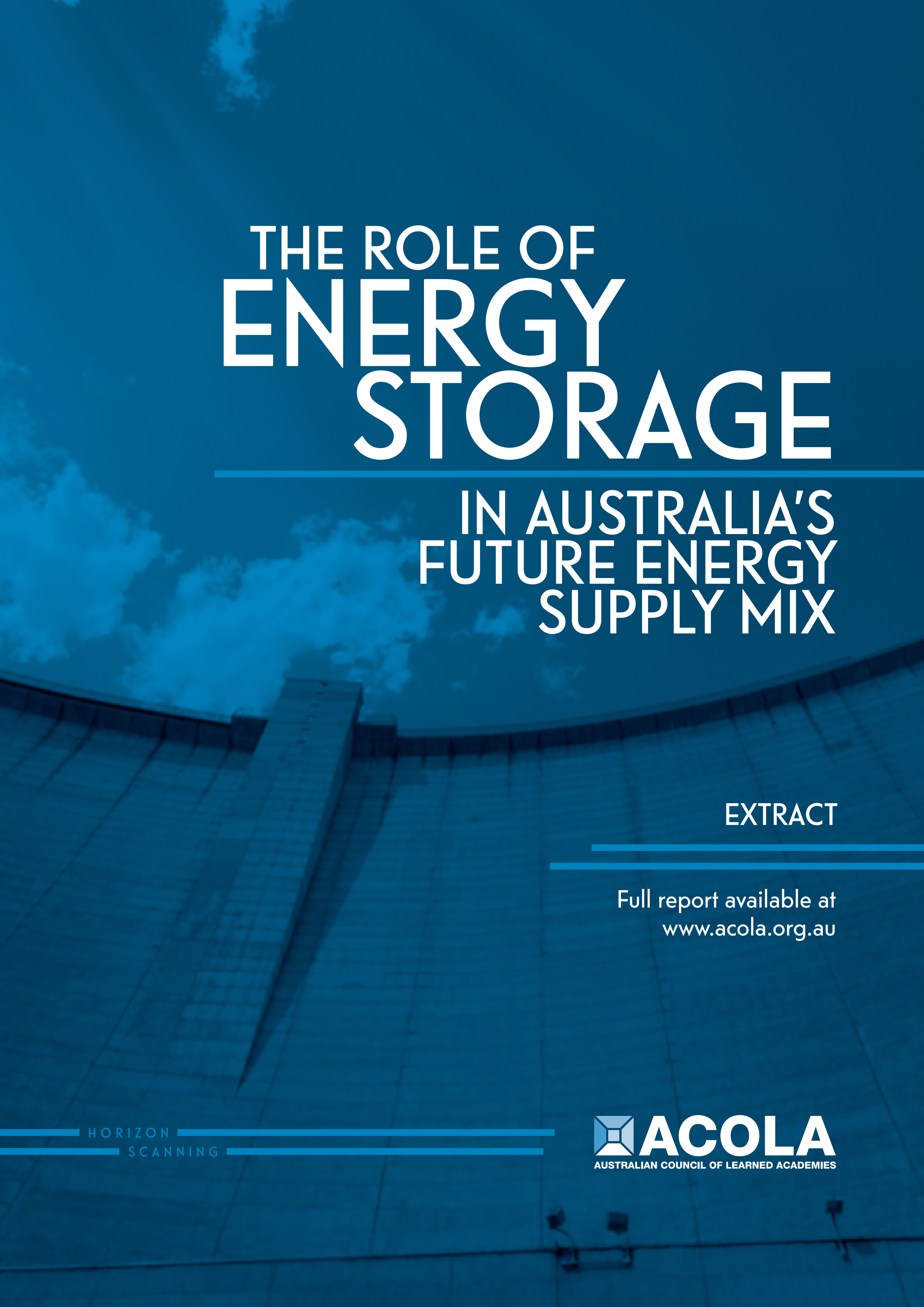

THE ROLE OF ENERGY STORAGE

IN AUSTRALIA'S FUTURE ENERGY SUPPLY MIX

EXTRACT

Full report available at
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HORIZON SCANNING

ACOLA
AUSTRALIAN COUNCIL OF LEARNED ACADEMIES

EXPERT WORKING GROUP

Dr Bruce Godfrey FTSE (Chair)
Professor Robyn Dowling (nominated by AAH)
Professor Maria Forsyth FAA
Professor R. Quentin Grafton FASSA GAICD

AUTHORS

Dr Bruce Godfrey FTSE (Chair)
Professor Robyn Dowling (nominated by AAH)
Professor Maria Forsyth FAA
Professor R. Quentin Grafton FASSA GAICD

Support by Irene Wyld

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REPORT DESIGN

Lyrebird
jo@lyrebirddesign.com

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AUSTRALIA'S LEARNED ACADEMIES

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PROJECT AIMS

Delivered as a partnership between the Australian Council of Learned Academies (ACOLA) and Australia's Chief Scientist, the Energy Storage project studies the transformative role that energy storage may play in Australia's energy systems; future economic opportunities and challenges; and current state of, and future trends in, energy storage technologies and their underpinning sciences.

The project examines the scientific, technological, economic and social aspects of the role that energy storage can play in Australia's transition to a low-carbon economy to 2030, and beyond.

EXECUTIVE SUMMARY

Australia is undergoing an energy transformation that promises to intensify over the coming decades. In the electricity generation sector this transformation involves: a greater reliance on renewable energy in response to climate mitigation policies; relocation of where energy is generated and distributed as a result of changing economics of energy costs and technological developments; and how and when energy is consumed with the advent of 'prosumers'[1].

Energy storage is critical to a successful transformation as it provides the vital link between energy production and consumption (See Box 1) and allows for greater penetration of both utility scale variable renewable generation and distributed energy generation. Without effective planning, appropriate investment and also incentives to develop and deploy energy storage technologies, the costs of electricity in Australia will continue to increase and there will be less reliable (adequate and secure) electricity supply. These could have large negative implications on the Australian economy.

1. "Active energy consumers, often called 'prosumers' because they both consume and produce electricity, could dramatically change the electricity system. Various types of prosumers exist: residential prosumers who produce electricity at home – mainly through solar photovoltaic panels on their rooftops, citizen-led energy cooperatives or housing associations, commercial prosumers whose main business activity is not electricity production, and public institutions like schools or hospitals." (European Parliament Think Tank, 2016).

Box 1: Energy security and reliability in Australia's electrical power system

Physical energy security for electricity generation and transmission comes from ensuring the ability to rapidly cope, within seconds or less, with fluctuations in energy demand and supply. Historically, security is provided by the 'mechanical inertia' of moving turbines. This inertia allows the system frequency (50 cycles per second in Australia) to cope with the ups and downs of supply and demand and ensures there is no blackout. Indeed, blackouts occur when the frequency drops too low because demand exceeds supply by too much and for too long. 'Load shedding', where demand is reduced or parts of the system are 'switched off', can be used – but with big disturbances in interconnected electricity grids there can be a cascading failure that results in a major power disruption.

Energy storage that can provide electricity into a grid at a moment's notice is an alternative to spinning turbines to provide electricity security and balance energy demand with supply. Adequate, appropriate and available (i.e. connected to the grid) energy storage in South Australia would have likely prevented the South Australian electricity blackout of 28 September 2016 as well as the need for emergency load shedding in New South Wales and South Australia in February 2017.

Energy reliability refers to the ability to balance electricity supply and demand over longer periods (other than seconds to minutes as explained above for energy security). For instance, there may be a peak load demand for electricity generation at the end of a very hot summer's day as people switch on their air conditioners when they return home from work. An adequate electricity supply is needed at these times to meet this peak demand, which may not coincide with peak variable renewable supply. Having readily available electricity generation sources (e.g. gas turbine generators) that can be powered up at these peak times can provide reliability, but this may be an expensive option if the plant only operates at peak demand periods.

An alternative is energy storage where the electricity is stored in a physical (pumped hydro), electrochemical (batteries) or high temperature thermal (e.g. molten salts, graphite or silicon) way when variable renewable energy is available (such as when the sun is shining for solar power or the wind is blowing for wind turbines). Energy storage is also a potentially less expensive alternative to keeping standby power plants idle most of the year, because of the other system purposes to which storage can be applied (i.e. security).

Uptake of Storage Solutions

Energy storage is an emerging industry globally and the application of storage in high volumes for both the stationary and transport sectors is still immature. Storage comes in many forms and can be applied in many scenarios. These include: in-front-of-the-meter large scale grid storage or community based or micro grid storage; behind-the-meter individual consumer storage coupled to solar generation (there are more than 1.8 million buildings, mostly households, in Australia with roof-top solar power systems); electrified transport (buses, cars, motorcycles and heavy and light vehicles for delivery); new defence requirements (notably the new submarine, unmanned aerial vehicle (UAVs) etc.); as well as numerous other applications with niche requirements (e.g. mining or off-grid applications).

While acknowledging these diverse applications for energy storage, this report primarily considers the transformative role that energy storage can play in Australia's electricity systems. It identifies future economic opportunities and challenges and describes the current state of and future trends in energy storage technologies. It examines the scientific, technological, economic and social economy aspects of the role that energy storage can play in Australia's transition to a low-carbon economy by 2030, and beyond to a low-carbon economy.

Over the coming decade or two there is unlikely to be only one favoured form of storage. Based on expected-cost curves, the most likely forms of energy storage will include: pumped hydro, batteries, compressed air and molten salt (coupled with solar power generation). These different technologies have varying costs and other characteristics, so determining which is the 'best' form of energy storage depends on where it is needed, for what purpose (either reliability or security or both), the nature of the electricity grid, and the current and future types of electricity generation.

Battery systems are the most cost effective when stabilising the grid, provided they have a 'fast frequency response' (FFR) capability through appropriate power electronics to synthesise the FFR, and are ready for immediate discharge when required. By comparison, where geology and water availability permit, large-scale energy storage by pumped hydro is most cost effective for delivering energy reliability.

Both batteries and pumped hydro technologies can provide energy security and energy reliability. Notably, having invested in batteries for security then the incremental cost of adding more storage capacity for reliability depends on the relative cost of the battery cells and the balance of plant (the supporting components and auxiliary systems of a power plant needed to deliver the energy). There will be circumstances when adding cells to a battery storage scheme will be cheaper than using pumped hydro, even though pumped hydro would represent the cheapest stand-alone solution.

Behind-the-meter energy storage will also increase as more consumers choose to take control of their electricity needs (e.g. those already with solar) and with the increasing possibility of microgrids being established. These types of deployment offer opportunities for aggregation of distributed storage assets to boost security and reliability, particularly at the local distribution level in electricity networks.

Models and requirements for uptake

A National Electricity Market (NEM) model was used to assess the requirements of energy storage out to 2030. The model was based on hourly supply and demand data for a year where there was the longest period of low availability of variable renewable resources (worst case scenario for variable renewable supply). Three scenarios underpinned the modelling in this report: (1) 'LOW RE' low renewable energy scenario (where variable renewables account for approximately 35 per cent generation); (2) 'MID RE', where variable renewables account for approximately 50 per cent generation); and (3) 'HIGH RE', a high renewable energy generation scenario (where variable renewables account for approximately 75 per cent generation). State levels of variable renewable electricity generation are also provided in this model, and these could be as high as 100 per cent for South Australia and Tasmania, depending on the scenario.

Energy security requires higher overall storage power capacity (measured as GW) than required purely for energy reliability, but the latter requires considerably more stored energy (GWh), as shown in Figure 1, particularly for high RE penetration levels. This is because for energy security purposes the electricity supplied is typically only required for very short periods (seconds or minutes), while for energy reliability the energy is needed for balancing supply and demand over several hours to meet peak loads.

Under the three scenarios, storage capacity requirements for energy security and reliability as a proportion of total generating capacity (GW) in the NEM in 2030 are shown in Table 1.

The requirements for energy reliability and security are calculated separately and have not been optimised. Therefore, the total energy storage required as a proportion of total capacity, especially in the high renewable energy scenario, would be less than the sum of requirement for the individual requirements for energy reliability and for energy security.

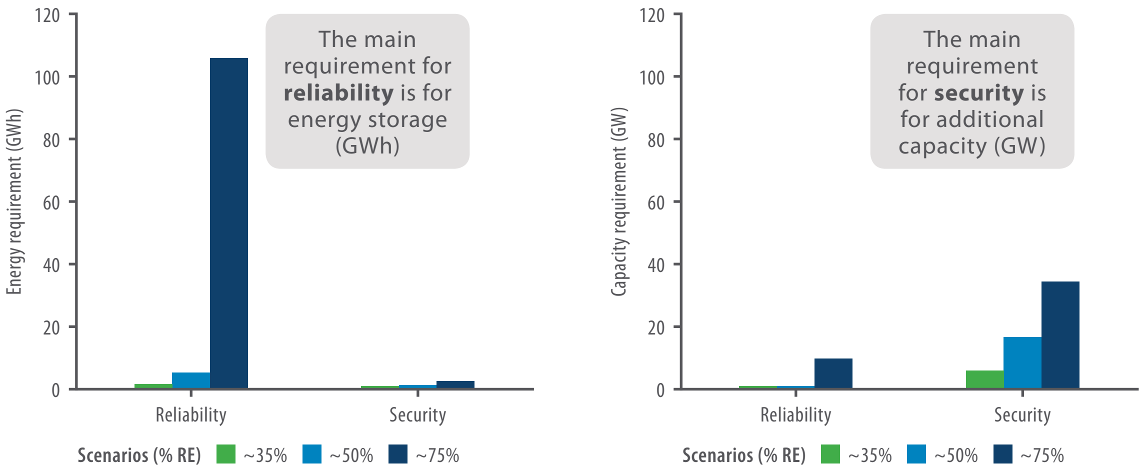


Figure 1: Reliability (GWh) and security (GW) requirements at 2030 across the three scenarios

Capacity (GW) Requirement	LOW RE	MID RE	HIGH RE
Reliability	0.5 per cent	2.4 per cent	9.8 per cent
Security	7.3 per cent	19.8 per cent	34.5 per cent

Table 1: Storage capacity requirements under the three scenarios

The costs of ensuring sufficient energy storage depend on assumptions about the levelised costs of storage in 2030. For energy security alone, the costs in 2030 prices could range from $A3.6 billion, under the LOW RE scenario, to $A11 billion under the MID RE scenario (which would also easily meet the reliability requirements at that time) and to as much as $A22 billion under the HIGH RE scenario. By comparison, network capital spending in the NEM is currently between $A5–6 billion each year, equating to approximately $A70 billion in total if this level of expenditure is continued annually through to 2030.

Energy storage is both a technically feasible and an economically viable approach to responding to Australia's energy security and reliability needs to 2030, even with a high renewables generation scenario. Nevertheless, there will need to be suitable planning and policies, and financial incentives, for either states or the private sector to build the appropriate level of storage. Achieving the right balance between technology neutrality and making strategic choices is essential to achieving resilient and cost-effective outcomes.

Public Attitudes to Energy Storage

Australians' knowledge of, and attitudes towards, energy storage will shape acceptance and adoption. General knowledge of energy storage options is limited, and largely restricted to batteries (the 'Tesla effect'). This lack of knowledge is one of the factors limiting uptake of storage, especially at the domestic scale. From focus group and national survey work undertaken for this report, there is low trust in the Australian energy system's capacity to deliver consistent and efficient electricity provision at reasonable prices. This low level of trust includes government, but also extends to energy providers and retailers. Regaining consumer trust in the energy system, including articulating the costs and benefits of energy storage, is vital for enabling the uptake of energy storage.

There is a demand for domestic scale energy storage by households across Australia as a means of future proofing against further electricity price rises and to take control of energy supply. Under certain conditions, Australians would be willing adopters of home-based batteries for energy storage. These conditions include policy and market certainty that allows households to calculate the costs and benefits of domestic scale storage, given that it requires significant initial outlay. Households would also like assurances that safety standards for batteries are in place and adhered to, and that battery systems are installed safely. While there is limited consumer knowledge of storage options, there are indications that should policy and market settings change then uptake may quickly follow. The experience of the post-2008 policy framework and rollout of rooftop solar photovoltaics (PV) is instructive for domestic-scale energy storage. With premium feed-in-tariffs being phased out, households with rooftop solar PV are likely to be early adopters of energy storage.

There is a latent demand for storage. Almost 60 per cent of people surveyed preferred a scenario comprised of a higher renewables mix in 2030, and nearly three-quarters of this group preferred that energy storage, rather than coal and gas, bolster grid reliability. Energy storage beyond the individual dwelling – at grid scale or for multiple dwellings – is not well known, with pumped hydro being the form most identified. People have environmental concerns with pumped hydro, but this may stem from inadequate knowledge.

Opportunities for Australia

This report identifies significant energy storage technology opportunities for Australia across global supply chains, as summarised in Table 2.

Australia has world-class resources of raw materials used in battery manufacturing, most notably lithium. Our raw materials, together with our world-class expertise in the development of energy storage solutions, including batteries, the design of software and hardware to optimise integration in smart energy systems, and expertise in the design and deployment of systems for off-grid energy supply and micro-grids, demonstrate that Australia has the potential to become a world leader.

While the possibility of Australia becoming a manufacturer of existing battery technologies is highly unlikely, there is opportunity for manufacturing of next generation battery technologies. This is particularly true in niche markets such as situations where safety is paramount, defence applications, and for Australia's high ambient temperature conditions. Given that current lithium-ion technology was not designed for stationary storage or electric vehicles, but for portable electronics, then an Australian technology that is purposed for a specific application (e.g. hot conditions or defence applications) could underpin the establishment and growth of a local manufacturing capability. We are currently manufacturing, for example, lead-acid batteries specifically for Australian submarines.

Chemical storage is identified as a potential major new export opportunity as countries such as Japan and Korea embrace hydrogen energy. Australia is already committed to supply hydrogen to Japan, but this will be produced using coal. There are opportunities to use our solar energy resources to produce and export renewable hydrogen and ammonia, enabling growth of a new industry that may be suited to northern Australia.

While Australia is very capable in the research and development (R&D) of energy storage

Technology	Raw Resources	Beneficiation*	Manufacturing	Deployment	End of Life
Established Battery Technologies	✓✓✓	✓		✓✓✓	✓
Next-Generation Battery Technologies	✓✓	✓	✓	✓✓✓	✓
Renewable Hydrogen and Ammonia	✓✓✓		✓✓	✓✓✓	
Thermal Energy Storage			✓	✓✓	
Pumped Hydro Energy Storage	✓✓			✓✓	
Integration and Control Technologies			✓✓	✓✓✓	

Table 2: Overview of industry opportunities by technology across the energy storage supply chain

✓✓✓ excellent opportunity ✓✓ good opportunity ✓ potential opportunity if blank: not applicable

*Any process that improves the economic value of a mineral ore by removing commercially worthless minerals, which results in a higher-grade product and a waste stream.

technologies, we do not have a history of converting this in to growth in local manufacture or the development of a local industry, with several examples identified where technology based on Australian intellectual property (IP) has been developed overseas Conditions required for Australia to create an energy storage industry may include the availability and support of start-up accelerators, creation of R&D incentives for industry to invest, and encouraging more venture capital.

The impact and risks of the various energy storage technologies vary. Pumped hydro was found to be a low risk, low impact technology. Despite the geographic limitations for pumped hydro, and the time (years) to implement new facilities, it is a technology that offers much potential for deployment in the grid.

While lithium-ion technology is the battery technology of choice for most energy storage applications, it comes with risks and impacts. For example, existing technologies rely on materials that have human rights impacts (for example mining of cobalt in the Democratic Republic of Congo) and availability of lithium resources. However, there is a potential opportunity for Australia, which has considerable lithium resources and where technologies for benefaction of lithium ores are being developed.

Recycling is identified as an opportunity for Australia, with a history of recycling more than 90 per cent of lead-acid batteries. Opportunities to develop technologies to recycle components of lithium batteries (including cobalt, nickel and lithium) could be further encouraged and supported.

Importantly, Australia has an opportunity to encourage product stewardship across the whole life cycle, including responsible sourcing of materials, development of mining standards and sustainability codes, and disposal.

Options for Further Work

Our findings provide reassurance that both energy reliability and security requirements can be met with readily available storage technologies. Notwithstanding, the market and technologies for energy storage and its integration into electricity networks continue to evolve. Research investment in the following will be valuable:

- The optimum balance of generation, storage and interconnection, taking into account cost optimisation and the long-term strategic opportunities for Australia.
- The role of 'prosumers' including their effects on the market, the system (equity and pricing concerns) and on their contribution to the energy transformation that is underway.
- The broader question of public literacy as Australians' knowledge of, and attitudes towards, energy storage will shape its acceptance and adoption.
- A deeper analysis of opportunities for growth of a substantial energy storage industry in Australia.

Conclusion

Over the past decade, Australia's electricity market has experienced change on an unprecedented scale. In a decentralised, yet integrated 21st century energy future, electricity networks must enable new opportunities for managing the complexity of multiple pathways for flows of electricity and payments. Energy storage has the potential to upend the industry structures, both physical and economic, that have defined power markets for the last century.

There is a legitimate role for governments to ensure that the right policy settings are enacted to drive growth in energy storage. Policy leadership will result in innovation, investment, the establishment of new high technology industries, the growth of existing high technology industries and increased or new energy exports. A proactive approach will provide the opportunity for Australia to lead and facilitate re-skilling of workforces and the creation of jobs across all levels of the value chain from mining and manufacturing through to consumer spending.

"Australia needs to move much faster to ensure its energy market is keeping pace with rapid technological change. The electricity system and regulation hasn't kept up with the furious pace of technology development …Technology is evolving so quickly … That's really where we're going in energy."

Audrey Zibelman
Chief Executive Officer
Australian Energy Market Operator (AEMO)
(*Australian Financial Review*, 28 March, 2017)

KEY FINDINGS

The key findings presented below are drawn from the four major chapters within this report – modelling of storage requirements for reliable electricity in Australia; opportunities for Australian research and industry in global and local energy storage supply chains; environmental benefits and risks from the uptake of energy storage; and the social drivers and barriers to uptake of energy storage.

1. **There is a near-term requirement to strengthen energy *security*[2] in NEM jurisdictions. Maintaining acceptable energy security levels for customers will dominate energy *reliability*[3] requirements until well in excess of 50 per cent renewable energy penetration.[4]**

   - Batteries are cost-effective for system security when installed with a high power-to-energy ratio, noting that there are other ways to strengthen system security (e.g. installation of more fast-start gas turbines, use of spinning reserve in wind turbines, and demand response and load shedding measures).

2. **At an aggregated national level[5], Australia can reach penetrations of 50 per cent renewable energy without a significant requirement for storage to support energy *reliability*.**

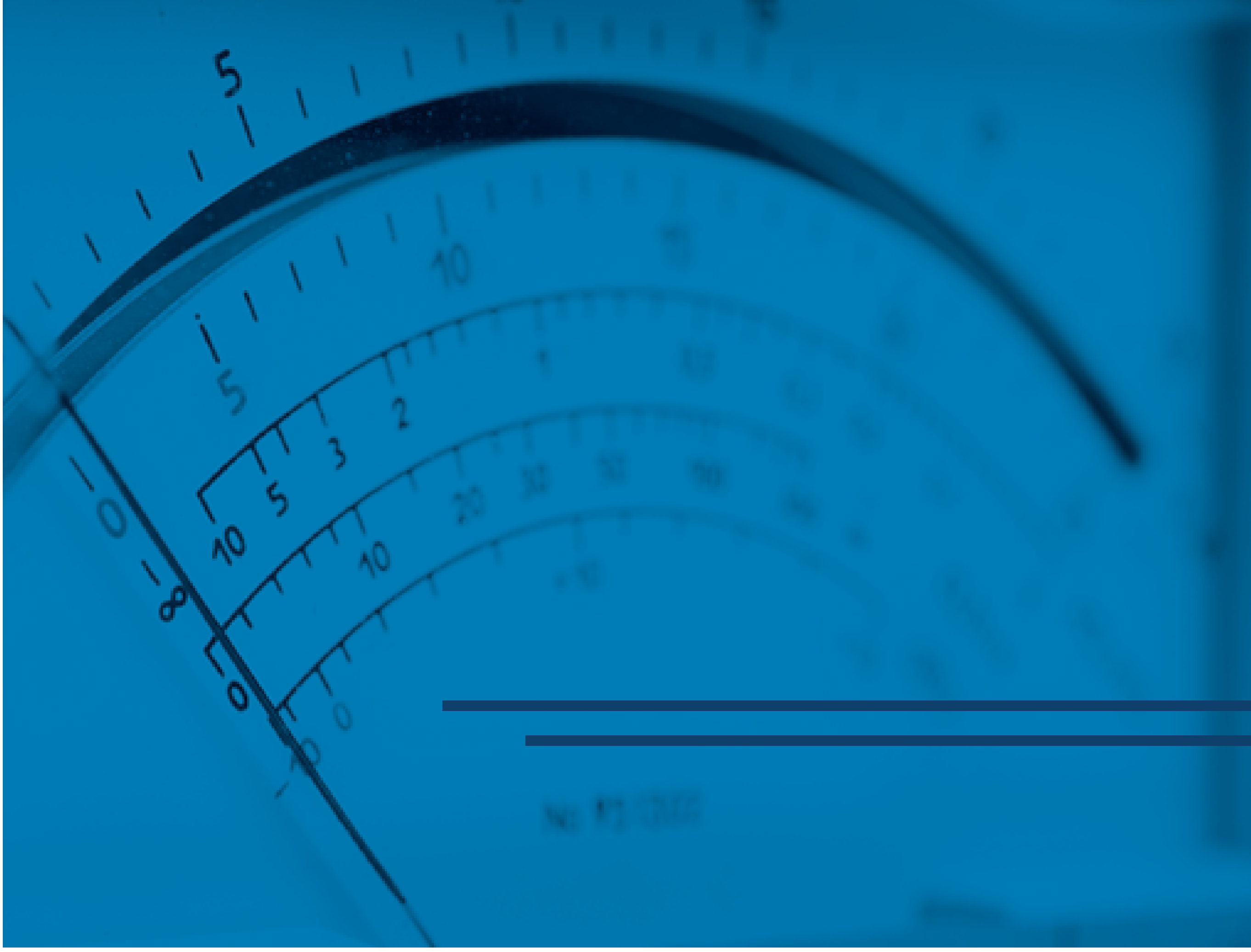
   - Installing the levels of storage power capacity (GW) required for the purpose of *security* creates the opportunity to expand energy stored (GWh) capacity for *reliability* at a lower marginal cost than would otherwise be the case.
   - Despite significant development time, pumped hydro energy storage (PHES) is presently the cheapest way to meet a reliability requirement. Projections indicate that the most cost-effective energy storage

2. "System security" is the ability to deliver near-instantaneous power (GW) for short periods (seconds to minutes) as fast frequency response to withstand sudden changes or contingency events in electricity generation (e.g. failure of a large generator), transmission (loss of a transmission line) or demand.

3. "System reliability" is the ability to meet electrical energy demand (GWh) at all times of the day, the year, and in future.

4. Ensuring system reliability and system security is a core function of the Australian Energy Market Operator (AEMO).

5. The storage requirements differ at a state level.



options available in 2030 will be PHES, lithium-ion batteries and zinc bromine batteries. These all have similar levelised cost of storage (LCOS), depending on the PHES sites selected and uncertainty in the rate of reduction of battery costs.

3. **Australia is well placed to participate in global energy storage supply chains. Business opportunities will arise, given appropriate policy decisions at State and Commonwealth levels, and incentives.**

- Australia has abundant raw mineral resources for batteries (most notably lithium), but could capture greater value through beneficiation (value-adding to the raw mineral resources).
- Australian companies and researchers are commercialising their energy storage intellectual property (software and hardware for battery integration, design and deployment of off-grid energy supply and micro-grids, and battery technology and components) through international and global partnerships.
- Australia has abundant resources (e.g. solar), appropriately skilled workforces and established supply chain relationships to generate renewable hydrogen and ammonia at the volumes required to supply potential export markets, such as Japan and Korea.

4. **Australia's research and development performance in energy storage technologies is world class, but would benefit from strategic focus and enhanced collaboration.**

- Australia is recognised as conducting world-leading research in several energy storage disciplines including electrochemistry, materials development and materials processing for advanced batteries, and power system design and modelling.

- Deriving the full return-on-investment from this research requires improved research translation through national and international industry-research collaboration and commercialisation.

5. **The availability of private sector risk capital and profitable revenue streams for Australian energy storage start-ups and projects is a challenge for new ventures, as is policy uncertainty.**

- Profitable revenue streams from energy markets together with consistent, stable and integrated energy and climate policies will be essential to drive investment in energy storage and other technology solutions that support decarbonisation of the electricity system while ensuring system security and consumer equity.
- Technology-neutral market-based reforms will be required to address these challenges at least cost.

6. **A high uptake of battery storage has a potential for significant safety, environmental and social impacts that would undermine net benefits.**

- The development of safety standards is required given anticipated rapid uptake of batteries.
- As an early market "test bed" for batteries, Australia has an opportunity to promote and lead development of sustainable supply chains from mining to disposal. This would use Australia's expertise in sustainable mining to lead and support the development of international standards.
- There are opportunities for consumers to influence commercial behaviour globally through improved awareness of the environmental and social impacts of battery development.

7. **Unless planned for and managed appropriately, batteries present a future waste management challenge.**

- Australia has an opportunity to play a product stewardship role to ensure the sustainable repurposing of used electric vehicle batteries and recycling of all batteries.
- Focused development of recycling infrastructure and technology will be crucial and provides an opportunity for industry development and job growth.

8. **Australians are deeply concerned by the sharp rise in electricity prices and affordability. They hold governments and energy providers directly responsible for the perceived lack of affordability.**
   - Deregulation of the electricity market, changes in feed-in-tariff schemes and other time of use tariffs have led to an underlying general mistrust of the government and energy providers.
   - Focus group participants believe that individual consumers who can afford home battery storage units may elect to become independent of the grid to avoid rising energy costs.
9. **Energy storage is not a well-known concept in the community and there are concerns that a lack of suitable standards at the household level will affect safety.**
   - A majority of respondents surveyed said they did not know enough to make an informed decision about whether to purchase a home battery storage unit.
   - Although a battery storage installation standard is currently being developed, there are concerns that an early incident may have serious ramifications for household deployment, with many referring to the "Home Insulation Program" failure.
   - "Pumped hydro" was recognised by some as an established utility scale technology, but that possible "social licence" issues may arise due to the perception of competing land use and a potential lack of water.
   - There is an opportunity for governments to increase the public's knowledge and awareness of energy systems (from energy generation through to storage – at utility and consumer levels).
10. **Australians favour a higher renewable mix by 2030, particularly PV and wind, with significant energy storage deployed to manage grid security.**
    - The majority of those surveyed suggested they would look to government to play a role in the future energy mix, but lacked confidence that their preference for higher renewables would be achieved without consistent energy policies.

INTRODUCTION

Electricity is both a basic part of nature (lightning being the most obvious example) and one of the most widely used forms of energy. It is a *secondary energy source* because *primary sources* of energy such as coal, natural gas, nuclear energy, solar energy and wind energy must be converted into electrical power. Electricity is also an *energy carrier*, which means it can be converted to other forms of energy such as mechanical energy or heat.

Traditionally, electricity is generated when a turbine spins to create an electric current. Energy to spin these turbines comes from burning coal or natural gas; capturing heat from nuclear reactions, the earth itself (geothermal energy) or concentrated solar energy; or harnessing the wind to rotate wind turbine blades. Solar energy can also be converted directly to electricity (solar PV), a technology increasingly deployed worldwide.

Sending electricity from a generating station to customers relies on complex transmission and distribution networks. Transmission lines are generally of a higher voltage to carry more power across longer distances, while distribution lines above or below city streets carry power to individual consumers. Both sets of networks are critical to deliver power to consumers.

The electricity system supporting Australia's economy and lifestyle was built on the economies of scale associated with large centralised generation technologies delivering electricity via one-way transmission and distribution networks to industrial, commercial and residential customers (Figure 2). This regulated, predominantly government-owned business model drove down the cost of electricity, fostered universal access, and provided reliable electric service.

To maintain a reliable and secure electricity transmission grid, an intricate physical balance must constantly be maintained between the amount of power that is generated and the amount that is consumed. Without energy storage, once electricity is generated it must be consumed at nearly the same time. All the fast-spinning turbines that are joined together

by three-phase electrical currents twisting along the transmission network maintain this delicate balance. Australia has the longest transmission network in the world.

Turbines are synchronised to deliver an alternating current at Australia's 50 Hz grid frequency, which is maintained with remarkable precision. Consumers provide the drag that slows the rotation of turbines, by drawing energy out of the system, while fossil fuel or hydro generators – and more recently wind and solar generators – provide the acceleration. The Australian Energy Market Operator (AEMO), which also has the parallel role of facilitating energy trading, is the system operator.

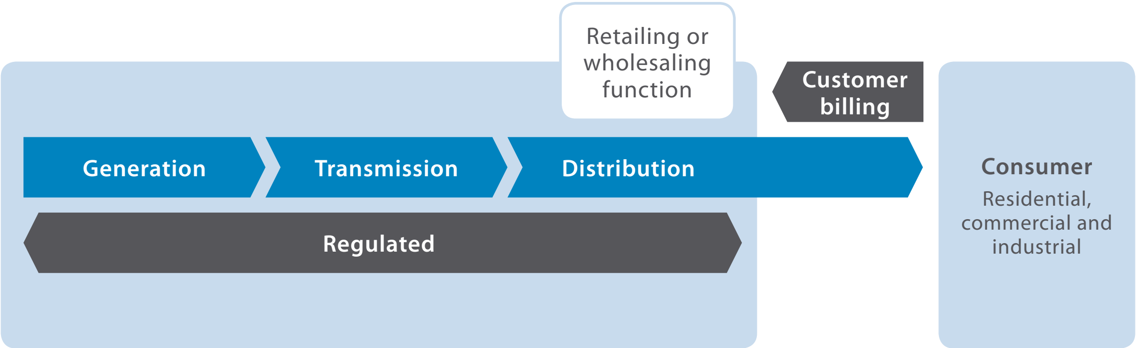


Figure 2: The 'one-way' traditional structure of the vertically integrated utility business model (adapted from Tuttle et al., 2016)

Australia's National Electricity Market (NEM) commenced operation in December 1998 as a wholesale market for the supply of electricity to retailers and end-users in Queensland, New South Wales, the Australian Capital Territory, Victoria and South Australia. Tasmania joined the NEM in 2005 and operations today are based in five interconnected regions that largely follow state boundaries. The NEM operates on the world's longest interconnected power system – from Port Douglas in Queensland to Port Lincoln in South Australia – a distance of around 5,000 kilometres. In 2016–17 more than $A16 billion of wholesale electricity was traded in the NEM to meet the demand of almost 10 million Australian Homes and businesses (AEMO, 2017).

Over the last decade, the NEM has experienced change on an unprecedented scale, and that change continues unabated. State and territory government-owned generators, transmitters and distributors of electricity has been variously privatised or broken up, with intrastate and interstate retail competition strongly encouraged and adopted.

The ownership and operating structures of most of the businesses in Australia's electricity systems, and particularly in the NEM, are radically different from those of 20 years ago.

In 2001, the Renewable Energy Target (RET) was established by the Commonwealth Government with the initial aim to source two per cent of Australia's electricity from renewable sources. The RET has undergone reviews and changes since, and in January 2011 was split into two parts:

- The Large-scale Renewable Energy Target, which creates a financial incentive to establish and expand renewable power

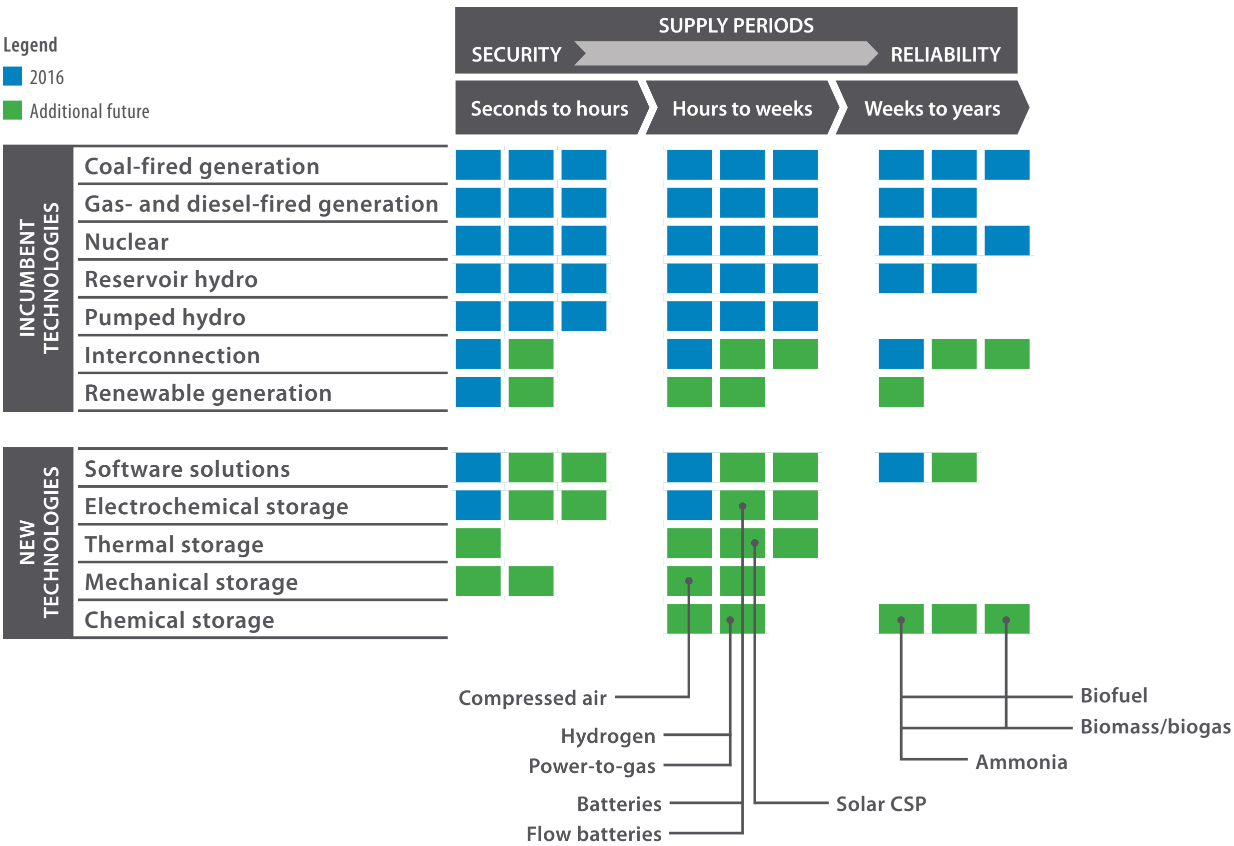


Figure 3: Technology options for balancing the future grid. The number of boxes represents the technology's ability to meet current (blue) and future (green) supply period demands (adapted from Liebreich, M., Bloomberg New Energy Finance, 2016).

stations such as solar farms, wind farms and hydro-electric power stations and deliver the majority of the 33,000 GWh 2020 target.

- The Small-scale Renewable Energy Scheme (SRES), which creates a financial incentive for individuals and small businesses to install eligible small-scale renewable energy systems such as solar panel systems, small-scale wind systems, small-scale hydro systems, solar water heaters and air source heat pumps.

Encouraged by the SRES as well as state and territory technology-specific energy policies, many Australians and Australian businesses have invested in new generation technologies (principally solar panel systems). This has allowed them to take control of both their energy use and supply (becoming 'prosumers') to support action on climate change while remaining connected to the established electricity networks.

The positive and negative impacts of these changes – together with a growing range of technology options (Figure 3) – are encouraging companies in Australia's electricity industry to adopt new technologies and business models as policy makers re-shape the regulatory regime and electricity market structures. Australia's continued transition to an electricity market with greater input from renewables will require market regulations that are both adaptable and dynamic to market needs.

> *Energy storage is seen by many as the next big change facing Australia's electricity system. The technology can solve challenges that range from smoothing the intermittency of renewable generation to providing power quality support, and managing peak demand to reducing customers' electricity bills.* (Cavanagh et al., 2015)

In a decentralised yet integrated 21st century energy future (Figure 4), electricity networks must enable new opportunities for managing the complexity of multiple pathways for flows of electricity and associated payments, while ensuring energy security, energy equity and

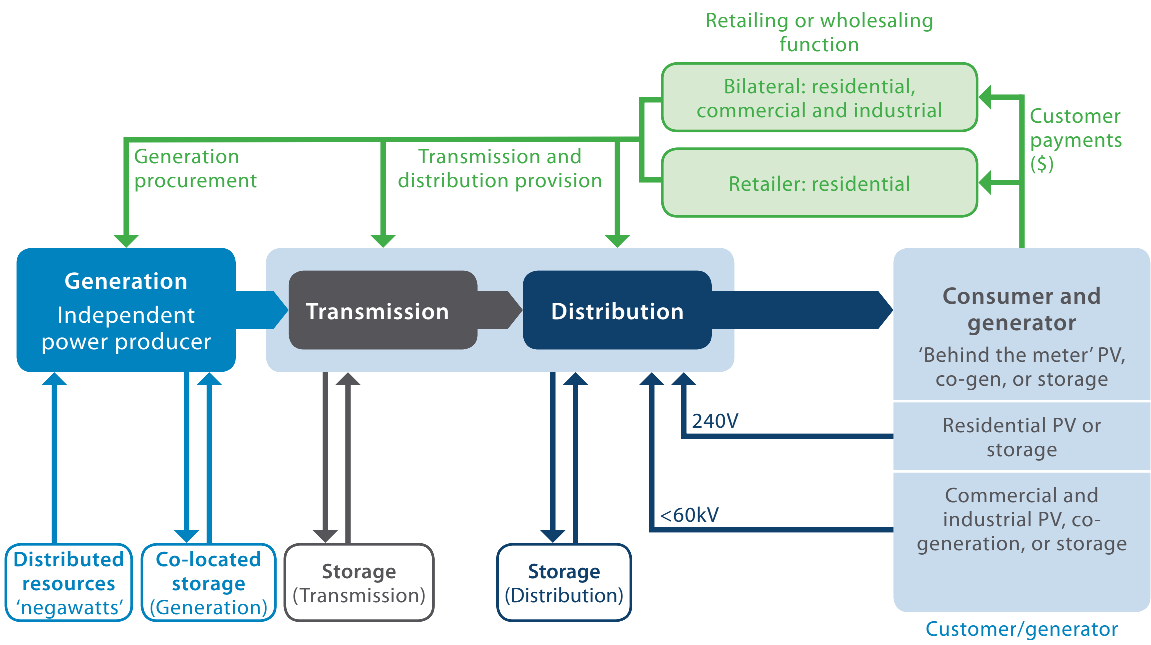


Figure 4: The electricity system of the 21st century will have multiple pathways for two-way flow of both money and electricity (adapted from Tuttle et al., 2016)

environmental sustainability. Energy storage can play a vital role in providing a balanced solution to this energy challenge (Figure 5).

Although energy storage is an emerging industry globally, it is not a new concept. There is a diverse range of energy storage technologies available with differing characteristics for a similarly diverse range of applications and services.

Importantly, energy storage can play a vital role in removing the energy and transport sector's reliance on fossil fuels through electrifying the transport sector and facilitation of high proportions of variable renewable electricity generation. Moreover, the domestic and global markets for energy storage technologies and services are expected to grow dramatically in the coming years, which presents an economic opportunity for Australia.

> *Storage will be an important component of intensely distributed electricity systems, providing operational flexibility. Widespread deployment of distributed storage systems will require overcoming market, regulatory and cost barriers. Meanwhile, the development and demonstration of cost-competitive storage systems continues internationally – and Australia historically has a strong reputation in electrochemical battery research and development, including successful commercialisation of novel battery technologies locally and internationally.* (Australian Academy of Technology and Engineering, 2013)

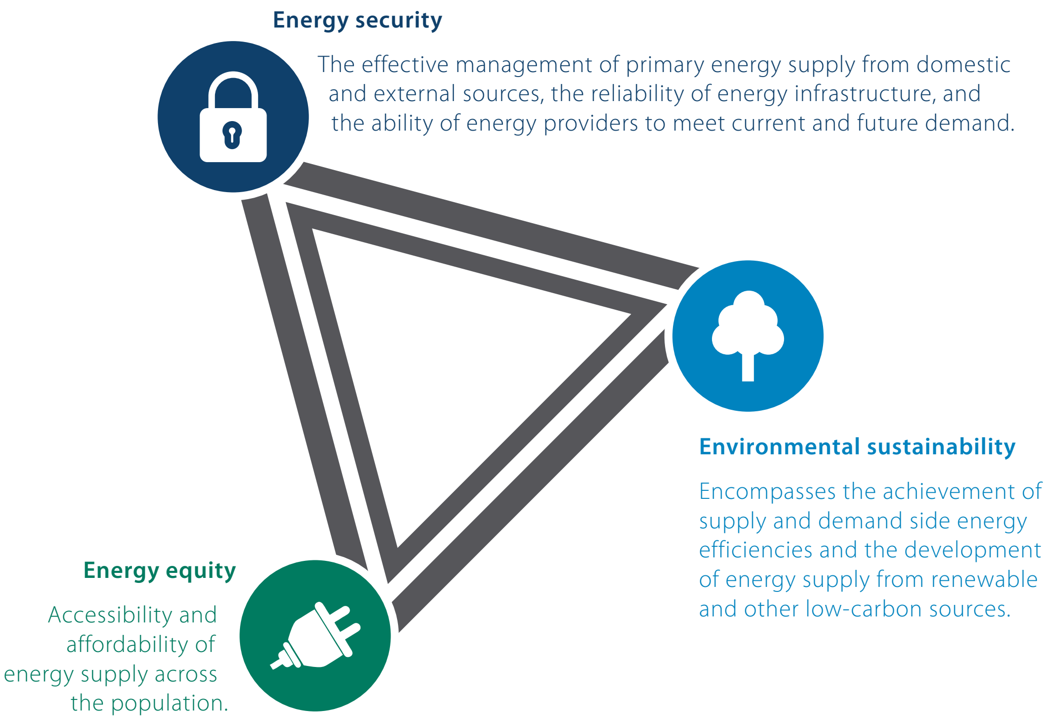


Figure 5: Balancing the energy trilemma (adapted from World Energy Council, 2016)

Australians favour a higher renewables mix by 2030, particularly PV and wind, with significant energy storage deployed to manage grid security

BACKGROUND

Delivered as a co-funded project between the Australian Council of Learned Academies (ACOLA) and Australia's Chief Scientist, this report considers the transformative role that energy storage can play in Australia's energy systems; identifies economic opportunities and challenges; and describes the current state of, and future trends in, energy storage technologies. It examines the scientific, technological, economic and social aspects of the role that energy storage can play in Australia's transition to a low-carbon economy over the coming decade and beyond. While acknowledging the diverse applications and services that energy storage technologies can provide (including for transport), this report focuses on storage of low-carbon energy for electricity supply in Australia, together with industry, export and research opportunities.

This project was commissioned in July 2016. Events since commissioning have focused the interest of governments, industry and the community on the potential and need for energy storage to play a role in Australia's transitioning energy supply mix. These events include:

- Extreme weather events that resulted in South Australia's state-wide blackout in September 2016, and emergency load-shedding in New South Wales and South Australia in February 2017.
- The announcement in November 2016, and completion on 31 March 2017, of the closure of Hazelwood power station in Victoria.
- Commissioning of two major reviews by the Australian Government:
  - 'An independent review into the future security of the National Electricity Market' led by Australia's Chief Scientist, Dr Alan Finkel (announced in October 2016); and
  - A review into retail electricity pricing in Australia to be undertaken by the Australian Competition and Consumer Commission (announced in March 2017).

- Establishment by the Australian Senate in October 2016 (report published in April 2017) of a Select Committee into the *Resilience of Electricity Infrastructure in a Warming World*. This inquiry reported on the role of storage technologies and localised distributed generation to provide Australia's electricity networks with the resilience to withstand the increasing severity and frequency of extreme weather events driven by global warming, and recommend measures that should be taken by federal, state and local governments to hasten the rollout of such technologies.
- Announcement by the Minister for the Environment and Energy in April 2017 that a special review on power system security, electricity prices and emission reductions was to be delivered jointly by the Climate Change Authority and the Australian Energy Market Commission. The report was delivered by 1 June 2017 to provide advice on policies to enhance power system security and to reduce electricity prices consistent with achieving Australia's emission reduction targets in the Paris Agreement.

- The development by Energy Networks Australia and CSIRO of an *Electricity Network Transformation Roadmap* (published in April 2017) which outlines a national plan to "keep the lights on, make sure bills are affordable and decarbonise our electricity industry by mid-century" (Graham, 2017).
- Announcements by the Premiers of South Australia and Victoria in March 2017 that their governments would invest $A150 million and $A25 million respectively into the delivery of energy storage projects in support of system security within those states.
- Announcement by the Australian Government (March 2017) that it would invest up to $A2 billion into the expansion of the Snowy Mountains Hydro Scheme (badged as Snowy Mountains Scheme 2), with a feasibility study to be concluded by the end of 2017.
  - In the 2017 Budget, announced on 9 May, the Australian Government indicated that it might take greater ownership of the Snowy Mountains Hydro Scheme from Victoria and New South Wales.
- Announcements of major projects involving energy storage including a $A1 billion project led by Lyon Energy to build a 330 MW solar farm with a 100 MW battery with four hours of storage in South Australia, the 250 MW Kidston solar farm and pumped hydro storage project in North Queensland (250 MW with six hours' storage), and the Lakeland solar project in North Queensland (a 10.8 MW solar farm and a 5.3 MWh battery).

Scope

The objective of this study has not been to forecast the stationary[6] energy mix that may be in place at 2030, but rather to determine the range of energy storage requirements that may arise given possible energy generation pathways. Three scenarios were chosen to study likely energy storage requirements:

- LOW RE – low uptake of renewable energy
- MID RE – medium uptake of renewable energy solutions
- HIGH RE – high uptake of renewable energy solutions.

The three scenarios, including energy from variable and dispatchable (able to adjust their power output supplied to the electrical grid on demand) renewable energy sources, respectively account for approximately 35 per cent, 50 per cent, and 75 per cent of total electricity generated and supplied in 2030. Sources of electricity include rooftop solar, large-scale solar, wind, pumped hydro or any other renewable energy technologies included in the 2030 energy mix. The modelling relied on other studies to provide data and to support the anticipated rapid expansion of small-scale storage requirements.

6. Because Australia is not a vehicle-manufacturing nation, this report has not attempted to forecast local use and supply of batteries for, nor to ascertain consumers' and other stakeholders' views on, electric, plug-in hybrid and hybrid vehicles. However, the contribution of Australian R&D and the implications for, and opportunities from, re-purposing, recycling and disposal of transport batteries are implicitly covered in this report.

The key energy storage technologies reviewed for their potential application in Australia's energy mix include:

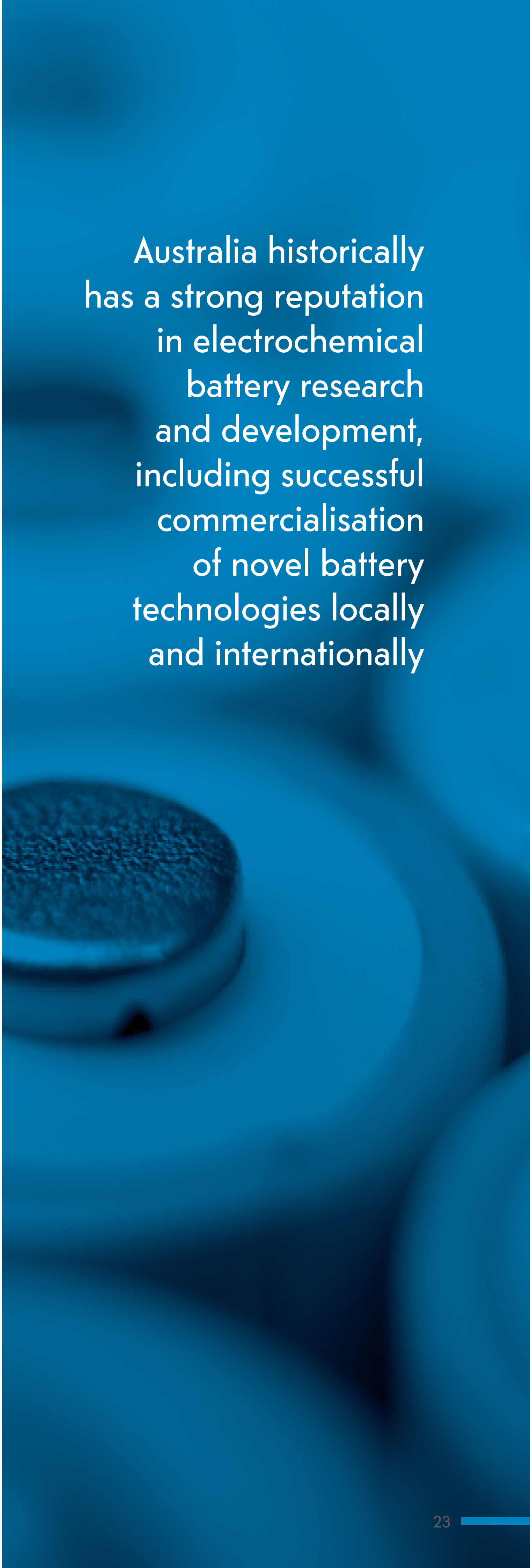
- Mechanical
  - Pumped hydro energy storage (PHES)
  - Compressed air energy storage (CAES)
- Electrochemical
  - Batteries
- Chemical
  - Power-to-gas (fuel synthesis using renewable energy)
- Thermal[7]
  - Molten salts
  - Liquid air energy storage (LAES)
- Thermo-chemical
  - Ammonia dissociation-recombination

Solar fuels and algal biofuels as a storage medium did not form part of the scope of this work.

The energy scenarios and the key energy storage technologies, as outlined, have informed the development of each of the four discrete work programs. The Expert Working Group comprising of Fellows or nominees from each of the four Australian Learned Academies (Australian Academy of the Humanities, Australian Academy of Science, Academy of the Social Sciences in Australia, and Australian Academy of Technology and Engineering) identified organisations to undertake each of the discrete work programs. The outcomes of these programs have, in turn, informed the development of this report.

The individual reports that resulted from the discrete work programs are available on the ACOLA website (www.acola.org.au).

7. Thermal storage in this context refers to storing energy in the form of high temperature heat for later use (electricity generation, process heat for industry) as opposed to low temperature thermal storage such as solar hot water or passive solar building features.



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