enabling energy storage and other demand management technologies and business models into Australia's energy markets. - **Prioritise** projects which overcome common barriers to deploying renewable energy through the use of energy storage using outcomes such as a rule change applications to AEMC, refinement of distribution/transmission loss factor assessment methodology, distributed generation assessment and streamlining or standardising grid connection processes across DNSP. - **Target** projects which consider smart metering, smart grid applications, demand management which also integrate energy storage and enable renewables. This includes exploring the metering and communication requirements that provide optimal information / benefit to NSP's	Interviews C5, C30, C37
Fringe-of-grid	Electricity supply to remote consumers is often cross-subsidised by network businesses to manage the high cost to deliver electricity to remote parts of the networks. Energy storage can provide a technical solution to offset the need to maintain and augment the network in fringe of grid regions. In particular, it can assist the integration of higher concentrations of renewables fringe-of-grid areas by reducing intermittency, providing peak capacity and managing reverse flow, and providing ancillary services. Embedded generation is often more competitive in fringe-of-grid areas due to the large distribution loss factors from centrally supplied generation. Valuing the system benefits in fringe of grid applications have historically been difficult to quantify however it is generally understood that network constraints in remote regions will likely be future use of energy storage, particularly when compared to often costly traditional infrastructure upgrade solutions.	It is commonly understood that the future electricity system will utilise more distributed energy resources. Through ARENA's support, utilities such as Ergon, Horizon, Power and Water Corporation are leading the market in alternative supply options through the use of energy storage in fringe-of-grid applications. Even though there isn't an exclusive linkage to renewables, energy storage integration into fringe-of-grid applications will provide a more robust network to enable greater renewable integration. Future ARENA support for energy storage should look to enable NSPs to further understand and quantify the benefits of the use of the technology as an alternative to the traditional options. Similarly, any fringe-of-grid integration of renewables should consider energy storage for providing dispatchable benefits such as load matching and ancillary services. ARENA may want to create a new program or refocus the RAR Program to be more focused on fringe-of-grid projects, particularly if proponents can demonstrate a business case for future uptake of renewable energy and assist industry to overcome regulatory or other perceived barriers. Improvements in the methodologies for quantifying distribution loss factors and investment deferral benefits associated with embedded generation will likely have the high future benefit [148]. ARENA may not have a direct role in influencing these regulatory changes although there are clear renewable uptake benefits in some regions for resolving these barriers, justifying a reason for ARENA to exert its influence through the support funding it provides.	Some higher value areas for further consideration are: - **Consult** further with network businesses, regulators and government on the structure of its future support for T&D network management and investment deferral (including fringe-of-grid areas) - **Target** providing greater network constraint transparency, providing opportunities for integrating energy storage or other demand/supply management technical solutions (i.e. build on UTS ISF Network Opportunity Mapping DANCE project) - **Target** projects that attempt to demonstrate economic benefits of islanding fringe of grid locations with renewable energy hybrid solutions. Particular focus should be given to locations where storage might lead to deferred network investment - **Target** projects that demonstrate quantifiable network benefits through alleviating supply, power quality or capacity constraints through the use of energy storage combined with renewable energy generation. - **Target** outcomes from funded project/s which define a methodology for quantifying the network benefits which can be used by project proponents, NSPs and regulators in the future. Similarly, seek to promote rule or standard changes to overcome regulatory barriers to future uptake. - **Share** the learnings and business case considerations with retailers, demand management aggregators, NSPs and developers to ensure that future funding support has a strong basis and is targeted.	Interviews C1, C2
Behind-the-meter (consumer)	Consumers are motivated to minimise their costs. Pairing solar PV with storage provides an avenue for them to load shift and match their generation to times of high energy demand and/or tariffs. This market segment has a large opportunity for shared benefits	Energy storage is a natural solution for consumers to maximise their use of their renewable generated energy. However, the real value of energy storage should extend beyond the meter. Rather than seeking to fund individual installations, ARENA would	- **Target** projects which consider the use of energy storage at a community or regional level which can provide shared benefits to the network businesses with the aim of off-setting network charges for consumers, reducing energy infrastructure costs and outlining the benefits of the	Survey S11 Interviews

Investment priority	Context and drivers	Recommended focus for ARENA	Implementation considerations	Consultation references
	between consumers and networks. In particular, reducing peak capacity impact on network infrastructure constraints leading to deferral of network investment, which reduces future network costs. Similarly, load shifting with energy storage reduces the prospect of reverse power flow of solar PV generation on the electricity system. Offsetting grid-supplied electricity consumption is currently the best-defined business case for storage in on-grid applications (i.e. the main revenue stream is easily quantifiable and it is not subject to approval from the regulator). However, it is still vulnerable to how 'cost reflective' pricing will be implemented by NSPs. The design of network tariffs will directly impact the business case for pairing solar PV with energy storage.	obtain greater benefit if its focus is through supporting the future market led roll-out of energy storage solutions. Priority should be on sharing knowledge that enables consumers and industry to further understand the benefits of retrofitting existing PV sites with energy storage by deploying regional or community level funding support targeted particularly at areas with current or predicted high PV penetration. The focus should be on enabling energy users to use energy storage to reduce their maximum demand and capacity charges by storing solar PV generated electricity. Energy users should be encouraged to also participate in demand management programs particularly where there are network constraints. Despite the economics being more challenging (due to lower electricity prices), ARENA should extend its support toward commercial and industrial installation where load shifting can be obtained through the promotion of renewable with energy storage. Also greenfield housing developments where renewable and energy storage can reduce the upfront infrastructure costs associated with peak demand capacity requirements could have high future potential. ARENA should also seek innovative business models that explore the use of 'virtual net metering' where energy is locally generated and consumed, thereby avoiding network infrastructure use and demonstrating the real value of localised and dispatchable distributed generation to consumers and NSPs.	technology to industry. - **Target** projects in locations which already have high concentrations of rooftop solar as well as imminent network constraints associated with the high concentration of solar. Community based' renewable + energy storage projects could be supported in these locations as an extension to the solar cities model. - **Share** learnings on how to enhance the multiple uses or benefits of energy storage through intelligent metering and controls systems. - **Explore** a variety of business models and ownership structures for the deployment of behind-the-meter energy storage i.e. NSP driven, retailer driven, demand management aggregator driven, developer driven, leasing vs. sale. - **Support** partnership programs between regional councils, state or territory governments, community groups, housing developers, NSPs or retailers which provide broader industry-wide knowledge benefits. - **Target** ownership models and operating regimes for behind-the-meter battery systems that demonstrate maximum benefits from the shared use of distributed energy resources, with the aim of facilitating a deeper understanding of the value of energy storage across various market segments.	C8, C16, C18
Electric vehicles	Most of the world's major vehicle manufacturers are currently developing, or have plans to develop electric vehicles for the mass market. It is anticipated that widespread adoption of EVs will take place in Australia over the next 30 years. EV uptake outside of Australia is increasing rapidly with some countries having passed more than 5 per cent market share point in 2013 [3]. While the base cost of the vehicles has dropped dramatically in the past 5 years, pay-back periods remain challenging.	There are three main opportunities for electric vehicles to facilitate renewables: - Electric vehicles powering public charging stations from renewable energy - Electric vehicles effectively proving batteries behind-the-meter to end consumers, offering all the benefits discussed in the *Behind-the-meter (consumer)* section - Re-use of EV batteries once their "in-car" lifetime has ceased ARENA's focus should be on providing consumers with developed business models and technical solutions to use their EV in conjunction with their renewable plant.	Some higher value areas for further consideration are: - **Target** business cases which enable greater uptake of EV's where there is a direct linkage to the use of renewable energy. - **Consider** assisting EV infrastructure providers to streamline network application process - **Consider** outcomes which demonstration the benefits of EV's, so consumers are making informed choices and can better understand the business case (particularly associated with use of renewable energy). - **Consider** funding studies or projects into understanding the role and costs of providing network benefits from EV batteries.	Survey S17 Interviews C23, C24
Capacity Building				
Codes and standards	There is currently a lack of Australian standards for modern energy storage technologies. This includes manufacturing, installation, housing, testing and maintenance. A safe installation standard for batteries has recently been announced as a priority for development by Standards Australia (proposal titled "Electrical installations – safety of battery systems for use in inverter energy systems") and an E-Waste standard exists (AS5377) which partly deals with battery recovery and processing at end of life. Similarly, AS4777 (connection standards) is being updated to include battery energy storage. Consultation with stakeholders highlighted the importance of establishing installation and battery housing standards to ensure that minimum safety requirements are established prior to any large-scale rollout of battery systems.	The timing of standards development is a compromise between having sufficient knowledge of the technology and market to make high quality standards without compromising innovation and establishing standards prior to mass uptake. There is currently an opportunity to develop good standards prior to mass uptake and ensure the safety and sustainability of the emerging energy storage industry. The Clean Energy Council is currently driving the development of energy storage standards and has received financial support from ARENA. ARENA may have an additional role to support the development of these standards through sharing the learning outcomes of relevant demonstration projects that it supports. To be effective, learnings need to be shared in a timely manner to enhance process that is currently underway.	Some higher value areas for further consideration are: - **Target** accelerated knowledge sharing for those projects that can assist in development of standards for installation and housing of household/small-scale battery installations - **Support** the Clean Energy Council in its task of developing meaningful, practical and safe standards for energy storage - **Consider** and test the robustness of the newly developed standards during energy storage pilot programs, sharing learnings to help shape the development of standards with relevant stakeholders - **Consider** any need and timing for further development of standards beyond installation and housing (e.g. manufacturing, testing, maintenance) prior to widespread uptake of battery storage technologies - **Consider** differences between different battery storage technologies	Survey S8, S14 Interviews C7, C10
Rules and laws	The consultation process revealed a number of limitations in the National Electricity Law and National Electricity Rules that may limit the role of energy storage. This includes: - Battery owners/aggregators supplying power to 3rd parties are currently required to seek an exemption from requiring a	While ARENA cannot directly change energy regulations or law, ARENA may have a role in commissioning a research study which provides a comprehensive overview of rule/law changes required to help facilitate the integration of energy storage into the market. In addition, ARENA should seek to identify and publicise any regulatory	Some higher value areas for further consideration are: - **Consult** further with the AEMC, AER and industry to identify comprehensive rule and law changes required to facilitate renewable energy deployment. ARENA role should focus on building evidence based outcomes and influencing others to inform their consideration of changes to	Survey S11 Interviews C9, C37

Investment priority	Context and drivers	Recommended focus for ARENA	Implementation considerations	Consultation references
	retailer's licence - NSPs are unable to use the full functionality of energy storage systems due to competition restrictions (i.e. NSPs cannot use the energy component, just capacity) - There is no mechanism for NSPs to propose islanding/microgrid solutions to service isolated consumers which are currently fringe-of grid The AEMC is not currently working on any rule changes specific to energy storage among other distributed generation devices, however a number of changes currently under consideration (e.g. cost reflective network pricing, DMIS) are expected to impact demand for energy storage.	barriers that are identified during demonstration projects. Separate to ARENA, in time Government may also seek to adopt policy, as has been implemented internationally, which mandates comprehensive energy storage rollout targets.	policy, legislation, regulation, etc. - **Prioritise** outcomes of ARENA funded projects that present findings to regulators, include a high degree of consultation with authorities or possibly propose rule changes either themselves or through an industry association, where applicable. - **Integrate** further with ENA, state government, and others who drive / influence the rule change process. - **Preference** projects which seek to streamline the grid connection costs associated with renewable projects by optimising the shared benefits through the use of energy storage.	
Accreditation	Accreditation of energy storage products and installers can provide buyers with confidence in the quality and safety of their energy storage purchases. This is critical for the development of the residential and small-scale commercial markets and will reduce the risk of the industry being brought into disrepute through poor quality products and installation.	Currently the Clean Energy Council accredits products and installers of solar PV in Australia, which has proven invaluable to the industry. The Clean Energy Council may also be an appropriate body for fulfilling the same role for energy storage products. ARENA may consider funding the Clean Energy Council to help it develop its accreditation process.	Some higher value areas for further consideration are: - **Support** the development of an accreditation process for energy storage products and installers. - **Consider** assisting industry to develop registration processes for energy storage systems including regulation/incentive options	Survey S15 Interviews C7
Education and knowledge sharing	Energy storage is a new, evolving technology, which is entering a market that it will inevitably disrupt the status quo. As such, there are many knowledge limitations, including: - Knowledge of technology value to potential buyers - Understanding of energy storage business case - Capability and limitations of new technologies - Capability of suppliers to support projects - The ability to correctly conceptualise projects, including suitable location, technology, sizing, design, and business models (i.e. revenue streams) - Regulatory barriers	ARENA has a vital role to play to help develop and share energy storage knowledge, to help facilitate further deployment of renewable generation. ARENA can help generate knowledge through demonstration projects and research projects. We acknowledge ARENA already incorporates detailed knowledge sharing obligations in funding agreements for new projects.	Some higher value areas for further consideration are: - **Target** disseminating information and learning from ARENA funded projects through various communication channels. - **Target** the development of a 'buyer guide' providing consumers with insights into technology options, installation sizing, the role of solar PV, tariffs, load shapes, charging patterns, revenue streams, installation and operational factors, and the use of EVs. - **Target** the development of a simple financial assessment tool, suitable for household use (i.e. tariff offsetting revenue only) - **Target** the development of an Industry Best Practice Guide - **Target** supporting projects that seek to verify the value of more complex value streams (e.g. FCAS, wholesale arbitrage, network capacity) - **Consider** international collaboration for knowledge sharing, including technology providers, policy makers and project developers - **Consider** amalgamating the learnings from all energy storage projects together into one knowledge sharing program.	Survey S10 Interviews C5, C15, C20
Technology Development				
Energy storage alternatives (e.g. demand-side participation, solar forecasting)	In some scenarios, the desired enabling functionality of energy storage can be delivered (either in full or in part) by alternative technologies. The high cost of energy storage mean existing alternative technologies often can fulfil the same function at a lesser cost. This is reflected in international trends towards smart networks, with markets such as California, New York and the United Kingdom focusing on demand-side participation and smart grids (in addition to energy storage) to provide robust networks that can support higher penetrations of renewable energy. Technologies such as sun/wind resource forecasting can help reduce the requirement for energy storage / spinning reserve (particularly in off-grid applications), improving the financial attraction of high penetration renewables. Strong support for alternatives to energy storage was provided by a respondent to the Industry Survey who said: *"It is critical to understand that the storage is only part of the equation and not enough effort is focussed on developing and improving enabling devices which enable appropriate value*	ARENA should seek to support the development of enabling technologies which improve the efficient use of energy storage technologies specifically related to ARENA's renewable mandate. Focus should be on enabling technology breakthroughs that have a direct application to Australia through supporting pilot projects and R&D technology development. Smart grid integration, intelligent device control systems, renewable resource forecasting, and any technologies which can reduce cost or risk in both off-grid and grid connected applications should be considered. ARENA may look to fund the development of these technologies directly or target their integration into projects they are considering funding. It is suggested that ARENA should not only limit its future support to energy storage devices, but seek to support innovative solutions (such as forecasting and control systems) which offer the significant economic benefits.	Some higher value areas for further consideration are: - **Target** technology breakthroughs which have a direct application in Australia through supporting pilot projects and R&D technology development. - **Target** technologies (e.g. control systems and forecasting tools) which optimise the use of intermittent renewable generation and the use of energy storage. - **Preference** renewable energy projects which include a component of demand side management or response because of the widespread application of DM management. - **Target** technologies which enable a stable operation of the network particularly in regions of high penetration or concentration of renewable generation. - **Target** technologies that offer solutions to load shifting, peak shaving, demand management, power quality improvements, reverse power control, anti-islanding, smart grid integration, intelligent device control systems, renewable resource forecasting.	Survey S5 Interviews C13, C32

Investment priority	Context and drivers	Recommended focus for ARENA	Implementation considerations	Consultation references
	stacking between different market segments."			
Balance of plant	Balance of plant are defined as all upfront cost associated with the energy storage system except the storage device itself. Energy storage prices (particularly battery prices) are expected to fall, driven by international technology and manufacturing improvements. Nonetheless, balance of plant costs currently contribute up to 60% of system costs and this component is not expected to experience the same price reduction drivers as the batteries.	ARENA should look to share balance-of-plant learnings from its funded demonstration projects and consult with researchers and industry on opportunities to deliver balance of plant cost reductions. Reduction in the cost of balance of plant, will likely come through sharing of experience and learnings which might reduce conservatism in first generation designs. It is important that quantifiable high value knowledge is shared by ARENA to the broader industry and that multiple projects are implemented involving varied stakeholders so that there is a broader distribution of direct project experience across all industry participants.	Some higher value areas for further consideration are: - **Target** cost reduction opportunities through technology improvements, design improvements and implementation efficiencies by sharing the learnings. - **Consider** supporting more innovative solutions even though they may be seen as high risk (i.e. breakthroughs which could dramatically reduce future balance of plant costs). -	Survey S16 Interviews C1, C19
Electric vehicles - vehicle to grid / home	Uptake of electric vehicles with large battery capacity is expected to increase rapidly over the next decade, providing immense energy storage capability in many Australian homes. There is an opportunity to use these batteries in behind-the-meter applications. The burgeoning EV market could help ARENA meet its renewable energy mandate by facilitating an improved value proposition for rooftop PV systems, when they are used to charge the vehicle battery. The battery can also provide renewables-enabling functionality such as demand-side participation.	While the electric vehicle market will grow organically, ARENA should look for opportunities to use EV batteries in a productive manner. In particular, there is a large opportunity to utilise EV batteries within the home, enabling greater use of rooftop solar, retail price arbitrage and demand-side participation. - ARENA should seek to support demonstration projects that seek to investigate the charging behaviour of EV drivers and how this might be managed and utilised in combination with PV generation.	Some higher value areas for further consideration are: - **Target** key challenges including vehicle-to-grid connection and standardisation of charging infrastructure - **Target** proof of concept through trials that utilise rooftop PV to charge vehicles, measuring the utilisation of PV by the vehicles and charging behaviours - **Consider** funding projects which involve the NSP with the aim of demonstrating the potential increase it network utilisation through well-designed EV charging systems	Survey S17 Interviews C22, C25
Battery technologies	The rational for the development of new battery technologies is to economically improve performance which would be defined differently for each application. Performance improvements could include improved cycle efficiency, improved energy and power density, reduced battery degradation due to time, environment and application factors such as cycling, charge/discharge rate, maximum and minimum depth of discharge. Given Australia's wealth of lithium resource and skills in mineral processing governments could consider supporting development of advanced lithium extraction and recovery processes which in turn could improve Australian competitiveness, lower raw material costs for battery manufacture and improve the economics of energy storage. Enhancing lithium recovery techniques could equally have applications in recycling and recovery of materials from used batteries.	Australian battery research should primarily focus on new or step-change technologies as optimisation of existing battery materials and battery manufacture processes is likely to be driven largely from overseas. The research focus within Australia could include developing and demonstrating world class safety and performance test frameworks suitable for Australian applications and environments to assist industry, consumers and regulators differentiate technologies and products. For portable applications the focus of the research could be directed on lithium-ion and lithium-polymer batteries, as well as alternatives that offer potential to increase power or energy density, can operate over broad operating conditions and are physically robust. In stationary applications, research should focus on improvements to battery management systems and the overall system design.	Some higher value areas for further consideration are: - **Consider** projects which apply innovative load or renewable management solutions through the use of transportable battery storage technologies to help manage the seasonal or intraday demand/supply variances, critical peak load events or integration of high volumes of renewables into networks. Mobile energy storage has potential to minimise infrastructure costs for areas which exhibit high season peaks (e.g. holiday destinations). - **Consider** supporting credible institutes in development of standardised testing to differentiate safety and/or capability of various battery and battery management system technologies. Results of testing could be fed into consumer information guides and industry knowledge sharing. - **Target** support for technologies that offer step changes in performance (e.g. nanotechnology for electrode improvements and ultracapacitor development) - **Consider** support for research into processing/ recycling of used battery materials. which aligns with Australia's expertise in materials handling and mineral processing - **Consider** encouraging wider Government assistance of research into upstream processing (Li extraction) which aligns with Australia's resource development objectives and mineral processing capability	Survey S10 Interviews C5, C10, C32
Thermal storage technologies (behind-the-meter)	Behind-the-meter thermal storage is an alternative way of providing network support through demand-response and load-shifting. It is most suitable for HVAC applications where conversion to/from electricity is not required. Cold-storage applications often incorporate a phase-change material to utilise the large amount of latent-energy stored in the change of phase (i.e. solid to liquid). Applications are typically load shifting and have no direct relationship with renewables (although they can help provide more robust distribution networks). However, some solar heating and solar air-conditioners do exist (though rare due to limited financial drivers) and can be paired with thermal storage to continue providing heating or air-conditioning beyond daylight hours.	Where aggregated and used in a DM application there may be a direct linkage to supporting the renewable sector through the use of thermal energy storage behind-the-meter. Ice thermal energy storage is a proven solution toward providing demand management or response solutions (e.g. Southern California Edison has recently contracted 25 MW of grid support from Ice Energy in the US) and could be utilised to support load shifting requirements. ARENA is recommended to monitor opportunities which include behind-the-meter thermal storage and assess each application on its individual merits.	Some higher value areas for further consideration are: - **Monitor** opportunities to support thermal storage opportunities behind-the-meter and assess its benefits if the broader project outcomes align with its mandate.	Survey S18 Interviews C32

Investment priority	Context and drivers	Recommended focus for ARENA	Implementation considerations	Consultation references
Recycling and reuse	As energy storage devices become more prevalent there will be a growing need to recycle their use at end of life. The Australian Battery Recycling Initiative in conjunction with the CEC is already working on guidelines for industry to adopt. The transportation and disposal of used batteries are currently governed by Australia's hazardous waste and dangerous goods regulations however it is likely that further education will be required as the automotive and stationary battery markets mature.	Despite there being no direct linkage to ARENA's renewable mandate, ARENA could assist the industry to ensure that the risks associated with the disposal of heavy metals often found in batteries do not create hazards to human health and the environment and public perception issues – particularly from any of the ARENA funded projects. ARENA should also look to consider opportunities to enable consumers and industry to efficiently and safely reuse batteries, particularly from automotive to stationary applications.	Some higher value areas for further consideration are: - **Preference** projects where proponents can demonstrate a clear plan to recycle battery technologies and minimise the disposal to landfill. - **Preference** opportunities to commercialise the value in second life of battery technologies or reuse materials such lead, cadmium, mercury, lithium, manganese, nickel and zinc which can be used to make batteries. - **Consider** funding projects which enable the reuse of automotive batteries to stationary energy applications.	Survey S9 Interviews C31
Concentrated solar thermal storage	Utility scale thermal storage technologies are typically paired with concentrated solar thermal generators. Few solar thermal projects have been built in Australia, however large projects have recently been completed overseas, including the 392MW Ivanpah plant in California. Solar thermal plants typically require very large projects (larger than 100MW) to achieve sufficient economies of scale to make it relatively cost-competitive with solar PV (particularly central receiver design types). As such, utility-scale thermal storage technologies are typically only suitable for supply-side applications. Therefore, to make the storage component of a solar thermal plant financially viable (in the existing market structures) a large spot price differential is required between daytime and evenings or significant technology / cost improvements over time.	The current market is not conducive to supporting this business case (see *Wholesale arbitrage* applications above); however, with changing market dynamics, concentrated solar thermal and thermal energy storage technology improvements, it may become a viable prospect in the medium-long term, particularly as very higher penetrations of renewables are targeted. Currently, the best opportunities will lie in off-grid applications, where generation costs are high and spare generation capacity is low.	Some higher value areas for further consideration are: - **Consider** that supply-side value (wholesale arbitrage and FCAS) can be supplied by all energy storage projects as a secondary revenue stream (i.e. not only on the supply side) - **Monitor** overseas projects for price trends - **Monitor** existing market conditions for indications of future capacity shortfalls and potential spot price volatility - **Consider** project or studies at off-gird locations (outside market conditions) where generation costs are high and spare capacity is low	Survey S4
Other bulk storage technologies	Bulk energy storage technologies such as PHS have been commercially adopted as a proven technology globally to shift electricity supply across electrical systems. However the future of new PHS is challenged by the environmental siting impacts, extensive development costs/timeframes and economies scale require larger plants to be considered (i.e.>200MW). Consequently other bulk storage technologies, such as CAES, may provide unique solutions to the bulk energy storage market needs.	It is likely with growing demand for renewable energy there will be a growing need for bulk energy storage devices globally and in Australia. Given the long and costly development periods for bulk energy storage technologies, there is likely a place for ARENA to support some development costs. Noting that for PHS there will be limited influence it can have over the technology maturity where there may well be considerable technology improvement available in emerging bulk energy storage technologies (i.e. hydrogen, nitrogen, ammonia, air or other storage mediums).	- **Consider** supporting the development, demonstration or feasibilities of bulk storage technology which may provide breakthroughs to overcome the challenges experienced by PHS (i.e. environmental, scale and cost). - **Monitor** the need for bulk energy storage in the wholesale market once renewable energy targets are confirmed.	

5.4 Investment option evaluation

The investment priority options from Table 33 above were evaluated to measure their alignment with ARENA's objectives. ARENA has two objectives: to improve the competitiveness of renewable energy technologies, and to increase the supply of renewable energy in Australia. ARENA has identified energy storage as an important enabling technology that is critical to the way that intermittent renewable energy integrates into the energy system.

AECOM has used a simple evaluation methodology where each investment option is evaluated against a set of criteria and subsequently ranked. The evaluation process is inherently subjective; however this methodology provides transparency towards the rationale behind the process used to prioritise our recommendations. Note that despite the ratings provided, it is acknowledged that in some instances, the evaluations provided may not align to the specific merits of a particular investment option. As a result, this section is provided as a guide to ARENA when prioritising its future programs, rather than a definitive ordered recommendation.

AECOM's evaluation methodology utilises simple evaluation criteria, defined below.

1) *Alignment with ARENA's objectives*

   Some investment options have a more precise alignment with ARENA's objectives than others. While all energy storage applications can have an enabling effect on renewable energy, some applications are more focused on either facilitating or directly supporting additional renewable energy supply. This evaluation criterion aims to differentiate options based on their ability to improve the competitiveness of renewable energy technologies and to increase the supply of renewable energy.

2) *Investment influence*

   This criterion is an assessment of how much impact ARENA can have through supporting any given investment option. ARENA's influence is assessed in terms of how much its investment could improve the technical and commercial readiness of the application or technology, either through direct experience or industry knowledge sharing and education.

3) *Replicability*

   This criterion is an assessment of the initiative's ability to facilitate an increase in the supply of renewable energy through repeated future deployment. The assessment also considers current and medium term (<10 years) market demand for energy storage.

The evaluation assessment has drawn on the findings from the international and domestic market reviews, the industry survey, stakeholder consultation combined with AECOM's own knowledge and experience. AECOM has also provided explanation of the rationale behind the evaluation.

Each investment option is evaluated against each evaluation criterion with a mark out of 5, where 5 represents the highest value and 1 represents the lowest value.

Table 34 Definitions of marking criteria as used in the evaluation process

		Alignment with ARENA's objectives	Investment influence	Replicability
5	High Value	Initiatives that have a definitive alignment with ARENA's objectives	Initiatives where ARENA's support will provide large improvements in technical and/or commercial readiness	Initiatives which support applications with large markets size, providing high levels of replicability
4				
3	Medium Value	Initiatives that have a somewhat aligned with ARENA's objectives	Initiatives where ARENA's support will provide medium improvements in technical and/or commercial readiness	Initiatives which support applications with moderate replicability
2				
1	Low Value	Initiatives that have a little alignment with ARENA's objectives	Initiatives where ARENA's support will provide negligible improvements in technical and/or commercial readiness	Initiatives which support applications with minimal replicability

The evaluation has been redacted.

5.5 Summary of investment priorities

Using the above evaluation, AECOM has identified a list of the seven most important investment priorities for ARENA, briefly summarised in the table below. For a more detailed description, please refer to Section 5.3. ARENA should by no means restrict its funding support to this list. Rather, this list highlights where ARENA can provide the most value to its energy storage and renewable energy objectives.

Table 35 Recommended ARENA funding priorities

Initiative	Description
Capacity Building	
Education and knowledge sharing	ARENA already completes an education and knowledge sharing role in the renewable energy sector. It is natural for ARENA to expand this role to energy storage to promote its interests in the synergy between renewable energy and storage. The education and knowledge sharing role is vital to help build industry capacity through sharing of project learnings and educational tools. ARENA must also be careful to ensure that knowledge sharing requirements articulated in funding agreements have clear definition of requirements and expectations. All of ARENA's initiatives (including the recommended Demonstration Projects and the Technology Development initiatives) should flow into its education and knowledge sharing program.
Demonstration Projects	
Behind-the-meter	ARENA should help facilitate the future market-led rollout of energy storage solutions in behind-the-meter applications. The priority should be proving the technology and business case, defining revenue streams, and educating stakeholders of the benefits of pairing energy storage with rooftop PV (particularly in areas with high PV penetration). There is particularly large opportunity to retrofit storage on households that have already installed solar PV, particularly if there is no feed-in tariff in place (e.g. NSW Solar Bonus Scheme finished at the end of 2016). An additional focus should be supporting energy storage systems that provide network capacity benefits. This will naturally lead to shared benefits between the consumer and the NSP. Following demonstration of this concept, ARENA can work with NSPs in an attempt to monetise this value stream.
Fringe-of-grid	Through ARENA's support, utilities such as Ergon, Horizon, Power and Water Corporation are already leading the market in alternative supply options through the use of energy storage in fringe-of-grid applications. ARENA should closely monitor and share learnings from these projects before seeking to refocus its objectives on future projects. In particular, ARENA should seek to identify innovative ways for energy storage to provide value through renewable integration, including islanding fringe-of-grid areas, reducing dependency on SWER lines by targeting peak demand as well as addressing technical issues resulting from intermittent generation by integrating storage. Like off-grid applications, fringe-of-grid application will provide invaluable knowledge of operating electricity systems with high penetrations of renewables.
Off-grid RE hybridisation	The strength of the off-grid hybridisation application is its simple value proposition as well as its relative costs competitiveness. Further development of this market will help prove large-scale energy storage technology capability, establish a number of storage suppliers in Australia's market and help familiarise the industry with the commercial and technical requirements of energy storage requirements for high-penetration renewables.

Initiative	Description
	Given that ARENA's RAR and CARRE programs have already committed funding to a number of off-grid projects, it will be worthwhile waiting for the completion of funded projects before assessing any remaining technical, regulatory or commercial issues that need to be addressed. The outcome of the project reviews should be used to refocus ARENA's objectives for the RAR and CARRE programs and consider a possible transition towards a market-based mechanism for funding off-grid projects.
Technology Development	
Balance-of-plant	Balance-of-plant (such as inverters, transformers, housings, battery controllers, safety systems, SCADA, integration costs) can make up over 50% of energy storage projects. Whilst battery prices are falling Balance-of-plant costs are a good target for cost savings – particularly savings that could be realised by integration learnings from completed projects. ARENA must look to share balance-of-plant learnings from its funded demonstration projects and consult with researchers and industry on opportunities to find balance of plant cost reductions. Cost reductions will come through experience and learnings which will assist to reduce the conservatism found in first generation designs. As such, it is important that quantifiable high value knowledge is shared by ARENA to the broader industry and that multiple projects are implemented involving varied stakeholders so that there is a broader distribution of direct project experience.
Storage alternatives (e.g. solar forecasting, demand-side participation)	ARENA should seek to support the development of other enabling technologies which improve the efficient use of energy storage technologies. The focus should be on enabling technology breakthroughs that have a direct application to Australia (such as our large off-grid and fringe-of-grid markets). Support can be provided through pilot projects or R&D technology development. Technologies such as smart grid integration, intelligent device control systems and renewable resource forecasting should be considered. ARENA may look to fund the development of these technologies directly or target their integration into demonstration projects.
Battery Technologies	ARENA should seek to support battery research focussed on new or step-change technologies as optimisation of existing battery materials and battery manufacture processes is likely to be driven largely from overseas. Research focus within Australia could include developing and demonstrating world class safety and performance test frameworks relevant to Australian applications and environments to assist industry, consumers and regulators differentiate technologies and products.

5.6 Additional considerations

5.6.1 Technology discussion

From the international market review, it is clear that Li-ion technologies are being favoured over other battery technologies in the most recent flagship storage projects. This sentiment was strongly supported by the findings from the stakeholder consultation and the industry survey, where Li-ion batteries were strongly favoured as the technology with the most potential in Australia. This is largely because recent improvements in Li-ion technology has led to an improvement in expected lifetime, performance and cost, in addition to other favourable characteristics of high energy density, low self-discharge and high charging efficiency. Other technologies competing with Li-ion for market share include flow batteries (e.g. vanadium redox batteries) and advanced lead-acid batteries. In addition, there are many other emerging technologies including next generation lithium technologies (e.g. lithium sulphur, LiS), sodium ion and liquid metal.

Embedded thermal energy storage is a technology with high capability for load shifting and demand response applications and it performed well in the industry survey; however its applications are limited compared to battery technologies and it has an indirect link to renewables as an enabling technology (given that thermal storage is rarely paired with renewable generation, instead acting as load shifting). In contrast, thermal storage paired with

Concentrated Solar thermal Power (CSP) generators is directly linked to facilitating renewables; however the supply-side market is not currently conducive to the value of storage within the NEM due to depressed, non-volatile wholesale prices and small revenues from FCAS markets. This may be a different prospect long term as higher penetrations of renewables come online. In the medium term, there may be opportunities for CSP with storage in off-grid applications (noting that CSP plants should be larger than 100MW to ensure sufficient economies of scale to make it moderately price competitive).

Pumped storage also rated moderately in the survey, possibly because it is technically and commercially established. For this reason, it has not been considered a relevant funding target for ARENA, as no meaningful technology or commercial progress could be obtained through funding a mature technology. In addition, as discussed in Section 5.1, the supply market for storage is not currently conducive for energy storage and few (if any) pumped storage projects are being developed, despite it being an established technology.

Compressed Air Energy Storage (CAES) ranked poorly on the industry survey and it is not a natural facilitator for renewable generation because it is typically paired with a natural gas engine. Similar to CSP and pumped storage, it is best suited to large-scale applications and therefore operates on the supply-side of the market (as opposed to the demand-side). Another barrier is that it typically requires a nearby depleted gas field for storing the compressed air. Therefore, like pumped storage, CAES should not be considered a funding target for ARENA.

Hydrogen storage technologies are appropriate for both small and large applications. In addition, hydrogen storage tanks have the capacity to supply kW or MW of demand over discharge timeframes ranging from hours to months [11] [15]. Hydrogen fuel cells typically have a response time of seconds to minutes, making it technically suitable for most storage applications. It is also readily paired with intermittent renewable energy generators either behind-the-meter or at a utility scale [11] [149]. The main drawbacks of hydrogen storage include safety requirements and low charging cycle efficiency (currently below 50 percent, although there are recent reports of cycle efficiencies of 75% or more [11] [15]).

Nonetheless, there is little reason for ARENA to actively favour one technology over another within its investment priorities. This is because some technologies lend themselves naturally to certain applications more than others. Furthermore, as technology improvements continue to occur, the hierarchy of technologies is likely to evolve. Hence, for any given demonstration initiative, the most technically suitable and commercially promising technology should be selected. For R&D initiatives, ARENA should seek to support various technologies that show step-change potential in performance, safety and economic measures.

5.6.2 Business models

Given the energy storage market is in its infancy, business models will evolve and diversify to capture economic benefits. There are several dominating factors that will influence how businesses adapt and create their models, such as; high CAPEX, different ownership models (e.g. NSP-owned, leasing), cost sharing, revenue sharing and aggregators in the industry.

It is in ARENA's interest to seek out and support innovative business models that unlock additional value and allow value to be appropriately shared among the stakeholders that energy storage can offer such as decongesting networks and power quality. ARENA has already begun supporting third party participation behind-the-meter through Reposit Power's trial to achieve shared value through multiple value streams (utilising solar generation, wholesale arbitrage, retail tariff arbitrage, FCAS and network capacity support. The strength of this model is its ability to monetise all available value streams and its aim to share the financial benefits across each of the relevant parties in an efficient manner. ARENA should closely analyse the capability and potential of similar retail/aggregator business models before looking to carry out larger pilot projects to better quantify the business case and compare the relative advantages of various models.

One alternative business model adopted in New Zealand by Vector Energy, who are conducting a trial which offers leasing arrangements to customers for rooftop solar, Li-ion batteries and control devices. The trial has focused on the NSP having the ability to control the battery to provide capacity benefits to the network, whilst simultaneously offering energy benefits to the end customer (through higher behind-the-meter utilisation of solar power). This model could encounter regulatory issues in Australia due to restrictions on DNSP's ability to incorporate behind-the-meter storage into its Regulated Asset Base.

6.0 Conclusion

The rapid growth in intermittent renewable energy, namely solar PV and wind, is catalysing efforts to modernise the electricity system. At high levels of penetration, intermittent renewable generation increases the need for resources that contribute to system flexibility such as energy storage, which can help ensure system stability by matching supply and demand of electricity. Energy storage can be deployed throughout electricity systems to help facilitate increased penetrations of intermittent renewable generation, while producing numerous other operational benefits in parallel, such as load shifting and power quality.

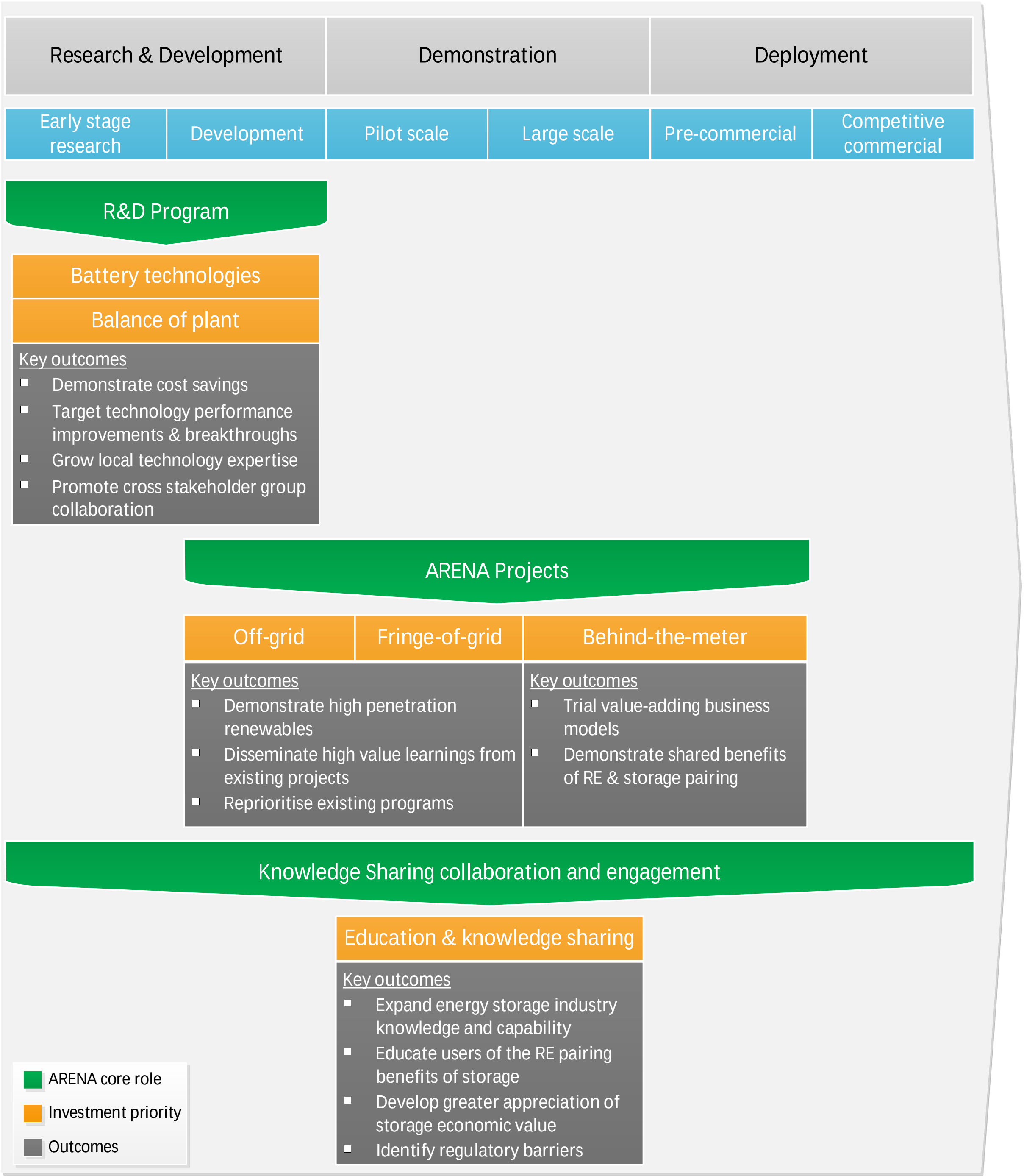
In the global context, it is clear that international markets are looking at energy storage as part of a suite of facilitating technologies to aid increased penetrations of renewables, achieve improved system flexibility and more efficient utilisation of electricity networks. The greater suite of solutions includes embedded generation, energy efficiency, smart operation of loads (e.g. load shifting), demand-side response and peaking generators. ARENA should also consider the value of these alternatives for achieving its renewable energy objectives. Nonetheless, it is recognised that energy storage has a unique ability to be paired with intermittent generation, directly address the issues of intermittency and dispatchability, and provide capacity and power quality benefits to electricity networks.

Government support has been a key driver for energy storage demonstration projects all over the world, providing a productive foundation of operational knowledge, data and industry participation. The US, China, Japan and Germany are leading the implementation of battery energy storage. While Australia has implemented very few modern energy storage projects or programs, ARENA is able to play a pivotal role in building the industry capacity to adapt to this emerging technology by supporting high value demonstrations and technology development.

While ARENA has supported energy storage projects in the past, this study has sought to outline a more coordinated and targeted approach for ARENA. AECOM has identified, defined, evaluated and ranked a number of investment priorities for ARENA to focus on. The key investment priorities identified in this study are illustrated in Figure 33.

Based on our assessment, ARENA is recommended to target and coordinate its energy storage funding to maximise its industry development impact, focusing on building the capacity of industry to further appreciate the benefits of adopting energy storage. ARENA should by no means restrict its initiatives to those highlighted in Figure 33. Rather, this list highlights where ARENA might achieve the most progress towards its overall mandate given current insight into trending market conditions. Given the expected rapid evolution of the energy storage market, it is recommended that ARENA’s priorities are reviewed regularly to ensure continued market relevance.

Figure 33 Recommended ARENA funding priorities



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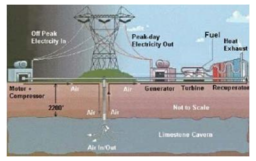
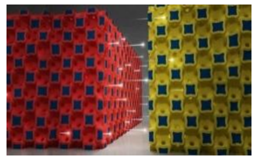
Appendix A

Storage Technologies

The following table provides an overview of megawatt-scale energy storage systems that are either in demonstration or commercial phases of maturity and applicable to electricity grid applications. R&D phase technologies have not been identified and figures have been sourced from various literature reviews and may not be completely accurate or comprehensive. [10] [12] [150] [5]

Characteristics	Bulk Energy Storage		Grid Support and Load Shifting (can also be both Power Quality and Bulk Storage)						Power Quality	
	Pumped Hydro	Compressed Air Energy Storage	Sodium-Sulphur	Flow Batteries (Vanadium Redox)	Flow Batteries (Zn-Br)	Valve Regulated Lead Acid (VRLA)	Advanced Lead-Acid	Lithium-ion (Li-Ion)	Super Capacitor	Fly Wheel
			 Source: NGK website	 Source: Prudent Energy	 Source: RedFlow		 Source: Ecoult			
Maturity	Mature	Commercial	Deployment	Commercial	Commercial	Mature	Commercial	Commercial	Commercial	Commercial
Energy Range (MWh)	>1,000	>1,000	5 - >100	< 250	< 250	10 - 20	< 250	1 - 25		< 5
Power Range (MW)	300 – 3,000	50-180	1 - 50	1 – 100	1 – 100	1 - 50	1 - 50	< 100	< 1	< 20
Duration (hrs)	6 – 12	8 – 30	6 – 8	3 – 5	1 – 5	2 - 4	1 min – 8h	1 min – 8h	Milliseconds – 1hr	Milliseconds - 0.25hr
% Efficiency	80 – 85	40 – 75	70 – 90	65 – 75	60 – 70	85 – 90	90 - 94	85 – 98	80 - 98	85 – 95
Total cycles			2,500 – 4,500	>10,000	>10,000	1500 – 5,000	4,500 – 10,000	1,000 – 10,000+		>100 000
Operating life (years)	Up to 60	20 - 30	5 – 15	15 – 20	20	3 - 15	5 - 15	10 - 20	8 – 20+	15 – 20
Advantages	Mature, cost effective, large scale, efficient	Cost, flexible sizing, large scale	Efficient, density (power & energy), cycling (vs. other battery)	Independent energy & power sizing, scalable		Mature, power density	Efficient, density (energy & power)	Efficient, density (energy & power), mature for mobility	High power density, efficient and responsive	Power density, start times, efficient, scalable, low maintenance
Drawbacks	Low energy density, availability of sites, environmental impacts	Lack of suitable geology, low energy density, need to heat the air with gas	Safety, discharge rate (vs. other battery), must be kept hot	Cost (more complex balance of system)		Environmental impact, Lifespan.	Cost, case studies in alternative applications	Cost, safety	Low energy density, cost ($/kWh), voltage changes	Cost, low energy density, high self-discharge
Identified Suppliers *List is not exhaustive*	Australian Presence: Snowy Hydro, Hydro Tasmania, CS Energy.	Various	Australian Presence: NGK Stanger Pty. Ltd. GE (Sodium/Nickel/ Chloride)	Non Australian Presence: Prudent Energy	Australian Presence: ZBB, RedFlow	Australian Presence: Sonnenschein	Australian Presence: Alcobatt, Ecoult (Australian developed technology)	Australian Presence: Kokam, Samsung, SAFT Non Australian Presence: UNICOS, Siemens, NEC	Australian Presence: Glyn (Maxwell products)	Australian Presence: ABB

Appendix B

Consultation

Industry market survey

Survey structure

The survey was designed to garner the opinions of the energy sector in relation to areas in which energy storage is seen as high value, high potential or high priority in terms of technology type, application or project scale. The survey also asked respondents to rank types of purchasing considerations, potential initiatives, and project barriers then asked respondents to identify any specific technical, commercial or financial barriers that need to be addressed to enable energy storage in the industry.

Respondents were asked to nominate details including their professional role, the type of organisation, their geographical location and the type of sector in which they work.

The survey questionnaire is shown in Appendix C.

Demographics of survey respondents

To disseminate the survey a direct email was sent to 733 energy industry participants collated through AECOM industry contacts and the survey was also advertised through industry bodies including the Australian Energy Storage Alliance and the Australian Energy Storage Council (Australian Solar Council).

The survey received 110 complete responses. Respondents were mainly based in Sydney (31%), Melbourne (21%), followed by Brisbane, Canberra and Perth (7-8%). Figure 34 shows that approximately 70% of the respondents worked in the solar PV industry and 34% indicated that they worked in the hybrid / enabling field, while only 20% of respondents indicated that they were “technology neutral”.

Figure 34 Industry survey response – relevant industries for respondents; multiple industries possible (question 4)

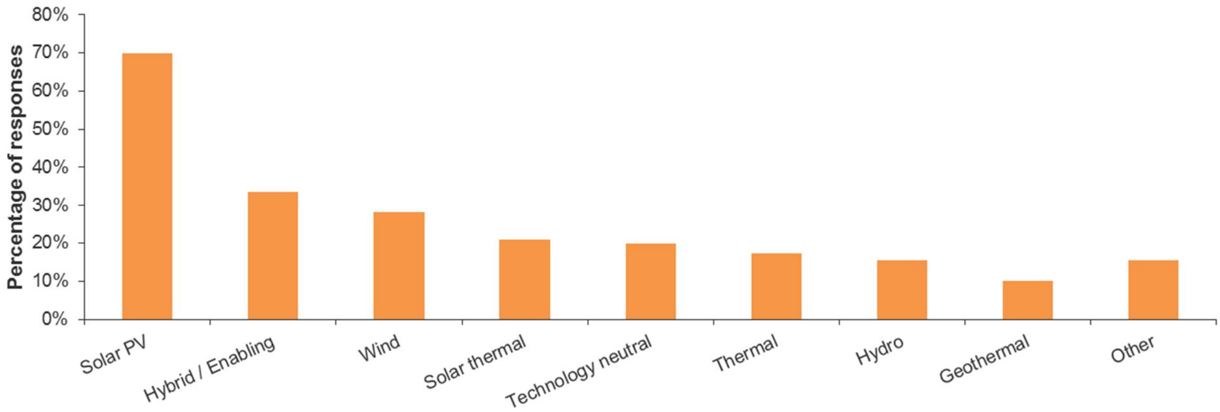


Table 36 indicates that the survey represents participants from a variety of organisational types, which is dominated by equipment / technology supplier/manufacturer (28%) and professional services (18%). Researchers, project developers, retailers and NSPs had representation ranging from 6-9%. Consumers, financiers, government and regulators had little representation at 1-2% each.

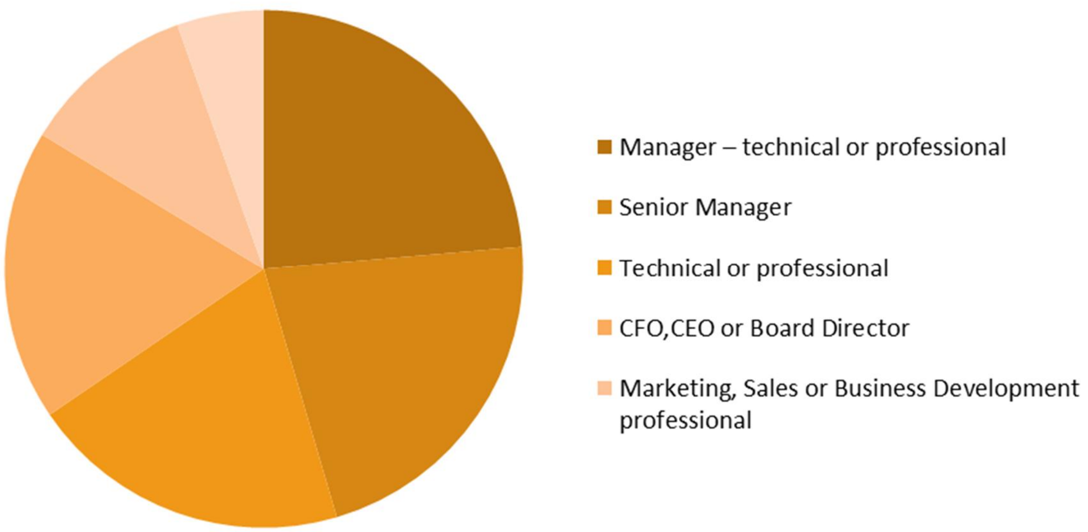
Table 36 Industry survey response - organisational type (question 3)

Type of organisation	Percentage
Equipment / technology supplier / manufacturer	28.2%
Professional Services	18.2%
Other (construction, consultant, education institution)	12.7%
Researcher	9.1%
Project Developer	7.3%
Retailer	6.4%
Network Service Provider	6.4%
Mining	3.6%

Type of organisation	Percentage
Generator	2.7%
Energy consumer	1.8%
Finance	1.8%
Government	0.9%
Regulator	0.9%

The breakdown of occupation type shown in Figure 35 indicates that approximately 85% of respondents come from the four position categories listed as technical/professional manager, senior manager, technical professional or CFO/CEO or board director. These were represented relatively evenly and 10% of respondents were in marketing / sales functions.

Figure 35 Industry survey response – role in organisation (question 1)



Survey results

Survey respondents were asked to rate the significance, value or importance of various areas of the energy storage market. A score of five was the highest rating and zero was the lowest. The average score of the zero to five rating has been calculated to indicate how the 110 respondents rated the various areas of the market.

Figure 36 highlights that respondents are interested in all scales of energy storage projects, ranging from under 20kW to over 10MW.

Figure 36 Level of survey participant interest for various energy storage project sizes (question 5)

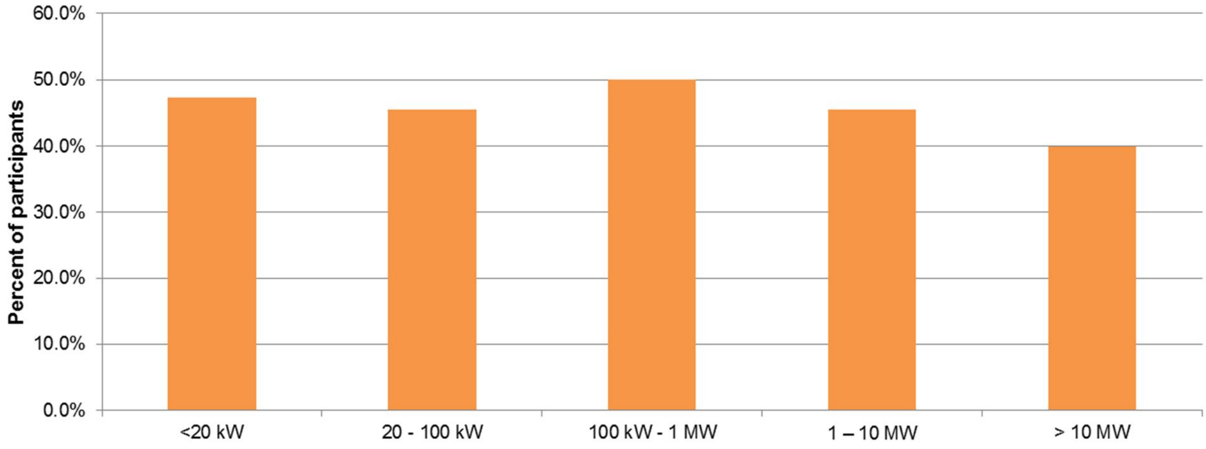


Table 37 shows that Li-ion batteries are considered to have the highest potential of the technologies presented in the survey due to its variety of applications, relatively low cost (and future low cost potential), reliability and operational flexibility.

Respondents also provided a relatively high rating for thermal storage, citing its suitability for integration with CSP and its scalability for 24 hours of storage.

Respondents choosing the "other" referred to hybrid super capacitors and advanced lead acid batteries, rating them highly in terms of potential in the Australian market.

Table 37 Energy storage technology by potential (question 6)

Technology type	Average (out of 5)
Lithium ion battery	4.3
Other (hybrid super capacitor, advanced lead acid battery)	3.6
Thermal energy storage	3.5
Lead acid battery	3.3
Pumped storage hydro	3.3
Flow battery	3.0
Sodium sulphur battery	2.7
Liquid metal battery	2.6
Flywheel	2.3
Compressed Air Energy Storage (CAES)	1.7

Table 38 indicates that most respondents rated renewable integration / balancing / load shifting / dispatch as a highly beneficial application for energy storage (4.4), followed by off-grid (3.9), and behind-the-meter use (both commercial and residential 3.6-3.7). Wholesale market arbitrage rated poorly (2.6) indicative of the current flat spot market for energy and oversupply of generation capacity.

Table 38 Benefit of different energy storage applications (question 8)

Benefits of different applications	Average (out of 5)
Renewable integration / balancing / load shifting / dispatch	4.4
Off-grid	3.9
Residential use (behind-the-meter)	3.7

Benefits of different applications	Average (out of 5)
Commercial / industrial use (behind-the-meter)	3.6
T&D network management and investment deferral	3.6
Power quality regulation / network support / ancillary services	3.4
Reserve capacity/UPS/black start	3
Wholesale market arbitrage	2.7
Other (power factor correction, energy independence for Australians)	2.6

Table 39 shows that when considering what influences consumers' purchasing decisions for energy storage technologies return on investment (4.4), safety (4.4) and capital cost (4.3) are most important. Recycling and the secondary use of technologies scored well below the other average scores.

Table 39 The relative importance of purchasing considerations for energy storage technologies (question 9)

Purchasing considerations	Average (out of 5)
Return on investment	4.4
Safety	4.4
Capital cost	4.3
Operating costs	4.0
Maturity of technology	4.0
Ease of integration and control	4.0
Commercial terms	3.9
Recycling and secondary uses	2.9

Table 40 shows the results for when respondents were asked to rate the value of potential initiatives. Respondents gave the highest rating to lifecycle performance and efficiency comparison of different storage technologies (4.1) as well as supporting the development of price signals to capture the benefits of energy storage (4.1). Support for new energy storage technology breakthroughs, however, was not given a high rating.

Table 40 The value of potential initiatives for achieving business objectives (question 10)

Potential initiatives	Average (out of 5)
Lifecycle performance and efficiency comparison of different storage technologies	4.1
Supporting the development of clearer price signals (or other incentives) to capture the benefits of energy storage	4.1
Market and capital costs information	3.7
Energy storage project capital assistance	3.6
Improvement of standards and regulations to support the integration of energy storage	3.5
Energy storage project demonstrations	3.5
Support for new energy storage technology breakthroughs	3.1

Table 41 indicates that all initiatives for supporting the commercialisation of energy storage projects were considered suitable by respondents, all scoring 3.2 to 3.7. However, capital assistance for projects/systems (3.7) and tools to assess the economic benefit of energy storage (3.7) were rated the highest of the potential initiatives, along with development of standards (3.7).

Table 41 The value of Initiatives for commercialisation (question 11)

Initiatives	Average (out of 5)
Capital assistance for projects/systems	3.7
Tools to assess economic benefits of energy storage	3.7
Development of standards for energy storage systems	3.7
Regulations support	3.6
Development of a simple to use model that assists customers/households to determine economic benefit of energy storage	3.6
R&D support	3.5
Support for industry association / knowledge sharing	3.4
Other (accreditation scheme, development of standards for NSPs, market enablers to link different value chains)	3.2
Targets for Network Service Providers	3.2

Table 42 shows that high capital cost (4.3) and poor return on investment / lack of appropriate incentives (4.2) were rated as the most significant barriers to battery energy storage, with safety requirements considered the least important by many. This is interesting given that safety was rated one of the most important purchasing considerations for energy storage technologies, found in Table 39, and indicates that the respondents are comfortable that energy storage systems can be used in a safe matter.

Table 42 Barriers of battery storage (question 12)

Barriers	Average (out of 5)
High capital costs	4.3
Poor return on investment / lack of appropriate incentives	4.2
Regulatory barriers	3
Industry acceptance	2.9
Technology reliability	2.9
Oversupply of existing generation	2.8
Safety requirements	2.6

Additional feedback

The survey gave respondents opportunities to provide customised feedback in text responses. Some key messages are provided below under relevant categories.

Enabling technologies

"It is critical to understand that the storage is only part of the equation and not enough effort is focussed on developing and improving enabling devices and enable appropriate value stacking between different market segments."

Technology

"Commercial reference sites which enable technical aspects to be resolved in 'real life' situations. Critical technical cost areas, where savings are desirable, include inverters, control systems, capacitors and turbines"

Residential thermal storage has major potential - the use of PV + heat pumps to store energy (hot and cold) in the form of hot water, heat banks, phase change materials and in the building fabric, in order to minimise sell-back to the grid"

Regulation and standards

"Price needs to come down more but at this stage I am worried if it comes down too quickly the industry will not be ready as we do not have safety standards in place."

"Need regulatory certainty. Network tariffs have the ability to make or break storage."

"Standardisation of energy storage interconnection and controls. Every site shouldn't be a new project that requires extensive technical development, interconnection studies and new engineering."

"Regulator needs to define storage as something new, it's a generator and load with some smart electronics."

"Ability for the network operator to put the asset into the RAB in some cases volume related cost-down."

"Ensure standards and accreditation are in place initially, then support many small projects at a domestic scale. This will maximise industry exposure and learning, ensuring that installations are safe."

Education

"To be able to explain to the general public - not the politicians and bureaucrats - through appropriate visual presentations of both the simplicity and the relevance of this revolutionary innovation."

"New storage technology breakthroughs are far less important than maximising the utility, simplicity and case for storage technologies. High profile storage project demonstrations are critical to proving the capability, relevance and viability of storage technology."

"Auto industry with electric vehicle can support peak lopping and used as energy storage. However the difficult challenge comes from a mindset understanding from non-technical people."

ARENA's role

"ARENA should be aware of other work streams going on in the industry. Efficient investment would seek to support them, rather than starting from scratch."

Key learnings - survey

A summary of the learnings obtained through the survey are shown in Table 43. The key learnings are cross referenced from Table 33 using the reference numbers (left hand column) to support proposed investment priorities with specific learnings from the industry survey.

Table 43 Survey key learnings

No.	Theme	Learning	Survey Qu Ref.
S1.	Technology	Li-ion batteries are considered to have the highest potential (4.3 out of 5) of the technologies presented in the survey.	6
S2.	Technology	Pumped hydro storage was not highly rated (3.3 out of 5) for potential, however, makes up a large proportion of the current renewable energy generation in Australia.	6
S3.	Technology	Compressed air energy storage was rated the lowest (1.7 out of 5) for potential in the Australian energy market.	6
S4.	Thermal storage	Respondents also provided a relatively high rating for thermal storage, citing its suitability for integration with CSP and its scalability for 24 hours of storage.	6
S5.	Applications, integration, off-grid	A large proportion of respondents rated renewable integration / balancing / load shifting / dispatch as a highly beneficial application for energy storage (4.4 out of 5), followed by off-grid (3.9 out of 5).	8
S6.	Applications, arbitrage	Wholesale market arbitrage was given the lowest rating (2.7 out of 5) by respondents with respect to benefits of different applications.	8
S7.	Cost	When considering what influences consumers' purchasing decisions for energy storage technologies it is clear that return on investment (4.4 out of 5) and capital cost (4.3 out of 5) are very highly rated.	9
S8.	Safety	Safety of technology is another highly rated (4.4 out of 5) consideration when consumers buy energy storage products, but is not viewed as a barrier for energy storage	9

No.	Theme	Learning	Survey Qu Ref.
S9.	Recycling	The recycling and secondary use of technologies scored well below the other average scores when respondents were asked about purchasing considerations.	9
S10.	Initiatives, education	Lifecycle performance and efficiency comparison of different storage technologies was highly rated (4.1 out of 5) when asked about the value of potential initiatives with respect respondents' business objectives. Helping the public understand energy storage and its applications is a significant challenge.	10, Additional comments
S11.	Regulatory	Supporting the development of clearer price signals (or other incentives) to capture the benefits of energy storage also scored highly (4.1 out of 5) as a potential initiative for supporting business objectives.	10
S12.	Technology, R&D	Respondents did not see high value in seeking to achieve energy storage technology breakthroughs	10
S13.	Cost optimising	Capital assistance and economic evaluation tools were the most valued potential initiatives	11
S14.	Standardisation	Standardisation of household level installations is required for repeatability and the safe large-scale deployment of battery energy storage systems	Additional feedback
S15.	Accreditation	Accreditation bodies are required before to ensure safe and qualified products and installers are used	Additional feedback
S16.	Balance-of-plant	Project learnings should target critical cost areas where large savings can be achieved. In particular, balance of plant items such as the inverters and control systems might offer large system savings.	Additional feedback
S17.	Electric vehicles	Electric vehicles can be used for energy storage and have a large capacity for load shifting and demand-side participation.	Additional feedback
S18.	Residential thermal storage	Residential thermal storage can utilise excess solar PV to store energy (hot and cold) in order to minimise sell-back to the grid.	Additional feedback

Targeted stakeholder consultations

To obtain further insight from industry stakeholders and to distil more detailed industry generated feedback into the investment priorities, a number of consultations were completed with representatives from regulators, product suppliers, industry associations, research institutions, NSPs, retailers and government. The majority of these consultations were performed one-on-one so that tailored questions could be asked and to foster open responses. Consultations were completed over the period 2 February to 5 March 2015.

Records of each conversation are provided in Appendix D. The below table lists the consulted parties and describes the key topics covered in that consultation.

Table 44 Stakeholder consultations

Organisation	People	Key topics	Communication medium
Regulators (1)			
AER	Sarah Proudfoot	AER to facilitate market entry for retailers, solar PPA & energy storage now entering the market.	Teleconference
AEMC	James Eastcott	Not actively working on any battery technology related rule changes. Energy storage raised in COAG Energy Council.	Teleconference
Standards Australia	Varant Mequerditchian, Erandi Chandrasekare	Investigate international standards, conformity assessment being developed by IEC.	Teleconference
Suppliers (2)			
ABB	Juergen Zimmermann, Heath Lang	Pipeline, barriers, revenue, client evaluation factors, ARENA's role.	Teleconference
Zest Energy (agent for Kokam)	Dr. Jon Pemberton	Scale, household product & standards, other applications, initiatives.	Teleconference
Magellan Power	Lyndsay Meek		
Eltek	Thomas Hellmich	Opportunity for storage, market description, solutions, additional market.	Face-to-face
Ecoult	John Wood, Sean Jobe	Role of ARENA, challenges, recommendations, applications.	Teleconference
Sunpower / Sunverge	Jamie Robles	SunVerge partnership with SunPower, storage products and applications, barriers, ARENA's role.	Teleconference
Tesla	Evan Beaver	Household battery product, vehicle to grid, 2nd hand batteries, business models, barriers.	Teleconference
Reposit Power	Luke Osbourne	Residential market, challenges, ARENA actions, FCAS	Teleconference
Suntech/Powim	Stefan Jarnason, Hui Wu	T&D application barriers, overseas experience, ARENA options	Teleconference
Industry associations (3)			
Energy Storage Alliance	N/A	All	Survey to members
Energy Storage Council	N/A	All	Survey to members
Californian Energy Storage	Mark Higgins	Drivers, Californian Energy Storage Mandate & objectives, business models, regulations and codes.	Teleconference
Clean Energy Council	Tom Butler, Russel Marsh, Darren Gladman, Sandy Atkins	Development of standards, future proofing – distribution networks, suggested focus areas, CEC opinion.	Teleconference

Organisation	People	Key topics	Communication medium
Research institutions (4)			
CSIRO	Kate Cavanagh, Sam Behrens, Mark Paterson	Key opportunities in the R&D space, scale, technology potential, applications, purchasing considerations, initiatives, barriers.	Workshop in Sydney
Uni Sydney	Tony Vassallo, Penelope Crossley		
UTS Institute for Sustainable Futures (ISF)	Chris Dunstan, Anjon Kumar Mondal, Guoxiu Wang, Sebastian Oliva Henriquez		
Uni of NSW	Tim Dixon		
Network Service Providers (5)			
TransGrid	Sam Christie	Role of storage for TNSPs, drivers, barriers, initiatives.	Teleconference
Electranet	Michael Dobbin		
AusGrid	Craig Tupper, Rob Simpson	Role of storage of DNSPs, regulatory barriers, recommended initiatives.	Teleconference
Ausnet Services	Yogendra Vashishtha		
Power and Water Corporation (PWC)	Dow Airen, Phillip Maker, Trevor Horman	Applications that interest DNSPs, quantifying benefits, major commercial considerations, initiatives, barriers, standards/regulations.	Teleconference
Horizon (tbc)	David Edwards, Keli Friar, Laurie Curro		
Ergon Energy	Don McPhail	Frindge of gride trail, standards, ARENA's role.	Teleconference
AGL	Miguel Brandao	Focus on the end-user market, initiatives.	Teleconference
Synergy	Adrian Moorecrouch	Residential, supply side, community project – Alkimos Beach	Teleconference
Government (7)			
Department of Industry	Michael Whitfield, Cai Von Ahlefelt	Consultation to advise COAG Energy Council, initiatives.	Teleconference

Key learning – stakeholder consultation

A summary of the learnings obtained through the stakeholder consultations is shown in Table 45. The key learnings are cross referenced from Table 33 using the reference numbers (left hand column) to support the proposed investment priorities with specific learnings from the targeted stakeholder consultation. The below table also identifies the reference group(s) that supplied the key learning.

Table 45 Targeted consultation key learnings

No.	Theme	Learning	Reference groups
C1.	Integration costs	Market is recognising the critical role of integration and network connection. ARENA cannot impact battery prices however ARENA support could help lower integration costs by assisting further project development "learning by doing".	2, 5
C2.	Cost optimising	With high capital costs, battery projects with smaller energy-to-power ratios are cheaper. This suits projects with shorter-term output applications.	2
C3.	Education	Market immaturity means detailed specifications do not exist – lack of understanding from NSPs and developers regarding technology, capability and requirements.	2, 3
C4.	Off-grid	Value proposition easier to define on off-grid systems, utilities have more difficulty defining a value proposition.	2, 4, 5
C5.	Education	Support and learning are important for client, customers and industry and can be achieved through demonstration and knowledge sharing.	1, 2, 4, 6
C6.	Economics	Value stack/economic modelling tool would be useful but it would be challenging to make a tool relevant for all applications and specific network areas. Industry collaboration would be required to quantify all available benefits of energy storage applications. Large scale has more complex revenue/value streams. (Note Synergy believes they have a good understanding of value stack).	2, 3, 4, 5
C7.	Standards, certification, safety	Lack of standards, installer training, certification technical and safety regulation needs to be addressed urgently particularly for residential installations – requires industry wide approach. CEC's accreditation work in PV sector was very well regarded and could be used as a template for energy storage industry. Standards development does need to allow innovation.	1, 2, 3, 4, 5
C8.	Regulation	Regulators need to facilitate market entry for retailers and renewable energy providers.	1, 5
C9.	Regulation	Regulators are not working on any rule changes specific to energy storage – despite the required long gestation period (12-18 months).	1, 7
C10.	Product testing R&D	Standard lifecycle testing of battery technology may provide some beneficial insights but unlikely to represent real application and may miss some subtlety of product performance.	2, 5
C11.	R&D	ARENA's existing mechanisms provides solid support for fundamental technology R&D.	2, 4
C12.	Off-grid	Off-grid projects currently offer the highest value but there should be a stronger requirement to demonstrate learnings to broader applications as off-grid systems can be viewed as having little technology development value and limited alignment with ARENA mandate of broad renewable deployment.	2
C13.	Off-grid, enabling technologies	Energy storage has potential to facilitate diesel off mode in off-grid systems – significant cost savings (avoided fuel and maintenance), environmental benefits and align with ARENA's mandate. Enabling technologies (predictive forecasting, control) can provide further synergies (N.B. This is an apparent contradiction of feedback provided in C12).	2, 5
C14.	Local industry support	To assist local technology development, ARENA could require local content (some manufacturers/suppliers have access to funding overseas as well as	2

No.	Theme	Learning	Reference groups
		Australian funding).	
C15.	Education	Residential customers aren't well educated on product safety, network safety, warranty or financing issues/options. Community acceptance of battery systems and actual siting of batteries requires education.	2, 3, 4, 6
C16.	Community	Community level projects have potential to involve multiple parties e.g. DNSPs retailers, customers, regulators. They allow land developers and NSPs to minimise infrastructure requirements.	2, 6
C17.	Defection	No value proposition exists currently to take customers off-grid.	2
C18.	Education, tariffs	Tariff reform (time of use/cost reflective pricing, demand management, virtual net metering) will have a large impact on the long term value proposition (either positively or negatively).	2, 3, 4, 6
C19.	IP and knowledge sharing	Projects that receive ARENA support risk IP release. Some proponents suggest incorporating a research institute with a grant may allow relevant development and appropriate dissemination of useful knowledge/IP.	2, 4
C20.	Education	Buyer's guide to inform customers (could include residential energy storage sizing tool) may be useful to explain the value and potential payback of energy storage.	2, 3, 6
C21.	Network constraints NSPs	Identification of network constraint "hot spots" (where value of storage is high) by a neutral party could assist project proponents and avoid conflicts that may arise with NSPs.	2, 3, 5
C22.	EV	EV manufacturers have a strong desire to utilise renewable energy. Consumers wish to support renewable energy charging e.g. incentivise PV to vehicle charging.	2
C23.	EV network connection	Supporting rollout of EV charging infrastructure should minimise costs for future charging infrastructure developments e.g. network connection issues/processes. Battery swap is an order of magnitude more expensive than charging, and is not considered a priority.	2
C24.	EV	Some EV manufacturers will be offering residential energy storage products this year and used EV batteries will provide a large opportunity for re-use as low cost stationary energy storage in the future.	2
C25.	EV	Vehicle-to-grid functionality from EVs is currently not being marketed but will be an option in the medium term. Uncontrolled charging of EVs has potential to create significant network peak issues.	2
C26.	Collaboration	Overseas programs have brought industry and regulators together on energy storage projects to address issues such as network connection and regulatory compliance. This could also be valuable for Australia.	3, 6
C27.	Market potential	Industry would benefit by assistance in determining current and future energy storage market size by application (i.e. off-grid, behind-the-meter, T&D, fringe-of-grid etc.)	3
C28.	Initiatives	ARENA's programs should help address Australia's unique market characteristics (e.g. low population density, "long stringy network", large off-grid sector, high rooftop capability)	4
C29.	R&D initiatives	Creating additional financial incentives to develop technology e.g. R&D tax credit may be helpful	4
C30.	Metering and communications	Advanced metering and communications is required to unlock the full potential of energy storage systems.	2, 4, 6
C31.	Recycling, R&D	Recycling and reuse of lithium batteries is a market opportunity. However, Australia has large lithium resources as well as materials processing, chemistry and chemical engineering capability.	2,4
C32.	Technical	Li-ion is currently superior for small to medium scale storage. Other	3, 4

No.	Theme	Learning	Reference groups
	R&D	technologies including ammonium, sodium sulphur, lithium sulphur and hydrogen fuel cells may have broader potential. Small-scale projects may have more technical (R&D) learning potential as large scale projects are slow and may miss relevance by project finalisation. In addition to battery technologies, other technologies can have a similar enabling value, e.g. solar/wind forecasting tools, demand response, behind-the-meter thermal storage etc.	
C33.	Infrastructure	Network contraction is occurring and future PV and energy storage development is expected to continue the contraction	5
C34.	Education, NSP applications	There is a requirement to educate regulators of network assets in relation to cross benefits of energy storage (cross benefits to be included in RIT-D process)	5
C35.	Behind-the-meter	End of NSW Solar Bonus Scheme from 2017 provides large numbers of customers rolling off strong incentives schemes. Expectation is that customers will seek additional value form their systems by switching to net-metering and considering battery storage.	5
C36.	Past trials	Previous trial programs have encountered issues with poor battery performance and issues with protection settings.	5
C37.	Regulation	Regulation unclear whether NSPs can own energy storage to provide network services. Network regulations and network incentives appear to be a barrier.	5, 6
C38.	Behind-the-meter	Expectation is that for network connected systems, residential energy storage will be first to be cost effective, followed by commercial systems	6
C39.	Infrastructure	Potential applications exists to explore cost / benefit options to island customers currently on end of life fringe-of-grid locations however NSP's have little incentive to do so.	5
C40.	Utility Scale	Utility scale projects will provide greatest alignment with ARENA mandate	2

Appendix C

Survey Questionnaire

Energy Storage Survey

AECOM, on behalf of ARENA, invites you to complete a 10 minute anonymous online survey on the subject of energy storage to help inform its view on this emerging technology sector.

The survey is open until 11 February 2015.

Many thanks in advance for your feedback.

If you have any questions or problems, please email carl.christiansen@aecom.com

Energy Storage Survey

Demographic Information

*1. Which category best describes your position in your organisation?

- CFO,CEO or Board Director
- Senior Manager
- Manager – technical or professional
- Technical or professional
- Marketing, Sales or Business Development professional
- Technician/ trade worker
- Clerical and administration
- Other professional
- Other (please specify)

*2. In which city or town are you based?

*3. Which type of organisation do you work for?

- Equipment / technology supplier / manufacturer
- Researcher
- Project Developer
- Generator
- Retailer
- Network Service Provider
- Energy consumer
- Government
- Finance
- Mining
- Professional Services
- Regulator
- Other (please specify)

*4. What energy sectors do you work in?

- [ ] Thermal
- [ ] Hydro
- [ ] Geothermal
- [ ] Solar thermal
- [ ] Solar PV
- [ ] Wind
- [ ] Hybrid / Enabling
- [ ] My organisation is technology neutral
- [ ] Other (please specify)

*5. What scale of energy storage projects are you interested in?

- [ ] <20 kW
- [ ] 20 - 100 kW
- [ ] 100 kW - 1 MW
- [ ] 1 – 10 MW
- [ ] > 10 MW
- [ ] Other (please specify)

Energy Storage Market Analysis

*6. Please rate (5 being highest) each energy storage technology according to their potential in Australia (we ask that you try to differentiate your responses).

	0	1	2	3	4	5	Not sure
Compressed Air Energy Storage (CAES)	○	○	○	○	○	○	○
Flow battery	○	○	○	○	○	○	○
Flywheel	○	○	○	○	○	○	○
Lead acid battery	○	○	○	○	○	○	○
Lithium ion battery	○	○	○	○	○	○	○
Sodium sulphur battery	○	○	○	○	○	○	○
Liquid metal battery	○	○	○	○	○	○	○
Thermal energy storage	○	○	○	○	○	○	○
Pumped storage hydro	○	○	○	○	○	○	○
Other (Please specify)	○	○	○	○	○	○	○

What characteristics differentiate your preferred technology?

*7. Which scale of energy storage projects do you believe has the most potential in Australia?

	< 20 kW	20 - 100 kW	100 - 1 MW	1 - 10 MW	> 10 MW
0 - 5 years	○	○	○	○	○
5 - 10 years	○	○	○	○	○
>10 years	○	○	○	○	○

Why?

***8. Please rate (5 being highest) the level of benefit to Australia of each of the following applications of energy storage (we ask that you try to differentiate your responses).**

	0	1	2	3	4	5	Not sure
Renewable integration / balancing / load shifting / dispatch	○	○	○	○	○	○	○
Wholesale market arbitrage	○	○	○	○	○	○	○
Off-grid	○	○	○	○	○	○	○
Commercial / industrial use (behind the meter)	○	○	○	○	○	○	○
Residential use (behind the meter)	○	○	○	○	○	○	○
T&D network management and investment deferral	○	○	○	○	○	○	○
Power quality regulation / network support / ancillary services	○	○	○	○	○	○	○
Reserve capacity/UPS/black start	○	○	○	○	○	○	○
Other (please specify below)	○	○	○	○	○	○	○

Define "other"

***9. Please rate (5 being highest) the relative importance of purchasing considerations for energy storage technologies (we ask that you try to differentiate your responses).**

	0	1	2	3	4	5	Not sure
Maturity of technology	○	○	○	○	○	○	○
Commercial terms	○	○	○	○	○	○	○
Ease of integration and control	○	○	○	○	○	○	○
Capital cost	○	○	○	○	○	○	○
Operating costs	○	○	○	○	○	○	○
Return on investment	○	○	○	○	○	○	○
Safety	○	○	○	○	○	○	○
Recycling and secondary uses	○	○	○	○	○	○	○
Other	○	○	○	○	○	○	○

(Please specify)

Energy Storage Survey

***10. Please rate the value (5 being most valuable) of the following potential initiatives to you in achieving your business objectives with respect to energy storage (we ask that you try to differentiate your responses).**

	0	1	2	3	4	5	Not sure
Market and capital costs information	○	○	○	○	○	○	○
Lifecycle performance and efficiency comparison of different storage technologies	○	○	○	○	○	○	○
Supporting the development of clearer price signals (or other incentives) to capture the benefits of energy storage	○	○	○	○	○	○	○
Improvement of standards and regulations to support the integration of energy storage	○	○	○	○	○	○	○
Support to new energy storage technology breakthroughs (Please specify)	○	○	○	○	○	○	○
Energy storage project demonstrations (Please specify)	○	○	○	○	○	○	○
Energy storage project capital assistance	○	○	○	○	○	○	○

Additional comments (optional)

***11. Please rate the suitability (5 being most suitable) of each initiative for supporting the commercialisation of energy storage projects (we ask that you try to differentiate your responses).**

	0	1	2	3	4	5	Not sure
Targets for Network Service Providers	○	○	○	○	○	○	○
Capital assistance for projects/systems	○	○	○	○	○	○	○
R&D support	○	○	○	○	○	○	○
Regulations support	○	○	○	○	○	○	○
Development of standards for energy storage systems	○	○	○	○	○	○	○
Development of a simple to use model that assists customers/households to determine economic benefit of energy storage	○	○	○	○	○	○	○
Tools to assess economic benefits of energy storage	○	○	○	○	○	○	○
Support for industry association / knowledge sharing	○	○	○	○	○	○	○
Other	○	○	○	○	○	○	○

(Please specify)

***12. Please rate the significance (5 being the most significant) of the following barriers to battery storage (we ask that you try to differentiate your responses).**

	0	1	2	3	4	5	Not sure
Poor return on investment / lack of appropriate incentives	○	○	○	○	○	○	○
High capital costs	○	○	○	○	○	○	○
Technology reliability	○	○	○	○	○	○	○
Safety requirements	○	○	○	○	○	○	○
Regulatory barriers	○	○	○	○	○	○	○
Industry acceptance	○	○	○	○	○	○	○
Oversupply of existing generation	○	○	○	○	○	○	○

13. What do you believe are critical technical factors that need to be addressed to enable energy storage in your sector?

14. What do you believe are critical commercial factors that need to be addressed to enable energy storage in your sector?

15. What do you believe are critical regulatory factors that need to be addressed to enable energy storage in your sector?

16. Are there any other issues you would like to see addressed or discuss further?

- No
- Yes (please specify)

Appendix D

Meeting Records

Stakeholder meeting minutes are confidential and therefore have been redacted.