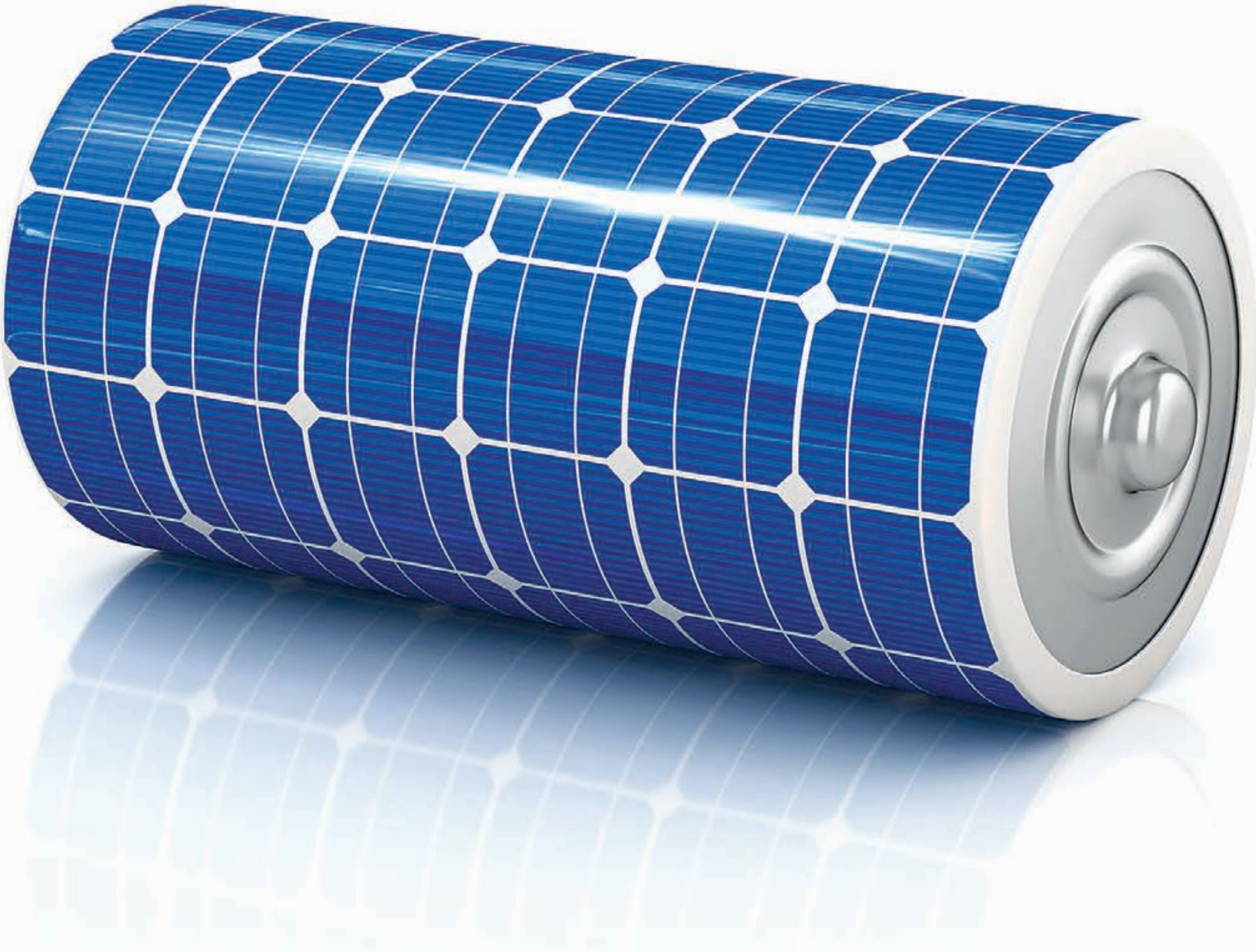

Energy Storage: Opportunities and Challenges of Deployment in Australia

Work Package 2: Research and industry opportunities and challenges

Prepared by the Australian Academy of Technology and Engineering (ATSE)
for the Australian Council of Learned Academies (ACOLA) Energy Storage project

AUSTRALIAN ACADEMY OF
TECHNOLOGY AND ENGINEERING

AUTHORS
Dominic Banfield
Emily Finch
Dr Matt Wenham

EXPERT REFERENCE GROUP
Dr Lachlan Blackhall
Denise Goldsworthy FTSE
Mr John Grace FTSE
Professor Douglas MacFarlane, FAA FTSE
Dr Leonie Walsh FTSE

EXPERT WORKING GROUP SUPERVISORS
Dr Bruce Godfrey FTSE
Professor Maria Forsyth FAA

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Project Aims

Delivered as a partnership between the Australian Council of Learned Academies (ACOLA) and Australia's Chief Scientist, the ACOLA report on *The Role of Energy Storage in Australia's Future Energy Supply Mix* 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. The full report is available at www.acola.org.au.

This contributing report, undertaken by the Australian Academy of Technology and Engineering (ATSE) for ACOLA investigates the opportunities and challenges that energy storage technologies are creating for Australia's industry and research sectors.

The report aims to identify the potential economic benefits and challenges together with additional employment opportunities for Australian research and industry in the global and local energy storage supply chains. It considers the opportunities and challenges for value add in both domestic and export markets in terms of manufacturing, software, instruments, knowledge, services and resources (including stored energy). The report aims to:

> Map the energy storage supply chain, both in Australia and internationally, and identify the key participants and gaps at each stage.

> Identify where Australia's energy storage research and industry strengths and weaknesses lie in an international context.

> Identify existing successes and where there is scope for growth and potential for exports.

> Identify the enabling conditions to promote growth in Australian industry and successful research outcomes in Australian research institutions.

> Identify prospective new energy storage technologies that are entering the development phase but are not yet commercial and map the technology readiness of these.

> Identify the potential value add of Australia's strengths in energy storage (resource to technology to products to services) across the energy supply chain to ascertain the greatest opportunities.

> List existing policy and regulatory measures (at state and AEMO level) that impact this work package and identify those institutional and regulatory barriers that may be inhibiting industry growth and research and development in energy storage.

> Considering international and domestic leading practices, evaluate how new or modified programs/policies/regulations might enable innovation and growth in the sector and support achievement of the aspirational scenario.

Executive Summary

Australia has the potential to be at the forefront of deployment of energy storage technologies. High penetration of rooftop solar systems coupled with high energy prices by international standards mean the appetite for distributed storage is large. In addition, the need to address the Energy Trilemma – providing secure, affordable electricity while transitioning to a low emissions economy – means that large-scale storage technologies are likely to be needed. These factors suggest that Australia can be a testbed for the deployment of energy storage technologies, which creates a number of opportunities for research activity and industry growth. Australian researchers and companies are active across the supply chain for energy storage technologies. This report aims to understand where the most significant opportunities lie for creating new jobs, companies, industries and technologies in Australia.

The project involved mapping the energy storage supply chain for all the major energy storage technologies, including batteries, pumped hydro and hydrogen. This mapping looked at which aspects of the supply chain are undertaken in or by Australia, against a global context of key providers and market players. The report also examined emerging technologies and areas of research strength in Australia. In addition to this mapping exercise, over 80 consultations were conducted with key stakeholders in the energy storage sector, including universities and research institutions, small and large companies (including start-ups, manufacturers, energy generators and distributors), industry groups, and government agencies and regulators. The perspectives provided through these consultations, combined with the supply chain mapping and desktop research, led to an assessment of which technology areas offered the greatest opportunities for Australian research and industry. An overview of this assessment can be found in Table 1: Overview of industry opportunities by technology across the energy storage supply chain.

Table 1 Overview of industry opportunities by technology across the energy storage supply chain

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	■	■	++	+++	■

+++ : excellent opportunity ++ : good opportunity + : potential opportunity ■ : not applicable

Key Findings

Summaries of the key themes for each stage of the energy storage value chain are shown in Figure 1. Five key findings based on these themes are identified and discussed below. The full list of findings is located at the end of the executive summary.

Australia's performance in energy storage research and development is world class. However, it could benefit from greater strategic focus and enhanced collaboration. Australia is recognised as conducting world-leading research in a number of energy storage disciplines. However, deriving the full benefit from this research will require improved performance in research translation, industry-research collaboration and commercialisation. There are opportunities for Australian IP to be developed via international partnerships and participation in global value chains.

Australia is well placed to participate in national and global supply chains for raw materials, but could capture greater value through local beneficiation. Australia has significant reserves of a number of raw materials used in energy storage manufacturing, most notably lithium. In addition to the extraction of these minerals, conducting more value-adding in Australia has potential if processing and energy costs can be reduced. Deployment of improved extraction and processing technologies developed in Australia's world class METS sector has potential to improve Australia's competitiveness.

Australia has a competitive advantage in design of software and hardware to optimise the integration of energy storage in smart energy systems, and is developing expertise in the design and deployment of systems for off-grid energy supply and microgrids. The rapid uptake of distributed and behind-the-meter energy storage in Australia has encouraged Australian businesses to develop systems that enable optimised management, operation, and market participation of grid-connected behind-the-meter energy storage and embedded networks. These technologies and expertise have the potential to be applied in a number of international markets. The structure of Australia's electricity grid, with many regions at the end of thin networks or off-grid entirely, offers opportunities for the development and deployment of microgrid and off-grid systems. In addition to being needed in Australia, these systems may be useful in similar areas of the world, particularly in developing countries.

Figure 1 Summary of key themes for each element of the energy storage value chain

Research and Development			
Australia's research and development performance in energy storage technologies is world class. However, it could benefit from greater strategic focus and enhanced collaboration.			
Raw Resources and Beneficiation	**Manufacturing**	**Deployment**	**End of Life**
Australia is well placed to participate in national and global supply chains for raw materials, but could capture additional value through local beneficiation.	Australia has a competitive advantage in the design of software and hardware for energy storage and smart energy systems.	Australia is developing expertise in the design of systems for off-grid energy supply, microgrids and embedded networks. Australia has a major opportunity to produce renewable hydrogen and ammonia for export.	Greater deployment, end-of-life regulations, and improved recycling technologies would help support Australia play a greater role in the repurposing and recycling of used batteries.
Enabling Conditions			
New energy market mechanisms and integrated energy and climate policy will drive efficient investment in energy storage (and other technology) solutions that can support decarbonisation of the electricity system while ensuring system security and customer equity.			

Australia has a major opportunity to generate renewable hydrogen and ammonia for export. Australia is well placed to supply renewably generated hydrogen and ammonia to export markets in emerging hydrogen economies such as Japan and Korea. In addition to its excellent renewable resources, Australia also has expertise that could be used to improve the efficiency of hydrogen synthesis and utilisation. Australia possesses significant expertise and infrastructure for the export of liquefied natural gas (LNG), which could potentially be repurposed for ammonia transport.

New energy market mechanisms and integrated energy and climate policy will be essential to drive efficient investment in energy storage (and other technology) solutions that can support decarbonisation of the electricity system while ensuring system security and customer equity. Energy storage technologies can help to address many of the challenges to energy security, affordability and sustainability currently being faced by the National Electricity Market (NEM). To address these challenges at least cost, technology-neutral, market-based reforms are required. These reforms will allow energy storage technologies to compete on an equitable basis with other technology options by providing revenue potential for emerging market players. Consistent policy settings will help create a market for energy storage technologies based on their ability to improve network security and transition to lower emissions generation. A stable policy environment will provide predictability for investors and allow for larger, longer-term investments in storage technologies.

Findings

Finding 1 Australia's research and development performance in energy storage technologies is world class and is regarded as a great national strength. However, if Australia is to maximally benefit from this strength then strategic focus and enhanced collaboration with national and international companies is required.

Finding 2 Australia is not lacking in locally developed energy storage technologies but, as in other fields in Australia, their commercialisation track record within Australia is poor and the local industry is small.

Finding 3 Australia has world-scale resources for many of today's and tomorrow's energy storage technologies, and is well placed to participate in national and global supply chains for raw materials. However, value-adding by beneficiation of minerals has been declining in Australia, due in part to the high cost of energy required to power the processing plants.

Finding 4 High-volume manufacturing of existing energy storage technologies is not expected to be undertaken in Australia. Nonetheless, Australian companies are commercialising their energy storage IP through, and supplying products to, international and global partnerships. Identifying opportunities to participate in global energy storage value chains will be important for the growth and success of Australian companies.

Finding 5 Australia has significant leadership and market opportunities in the design of software and hardware for energy storage management, integration and aggregation, but will face competition from international companies.

Finding 6 Australian companies are developing expertise in the design and deployment of microgrids and standalone systems for off-grid energy supply and smart systems for the management of behind-the-meter energy storage and embedded networks.

Finding 7 Higher penetrations of variable renewable energy systems in the national electricity market will require supporting technologies, such as distributed and large-scale energy storage, to ensure network reliability and security.

Finding 7 Australia's excellent renewable energy resources offer a major opportunity to generate renewable hydrogen and ammonia for export.

Finding 8 Australia will have an opportunity to play a greater role in the repurposing and recycling of used batteries once local deployment reaches sufficient scale. The development of supportive end-of-life regulations and standards, and the potential development of improved recovery technologies would also facilitate this industry opportunity.

Finding 9 Current policies and design of the NEM do not efficiently encourage solutions, including deployment of energy storage, that support decarbonisation of the electricity system while ensuring system security and customer equity.

Finding 10 Access to private sector risk capital for Australian energy storage start-ups and projects is a key challenge for new energy storage ventures.

Finding 11 Wider actions to address the systemic challenges in industry-research collaboration are expected to benefit the energy storage industry and drive enhanced knowledge transfer and application.

1. Introduction

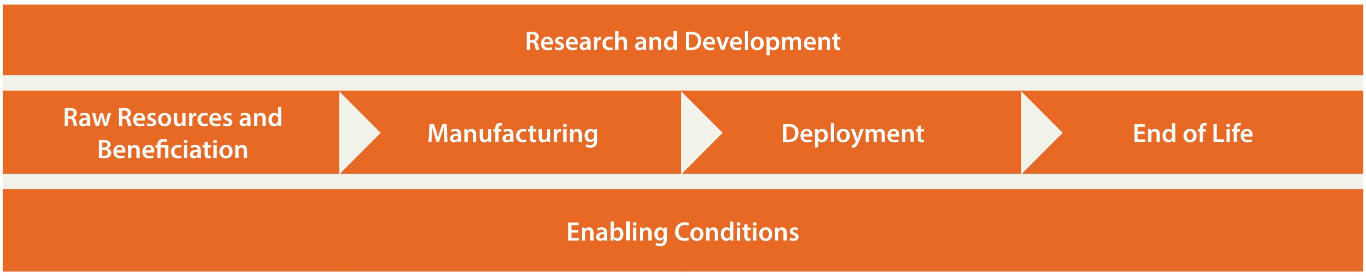
The development of a global market for energy storage presents opportunities and challenges for Australian research and industry stakeholders. The global energy storage market is growing rapidly, and Australia is one of the fastest growing markets, albeit far from the largest. This contributing report aims to identify the array of challenges and growth opportunities for Australian research and industry in the global and local energy storage supply chains.

This research was informed by evidence gathered through a combination of targeted stakeholder invitations and written submissions. This was supported by a thorough review of literature in the public domain. ATSE received input from over 80 stakeholders and experts from the energy and energy storage sectors (see Evidence Gathering).

This contributing report considers a wide range of energy storage technologies with direct applications in Australia's electrical systems including both established and next-generation batteries, chemical storage (e.g. renewable hydrogen), thermal energy storage systems (e.g. concentrated solar thermal power and co-generation applications), compressed air energy storage and pumped hydro. Technologies and expertise related to the control and integration of energy storage technologies is also considered. Energy storage for transport purposes, portable electronics, and purely thermal storage are considered to be out of scope.

Potential opportunities for Australian organisations to participate in global energy storage value chains are identified and discussed across Research and Development (Section 2), Raw Resources and Beneficiation (Section 3.1), Manufacturing (Section 3.2), Deployment (Section 3.3) and End of Life (Section 3.4). Key participants, leading examples and existing successes are identified for each element of the value chain. The report also discusses potential Enabling Conditions (Section 4) with potential to support growth and development of Australia's energy storage researchers and businesses. These conditions consider government policy, market design and regulation, access to capital, and strategic coordination and collaboration. The overarching analysis framework is illustrated in Figure 2.

Figure 2 Energy storage value chain analysis framework



2. Research and Development

2.1. Australia's research strengths

Australia's strength in research and development is recognised as one of the country's greatest opportunities in the energy storage supply chain. Australia is recognised for having world-class researchers in electrochemistry, electrical engineering and other related fields. Opportunities may include improving on existing energy storage designs or developing new technologies.

The Excellence in Research for Australia (ERA) evaluation identifies 11 Australian universities involved in energy storage research as having engineering and materials chemistry research performance that is typically above to well above world standard. These are presented in Table 2 (*ERA score 4-5; Australian Research Council, 2015*).

> **The Australian Centre of Excellence for Electromaterials Science** (ACES) has energy storage projects (including metal-air batteries, the electrolysis of water hydrogen, and nitrogen reduction to ammonia) based at Monash University, Deakin University and the University of Wollongong.

> **The Australian Nuclear Science and Technology Organisation** (ANSTO) is working on the development of new materials for use in molten salt reactor systems, and is involved in research on concentrated solar thermal, hydrogen energy storage, lithium batteries, and fuel cells.

> **The Australian Solar Thermal Research Initiative** (ASTRI) is an 8-year international collaboration between research institutions and industry, including CSIRO, ARENA, Flinders University, University of South Australia, ANU, The University of Adelaide, Queensland University of Technology, The University of Queensland (UQ), investigating concentrated solar thermal power technologies .

Table 2 Australian universities rating above world standard in energy storage research fields

University	Engineering	Electrical Engineering	Materials Engineering	Materials Chemistry
Australian National University	4	5	5	4
Curtin University	4	5	4	N/A
Deakin University	4	4	5	5
Monash University	5	4	5	5
Queensland University of Technology	4	4	5	5
University of Adelaide	4	5	5	5
University of Melbourne	5	5	5	5
University of Newcastle	4	5	4	5
University of New South Wales	5	5	4	5
University of Queensland	5	4	5	5
University of Technology Sydney	3	3	4	5
University of Wollongong	4	5	5	5

Although these ERA scores are not specific to energy storage, they demonstrate Australia's overall strength in the engineering and chemical sciences fields applicable to energy storage.

Public sector organisations researching energy storage include:

> **Australian National University**'s (ANU) Energy Change Institute conducts research on fuel cells, energy nanomaterials, pumped hydro, and solar thermal energy storage. Researchers in the College of Engineering and Computer Science at ANU, alongside researchers at the University of Sydney and industry partners, were recently awarded an ARENA grant to develop network aware co-ordination algorithms and capabilities for residential energy storage on Bruny Island (Consort, 2016).

> **The Commonwealth Science and Industrial Research Organisation** (CSIRO) has experience with a range of energy storage technologies including various battery chemistries, supercapacitors, fuel cells, and hydrogen energy storage.

> **Curtin University**'s Fuels and Energy Technology Institute is currently investigating the properties hydrogen storage materials suitable for transport applications such as cars; high temperature hydrogen storage materials suitable for heat storage

in concentrated solar thermal power (CSP) applications, and the properties of hydrogen storage materials suitable for CSP, static and heavy transport applications (Curtin University, 2016). Additionally, Curtin's Hydrogen Storage Research Group (HSRG) aims to produce technologically viable new hydrogen storage materials that will meet the ground transportation and static applications associated with a transition to a solar hydrogen economy.

> **Deakin University**'s Institute for Frontier Materials investigates new battery chemistries such as metal-air and sodium-based batteries, as well as improving the performance of existing technologies. In 2016, Deakin established the Battery Technology Research and Innovation Hub (BatTRI-Hub) as a joint venture with CSIRO. BatTRI-Hub collaborates with industry groups with the aim of developing new battery technologies for manufacturing in Australia (Deakin Research, 2016).

> **Griffith University** is developing a forecast-based energy storage scheduling and operation system for better load balancing and management of energy supply from solar photovoltaics (Bennett, Stewart, & Lu, 2015).

> **Monash University**'s Energy Materials and Systems Institute (MEMSI) has world-leading graphene supercapacitor experience, including spinoff company SupraG. Monash also has active research programs in magnesium- and aluminium-based batteries, and hosts the Energy Program of the ARC Centre of Excellence for Electromaterials Science (ACES), which is developing chemical energy storage technologies including nitrogen reduction to ammonia.

> **The Queensland University of Technology** has a microgrid facility for trialling energy storage technologies (Queensland University of Technology, 2016), and have active research in graphene supercapacitors, and optimisation of metal-air and lithium metal phosphate batteries.

> **The University of Adelaide**'s Australian Energy Storage Knowledge Bank is an ARENA-funded energy storage research hub that trials energy storage technologies, with a focus on system design and integration.

> **The University of Melbourne**'s Melbourne Energy Institute conducts research into pumped hydro, hydrogen storage, and liquid air energy storage.

> **The University of New South Wales**' Material Energy Research Laboratory in Nanoscale (MERLin) is currently researching metal-air batteries, sodium-based batteries, and hydrogen storage, including the EnergyH Project. This is a crowd-funded project to support research and commercialisation of hydrogen-based energy technologies. The Vanadium Redox Flow Battery was also invented at University of New South Wales (UNSW) by Emeritus Professor Maria Skyllas-Kazacos FTSE.

> **The University of Queensland**'s researchers investigate energy storage through the application of a RedFlow zinc bromine flow battery to their UQ Solar array, including systems integration and monitoring (The University of Queensland, 2016).

> **The University of Technology Sydney**'s Centre for Clean Energy Technology focuses research efforts on advanced battery technologies, supercapacitors, hydrogen production and storage, fuel cells, and graphene applications for energy storage.

> **The University of Wollongong**'s Institute for Superconducting and Electronic Materials is building a pilot-scale sodium battery production facility to develop battery packs for testing in residential and industrial settings (University of Wollongong, 2016). They also have active research in lithium-ion air batteries, potassium-ion batteries, hydrogen storage, and anode materials.

2.2. Success stories

There have been several successful energy storage research and development outcomes in Australia, especially where there is collaboration between research groups and industry. The UltraBattery is a well-known example of this. The CSIRO-developed hybrid battery combines a supercapacitor and lead-acid battery in a single unit, and has been successfully commercialised by Australian company Ecoult. CSIRO has also ensured Australia is a leader in supercapacitor technology through a project with Plessey Ducon Pty Ltd that commenced in 1992. This resulted in the start-up company CAP-XX Pty Ltd, which developed and commercialised the world's most advanced high power small form factor supercapacitors (CSIROpedia, 2005).

In early 2016, UQ signed a commercialisation agreement with Australian energy storage company Redback Technologies (Swan, 2016). This allows Redback direct access to researchers and developing energy storage technologies.

Professor Dan Li and his research team at Monash University have developed graphene super-capacitors that allow a three-fold increase in energy storage capacity. These are being commercialised by Monash spinout company SupraG Energy (Monash University, 2016).

Deakin University and CSIRO's BatTRI-Hub is an example of research institutes pooling their resources to facilitate collaboration and develop research focus. The Hub is a world-class research centre that was created to develop the next generation of battery technologies, with an aim to grow the battery manufacturing industry in Australia (Deakin Research, 2016).

Spinout company Aquahydrex was formed in 2011 to develop a technology that uses solar energy to produce hydrogen from seawater from the Australian Centre of Excellence for Electromaterials Science (ACES) at University of Wollongong and Monash University (Goldie, 2012).

EnSync Energy Systems (formerly known as ZBB Technologies) and Murdoch University collaborated to develop the zinc-bromine battery, which has been commercialised by Redflow in Australia and ZBB in the US (Australian Academy of Science, 2016).

2.3. Challenges

Consultations identified several challenges that should be overcome in order to promote further success in energy storage research and development in Australia. Greater collaboration between researchers and industry needs to be facilitated, through initiatives such as new models for intellectual property (IP) ownership and flexibility of business models to incorporate new technologies. It is also reported that the strategic focus of energy storage research would benefit from the establishment of domestic and international sector hubs to facilitate collaboration. Deakin and CSIRO's BatTRI-Hub is a step toward this.

Systemic issues in research-industry collaboration (not specific to energy storage) were also identified as a challenge for commercialisation. An example of this is the vanadium redox flow battery. This technology was invented by Professor Maria Skyllas-Kazacos at UNSW in 1985 (Skyllas-Kazacos, Rychick, & Robins, 1988), but subsequently manufactured and commercialised in China, Germany, Japan, United Kingdom, and the United States because there was limited interest in commercialising the technology in Australia. These issues are being targeted via Australian Government initiatives such as the National Innovation and Science Agenda (NISA) (Commonwealth of Australia, 2015).

Analysis of the optimum size, location, and operation of energy storage, as applied to Australia's energy grids, is required to improve cost effectiveness of these systems (Australian Academy of Science, 2016). This includes improving energy efficiency transfer into and from storage, which a portion of the research effort is already working towards.

A key challenge is a lack of funding in this area to take developments to full commercial potential. The Accelerating Commercialisation grants, Cooperative Research Centre Project grants, and ARENA-based schemes provide funding to assist enterprises to further develop technologies; however, failure rates remain high for companies transitioning from research to the stage of development that attracts commercial involvement to allow access to these schemes. The Small Business Innovation Research program in the US is a mechanism that specifically identifies and targets this gap by encouraging small businesses to address government challenges. As part of the National Innovation and Science Agenda, Australia is piloting a similar scheme as the Business Research and Innovation Initiative (Commonwealth of Australia, 2016a).

A researcher uses a manual draw-down coating process to prepare small-scale electrode foils at BatTRI-Hub. CREDIT: DEAKIN UNIVERSITY

2.4. Emerging energy storage technologies

Research is very active in the energy storage field. Current trends include hydrogen and ammonia, optimising concentrated solar thermal storage, improving existing batteries, and developing new battery technologies. Some of the most promising developments in energy storage technologies are discussed below. Where possible, technology readiness levels (TRL) are estimated. The TRL system is a globally accepted index for tracking the development of technologies from blue sky research to demonstration. The TRL levels are described in Table 3, which was adapted from ARENA (2014).

2.4.1. Renewable Fuels

Hydrogen can be sustainably produced by using renewably generated electricity to split water (a process referred to as electrolysis). This is viewed as a significant national export opportunity due to high insolation in Australia. There is huge potential for renewable hydrogen generation in remote, high insolation areas of Australia. In a carbon-reducing economy, there is a demand for renewably sourced hydrogen in countries with limited renewable resources such as South Korea and Japan (Cross-ministerial Strategic Innovation Promotion Program, 2015). These significant potential markets will drive export opportunities for Australia. This is discussed further in Section 3.3.3. Importantly, this will create opportunities for new technologies to more efficiently produce, store, and utilise hydrogen and ammonia. Hydrogen production using renewable energy can also be used to absorb excess power production from renewables when demand in the system is low.

Hydrogen can be converted to ammonia for transport to increase safety and reduce its volume. The ammonia can then be converted back to hydrogen (ammonia cracking) after transport for use

Table 3 Technology Readiness Levels for renewable energy technologies

Technology Readiness Level	Summary
1	Basic principles observed and reported: Transition from scientific research to applied research. Essential characteristics and behaviours of systems and architectures. Descriptive tools are mathematical formulations or algorithms.
2	Technology concept and/or application formulated: Applied research. Theory and scientific principles are focused on a specific application area to define the concept. Characteristics of the application are described. Analytical tools are developed for simulation or analysis of the application.
3	Analytical and experimental critical function and/or characteristic proof of concept: Proof of concept validation. Active research and development is initiated with analytical and laboratory studies. Demonstration of technical feasibility using breadboard or brassboard implementations that are exercised with representative data.
4	Component/subsystem validation in laboratory environment: Standalone prototyping implementation and test. Integration of technology elements. Experiments with full-scale problems or data sets.
5	System/subsystem/component validation in relevant environment: Thorough testing of prototyping in representative environment. Basic technology elements integrated with reasonably realistic supporting elements. Prototyping implementations conform to target environment and interfaces.
6	System/subsystem model or prototyping demonstration in a relevant end-to-end environment: Prototyping implementations on full-scale realistic problems. Partially integrated with existing systems. Limited documentation available. Engineering feasibility fully demonstrated in actual system application.
7	System prototyping demonstration in an operational environment: System prototyping demonstration in operational environment. System is at or near scale of the operational system with most functions available for demonstration and test. Well integrated with collateral and ancillary systems. Limited documentation available.
8	Actual system completed and qualified through test and demonstration in an operational environment: End of system development. Fully integrated with operational hardware and software systems. Most user documentation, training documentation, and maintenance documentation completed. All functionality tested in simulated and operational scenarios. Verification and Validation (V&V) completed.
9	Actual system proven through successful operations: Fully integrated with operational hardware/software systems. Actual system has been thoroughly demonstrated and tested in its operational environment. All documentation completed. Successful operational experience. Sustaining engineering support in place.

in hydrogen fuel cells and electric vehicles. Ammonia synthesis and cracking are established processes, but have low efficiency and high cost. High efficiency electrochemical approaches to ammonia synthesis are under development at Monash University and CSIRO. Ammonia transportation by ship or pipeline is also well established.

A significant research effort is currently taking place in Australia and globally to improve the efficiency and cost of the hydrogen synthesis and transport process. In Australia, research is being conducted by numerous groups, including the Melbourne Energy Institute (University of Melbourne), ANU, CSIRO, Curtin University, Monash University, University of New South Wales, Australian Solar Thermal Research Initiative, Aquahydrex, Renewable Hydrogen, BOC, Siemens, Yara, and Hyundai.

One solution to the efficiency and cost issues surrounding ammonia cracking is direct combustion of ammonia, rather than reforming to hydrogen (Cross-ministerial Strategic Innovation Promotion Program, 2015). This requires the development of ammonia direct combustion technology, such as an ammonia fuel cell, which is being investigated both nationally (for example at Monash University) and globally.

2.4.2. Next Generation Batteries

Many organisations are working to improve on current battery designs or to create innovative battery solutions. Australia is competing in this area with well-funded international energy storage support programs such as the United States' Advanced Research Projects Agency-Energy (ARPA-E) Program, and the German Government's energy transition program. However, as outlined above, a number of Australian research groups are performing above world standard in this area, which could be capitalised on with strategic investments and prioritisation.

Lithium-ion is currently the most popular battery chemistry, but it is likely that over time different batteries will be used for different applications depending on technology development and market forces. There will likely be market opportunities for technologies that are cheaper, safer, more sustainable, and/or have better performance characteristics than current energy storage technologies.

Australia is well equipped to study and develop next generation batteries using facilities such as ANSTO's Australian Centre for Neutron Scattering, CSIRO's Centre for Hybrid Energy Systems and Stored Energy Integration Facility (CSIRO, 2016b), and the Deakin-CSIRO BatTRI-Hub.

In addition to working to improve current battery technologies, research is focusing on the use of non-lithium metals such as aluminium, magnesium, potassium and calcium. In Australia, many research groups are active in this area. Emerging technologies include metal-air batteries, sodium-based batteries, advanced lithium batteries, and next-generation flow batteries. Ionic liquid and solid state technologies appear to hold particular promise for next generation batteries.

IONIC LIQUID TECHNOLOGIES

Ionic liquids can be used as electrolytes in batteries, and have the benefit of having low vapour pressure, and being non-flammable (MacFarlane et al., 2016). There is significant research activity into ionic liquid technologies in Australia, including by start-up Gelion, who are developing a gel-based Zn-Br technology from IP developed at University of Sydney (TRL 4-5).

Researchers at Monash University, Deakin University and CSIRO are established international leaders in the ionic liquids field as applied to next generation battery technologies including Li metal, Na metal, Zn metal and Mg metal. This work has been funded through several Australian Research Council Discovery and Linkage Projects, as well as industry-funded projects with international companies including Toyota, Honda, Evonik, and Cytec. The University of Wollongong has an Australian Research Council Discovery Project currently researching lithium-ion air batteries with ionic liquid-based electrolytes (TRL 3-4). In the United States, ARPA-E-funded company Fluidic Energy has developed a zinc-air battery (TRL 9) using ionic liquids that is fully recyclable and contains no toxic elements (Anderson, 2016).

SOLID-STATE BATTERIES

Solid-state batteries use a solid electrolyte. This has the potential to improve performance, increase cycle life and remove the flammability risks posed by some current battery chemistries. Massachusetts Institute of Technology and Samsung Advanced Institute of Technology in the United States are developing a solid-state lithium battery (TRL 1-2) (Wang et al., 2015). First generation Lithium metal solid-state batteries (TRL 9) based on solid polymer electrolytes are currently commercially available through Bolloré group (Blue Solutions). These have seen deployment in vehicles (Jolly, 2015) and are being used in high-temperature climates such as Africa for stationary energy storage because of the increased safety and stability compared with Li-ion.

Australian researchers have established research strengths in polymer chemistry, including polymer electrolytes that could contribute to next generation solid state batteries. Deakin University's Institute for Frontier Materials has a collaborative project with the Indian Institute of Science Bangalore and the Indian Institute of Technology Bombay, sponsored by the Commonwealth Government's Australia-India Strategic Research Fund, to develop solid-state batteries based on polymer electrolytes and composites (Invenio, 2016).

2.4.3. Advanced Thermal Energy Storage Systems

Australian companies Graphite Energy and 1414 Degrees have developed thermal energy storage systems. 1414 Degrees is developing (TRL 6-7) a system that stores energy in molten silicon, building on IP developed by CSIRO (1414 Degrees, 2016). This can then be used to supply industrial-grade heat and/or generate electricity using a heat engine or gas turbine. The round trip efficiencies of thermal energy systems when used for electricity storage and generation are much lower than batteries or pumped hydro energy storage systems. For example, the 1414 Degrees prototype achieved 31 per cent efficiency for electricity (1414

Degrees, 2017). However, they are expected to be significantly cheaper than batteries, are highly scalable in terms of capacity and power, and do not have the location constraints of pumped hydro storage.

Purely thermal energy storage is outside of the scope of this study, however it is important to note that improved thermal energy management in domestic, commercial and industrial applications has great potential to improve energy productivity and reduce greenhouse gas emissions from the broader energy sector.

2.4.4. Supercritical CO_2 turbines

Although supercritical CO_2 turbines are not an energy storage technology, they were identified by multiple stakeholders as having great potential to improve the efficiency and economics of CSP systems, which currently rely on traditional steam turbines. An ARENA-funded project run by the CSIRO in collaboration with Sandia National Laboratories, National Renewable Energy Laboratory, University of Sydney, and Queensland University of Technology is currently investigating the performance of supercritical CO_2 turbines for use with combined with CSP (ARENA, 2012).

2.5. Key Findings

Finding 1 Australia's research and development performance in energy storage technologies is world class and is regarded as a great national strength. However, if Australia is to maximally benefit from this strength then strategic focus and enhanced collaboration with national and international companies is required.

Finding 2 Australia is not lacking in locally developed energy storage technologies but, as in other fields in Australia, their commercialisation track record within Australia is poor and the local industry is small.

3. Energy Storage Industry Opportunities

3.1. Raw Resources and Beneficiation

Australia has the opportunity to contribute to the supply chain for many energy storage technologies due to the relative abundance of natural resources in this country, compared with other countries. The future demand for raw materials for energy storage will be dependent on which technologies are most successful in end-use markets in the coming decades. A range of mineral resources are required for the production of energy storage technologies, including lead, nickel, cadmium, lithium, cobalt, graphite, manganese, phosphorus, magnesium, sodium, zinc, bromide, aluminium, iron, potassium, and vanadium. Of these, Australia contains the world's largest Economic Demonstrated Resources (EDR[1]) of iron ore, lead, nickel, and zinc (Britt, 2016). Additionally, Australia's bauxite (aluminium oxide), cobalt, lithium, magnesite (magnesium ore), manganese ore, tin, and vanadium EDR all rank in the top five worldwide (Britt, 2016). Secondary processing of raw materials has been declining in Australia, with one of the major contributing factors being the high cost of energy. As a result, raw materials required to manufacture energy storage systems are likely to be imported and high cost, making manufacturing in Australia uncompetitive. Specific pricing or policy structures could reduce the costs of energy-related commodities to support the growth of manufacturing of new battery storage technologies in Australia. Pumped hydro energy storage does not rely on specific minerals, but instead requires specific geographical features. The resources relevant to various energy storage technologies are outlined below.

3.1.1. Existing mineral resource opportunities

The following raw resources are those currently being used in the energy storage market.

LITHIUM

At present, the most significant raw material opportunity for Australia is in lithium. Lithium-ion batteries are currently one of the most popular energy storage technologies, especially for distributed and behind-the-meter energy storage markets (Navigant Research, 2016b). Tesla's intention to significantly increase production to 35 GWh/year of lithium-ion battery cells by 2018 (Tesla, 2017) is but one example demonstrating the increasing demand for lithium over the coming years. Kingsnorth (2015) estimated 10–15 per cent average annual growth in lithium demand for batteries between 2015 and 2025, contributing to a total lithium demand of 350–400ktpa in 2025 (up from 150–170ktpa in 2015).

Australia's lithium deposits account for just over 11 per cent of the world's EDR, ranking fourth globally after Chile, China, and Argentina, and Australia is currently the biggest single supplier of lithium (Britt, 2016). The world's largest and highest grade spodumene ($LiAlSi_2O_6$) deposit, Greenbushes, is located in Western Australia and hosts 82 per cent of Australia's lithium EDR (Britt, 2016). This mine is operated by Australian mining company Talison Lithium.

Lithium Australia has developed a new lithium process, Sileach, which is predicted to reduce the cost of processing lithium from spodumene and recycled lithium (Griffin, 2017). The process also has the potential to reduce by-products and waste, and has low energy consumption. The Sileach process is expected to be operating at a commercial scale by 2018 (Griffin, 2017).

A new lithium plant to be installed in Kwinana, Western Australia will process concentrate from the Greenbushes mine, commencing production in late 2018 (Tianqi Lithium, 2016). This will be exported primarily for use in lithium battery manufacturing. The Kwinana lithium production plant is owned by Chinese company Tianqi Lithium, but is expected to create up to 615 jobs locally (Tianqi Lithium, 2016).

An additional lithium chemical plant is currently undergoing commercial and technical feasibility assessment by Australian companies Neometals Ltd and Mineral Resources Ltd (Neometals, 2016). The plant would be located in the Eastern Goldfields of Western Australia, and would use lithium from the Mt Marion mine to produce lithium hydroxide for use in battery cathode production (Neometals, 2016).

LEAD

Lead is required for use in lead acid batteries. Australia has the largest lead EDR, accounting for 40 per cent of world resources, and is the second largest producer of lead after China (US Geological Survey, 2017). There are currently 18 lead mines operating throughout Australia (Britt, 2016). These include world-class deposits such as the Broken Hill lead-zinc-silver mine operated by Australian company Perilya, and the Cannington mine in northern Queensland, which is operated by Australian company South32 and is one of the largest producers of lead in the world.

Smelting and refining of lead takes place at Port Pirie, South Australia, operated by Swiss company Nyrstar. This plant is currently being upgraded to an advanced multi metals processing

1 EDR includes Joint Ore Reserves Committee Proved and Probable Ore Reserves as stated in company annual reports and reports to the Australian Securities Exchange, as well as indicated and measured resources.

and recovering facility, with support from the South Australian Government (Nyrstar, 2015).

COBALT

Cobalt is commonly used in lithium-ion battery cathodes. In 2015 and 2016 China was the world's largest consumer of cobalt, with almost 80 per cent of its consumption in the energy storage industry (US Geological Survey, 2017). This presents a significant opportunity for Australia, as the national cobalt resource is 15 per cent of the world's resource, second only to Congo (Britt, 2016; US Geological Survey, 2017).

Australian cobalt usually occurs in association with nickel and is mostly mined in Western Australia. Emerging mining company Cobalt Blue, a subsidiary of Broken Hill Prospecting, plans to capitalise on the demand for cobalt in the energy storage industry by developing one of the world's largest currently undeveloped cobalt resources, the Thackaringa Cobalt Project near Broken Hill in NSW (Macdonald-Smith, 2017).

NICKEL

Nickel is used in nickel-based batteries, as well as some lithium battery chemistries. Australia has the largest nickel EDR, accounting for 24 per cent of the world's total resource, and is ranked second for nickel production after The Philippines (US Geological Survey, 2017). Australia's nickel resources are contained in both primary and secondary weathered mineral resources, the majority of which are found in Western Australia (Britt, 2016). BHP Billiton subsidiary Nickel West operates two of these nickel mines, as well as the Kalgoorlie nickel smelter, Kwinana nickel refinery, and Kambalda nickel concentrator (BHP Billiton, 2005).

ZINC

Zinc is used in flow batteries, such as Redflow's zinc bromide battery technology, and could be used in metal-air batteries. Australia is the second highest producer of zinc, and has the largest zinc EDR in the world at 31 per cent (Britt, 2016). Queensland hosts 56 per cent of the nation's zinc EDR, primarily in the Mount Isa Basin (Britt, 2016). Australian companies mining zinc include Perilya and South32.

Zinc smelters are located in Hobart in Tasmania, Port Pirie in South Australia, and Townsville in Queensland. These are operated by Swiss company Nyrstar and Korean company Sun Metals. Nyrstar's Hobart plant is currently being upgraded to treat more complex concentrates, with financial support from the Tasmanian Government (Nyrstar, 2015).

3.1.2. Potential mineral resources opportunities

The raw resources discussed below have been identified as essential for emerging energy storage technologies, and could be opportunities for Australia depending on which storage technologies are commercialised.

VANADIUM

Vanadium can be used in redox flow batteries. Australia's vanadium EDR ranks fourth in the world, but there is currently no vanadium being produced in the country (Britt, 2016). Australian company Australian Vanadium Ltd is currently evaluating their tenements, including the Gabanintha deposit in Western Australia, with plans to leverage opportunities within the emerging battery storage market. Australian Vanadium has established a pilot vanadium electrolyte production plant, and has aspirations for vertically integrated operations (Australian Vanadium, 2016).

MANGANESE

Manganese can be used in lithium manganese oxide, and lithium nickel manganese cobalt oxide batteries. Australia's manganese EDR is the world's third largest behind South Africa and Ukraine (US Geological Survey, 2017). These resources are located in the Northern Territory and Western Australia (Britt, 2016), including the South32-owned Groote Eylandt manganese mine. A decrease in the manganese price led to the suspension of operations at manganese mines in Bootu Creek in the Northern Territory and Woodie Woodie in Western Australia in late 2015 and early 2016 respectively. Groote Eylandt manganese ore is shipped to South32's Tasmanian Electro Metallurgical Company manganese alloy plant for beneficiation.

Australian mining equipment, technology, and services (METS) company Mesa Minerals Limited has developed and is attempting to commercialise improved manganese processing technologies suitable for producing "consistently high purity, low cost electrolytic manganese dioxide suitable for use in the manufacture of both alkaline and lithium-ion batteries" (Mesa Minerals Limited, 2017).

ALUMINIUM

Aluminium is required for aluminium-air batteries and as high purity foil for current collectors in lithium-ion batteries. Australia has the second largest bauxite (aluminium ore) EDR in the world after the Republic of Guinea (US Geological Survey, 2017). In 2015, Australia was the leading producer of bauxite, the second largest producer of alumina, and the sixth largest producer of aluminium (Britt, 2016). Most of Australia's bauxite resources are located in Cape York in Queensland, Gove in the Northern Territory, and the Darling Range in Western Australia (Britt, 2016).

Historically, Australia has been involved in many aspects of the aluminium industry, including refining, smelting, and semi-fabrication. However, some of these processing operations have become economically unviable in recent years due to operation costs. This led to the closure of the Kurri Kurri (New South Wales) and Point Henry (Victoria) aluminium smelters, and the Gove alumina refinery (Northern Territory) between 2012 and 2014. As a result, several new operations are now direct-shipping bauxite overseas.

IRON

Iron is required for iron-air and nickel-iron batteries. Australia has the largest iron ore EDR in the world, with 28 per cent of the global total (US Geological Survey, 2017). Most of this (89 per cent) is located in the Pilbara region of Western Australia (Britt, 2016). In addition, Australia also has several large magnetite deposits which are mined for contained iron (Britt, 2016). The largest companies producing iron ore in Australia are BHP Billiton, Fortescue Metals and Rio Tinto.

MAGNESIUM

Certain chemistries of advanced lithium ion and metal air batteries require magnesium. Australia has the fifth largest EDR of magnesite (magnesium ore) in the world, but is only a minor magnesium producer (US Geological Survey, 2017). Magnesium is produced at Belgian company Sibelco's Queensland mining and processing operations and at Causmag International's (owned by Indian company Excel Colour and Frits Ltd.) Thuddungra mine in New South Wales. Queensland hosts the majority (56 per cent) of Australia's inferred magnesite resource, followed by South Australia (35 per cent), and Tasmania (5 per cent).

PHOSPHOROUS

Phosphorus can be used in anodes for advanced lithium-ion batteries. Australia has less than 2 per cent of the world's EDR of phosphate rock (phosphorate and guano; Britt, 2016). The Georgina Basin in Queensland and the Northern Territory contains the majority of Australia's phosphate rock and 90 per cent of contained P_2O_5 (Britt, 2016). Production is also taking place on Christmas Island and in South Australia. The Phosphate Hill mine in western Queensland is the largest source of phosphate rock in Australia. This mine is operated by Incitec Pivot Limited, which uses the phosphate to make fertiliser.

POTASSIUM

Potassium can be used in metal-air batteries or as potassium nitrate for use in concentrated solar thermal energy storage. Canada has the largest potassium resource (US Geological Survey, 2017). Australia has only minor potassium in mineral form (Britt, 2016), which is currently being explored mainly in Western Australia by Australian companies such as Reward Minerals, Rum Jungle Resources, Salt Lake Potash Ltd, and Parkway Minerals. However, there are large reserves of potassium associated with solar salt production from sea water and brines (e.g. Rio Tinto, 2017). This potassium is treated as a waste by-product because the costs of recovery are not currently economic. A change in the potassium value chain could allow Australia to utilise the solar salt resource and become a large potassium producer using flow sheets that are used in solar salt fields in the United States and China.

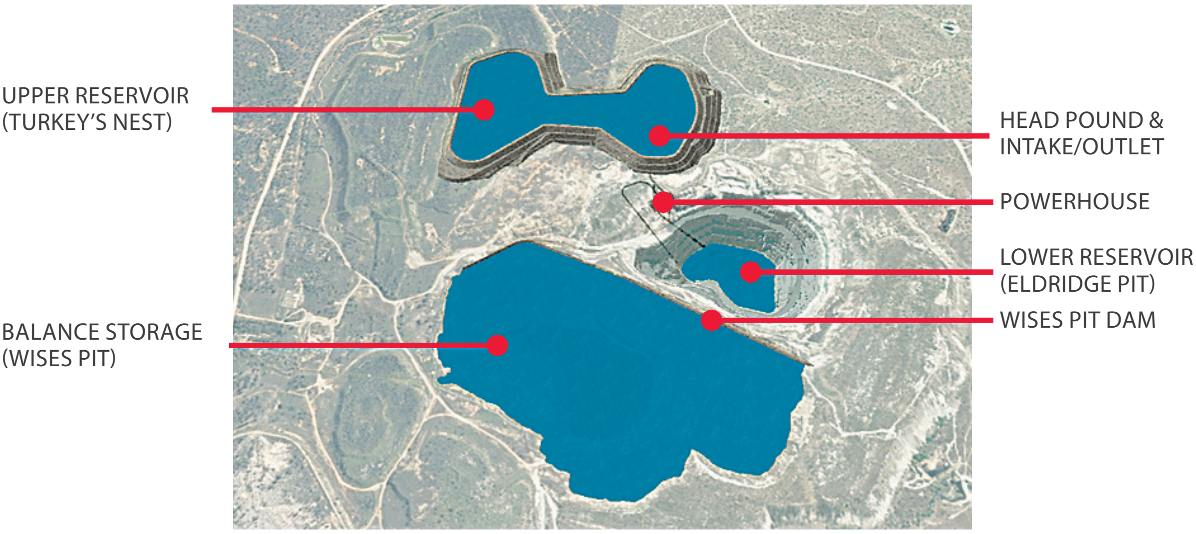
GRAPHITE

Graphite has the potential to be used for thermal energy storage, and in graphene-based batteries. The leading producers of graphite are China, India, and Brazil (US Geological Survey, 2017). Turkey has the largest graphite resource, followed by the United States (US Geological Survey, 2017). Australia's EDR of graphite is relatively minor compared with other nations, and is located in Western Australia and South Australia (McKay et al., 2013). There are no current graphite mining operations in Australia.

3.1.3. Geographical resources

The viability of pumped hydro energy storage is strongly dependent on locating sites with suitable geographic characteristics, including upper and lower reservoirs that have an appropriate elevation difference (Hearps et al., 2014). These can be river-based, or off-river at locations such as hilly regions, along coastlines, or even at decommissioned mine sites (Blakers, 2015). Land use and water requirements for pumped hydro systems have potential to impact on the social licence for the technology if environmental and water use impacts are not appropriately managed.

Several locations in Australia have already been identified as suitable for pumped hydro energy storage, in addition to the three operating pumped hydro sites in the Snowy Mountains and Queensland. These include the Portland area in western Victoria (Hessami & Bowly, 2011), central Tasmania, the Araluen Valley in New South Wales (Blakers, Pittock, Talent, & Markham, 2010), Borumba Dam and Mount Byron in Queensland, and the Eyre Peninsula in South Australia (Worley Parsons, 2011). The ARENA-funded Atlas of Pumped Hydro Energy Storage study being



Genex Power's proposed 250MW PHES project at Kidston, Queensland. CREDIT: GENEX POWER undertaken by ANU, ElectraNet, and VTara Energy Group aims to identify more potential sites for off-river pumped hydro projects (Vorrath, 2016).

The Kidston Pumped Storage Hydro Project (250 MW) is an example of an off-river pumped hydro site. This project utilises the disused Kidston Gold Mine in northern Queensland, which has large existing pits suitable for pumped hydro (Genex Power, 2016). Construction of the project is expected to commence in late 2017, pending financial arrangements. Energy Australia has also proposed a coastal pumped hydro project for South Australia that would utilise the ocean as its lower reservoir (Reid, 2017), which would avoid the potential environmental and social challenges of its water dependency.

3.1.4. Key Findings

Finding 3 Australia has world-scale resources for many of today's and tomorrow's energy storage technologies, and is well placed to participate in national and global supply chains for raw materials. However, value adding by beneficiation of minerals has been declining in Australia, due in part to the high cost of energy required to power the processing plants.

> Australia is currently the largest single producer of lithium and is well placed to play a significant role in the lithium supply chain.

> Adoption of enhanced exploration, extraction, and processing technologies and methodologies developed by Australia's world-class METS sector may help Australia capitalise on these opportunities.

3.2. Manufacturing

Australia has limited potential to take a leading role in energy storage manufacturing for current technologies. The energy storage sector is developing at a rapid pace globally and attempting to compete against global manufacturers in established technologies would pose great challenges. Regardless, Australia should look for opportunities in manufacturing where it has competitive strengths. Stakeholders saw potential industry opportunities in the creation of high-value, low-volume energy storage solutions for niche applications, and technologies and software for system integration and control.

3.2.1. Local energy storage manufacturing

Australia has well-documented challenges and a fraught history in manufacturing of high-volume products. The 2016 Global Manufacturing Competitiveness Index shows Australia's manufacturing competitiveness ranking declined from 16th to 21st over 3 years (Deloitte, 2016). This decline has been attributed to issues such as high labour and energy costs, distance from key markets, and lack of access to growth capital. These challenges are just as relevant to the manufacture of energy storage technologies.

Australia is not expected to compete with international manufacturers on any battery technology that has already been commercialised and manufactured at scale. It will be very difficult to compete with established battery manufacturers, such as Panasonic (Japan), Samsung SDI (Korea), LG Chem (Korea) and ATL (China) who together dominate global Li-ion production.

Despite the challenges, there is still some interest in developing a local battery manufacturing sector. For example, Australian Vanadium and its subsidiary, VSun Energy, have expressed an intention to develop a vertically integrated Vanadium Flow Battery operation in Australia. If successful, they would mine vanadium and produce vanadium electrolyte for use in their own batteries. This project is currently in a capital raising phase.

Manufacturing of high-value, low-volume energy storage solutions is considered by some stakeholders to be a potential opportunity for Australian industry. CSIRO's Advanced Manufacturing Roadmap also recognised customised high-margin solutions such as these as a growth opportunity for Australian businesses (CSIRO, 2016a). The only battery manufacturing occurring in Australia at the time of writing is by PMB Defence in South Australia. PMB Defence develop and manufacture batteries for submarines, including the Collins Class battery system (PMB Defence, 2017). Other high-margin opportunities could include customised solutions for niche applications or novel technology developments commercialised from Australian IP. Technologies such as the CSP technology developed and demonstrated by Vast Solar (Vast Solar, 2016) and the silicon-based thermal energy storage system developed by 1414 Degrees for industrial and grid applications. 1414 Degrees expect that their systems could be manufactured in Australia as it will be a low-volume, high-value product with a niche market due to its large storage capacity (testing and design of 10MWh and 200MWh models is underway) and ability to provide both heat and electricity (1414 Degrees, 2017). 1414 degrees intends to supply customised energy storage solutions through partnership arrangements so that they can retain ownership and control of their systems. Developing energy storage solutions that address issues specific to Australian conditions may have potential markets in the electricity grids of developing nations (e.g. high-temperature environments, fringe-of-grid or off-grid systems).

This lack of confidence of stakeholders in finding commercial manufacturing success reflects a general attitude across many knowledge-intensive industry sectors in Australia. Australia has a well-documented weakness in translating its research and development (R&D) and IP strengths into commercial applications. The most recent audit of the innovation system has found that there is no inherent or fundamental reason why this should be the case (Innovation and Science Australia, 2016), but given the historical systemic difficulty in this area, a suite of policy and cultural changes will be required to improve Australia's performance. Provided it is supported by continued focus from government, the National Innovation and Science Agenda is anticipated to help address some of these issues. Stakeholders viewed significant local job creation in energy storage manufacturing as unlikely without either government support or international partnerships. It should be noted that strategic investment by governments in other countries has been critical in supporting nascent manufacturing industries, and similar initiatives in Australia could help improve the ability of Australian companies to commercialise more of their IP domestically.

Manufacturing globally is moving from being highly labour dependent to highly intellectual property (IP) and capital dependent, driven by increasing automation. Energy storage technologies are no different, so aside from its geographic isolation from key markets the key issues for Australia are no longer high labour costs but rather access to IP and sufficient capital. Given Australia's strength in knowledge creation, access to capital remains a key challenge for the manufacturing industry. This issue and other enabling conditions are further explored in section 4.

3.2.2. Participation in global value chains

Although there is little stakeholder confidence in the ability of Australia to develop a battery manufacturing sector, Australian companies have demonstrated some success in commercialising Australian IP through international partnerships. Ecoult has chosen to partner with international manufacturing companies in key markets including the US and India to produce the CSIRO-developed UltraBattery (an advanced lead acid battery technology) (ARENA, 2017b). A representative of an Australian startup aiming to commercialise new battery IP expressed that local manufacturing would not make economic sense given their intention for large-scale manufacturing. In a further example, RedFlow has commercialised a zinc-bromide flow battery technology. However, despite basing their R&D operation in Australia, they outsource the manufacturing of their products to a global company to allow for scalable manufacturing and the ability to have greater proximity to key markets (Redflow, 2017).

Identifying opportunities in global energy storage value chains will be essential for most companies in the Australian energy storage industry. Incremental improvements on established energy storage technologies are unlikely to offer local manufacturing opportunities, however Australian companies may be able to contribute technologies and IP to different components of energy storage systems. As an example, Australian company Nano Nouvelle has developed a tin anode for lithium ion batteries that uses nanotechnology to improve battery performance. A key design goal for the electrode was for it to be compatible with existing battery technologies and manufacturing processes to make it easy for manufacturers to adopt the technology (Nano-Nouvelle, 2016).

3.2.3. Technology for energy storage integration and control

Energy storage may present opportunities for Australian manufacturing outside of the manufacture of the storage technologies themselves. Many stakeholders suggested that Australia has greater competitive advantages and potential for manufacturing success in the hardware and software systems that will be required for smart management and integration of energy storage systems.

Developing technology solutions that allow for the integration and coordination of energy storage and other distributed energy resources is expected to be a key opportunity for Australian industry and researchers. Australia is widely viewed as a test bed for the impacts and benefits for distributed energy storage due to its rapid energy storage market growth – 356 per cent growth between 2014 and 2015 (China Energy Storage Alliance, 2016).

Companies such as Reposit, GreenSync, Redback, Selectronic, and Evergen are leading the development and deployment of smart technologies for the integration and control of distributed energy systems (e.g. solar and storage) in Australia. The technologies developed by these companies typically allow greater transparency and control of energy and storage use (e.g. Evergen, 2016; GreenSync, 2016; Reposit, 2017). The application of modern information and communications technologies including cloud computing, machine learning, and the internet-of-things is allowing the creation of smart systems that can optimise customers' energy use and provide benefits to the electricity grid by reacting to price signals from energy utilities.

This area has received some support through various government programs. Reposit Power was awarded an Australian Government commercialisation grant, which assisted in development and commercialisation of their product (Dealflow, 2016). In early 2017, the Clean Energy Finance Corporation announced investment of $5 million through their Clean Energy Innovation Fund for GreenSync to develop smart grid technology (Clean Energy Finance Corporation, 2017). AGL have a strategic agreement with Sunverge Energy, a US-based developer of software solutions for aggregation of distributed energy resources (including storage) into virtual power plant systems. Both AGL and ARENA are investors in Sunverge Energy (AGL, 2016a).

The energy storage market is competitive, and although systems integration and design has been identified as a significant opportunity for Australia, the industry will need to act quickly to compete with international companies such as AutoGrid and Sunverge Energy in the United States, and Sonnen in Germany who are developing software and smart control systems for distributed energy resources. Global technology companies including ABB, GE and Siemens are also competing in this space.

3.2.4. Key Findings

Finding 4 High-volume manufacturing of existing energy storage technologies is not expected to be undertaken in Australia. Nonetheless, Australian companies are commercialising their energy storage IP through, and supplying products to, international and global partnerships. Identifying opportunities to participate in global energy storage value chains will be important for the growth and success of Australian companies.

Finding 5 Australia has significant leadership and market opportunities in the design of software and hardware for energy storage management, integration and aggregation, but will face competition from international companies.

3.3. Deployment

There are many potential services and applications of energy storage technologies in Australia's electricity system. This section of the report seeks to provide insight into the key opportunities and challenges for energy storage deployment that arose from the consultations.

Energy storage is recognised as a key enabling component of future energy grids with high penetrations of renewable energy (Australian Academy of Science, 2016; IRENA, 2017). The deployment of energy storage systems within Australia's energy sector offers significant scope for economic and environmental benefit. Companies that retail and install energy storage solutions (usually batteries coupled with solar PV systems) for residential and commercial customers are an early example of industry growth in the energy storage sector. Another key growth area is in off-grid deployments, where high costs of diesel generation are providing an economic incentive to install solar PV and energy storage solutions. There is a growing appreciation of the importance of grid-scale energy storage deployments to support system reliability and security.

3.3.1. Distributed energy storage and system integration

Due to their high efficiencies and relatively small size, batteries are expected to remain the dominant technology for distributed and behind-the-meter energy storage solutions. Lithium-ion batteries are the most popular technology for these markets (Navigant Research, 2016b). Domestic and off-grid markets are currently considered to be the most attractive markets for battery installers in Australia.

Australia has a growing domestic battery market due predominantly to the high penetration of solar PV and the end of a number of feed in tariff (FiT) schemes. The cessation of FiT schemes in New South Wales, South Australia and Victoria will provide a financial incentive for solar PV owners to invest in household energy storage. Conversely, the generous and long-lasting FiT schemes in other jurisdictions can provide existing PV owners with a disincentive for uptake of domestic storage. In these jurisdictions (including ACT and Queensland) energy storage uptake is expected to be driven by rising retail electricity costs and a greater consumer interest in self-reliance and energy security.

The Essential Services Commission in Victoria has conducted analysis of the electricity network to assess the energy and network value of distributed generation. The research indicated that distributed energy generation can provide value to the network by alleviating network congestion. Furthermore, the network value can be optimised with the addition of storage and smart control systems (Essential Services Commission, 2016).

Australia is seeing rapid uptake of energy storage systems and is expected to have one of the highest penetrations of energy storage globally (China Energy Storage Alliance, 2016; IHS Markit, 2016). It also has weakly connected networks spread over vast distances. Because of these factors, Australia is seen as a test bed for the deployment of new grid solutions that integrate energy storage and distributed energy resources to help address the energy trilemma. Many stakeholders saw the design of smart grids, microgrids, embedded networks and off-grid solutions as a key opportunity for Australia to contribute to the energy storage supply chain. Network businesses and utilities are considering the opportunities and challenges that energy storage technologies pose to their business models. The assistance of grants and allowances has enabled utilities and network businesses to undertake trials and demonstration projects to develop expertise in the deployment distributed energy resources (DER) based systems and improve their ability to adapt to the transforming market. Examples include:

> **AGL's virtual power plant trial in SA:** which aims to demonstrate the ability to centrally manage and monitor 1000 solar PV and battery systems (a total of 5MW/7MWh energy storage) for both consumer and network benefit (AGL, 2016b).

> **Microgrid trials undertaken by AusNet Services and other distribution networks:** demonstrating the feasibility of enabling communities to generate, store and share their renewable energy using local grid infrastructure (AusNet Services, 2016)

> **Fringe-of-grid solutions:** for example, Ergon Energy has developed an energy storage system called Grid Utility Support System to improve reliability for fringe-of-grid customers serviced by single wire earth return (SWER) networks. This system is able to reduce the load on a SWER and improve the voltage seen at the end of the network at significantly lower cost than traditional augmentation (Ergon Energy, 2016).

> **SA Power Networks' battery storage trial:** installed 100 batteries in a 3-year trial in Salisbury in Adelaide's northern suburbs. The trial uses smart systems to manage power generated by household solar panels, and supplies the grid with excess energy to manage network issues, especially those caused by adverse weather conditions (SA Power Networks, 2016).

Australia's large off-grid electricity market is a unique characteristic for a developed country. Microgrids and standalone power systems are anticipated to be an important energy supply solution especially for remote and fringe-of-grid communities in Australia. There is also interest in applying energy storage with solar PV systems to offset the high costs of diesel generation in remote areas. Sandfire Resources successfully commissioned a solar and storage system at the DeGrussa mine in June 2016. The project, which includes 6MW of lithium-ion battery storage, is expected to cut approximately 20 per cent off their annual diesel consumption (Sandfire Resources NL, 2016). This project received funding from ARENA and the Clean Energy Finance Corporation (CEFC), however stakeholders stated that in some cases fuel savings in off-grid settings make these projects viable without government support. The expertise developed from the design and integration of storage and renewable generation for standalone off-grid systems is expected to be of particular interest to small and/or remote communities in the Asia-Pacific region.

A number of stakeholders noted the potential for improved use of data, data analytics and system modelling to manage Australia's energy systems. As an example, Victoria (somewhat controversially) implemented mandatory smart meters, and now offers opt-in flexible pricing for energy consumers (Department of Economic Development Jobs Transport Resources, 2015). Other states, including New South Wales are rolling out smart meters on a voluntary basis. Smart meters collect energy consumption in real time; however this data is not yet being used to its full potential for decision making at a community and business level due to data access, privacy and ring fencing issues. Addressing these issues and unlocking this data could significantly benefit modelling and decision making for efficient and reliable use of integrated energy solutions.

The urgent need for standards for installation, safety, and performance of energy storage systems (particularly batteries) was raised by many stakeholders. Standards Australia is making progress on a work program to address this, and released a Roadmap for Energy Storage Standards in February 2017 (Standards Australia, 2017). Some stakeholders also expressed frustration at the variations between electrical safety regulations in different states and suggested that a national framework would be preferable.

3.3.2. Grid-scale energy storage

The Renewable Energy Target is driving increased penetrations of variable renewable energy in Australia's electricity networks. There is currently no significant policy driver to provide firm and dispatchable energy from renewable sources. However, recent energy security scares have driven increased interest and growing recognition of the potential of energy storage to contribute to the reliability and security of Australia's electricity market. In February 2017, ARENA and the CEFC were asked to "focus on encouraging the development of flexible capacity and large-scale storage projects in Australia" (ARENA, 2017a).

Australia has over 1.5GW of PHES connected to the National Electricity Market (NEM), although no large-scale pumped hydro facilities have been built in Australia within the last 30 years (AECOM, 2015). Pumped hydro energy storage (PHES) is expected to remain the most cost effective option for large-scale energy storage (>100MW) for some time. Genex Power has proposed development of a 250MW pumped hydro system in Kidston, North Queensland to support a large-scale solar project which is already under development. Genex is currently working to secure the financial arrangements for the project. ARENA has already

A battery installation at an offgrid telecommunication installation reduced diesel consumption by over 50% reduction through increased generator efficiency.

CREDIT: ECOULT

committed funding towards the project. ARENA has also awarded a $450,000 grant to Energy Australia, to fund a feasibility study into a 100–200 MW pumped hydro storage project in South Australia (Reid, 2017). The Spencer Gulf project would be the first pumped hydro plant in Australia to use the ocean as its lower reservoir, alleviating potential environmental and social concerns. Pumped storage projects have been estimated to create between 2.75–5.5 full-time equivalent jobs per MW in direct job creation for the length of the project (Navigant Consulting, 2009). Stakeholders noted that the large costs and long time scales required for the development make private investment in pumped hydro systems unlikely without risk mitigation efforts by government.

There appears to be very little interest in the development of compressed air energy storage (CAES) or liquid air energy storage in Australia. There are only two underground CAES deployments operating globally. Underground CAES requires very specific geological structures and above ground compressed air storage has been abandoned by the US-based start-ups leading its development (St. John, 2015).

The deployment of CSP was seen as offering significant potential by a number of interviewees, although few could point to specific evidence for this optimism. The deployment of CSP is an opportunity to capitalise on Australia's significant research investments through the ASTRI program. A large-scale demonstration plant will be an important step to demonstrate the viability of the technology. A 6MW pilot-scale plant by Australian CSP developer Vast Solar is currently operational in NSW. The company has aspirations to expand this development to a 30MW commercial-scale plant (Sparkes, 2016).

There is interest in using battery storage for grid-scale applications but large-scale battery storage is not yet economically viable in most cases, partially due to the challenges in capturing multiple value streams (Korte, 2016). Government supported trials are helping to develop knowledge in this area which will help to improve the economics of grid-scale battery deployments. The Victoria government recently announced that it intends to run a tender for deployment of a 20MW battery system to support the network and enhance opportunities for the integration of new solar and wind generation (Minister for Energy Environment Climate Change, 2017). Australian solar and storage company ZEN Energy has intentions to develop a large-scale (50MW/50MWh) battery project in Port Augusta (SA) to support their solar developments. The company is now exploring the potential for a 100–150 MW plant to address grid security issues demonstrated by the state-wide blackout in September 2016 and the load

Ecoult's wind-smoothing battery operating at Hampton Wind Farm in NSW. CREDIT: ECOULT shedding event caused by the heatwave in February 2017. However, they noted that market reforms would be necessary to enable the larger projects (ZEN Energy, 2017).

Global energy storage projections by Navigant Research predict that global deployments of energy storage for grid and ancillary services will reach 21.6GW by 2025. Companies such as AES Energy Storage, RES Group, S&C Electric, Siemens, GE, and LG are amongst the leading global companies supplying grid-scale battery storage solutions (Navigant Research, 2016a).

3.3.3. Renewable hydrogen and ammonia

Consultation identified synthesis and export of hydrogen from renewable sources as a significant opportunity for Australia. The opportunity is partly driven by Japan's recent investment and national economic strategy directed towards hydrogen projects, including hydrogen-powered vehicles and fuel cells (Cross-ministerial Strategic Innovation Promotion Program, 2015). Australia is an optimal environment for producing hydrogen using solar energy due to high solar insolation. Hydrogen gas is difficult to transport due to its low density; instead, it is suggested that hydrogen is converted to ammonia for transport, and then converted back to hydrogen for use. Australia possesses significant expertise and infrastructure from the export of liquefied natural gas (LNG), which could be utilised or converted for ammonia transport. The export of renewable hydrogen is reliant on improving the efficiency and cost of hydrogen synthesis and transport.

A significant research effort in this field is taking place in Australia by groups such as CSIRO, ANU, The University of Adelaide, ANSTO, Curtin University, The University of Melbourne, The University of Technology Sydney, The University of Wollongong, and the University of New South Wales. Much of the research effort is currently focused on improving efficiencies when converting hydrogen to ammonia and back again. The research being conducted by the Australian Solar Thermal Research Initiative is also likely to benefit hydrogen production. This ARENA-funded project combines researchers from CSIRO, Flinders University, University of South Australia, University of Adelaide, Queensland University of Technology, ANU, and UQ and has four main CSP research areas: reducing capital expenditure, increasing the capacity factor, improving efficiency, and adding product value (ASTRI, 2012). These efforts to enhance CSP are likely to improve the cost and efficiency of producing renewable hydrogen using CSP.

Australian industry promotion body Renewable Hydrogen is working to drive the creation of a pilot plant to generate solar energy in the Pilbara region of Western Australia (Turner, 2015). It

Sunrise during construction of Vast Solar's CSP pilot plant at Jemalong, NSW. The grid-connected plant features thermal storage that enables the delivery of dispatchable electricity, generated with 1.1MW power capacity. CREDIT: VAST SOLAR PTY LTD is planned that the solar energy will then be stored as hydrogen and shipped in the form of ammonia and liquefied natural gas to Japan, Korea, and Asia (Renewable Hydrogen, 2014).

Ammonia production is already taking place in Australia. Yara Pilbara Fertilisers operates an ammonia production plant in the Burrup Peninsula, Western Australia. Ammonia at the Yara plant is currently produced using natural gas as a hydrogen source, rather than renewable sources, and ammonia is exported primarily for fertiliser production (WA Country Hour, 2017).

3.3.4. Key Findings

Finding 6 Australian companies are developing expertise in the design and deployment of microgrids and standalone systems for off-grid energy supply and smart systems for the management of behind-the-meter energy storage and embedded networks.

> Expertise in the operation and management of microgrids and standalone energy systems has potential to be applied in countries with developing electricity networks.

> Expertise in the management, operation, optimisation and market participation of grid-connected behind-the-meter energy storage and embedded networks has the potential to be applied in a number of international markets including the US, UK, and Europe.

Finding 7 Higher penetrations of variable renewable energy systems in the national electricity market will require supporting technologies, such as distributed and large-scale energy storage, to ensure network reliability and security. New market mechanisms are needed to drive investment in appropriate solutions.

Australia's excellent renewable energy resources offer a major opportunity to generate renewable hydrogen and ammonia for export.

> Research and development is currently underway in Australia to improve the efficiency and sustainability of renewable hydrogen and ammonia systems.

3.4. End of Life

The predicted increase in uptake of energy storage technologies, particularly lithium-ion batteries (Randell, 2016), has led to the identification of end-of-life recycling and/or reuse as a significant opportunity for Australia. The Australian Energy Storage Roadmap states "appropriate arrangements for the safe disposal or recycling of end-of-life [energy storage] systems (product stewardship) are a vital part of maintaining community support and industry integrity" (Clean Energy Council, 2015). Despite the growing number of batteries being used, there are currently few options for recycling these in Australia.

At present only lead-acid batteries are recycled in Australia. There are three operational lead-acid battery recycling facilities nationally; two owned by Hydromet, located in Unanderra in New South Wales and Laverton in Victoria, and one owned by Enirgi Power Storage in Wagga Wagga, NSW. These facilities extract lead, polypropylene, and sulfuric acid for re-use. Australian company MRI also offers in-house processing of nickel cadmium batteries.

3.4.1. Strengths and Opportunities

Increased battery recycling and repurposing is promoted by the Australian Battery Recycling Initiative, and was identified as a potential opportunity in Australia during consultation with industry stakeholders. Apart from lead-acid, used batteries are currently being collected in Australia and sent overseas for recycling. Several valuable components, including metals, can be extracted from retired batteries, and the export of these components to battery-manufacturing countries could add significant value to the energy storage supply chain.

Some work is already taking place in this area. In August 2015, Australian company PF Metals commenced a trial project in resource recovery from lithium-ion batteries (PF Metals, 2017). From the trial they developed a method of extracting 95 per cent of the batteries' valuable components, but are not yet recycling these batteries commercially (PF Metals, 2017). Furthermore, Melbourne-based start-up Relectrify is working on technology to repurpose retired electric vehicle batteries for use in household energy storage to deliver more affordable residential energy storage solutions (Relectrify, 2016b). This relies on the availability of used electric vehicle batteries, so will likely become more viable if electric vehicle uptake increases in Australia.

Current research trends indicate that future energy storage technologies will favour sustainable and environmentally friendly end-of-life outcomes.

3.4.2. Challenges

The lack of recycling regulations for batteries along with the relatively small number of batteries available for recycling and the economics of material recovery, is likely a leading reason for the paucity of battery recycling facilities in Australia. As the battery industry in Australia grows, there will likely be greater opportunities for local recycling and repurposing of batteries, however, research will be important for improving the economics of this. This can be achieved through technology improvements, increase in the cost of recoverable materials, or the imposition of tariffs on export. CSIRO has already commenced research into developing economic recycling of batteries through a project which will analyse a range of potential battery treatment and extraction processes (Australian Battery Recycling Initiative, 2016).

Many other countries have implemented regulations for handheld batteries. These include law that requires all battery manufacturers and importers of rechargeable batteries to implement a system to recover them in Japan, the requirement of battery producers to have an approved product stewardship plan, such as Tesla's Closed Loop Battery Recycling Program (Kelty, 2011), in British Columbia, Canada, and minimum battery collection targets for countries in the European Union (Australian Battery Recycling Initiative, 2014). In Australia, batteries less than 5kg in weight were listed as a priority for consideration of possible product stewardship approaches in 2015, but have not yet been regulated (Department of the Environment and Energy, 2015). Battery recycling regulation would not only decrease the environmental impact of toxic battery chemicals in landfill, it may also assist a battery recycling and/or re-use market in Australia.

3.4.3. Key Findings

Finding 8 Australia will have an opportunity to play a greater role in the repurposing and recycling of used batteries once local deployment reaches sufficient scale. The development of supportive end-of-life regulations and standards, and the potential development of improved recovery technologies would also facilitate this industry opportunity.

Relectrify's co-founders Valentin Muenzel and Daniel Crowley with a battery system using repurposed used batteries.

CREDIT: RELECTRIFY PTY LTD

4. Enabling Conditions

A key focus of the consultations was to identify the enabling conditions that would underpin economic, social and environmentally beneficial growth for the Australian energy storage industry and successful research outcomes in Australian research institutions. Recurrent themes amongst the responses included strategic governance, improved energy market design and regulation, driving investment and improving access to capital, and enhanced coordination and collaboration between stakeholders.

4.1. Government policy and initiatives

4.1.1. Stable and integrated energy and climate change policy

Policy uncertainty was repeatedly suggested by stakeholders to be a key barrier to attracting investment in energy technologies generally. A lack of confidence in the longevity of the Renewable Energy Target scheme was noted by stakeholders across finance, industry and research sectors as a major factor deterring investment in the sector.

Bipartisan support for a unified climate and energy policy based on independent expert evidence was typically seen as an essential enabler of investment energy storage applications. While carbon emissions remain a market externality, greenhouse gas intensive resources are expected to dominate generation, the provision of inertia and other system services.

Stakeholders indicated that the implementation of a price on carbon or an emissions trading scheme would provide a level playing field for all generation technologies and incentivise development of innovative supply- and demand-side solutions, which is likely to hasten the deployment of significant quantities of energy storage.

4.1.2. Strategic government leadership

There are a range of different programs and incentives in Australia that support industry development and research opportunities in energy storage. In addition to ARENA and the CEFC, these initiatives include subsidies for domestic energy storage, support for industry trials, and even direct procurement of energy storage. However, many stakeholders suggested that national leadership and enhanced coordination of these programs would have greater benefit.

Many international governments have recognised the importance of energy storage to their energy systems and implemented long-term strategic plans and targeted support for research and industry development. The need for a strategic vision from government was echoed by a number of stakeholders.

In the US, a number of states have implemented policies to support energy storage, particularly at utility scale (Energy Storage Council, 2015). California in particular has an energy storage procurement target of 1325MW by 2020. The US Department of Energy's Advanced Research Projects Agency – Energy (ARPA-E) program has invested significantly in energy storage RD&D through a number of its programs. These programs set strategic goals for the projects. As an example, the Grid-Scale Rampable Intermittent Dispatchable Storage (GRIDS) program aimed to develop large-scale storage technologies for renewable energy integration at an investment cost of less than $100US/kWh (ARPA-E, 2010).

In 2011, the German Government recognised the transformational potential of energy storage and implemented the Energy Storage Funding Initiative. The initiative had two flagship project clusters which focused on improving the efficiency of renewable hydrogen/methane production and reconversion to electricity, and using energy storage to relieve pressure on distribution grids (Höll, 2014).

More recently, the UK Government flagged energy storage technology as an issue of central importance to its industrial strategy. The Government asked its Chief Scientific Adviser to investigate the case for a new research institution to focus work on "battery technology, energy storage and grid technology" (Her Majesty's Government, 2017).

Some governments have also specifically identified hydrogen and fuel cell technologies as being essential for energy storage and transport applications and have implemented programs to further their development and application. In 2006, Germany initiated the National Innovation Programme Hydrogen and Fuel Cell Technology. Between 2006 and 2016, this alliance of government, industry and research stakeholders invested €1.4 billion ($1.94 billion) (National Organisation Hydrogen and Fuel Cell Technology, 2017). In 2016, the German federal government decided to extend the program for a further 10 years. The Government of Japan has also expressed plans to use hydrogen extensively and released a Strategic Roadmap for Hydrogen and Fuel Cells in 2014 which identifies steps and targets for "dramatic expansion of hydrogen utilization, the full-fledged introduction of hydrogen power generation / establishment of a large-scale hydrogen supply system, and the establishment of a totally carbon dioxide-free hydrogen supply system" (Ministry of Economy Trade and Industry, 2016).

4.1.3. Existing government support for industry development and innovation

Australian governments have implemented a number of initiatives to support industry development. Examples of initiatives that have particular relevance to energy storage include:

- **Grant funding** - ARENA is seen as an important enabler of Australia's energy storage industry and research sector. Financial support for early-stage research and development is essential to support world-leading research and enable the transfer of knowledge through demonstration projects. ARENA's strategy has evolved over time and now has greater strategic focus, although stakeholders commented on the disruptive nature of the frequent political changes to its governance, funding and remit. Other programs, such as Victoria's New Energy Jobs Fund also target financial support for industry development in the energy sector. For example, funding was awarded to a partnership project between Victorian companies Relectrify and Selectronic to apply international 'plug and play' communications standards to locally developed technologies (Relectrify, 2016a). In another example, grants from AusIndustry have helped to fund collaborative research between 1414 Degrees and the University of Adelaide, and production of a prototype thermal energy storage system (1414 Degrees, 2017).

- **Subsidies for energy storage installation** – The ACT Next Generation Energy Storage Pilot (ACT Department of Environment and Planning Directorate, 2016) and Adelaide City Council's rebate scheme (Adelaide City Council, 2016) are good examples of subsidies provided for energy storage installation. Stakeholders expressed mixed views about the suitability of subsidies for energy storage installed at customers' premises. Some suggested that they are not equitable mechanisms for driving uptake, as they favour relatively wealthy customers that are able to invest in energy storage. A similar effect can be seen in the cross-subsidies that were created by premium feed in tariffs for solar PV (Wood & Blowers, 2015). Subsidy programs need to be carefully designed to capture value and to minimise regressive cross-subsidies.

- **Support for Startups** – Such as EnergyLab - a hub, co-working space and accelerator for clean energy startups - established with grant assistance from the NSW Government (EnergyLab, 2017; NSW Department of Industry, 2017). The National Innovation and Science Agenda also has a strong focus on encouraging startups.

- **Direct procurement** – The Victorian government has called for expressions of interest for the installation of a 20MW battery to improve grid reliability in the Victorian electricity network (Minister for Energy Environment Climate Change, 2017).

- **The R&D Tax Incentive** – The R&D Tax Incentive is viewed as an advantage for Australian industry, and an essential program for supporting high-tech start-ups across a number of sectors. Adoption of the recommendations from the Review of the R&D Tax Incentive (Ferris, Finkel, & Fraser, 2016) is expected to improve the efficiency and effectiveness of the mechanism.

4.2. Energy market design and regulatory frameworks

In the design of markets it is important to consider the primary goals of the market. Energy markets around the world are currently grappling with the energy trilemma of energy security, equity and sustainability and seeking to implement mechanisms to achieve these outcomes. Increasing the amount of energy storage in the electricity system should not be a primary goal of the electricity market's design. However, it is regarded by many stakeholders as a likely outcome of implementing mechanisms that incentivise least cost decarbonisation of the electricity system while maintaining system security and reliability. The Independent Review into the Future Security of the National Electricity Market currently underway aims to address these issues. The Review's Preliminary Report notes the potential of energy storage technologies to contribute to the security and reliability of the National Electricity Market in a number of ways (Finkel, Moses, Munro, Effeney, & O'Kane, 2016).

In the absence of a price on carbon or an emissions intensity scheme, the Renewable Energy Target (RET) is the primary mechanism for the decarbonisation of Australia's electricity systems. This mechanism rewards renewable electricity generation with no consideration of the time of generation and level of demand, or its effect on system security. The market signals need to change to incentivise the right balance of dispatchable generation and ancillary services provision to ensure the security of the power system as Australia's electricity markets incorporate high levels of renewable energy. Revised market frameworks such as the formation of a capacity market (i.e. a market to provide adequate resources on the grid to ensure that the demand for electricity can be met at all times) could help to drive investment in dispatchable generation, which could include energy storage technologies combined with renewables. A Capacity Market auction in the UK recently awarded over 3.2GW of contracts to battery storage projects for delivery in 2020/21 (Department for Business Energy Industrial Strategy, 2016).

Other policies that would encourage provision of firm renewables capacity and system security services should be investigated. The establishment of a Renewable Ancillary Services Target parallel to the RET that encourages deployment of low emissions solutions to maintain system reliability and security was suggested by one stakeholder. A number of stakeholders also suggested the introduction of a market for fast response services for grid services to provide synthetic inertia. Some stakeholders suggested that large-scale storage needed to be directly incentivised. However, there was generally agreement that technology-neutral mechanisms should be implemented to encourage lowest-cost provision of the required services.

Many stakeholders regard the 30 minute settlement period in the wholesale electricity market as an inefficient market design that does not incentivise fast response generation and demand response. A rule change request submitted to the Australian Energy Market Commission (AEMC) in December 2015 suggested instances of incidences of strategic late bidding by generators and withdrawal of generation as evidence of the market distortion caused by the current market structure (Sun Metals, 2015). Aligning settlement and dispatch times is likely to create a more efficient outcome. Large thermal generators are typically unable to achieve fast response times; however energy storage technologies (especially batteries) are able to respond in a single 5 minute dispatch interval. If the rule change is approved, it is expected to provide a more appropriate pricing signal for this capability and improve the efficiency of the market. A draft determination on the rule change is expected in July 2017 (AEMC, 2016c).

Regulations for grid-scale storage connections were viewed by some stakeholders as restrictive. However, it was rare that stakeholders were able to identify specific regulations that needed addressing. AEMC's investigations into the regulatory implications of energy storage did not suggest that there were any significant barriers to deployment of energy storage (AEMC, 2015). This review notes the challenges in optimising the benefits of storage and how different ownership models will realise different value streams. It was noted that "the current regulatory frameworks in the NEM encourage market-based solutions to these sorts of control and optimisation issues. This kind of approach may not mean a measured, controlled deployment of storage, but the regulatory frameworks are in place to reconcile the needs of networks with the desire for consumer-led decisions on technology deployment" (AEMC, 2015). Following this review, the AEMC began a work program to address improvements that may make energy storage installation simpler.

Energy storage has potential to offer a range of beneficial services when installed within distribution networks, including peak demand reduction. Distribution networks are evolving as they adjust to accommodate multi-directional energy and information flows from distributed energy resources (CSIRO & Energy Networks Australia, 2016; Pierce, 2016). Well-designed regulations regarding who can own and provide energy services are important to ensure efficient markets, yet if they are too restrictive they may stifle innovation. Rule change requests regarding the contestability of energy services are currently being investigated by the AEMC (2016a, 2016b).

Using energy storage in standalone power systems has potential to provide an alternative to grid connections, particularly in fringe-of-grid areas. Currently, network service providers are not able to investigate these alternatives, even though they may be able to provide more efficient outcomes. A pending rule change request seeks to address this issue (AEMC, 2016b). The network transformation roadmap developed by Energy Networks Australia recommends that network businesses be able to "deploy or procure microgrids or standalone power systems as a substitute for traditional delivery models where it is demonstrably efficient and fair to do so" (CSIRO & Energy Networks Australia, 2016).

Another market issue with influence on the uptake and effect of energy storage is tariff structures. As increasing numbers of energy consumers install distributed energy resources (DER) (e.g. rooftop solar PV) enter the network, tariff reform will be essential to ensure economic efficiency and equity in the energy system. Energy Networks Australia and the CSIRO argue that a cost-reflective pricing structure, such as demand based tariffs, will help to avoid cross subsidies from customers without DER to customers with DER, and reduce network investment by up to $1.4 billion by 2026 (CSIRO & Energy Networks Australia, 2016).

4.3. Access to venture capital and finance

Access to early-stage venture capital can be challenging in Australia. Many stakeholders expressed the sentiment that Australian investors have a low appetite for risk. Limited access to capital during the growth stage of a company has been suggested as a key reason for high-growth technology companies leaving Australia (Fitzsimmons, 2015). A stakeholder aiming to commercialise new energy storage IP told ATSE that they had to look overseas to access finance at the scale required for commercialisation. Some industry stakeholders suggested that the Government should consider mechanisms to drive domestic investment in new businesses. The UK's Seed Enterprise Investment Scheme was suggested as a successful international example of such a program. The tax incentives for investors in early-stage innovative companies announced in the Australian Government's National Innovation and Science Agenda is based on this scheme, albeit at a smaller scale (Commonwealth of Australia, 2016b).

Some interviewees suggested that there was a limited appetite for risk in the Australian finance sector. Stakeholders in the finance sector suggested that there was no shortage of finance for projects with appropriate risk/return profiles. Projects that require large investments and have significant development times – such as pumped hydro storage – are particularly challenging to finance in the current investment climate. For these reasons, the Clean Energy Finance Corporation (CEFC) is viewed as a positive initiative with great potential to stimulate growth in this industry. In September 2016, the CEFC made a $10 million commitment to help establish a Clean Energy Seed Fund to be managed by Artesian Venture Capital. The fund aims to invest a total of $20 million in 30–50 high growth potential startups over the next 4–5 years. Energy storage is one of the sectors that this fund intends to target (Clean Energy Finance Corporation, 2016).

Government efforts to mitigate investment risks can help to enable greater private investment in high capital projects, such as pumped hydro systems. The 2017 IRENA report, Rethinking Energy, notes that: "limited public funds need to be used in a way that maximises the mobilisation of private finance … this means a shift from traditional public financial instruments (e.g. grants and loans) toward risk mitigation instruments such as guarantees that cover political, currency and power-offtake risks" IRENA (2017).

4.4. Strategic coordination and collaboration

A number of stakeholders within research and industry expressed frustrations with the lack of industry-research collaboration and of strategic research coordination. Problems with industry-research collaboration are not unique to the energy storage sector. It is widely recognised that Australia has strengths in research and knowledge creation, but does not perform as well in the transfer and application of knowledge in Australia (Innovation and Science Australia, 2016).

Many stakeholders in the energy storage research sector noted the lack of coordination between different research groups, and often found it difficult to attract industry funding for research projects. Industry stakeholders had mixed experiences with research groups. Many noted the usual challenges of research-industry collaboration relating to IP ownership and long project lead times in universities. However, a number of industry stakeholders have had very positive experiences with researchers. Many energy storage technologies currently being commercialised by Australian businesses have originated from IP created by Australian universities or CSIRO (e.g. Ecoult, 1414 Degrees) or have benefited from collaborative research arrangements (e.g. Redback Technologies).

A number of stakeholders suggested that the energy storage research sector would benefit from greater strategic coordination and leadership. This could be achieved through collaborative research hubs such as the Battery Technology Research and Innovation Hub (BatTRI-Hub) at Deakin and ACES at the University of Wollongong.

Targeting strategic international collaborations and funding with major international research programs has potential to add further value and impact to Australian research initiatives. As evidenced at ACES, the establishment of research hubs can attract the participation of international partners. Another example is ASTRI, which has linkages to the United States Department of Energy SunShot program and seeks to mobilise the international CSP industry to invest in Australia (ASTRI, 2015).

4.5. Key Findings

Finding 9 Current policies and design of the NEM do not efficiently encourage solutions, including deployment of energy storage, that support decarbonisation of the electricity system while ensuring system security and customer equity.

> Establishing stable and integrated climate and energy policy would improve investment certainty for energy storage and other low carbon technologies.

> Government leadership and vision can play an important role in industry development. Striking an appropriate balance between technology neutrality and making strategic choices is essential to get the best outcomes.

> The current market design of the NEM does not efficiently encourage solutions that address the energy trilemma of security, equity and sustainability. Implementing market mechanisms that encourage decarbonisation of the electricity system and ensure system security and reliability are expected to drive deployment of energy storage. Technology neutral policies that encourage provision of firm capacity and system security services should be investigated.

> Tariff reform to ensure economic efficiency and equity in the energy system will become increasingly important as higher penetrations of distributed energy resources enter the network.

> Aligning settlements and dispatch periods in the wholesale market is widely expected to produce more efficient market outcomes and reward fast response generation, which includes many energy storage technologies.

> Deployment of energy storage in distribution and transmission networks may provide more efficient and economic solutions to network issues. Clarifying the regulations regarding appropriate use, management and ownership of energy storage by network businesses is essential to support this.

Finding 10 Access to private sector risk capital for Australian energy storage start-ups and projects is a key challenge for new energy storage ventures.

> Access to private venture capital and finance for Australian energy storage start-ups and projects was viewed as a key challenge by many stakeholders.

> ARENA and the CEFC are highly valued initiatives in the renewable energy and energy storage ecosystem.

Finding 11 Wider actions to address the systemic challenges in industry-research collaboration are expected to benefit the energy storage industry and drive enhanced knowledge transfer and application.

Glossary and Acronyms

ABB	ASEA Brown Boveri
ACES	ARC Centre of Excellence for Electromaterials Science
ACOLA	Australian Council of Learned Academies
ACT	Australian Capital Territory
AECOM	Architecture, Engineering, Construction, Operations, and Management
AEMC	Australian Energy Market Commission
AEMO	Australian Energy Market Operator
AGL	Australian Gas Light Company
ANSTO	Australian Nuclear Science and Technology Organisation
ANU	Australian National University
ARC	Australian Research Council
ARENA	Australian Renewable Energy Agency
ARPA-E	Advanced Research Projects Agency-Energy
ASTRI	Australian Solar Thermal Research Initiative
ATSE	Australian Academy of Technology and Engineering
BatTRI-Hub	Battery Technology Research and Innovation Hub
Beneficiation	Any process that improves the economic value of a mineral ore by removing the gangue (commercially worthless) minerals, which results in a higher grade product and a waste stream.
BSc	Bachelor of Science
BTM	Business Technology Management
CAES	Compressed Air Energy Storage
CEFC	Clean Energy Finance Corporation
CO2	Carbon dioxide
CSIRO	Commonwealth Science and Industrial Research Organisation
CSP	Concentrated solar thermal power
DER	Distributed energy resources
EDR	Economic Demonstrated Resources
ENA	Energy Networks Australia
ERA	Excellence in Research for Australia
FAA	Fellow of the Australian Academy of Science
FiT	Feed in tariff
FTE	Full time equivalent
FTSE	Fellow of the Australian Academy of Technology and Engineering
GE	General Electric
GRIDS	Grid-Scale Rampable Intermittent Dispatchable Storage
GW	Gigawatt
GWh	Gigawatt hour
HSRG	Hydrogen Storage Research Group
IP	Intellectual property
IRENA	International Renewable Energy Agency
ISA	Innovation and Science Australia
ISF	Institute for Sustainable Futures
Li-ion	Lithium ion
LNG	Liquefied natural gas
MEMSI	Monash University's Energy Materials and Systems Institute
MERLin	Material Energy Research Laboratory in Nanoscale

METS	Mining equipment, technology, and services
Microgrid	A localised collection of interconnected electricity loads and sources that can connect to the wider electricity grid and also disconnect from the grid and function autonomously. Also known as a mini grid.
MW	Megawatt
MWh	Megawatt hour
NEM	National Electricity Market
NSW	New South Wales
P2O5	Phosphorus pentoxide
PhD	Doctor of Philosophy
PHES	Pumped-hydro energy storage
PMB Defence	Pacific Marine Batteries Defence
PV	Photovoltaics
R&D	Research and development
RES Group	Renewable Energy Systems Group
RET	Renewable Energy Target
SA	South Australia
SWER	Single wire earth return
TRL	Technology Readiness Level
UK	United Kingdom
UltraBattery	A hybrid, long-life lead-acid energy storage device. It combines the fast charging rates of an ultracapacitor technology with the energy storage potential of a lead-acid battery technology in a hybrid device with a single common electrolyte.
UNSW	University of New South Wales
UQ	University of Queensland
US	United States of America
USD	United States dollars
WA	Western Australia
Zn-Br	Zinc Bromine

Expert Reference Group Biographies

Dr Lachlan Blackhall

Dr Lachlan Blackhall is the co-founder and CTO of Reposit Power, a technology company designing advanced control and optimisation systems for grid-deployed energy storage. Dr Blackhall holds a BE, BSc and a PhD in engineering and applied mathematics and is widely considered a leading expert in the optimisation, control and management of grid-connected energy storage systems.

Dr Blackhall has been heavily involved in the entrepreneurship, innovation, technology and investment domains for over a decade. He holds an appointment as an adjunct researcher in the College of Engineering and Computer Science at ANU where he contributes to both teaching and research activities.

Dr Blackhall has been the recipient of several awards for his research in complex systems and networks and for his contribution to engineering and innovation. In 2015 Dr Blackhall was awarded the inaugural Batterham medal from the Australian Academy of Technology and Engineering (ATSE).

Denise Goldsworthy FTSE FAIM GAICD

Denise Goldsworthy is an experienced non-executive director and advisor on research, technology and innovation. She has proven experience in the manufacturing (steel), mining (iron ore, industrial minerals) and technology / innovation sectors. Recognised as a master of constructive questioning, she utilises expertise in business engagement and system design to achieve reliable outcomes.

Denise is currently Chairman of ChemCentre WA; a non-executive director for EFIC; a member of Council at Edith Cowan University; a member of the Commercialisation Advisory Board for Curtin University; Chair of the Navy Clearance Diver's Trust; and a judge for the Prime Minister's National Science awards. Among Denise's honours is being named the 2010 Telstra Australian Business Woman of the Year. She is also a member of Chief Executive Women (CEW) and was inducted into the WA Women's Hall of Fame in 2011.

Mr John Grace FTSE

Mr John Grace operates a consultancy company TechAdvisory Pty Ltd. He is the Chair of UniSA Ventures Pty Ltd (the technology transfer company of the University of South Australia) and a member of the board of the Polymers CRC. His expertise is focused in the commercial development of leading-edge science, predominantly in Biotechnology. He was the CEO of AMRAD Corporation Pty Ltd from 1990 to 2001. He has been a director of a number of start-up companies in the health sciences space.

Mr Grace was previously a Council member of the Australian Institute of Marine Science, a director of Melbourne Ventures Pty Ltd, a Member of the ARC, a member of the Victorian Premiers' KISE Task Force and a Member of the IR&DB Board and many other government boards/committees. Mr Grace served on the ATSE board in 2008–2013.

Professor Douglas R. MacFarlane FAA FTSE

Professor MacFarlane is leader of the Energy Program in the ARC Centre of Excellence for Electromaterials Science (ACES). He has published more than 600 papers and 30 patents, including papers in Science, Nature, and Nature Materials (cited more than 33,000 times, h-index of 85). His interests include ionic liquids as solvents in fields including materials synthesis, electrochemistry, energy chemistry, green chemistry and biotechnology. Professor MacFarlane's group has contributed cutting edge work to all of these areas (recent papers on electrochemical materials in Nature Materials, on battery electrolytes in Energy and Environmental Science and on bio-fuels processing in Green Chemistry) as well as to the development of the next generations of energy storage devices (recent papers in Nature Communications and Advanced Materials).

Professor MacFarlane was elected to the Australian Academy of Science in 2007 and the Academy of Technological Sciences and Engineering in 2009. He is currently a member of the Editorial Advisory Boards of Chemical Communications, Green Chemistry, ACS Sustainable Chemistry and Engineering, ChemSusChem and Cryobiology. He is an Adjunct Professor at the University of Alabama, an International Fellow of the Queens University Belfast, and a Visiting Professor of the Chinese Academy of Sciences.

Dr Leonie Walsh FTSE

Leonie Walsh is an experienced leader and adviser in technological innovation with a background that spans more than 30 years of experience both locally and internationally across a diverse range of industries and markets.

Leonie draws from this experience to focus on strategic science and technology issues including innovation efficiency, technology commercialisation and the future skilled workforce through a range of related boards, advisory and advocacy activities. Leonie is also a strong advocate for attracting more women into science and technology and was recently named as the inaugural Ambassador for Women in STEMM Australia.

More recently Leonie completed a 3three year term as Victoria's inaugural Lead Scientist. In this capacity Leonie was a contributing member on the Future Industries Ministerial Advisory Council, provided contributions to the Education State activities and STEM plan via the Tech Schools STEM Future Industries Advisory Panel and the STEM advisory committee, represented Victoria on the Forum of Australian Chief Scientists and chaired and participated on a range of advisory committees and funding assessment panels spanning innovation, education, new energy and advanced manufacturing.

Leonie Walsh has received a Bachelor of Science and an Master of Science from Swinburne University, a Master of Business Administration (Executive) from the Australian Graduate School of Management and is a Fellow of the Academy of Technological Sciences and Engineering. In 2014 Leonie received an Honorary Doctorate from Swinburne University of Technology for contributions and leadership in scientific enterprises, innovation and the community.

Evidence Gathering

ATSE has received input from over 80 representatives and experts from the energy and energy storage sectors. This has been through a combination of interviews and written responses to discussion questions. The mix of stakeholders included representatives from government, industry, finance, research, not-for-profit industry associations. ATSE also received input from a number of its expert Fellows. ATSE received direct input from representatives of the following stakeholder organisations:

1414 Degrees
ACT Government
AECOM
AEMC
AEMO
AGL
ARC Centre of Excellence for Electromaterials Science (ACES)
ARENA
Australian Energy Storage Alliance
Australian National University
Australian Nuclear Science and Technology Organisation (ANSTO)
Clean Energy Council
Commonwealth Scientific and Industrial Research Organisation (CSIRO)
Curtin University
Deakin University
Defence Science and Technology Group
Department of Environment and Energy
Department of Industry Innovation and Science
Ecoult
Energy Networks Australia
Energy Storage Council
Enirgi Group
Ergon Energy
Gelion
General Electric
Genex Power
Geoscience Australia
GreenSync
Igniteer
Imagine Intelligent Materials
IT Power – Testing the Performance of Batteries
Marchment Hill Consulting
Monash University
Nano Nouvelle
NSW Government
Redback Technologies
Relectrify
Renewable hydrogen P/L
SA Department of Premier and Cabinet
SA Power Networks
Siemens
Tesla Energy Australia
University of New South Wales
University of Queensland
University of Technology Sydney
University of Wollongong
VAST Solar
VSun
Yara
Zen Energy

NB: Some interviewees requested that their organisation was not listed here.

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Level 1, 1 Bowen Crescent
Melbourne, 3004
Victoria, Australia

GPO BOX 4055
Melbourne, 3001
Victoria, Australia

T +613 9864 0900
F +613 9864 0930
E info@atse.org.au

AUSTRALIAN ACADEMY OF
TECHNOLOGY AND ENGINEERING