CLEAN ENERGY COUNCIL
FUTURE-PROOFING IN AUSTRALIA'S ELECTRICITY DISTRIBUTION INDUSTRY PROJECT

CLEAN ENERGY COUNCIL

ARENA

Australian Government
Australian Renewable Energy Agency

ENERGY STORAGE SAFETY

Responsible installation, use and disposal of domestic and small commercial systems

TASK 1B

REPORT BY: CSIRO

CLEAN ENERGY COUNCIL INTRODUCTION TO THIS REPORT

Australian consumers are leading the world in installing solar panels, driven by rising electricity prices and a desire to take charge of their power bills. These factors, combined with Australia's world-class solar resource, are set to cause the market for domestic and small commercial battery storage systems to take off.

With the battery storage system market growing, it is critical that consumer safety issues are fully understood and the right standards and installation integrity frameworks are in place.
This report, prepared by CSIRO, is Australia's first and most comprehensive assessment of stationary battery storage technologies and the safety risks they present. It analyses in detail the standards and installation practices for battery storage systems in Australian homes and small businesses, and identifies gaps in standards and recommends priority actions to ensure the integrity of this emerging industry.

The report's focus is on battery technologies and chemistry types that are well placed for mass uptake. Of these, lead acid and lithium ion are emerging as the most likely technologies. Although the technology and risks of stationary batteries of this scale are not well understood by consumers, it is important to recognise that they are already ubiquitous in modern life – similar to other household items with safety risks, like barbeque gas bottles and fuel tanks.
This makes it all the more important to address standards and installation best practices, and the CSIRO has clearly identified some key recommendations for immediate action. The Clean Energy Council supports all of these recommendations.

This study has two key components with its research extending into the field of social sciences for the development of a set of common consumer questions on battery storage safety. This web-based information portal is available via the CEC's website (solaraccreditation.com.au/consumers) and was developed in close consultation with both experienced installers and consumers. Targeted focus groups revealed that targeted information and training for different stakeholders was required. For example, installers require detailed technical information and training, while consumers need information that can build their knowledge from the ground up.

This report's findings and recommendations are important to ensuring the integrity of a battery storage installation industry. While some of them are being considered through our Energy Storage Roadmap (cleanenergycouncil.org.au/storage), like the recent launch of a Clean Energy Council accreditation program for installers of battery storage systems. Others require government leadership.

ACKNOWLEDGEMENTS

This report was produced with funding support from Australian Renewable Energy Agency (ARENA). ARENA was established by the Australian Government as an independent agency on 1 July 2012 to make renewable energy technologies more affordable and increase the amount of renewable energy used in Australia. ARENA invests in renewable energy projects supports research and development activities, and boosts job creation and industry development and increases knowledge about renewable energy.

The Clean Energy Council thanks the CSIRO for their efforts in preparing this report and the Future Proofing in Australia's Electricity Distribution Industry (FPDI) Project Steering Committee for their time and effort in providing crucial guidance and review of this work. These stakeholders include AGL, Alternative Technology Association, ARENA, AusNet Services, Australian Energy Regulator, CSIRO, Department of Industry and Science, Energex, Energy Networks Association, Energy Retailers Association of Australia, Energy Supply Association of Australia, Marchment Hill Consulting, Pacific Hydro Pty Ltd, Sunpower and University of Technology Sydney.

The Clean Energy Council also thanks all those who took part in the focus groups providing critical guidance on the format and content of the consumer-facing aspects of this work.

ABOUT THE FPDI PROJECT

With the objective of enhancing the flexibility and resilience of Australia's electricity distribution systems and the installations connected to them, the Clean Energy Council-led Future Proofing in Australia's Electricity Distribution Industry (FPDI) project is analysing existing and emerging issues associated with the increased penetration of renewable embedded generation and storage.

The project's detailed scope of work includes technical, economic and regulatory analysis, forums, knowledge gathering and dissemination of the project outcomes with key stakeholders and Clean Energy Council members.

Further details of the project can be found on the Clean Energy Council website at www.cleanenergycouncil.org.au/fpdi

ABOUT THE CLEAN ENERGY COUNCIL

The Clean Energy Council is the peak body for the clean energy industry in Australia. We represent and work with hundreds of leading businesses operating in solar, wind, energy efficiency, hydro, bioenergy, energy storage, geothermal and marine along with more than 4000 solar installers.

We are committed to accelerating the transformation of Australia's energy system to one that is smarter and cleaner. For more information on this project, visit fpdi.cleanenergycouncil.org.au

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CSIRO

Energy storage safety

Responsible installation, use and disposal of domestic and small commercial systems

Report for the Clean Energy Council

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CLEAN ENERGY COUNCIL

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Executive summary

Energy storage technologies are undergoing rapid development. Their uptake is predicted to track a similar path to that of market-driven solar panels (photovoltaics), or to be even faster. Industry is determined to be prepared for this predicted disruptor.

This report focuses on the diverse range of energy storage safety considerations for technologies with the potential for rapid uptake. Specifically, it describes a desktop study of safety performance in the Australian context that aimed to identify the present status, potential gaps and requirements for domestic and small commercial energy storage systems of greater than 1 kWh and less than 200 kWh. In this report, safety is considered in terms of the installer and designer working with energy storage, the consumer using energy storage and the effects of energy storage on the environment.

The investigation covered the following:

- description of the various energy storage technologies, compositions and functions, including battery chemistries
- installation and safety requirements common to technologies in the domestic and commercial stationary energy storage sector, and additional requirements specific to various chemistries
- present standards and best practice, as well as potential gaps that apply to existing chemistries and installation scenarios, transportation and handling, disposal and recycling
- operation information for storage installation and for the life cycle of that storage system, to ensure a safe environment for the batteries, their surroundings and residents
- advice on emergency response requirements in the event of a fault or unsafe condition
- advice on appropriate training and accreditation for energy storage designers and installers.

If the key findings and recommendations given below are addressed in a timely fashion, Australia will not only be prepared for the predicted energy storage uptake but will potentially be a world-leading example of safety performance for distributed energy storage.

Key findings

1. **There is a lack of knowledge on the variety of energy storage technologies, and thus on how to care for and operate them in a safe manner in the domestic and small commercial scale context**. Although battery storage is a low-risk technology, it is important that systems are installed and maintained by an accredited installer, and that industry best practice is developed.
2. **There is currently no consensus on the appropriate method to extinguish a lithium battery storage fire in the event of an incident.**
   There are many suggestions for extinguishing a lithium fire, each of which has advantages and disadvantages. Research is needed into the appropriate method for dealing with such an incident.
3. **There is insufficient accreditation and training to support and provide qualifications for designers and installers of energy storage systems.**
   The lack of accreditation and training is particularly relevant for the emerging lithium-ion battery technologies. The training and accreditation needs to cover safety protocols, and signage related to warnings and battery chemistry types.
4. **Emergency response teams (fire brigade, police and ambulance) have limited education about the issues related to an energy storage technology in the event of an incident.**
   Relevant safety signage needs to be on display and the response team needs to take into account the location of the battery system.

5. **There is a lack of standards for battery storage system disposal and recycling (except in the case of lead-acid battery system).**
   Battery storage systems can contain heavy or toxic metals that can be harmful to the environment if disposed of in a landfill. Consumers, designers and installers should be aware of and consider whole-of-life recycling practices.
6. **Australian standards for battery energy storage and connection to the electricity network are incomplete.**
   For the domestic storage market especially, there is a need to develop standards that incorporate installation, smart communication, training and maintenance, transportation, safety and emergency guidelines, and requirements related to the environment and recycling.
7. **Stationary energy storage installations and incidences are insufficiently reported.**
   Relatively few incidents have been reported, which may reflect the lack of records or reporting processes to capture such incidents, and the relatively low numbers of present installations.

Recommendations

1. **Improve awareness of and access to information on the variety of battery energy storage technologies and their appropriate operation and care among consumers (general public), designers (engineers and electrical tradespeople) and installers (electrical tradespeople).**
   As the battery storage industry is relatively new, there is limited knowledge across the different technologies available – in particular for the emerging lithium-ion battery storage systems – and the number of safety considerations for each.
2. **Research and identify the best methods for lithium-ion battery storage system recycling, and establish a lithium-ion battery recycling initiative.**
   Battery storage systems can contain heavy or toxic metals such as nickel, cobalt, cadmium and lead, which can be harmful to the environment if disposed of in landfill. In Australia, used rechargeable battery systems are classified as either a hazardous waste or a dangerous good, which means that they can create environmental (and safety) risks if disposed incorrectly.
3. **Research and identify the best methods to safely (passively) extinguish domestic and small commercial scale lithium-ion battery storage fires.**
   Presently there is no clear agreement as to how to appropriately extinguish a lithium battery fire. There are many methods in literature and the most appropriate emergency response may also depend on the size and conditions of the incident.
4. **Align Australian and international standards, and improve local regulatory and building codes relevant to energy storage systems.**
   A number of standards do exist for mature or established storage technologies and the connection of inverters to the electricity network. However, some of these standards are outdated and only consider specific cases, whereas modern use of these technologies has expanded to much broader applications.
5. **Establish a set of best practices specific to the battery storage industry, including development and upkeep of an installation, maintenance and incident reporting database for energy storage systems in Australia.**
   Best practice around battery energy storage is performed in some industries for selected technology types, for example, transportation of lithium-ion batteries in the aviation sector. However, domestic and small commercial scale stationary energy storage lacks guidance and consistency for safe selection and management of batteries. There are presently no established reporting processes or formal record-keeping for energy storage installations and incidents and thus no way of assessing the scope or resources required to assist industry.
6. **Develop training and nationally recognised accreditation pathways for designers and installers specific to energy storage in domestic and small commercial scales.**
   Present accreditation in the industry are established for Australia’s solar PV systems, but emergent for battery energy storage systems. There is presently insufficient accreditation and training resources to support designer and installer qualifications to install energy storage systems only.

1 Introduction and background

There is a growing demand for domestic and small commercial energy storage. The safe integration and use of such systems into the electricity network poses significant technical and regulatory challenges for the Australian energy industry.

This report provides an overview of the key technical, safety and standard impacts of domestic and small commercial energy storage. It describes the opportunities that such energy storage presents for domestic homeowners, and small commercial and network providers; identifies gaps in the present Australian standards; and recommends the best-practice options that may be pursued in the near future.

The report forms part of the Future Proofing in Australia's Electricity Distribution Industry project – a collaborative project involving the Clean Energy Council (CEC) and its members, the Australian Renewable Energy Agency (ARENA) and other key stakeholders. Further details of the scope, governance and objectives of this incentive are available online.[1]

1.1.1 Purpose

The purpose of this study was to undertake research and provide expert advice on best practice for installation and use of energy storage technologies. The work will be used to advise industry, prospective investors and users of battery technologies on best-practice solutions to ensure safety and industry integrity. In this report, safety is considered in terms of the installer and designer working with energy storage and the consumer using energy storage.

1.1.2 Audience

The report's intended audience is the CEC, its members and the broader energy industry. It has been developed with the CEC's stakeholders in mind, and it proposes recommendations that take account of stakeholders' objectives, for further consideration by the industry.

1.1.3 Objective

The objective of this study was to address uncertainties and define best practice regarding the safety of battery storage technologies and their installation. Focusing on technologies with the potential for rapid uptake (especially within a household or small to medium enterprise setting), the work aims to ensure that future investment decisions are well informed and that policy settings correctly account for safety. As such, the study analysed all available information and assessed the status of relevant Australian market conditions, standards and practices relating to the safe deployment and disposal of energy storage systems, together with the accreditation of domestic and commercial battery installations.

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[1] http://www.cleanenergycouncil.org.au/policy-advocacy/arena/FPDI-project.html

1.1.4 Research objectives

The overall objective includes two research objectives (RO):

- *RO1: Storage safety performance desktop study*
  Conduct a comprehensive literature review to provide a contemporary database of information on the diverse range of energy storage safety considerations. The data collected in this study will be collated into a detailed technical report identifying specific and potential issues, and will guide the precise definition of safety requirements for energy storage systems in Australia.
- *RO2: Storage safety consumer guide*
  Develop and deliver a 'user-friendly' consumer guide promoting energy storage safety best practice, based on the findings of the desktop study (RO1). The guide will identify and promote best practices for consumer, network and household safety. It will also identify and promote best practices to minimise environmental impacts of energy storage technologies.

This technical report is the output from RO1. For RO2 output, it can be found on CEC's website http://www.cleanenergycouncil.org.au/fpdi

1.1.5 Approach

This study, undertaken for RO1, involved reviewing and assessing the presently available national and international literature regarding domestic and small commercial stationary energy storage technologies. The literature included journal and conference publications, Australian and international standards, industry best practices, building and regulator codes, and government and industry technical reports. The study also considered several specific battery technologies that are either presently or likely to be deployed and make an impact on the Australian market. These include lead-acid, lithium-ion, nickel-cadmium, nickel metal hydride, flow and sodium-ion analogue batteries. The safety performance and regulations for each of these technologies were also investigated.

The main topics investigated in the desktop study were:

- the composition and function of various energy storage technologies (including battery chemistries)
- installation and safety requirements common to all technologies in the domestic stationary energy storage sector
- installation and safety requirements unique to specific technologies or chemistries
- present standards and best practices applied to existing chemistries and installation scenarios
- identification of new standards required to safely manage the storage systems in new contexts where existing standards are not fully aligned
- technical information required for the operation of the storage installation during its life cycle to ensure a safe environment for the batteries, their surroundings and owners
- emergency response requirements in the event of a fault or unsafe condition
- suggested requirements for accreditation of storage installers.

For RO2, data for the storage safety consumer and installer guide were obtained using a mixed-methods approach. The approach primarily comprised face-to-face interviews (or telephone interviews, where face-to-face was not possible) with battery installers, battery manufacturers and network distributors. The aim of the interviews was to develop an understanding of the following aspects of battery storage systems:

- transportation and handling
- installation
- operational safety and monitoring
- fault risks
- disposal and recycling.

Data from interviews were collated, categorised and translated into a preliminary ‘working draft’ version of the guide. The draft contained separate sections for consumers (general public) and installers (tradespeople), and was pilot tested on four focus groups:

- two installer groups
- one group of consumers with some energy storage or production
- one group of consumers without energy storage or production.

The focus groups helped to refine the contents and determine usability of the guide, but did not directly inform the technical report. A final text-based document is being produced for the CEC, containing relevant information in a format that the CEC can easily convert into a glossy illustrated guide for public distribution.

1.1.6 Scope of study

Energy storage technologies are rapidly being developed for use in domestic energy storage. This means that any studies are limited in what they can achieve while still keeping up to date with the technological developments. To be applicable to this developing field, this study focused on areas that are mostly independent of the technological changes. Hence, the study has three key limitations:

- This report is broad and shallow. Its main intention is to act as a foundation for further work by the CEC and its members. Hence, it addresses a broad number of topics and highlights areas for further work that, with time and resources, can be investigated in more depth.
- CEC members and stakeholders’ views were gathered through selected interviews and focus groups. During the project timeline, not all members and stakeholders were interviewed, meaning that the results do not necessarily represent all the views of relevant members and stakeholders. This is particularly important to consider in relation to the consumer guide.
- This study focused on domestic and small commercial systems of greater than 1 kWh and less than 200 kWh. It also considered only stationary energy storage; it did not consider electric vehicles. This situation aligns with energy storage standards work being developed by CEC.

1.1.7 Report outline

This report:

- provides an outline of safety considerations for various energy storage technologies likely for domestic and commercial uptake (Section 2, Battery storage technologies)
- addresses standards and regulations in this area of the energy storage industry, including installation requirements, operation and maintenance and emergency response for potential incidents (Section 3, Battery storage installations)
- discusses accreditation and training specifically for energy storage installations (Section 4, Accreditation and training)
- provides a gap analysis of the market (Section 5, Identification of key gaps in the market)
- provides conclusions and proposes recommendations (Section 6, Conclusions and recommendations).

2 Battery storage technologies

Over recent years, Australia has witnessed remarkable growth in residential domestic and commercial solar photovoltaic (PV) panels and installations. This growth clearly demonstrates the power of consumer, given the right economic signals and market conditions. However, the growth in solar PV can become a double-edged sword, because high penetration of distributed renewable energy can create variability within the electricity grid. Such variability can be difficult to manage, but energy storage can be deployed to alleviate the issue – it has the potential to stabilise and improve the efficiency of Australian's electricity grid. Also, by providing the opportunity to store energy for later use, storage can help to match energy generation and demand (commonly referred to in the energy industry as *arbitrage*). Thus, energy storage can help to:

- manage household peak power demand
- provide backup power
- adapt customer usage in response to customer electricity tariffs
- enable customers to maximise their renewable generation income by exporting energy to access feed-in tariffs.

Domestic energy storage may be connected to the electrical grid, to supply or receive electricity from the network. Alternatively, it may be a stand-alone system that is purely for the owner's use (Figure 1).

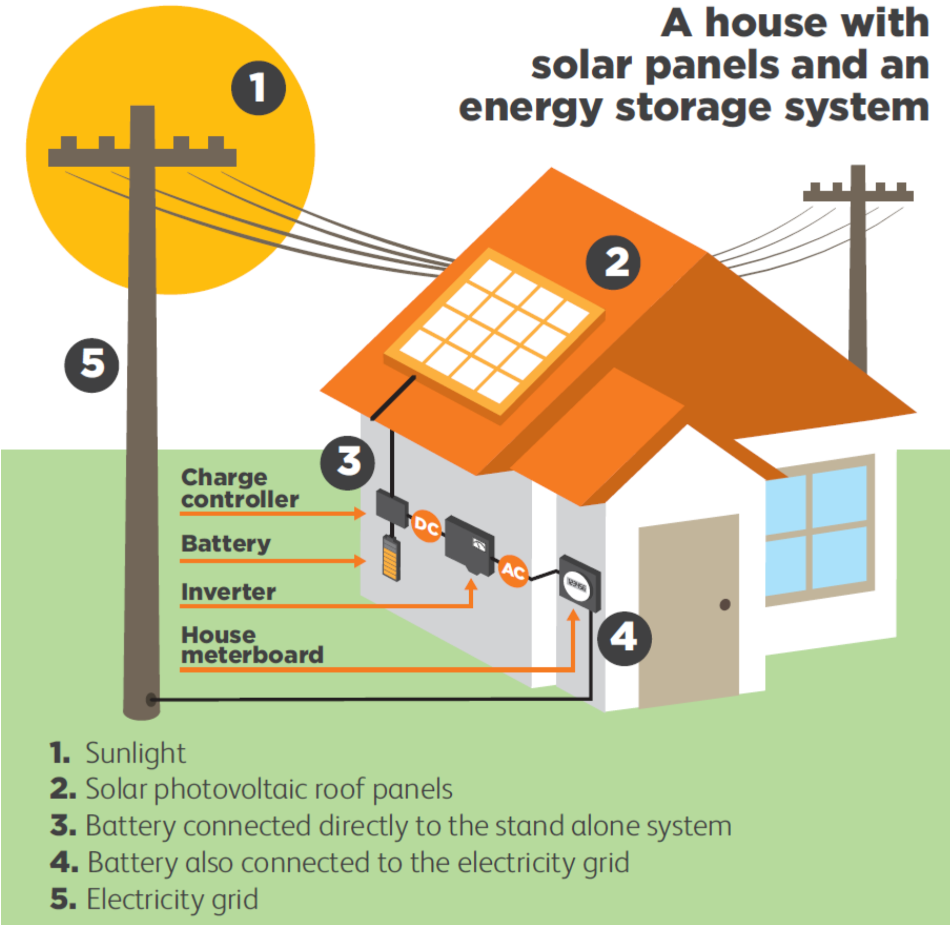

Figure 1: A house with solar panels and an energy storage system

Hailed as the next ‘energy revolution’, energy storage technologies are expected to rapidly decline in cost over the next 5-7 years [1]. At the same time, new pricing structures for electrical network usage are likely to focus on cost-reflective tariffs (i.e. tariffs that reflect the true cost of the energy); such structures will provide a greater incentive for consumers to reduce their energy use during times of peak electricity demand, when costs are highest. Some early adopters are already installing energy storage systems. Deployment rates are expected to increase – and could do so rapidly.

Energy storage technologies are available in many different physical forms, each of which has unique advantages and disadvantages. Examples include:

- electrochemical or electrical (e.g. supercapacitors, superconducting magnets, batteries and fuel cells)
- mechanical (e.g. pumped hydro, compressed air and flywheels)
- thermal (e.g. hot water, molten salt and phase-change material)
- chemical (e.g. hydrogen and synthetic natural gas).

Simple examples of energy storage include a battery-powered torch, which draws on stored energy to provide light, or an air compressor, which stores air under pressure to inflate a tyre. More energy storage technologies and examples are given in reference [1].

The most common forms of energy storage for larger scale stationary deployments (e.g. domestic, commercial and industrial applications) are battery storage technologies. Hence, the rest of this report considers only the key battery technologies most likely to be adopted, as defined by the scope of this study.

2.1 Overview of battery storage technologies

2.1.1 Key concepts

All types of battery are electrochemical energy storage devices, where electricity is stored and released by changes in chemical materials. Although many and varied with respect to internal chemistry, batteries share a number of similarities in their construction. The core unit of any battery device, the battery cell, comprises two electrodes – one positive (the cathode) and one negative (the anode) – as shown in Figure 2. In between the two electrodes is a layer of separator (a porous insulating material) containing an electrolyte, which allows the movement of ions within the cell. Depending on the type of battery, the electrolyte can be liquid, gel or solid.

The separators within each cell are insulating in order to prevent the electrodes from coming into physical contact; this helps to avoid short-circuiting. Additional safety features such as pressure-relief valves, fire retardants and other features may also be incorporated in some battery types. These features will be specific to the battery type and depend on the chemistry of the battery.

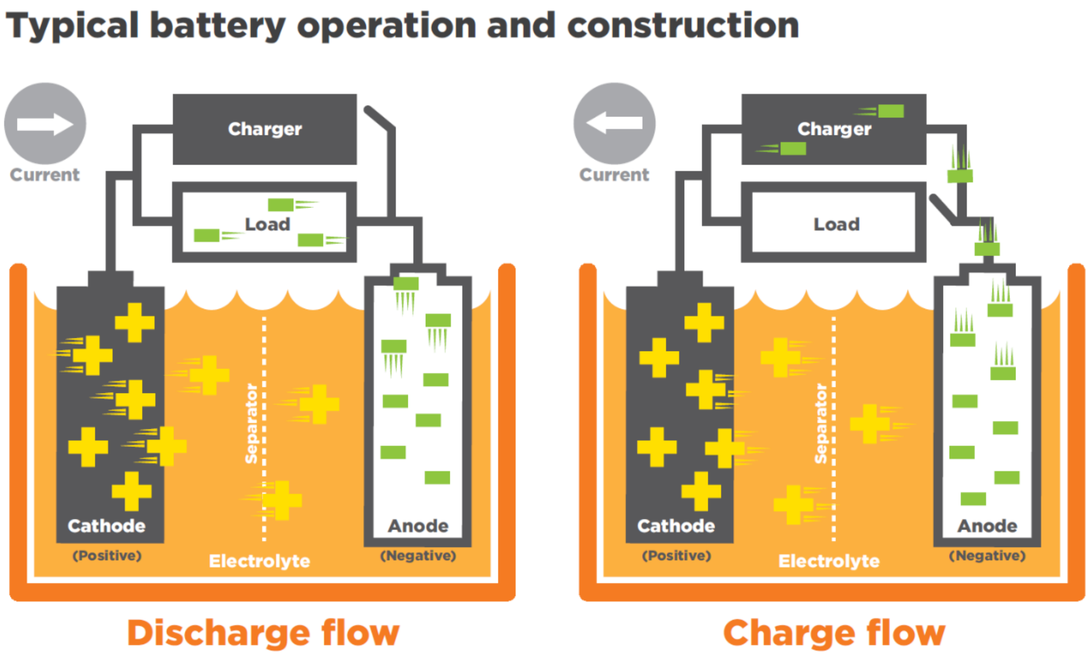

Figure 2: Typical battery operation and construction

The choice of chemical compounds used in a battery determines its performance characteristics. These characteristics include the nature of the device, redox reaction,[2] cell voltages, energy storage and power capability. Multiple battery cells are combined and integrated to create battery packs that meet the performance requirements for the desired application.

Batteries are classified into either *primary* or *secondary* systems. In primary systems, once the redox reaction occurs, the chemical compounds cannot be regenerated. These are termed disposable or single-use batteries (examples include household AA alkaline batteries). Secondary or rechargeable battery systems contain chemical compounds that can be regenerated into their original state when a current (of opposite polarity to that flowing during discharge) is applied to the device. The recharge reaction can be performed many times, with each complete discharge and charge termed a cycle. The remainder of this report considers only secondary batteries.

Batteries have both advantages and disadvantages compared with other forms of energy storage technologies. In terms of advantages, batteries are:

- easily scaled to meet domestic and commercial applications
- portable and well established
- able to store renewable energy in remote off-grid areas where electricity is not readily provided
- easily maintained and replaced
- recyclable (depending on chemistry type; e.g. lead-acid batteries are >80% recyclable).

In terms of disadvantages, batteries:

- can be used for only a limited time, or be recharged for a certain number of cycles
- have limited power or energy capabilities, the extent of which depends on the chemistry type
- can be potentially dangerous if not treated appropriately, and in extreme cases can lead to fires, explosion or chemical pollution
- need to be maintained and periodically checked (e.g. monthly)

[2] The redox reaction includes all chemical reactions in which the oxidation state of atoms changes.

- are sensitive to their environment (e.g. if installed in extreme hot or cold climates, long-term performance may drop or they may stop working altogether).

2.1.2 General technology overview

The most common categories of battery storage presently available in the Australian marketplace are:

- lead-acid (advanced, flooded-cell and sealed)
- lithium (ion and polymer)
- nickel-based (metal hydrides and cadmium)
- flow (zinc bromine and vanadium redox)
- sodium-ion analogue.

Lead-acid batteries are the most common battery type in domestic and small commercial storage systems. They have a long history of use within Australia, and since the late 1980s have been used for off-grid and backup power applications. Lithium-ion batteries are increasing in popularity, because they have a long life and high energy density (i.e. can store a lot of energy per volume). Nickel-based, flow and sodium-ion analogue batteries are less common, but can be useful in particular applications (e.g. flow batteries can be well suited to daily energy shifting, or sodium-ion may be the best choice at certain environmental temperatures). Figure 3 shows the broad categories of rechargeable battery energy storage presently available. The list for each category is placed in order, with the safest type at the top. Also, the technologies are ordered from left to right in accordance with their technological and market maturity, with the most mature on the left. A more comprehensive list of battery technologies is given in reference [1].

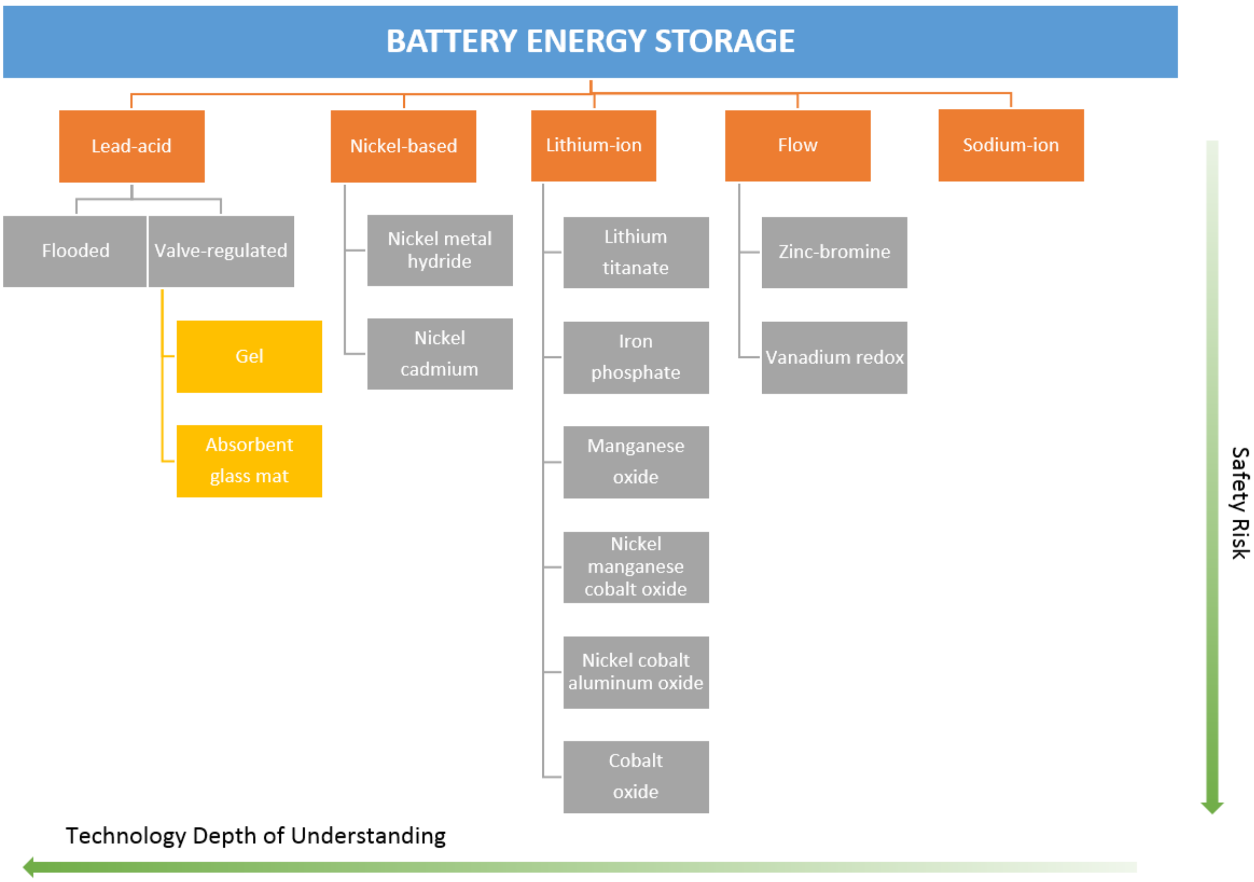

Figure 3: Categories of battery energy storage

Each type of battery technology, based on the various chemistries, is discussed below.

2.1.3 Lead-acid batteries

The lead-acid battery is one of the most well-known battery technologies, with well-established standards in place and highest rate of recycling. It is based on the reactions of lead dioxide (positive electrode) and elemental lead (negative electrode) with sulfuric acid in the electrochemical cell. The specific power and energy outputs of lead-acid batteries are based on the size and geometry of the electrodes. The power output can be improved by increasing the surface area for each electrode; that is, by using greater quantities of thinner electrode plates in the battery.

Lead-acid batteries can be either flooded-cell or sealed types, as shown in Figure 3. The flooded type is the more cost effective, uses liquid electrolyte, and has historically been used in automotive and industrial applications. The sealed type (also called valve-regulated lead-acid, VRLA) uses either a gel or liquid electrolyte absorbed into a fibreglass mat. This type is becoming more common in renewable energy storage applications, because they are safer and easier to maintain than flooded lead-acid batteries.

Although lead-acid chemistry is still the mainstay of the renewable energy storage industry, this is steadily changing as other battery chemistries (e.g. lithium-ion) offer potentially advantageous features. However, recent advances in lead-acid technology have resulted in performances approaching those of popular lithium-ion variants. Therefore, for the foreseeable future, accredited installers and designers will need to be familiar with a mix of technologies. Also, homeowners wanting to install energy storage will need to be educated on these technology options.

Lead-acid batteries are generally safe, but do emit a corrosive and explosive mix of hydrogen and oxygen gases during the final stages of charging. If these gases are not vented appropriately in accordance with regulations they can potentially ignite if exposed to a spark or flame. Hence, it is essential that this type of battery is located in a well-ventilated enclosure or place. Another hazard is that the sulfuric acid electrolyte can cause serious burns if spilt. These are risks that, if managed by appropriate care and use of the batteries, will not lead to a dangerous situation; they are much like the risks associated with driving a petrol-fuelled car, which remains a useful and prevalent technology in daily life.

The industry has well-established standards and operational frameworks for lead-acid battery technology. Further, this technology currently has the most recognised recycling and handling procedures and regulations in place.

2.1.4 Lithium-ion batteries

The term lithium battery is a 'catch-all phrase' that describes a wide variety of battery types. Examples include:

- lithium-ion – in which lithium ions enter or leave a host crystal and vice versa
- lithium polymer – in which the anode may be a lithium metal foil
- lithium metal batteries – in which the anode is a foil of lithium metal (this is not a rechargeable technology).

These different types of lithium battery have some similarities, but also clearly defined differences in characteristics such as operating voltages and temperatures, rechargeability, performance and lifetime. To those familiar with the field, the meaning of the phrase 'lithium battery' and the specific subtype is usually clear. However, for those not familiar with the field, the terms 'lithium battery' and 'lithium-ion' are used interchangeably. This report considers only lithium-ion batteries; that is, those in which lithium ions are exchanged in and out of a crystal matrix, in a rechargeable fashion. The report's discussion and recommendations refer only to this particular type of battery and should not be used for any other lithium battery variant.

Compared to traditional lead-acid batteries, lithium-ion batteries have higher energy storage densities (i.e. more energy can be stored in a battery of a given volume and weight), greater power densities (i.e. smaller batteries can produce greater instantaneous power outputs), better charging efficiency and longer lifespans. They can be more expensive to purchase initially, but this is rapidly changing as the markets are developing. The push for lower-cost batteries for electric vehicles and domestic energy storage systems has spurred on mass production in China, South Korea and Japan.

High nominal cell voltage levels of up to 3.7 volts (V) and beyond mean that the number of cells in series, with their associated connections and electronics, can be reduced to obtain the target voltage.

Lithium-ion batteries generally have a high coulombic (charge) efficiency, typically in the range of 95–98% (where efficiency is a measure of how much charge is wasted during a charge–discharge cycle). They deliver a similar capacity over a broad range of discharge rates, from seconds to weeks, which makes them a flexible and universal storage technology.

Common variants of lithium-ion batteries for storage systems are:

- lithium cobalt oxide
- lithium manganese oxide
- lithium nickel cobalt aluminium oxide
- lithium nickel manganese cobalt oxide
- lithium iron phosphate
- lithium titanate – in which lithium titanate replaces the graphite in the battery anode and the aforementioned cathodes are used.

Safety requires careful management for lithium-ion batteries. Most of the metal oxide electrodes are thermally unstable and can decompose at elevated temperatures. This releases oxygen, which can lead to thermal runaway (i.e. fire). Lithium iron phosphate and lithium titanate have been designed to reduce the risk of thermal runaway compared with other lithium-ion batteries, and are thus widely regarded as safer.

To minimise the risk of thermal runaway, lithium batteries must have an effective battery management system (BMS).[3] This enables each cell in the battery bank to be individually monitored when charging and discharging. Overcharged cells and cells discharged to below the minimum voltage point can cause cell failure, so a good BMS is important. Usually, a voltage balance circuit is installed to monitor the voltage level of each individual cell and prevent voltage deviations among them. The BMS must be tailored to the individual chemistry and battery type being used. Connection of battery systems to a BMS tailored to a different battery chemistry or type can lead to safety and performance issues. Thus, accredited installers must be aware that the lithium-ion name encompasses a wide variety of chemistry types and subclasses that would require their own specific BMS.

A 2011 report [2] noted that the term 'lithium polymer' has been previously used to describe lithium metal rechargeable cells that used a polymer-based electrolyte. However, as the technology is becoming more mature, the term lithium polymer is now used to describe a wide range of lithium-ion cells enclosed in soft pouches, with electrolyte that may or may not be polymer based.

2.1.5 Nickel-based batteries

Nickel-based batteries are a mature technology, and are widely available for use in a diverse range of applications and commercial products. Most nickel-based batteries use the same cathode material; that is, nickel oxyhydroxide in the charged state. The anode material may differ, and may include metals such as cadmium (nickel-cadmium, Ni-Cd), metal hydride (nickel metal hydride, NiMH), or iron (nickel-iron, Ni-Fe). During discharge, the nickel oxyhydroxide reacts with water to produce nickel hydroxide and a hydroxide ion. Upon recharge, the reaction process is reversed.

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[3] A BMS is an electronic system that manages a rechargeable cell or battery pack

The nickel-cadmium battery possesses greater energy storage capability and power capabilities than lead-acid batteries. Nickel metal hydride is superior in both power and energy to nickel-cadmium. Also, it doesn't suffer from the so-called 'memory effect' (i.e. a reduction in the longevity of a battery's charge, due to incomplete discharge in previous uses) but is hampered by increased self-discharge as the battery ages, which affects its long-term performance.

2.1.6 Flow batteries

Flow batteries store energy in one or more chemical species, which are dissolved into liquid electrolytes. The electrolytes are stored externally in tanks and pumped through electrochemical cells, in which the oxidized species[4] (cathode side) establish a potential difference against the reduced species (anode side). As shown schematically in Figure 4, when a load is connected to the cell, current flows as the dissolved active materials are consumed. The power output of a flow battery is largely determined by the design and area of the membrane within the electrochemical cell, whereas the energy or capacity depends on the volume of the tanks and the concentration of dissolved active materials.

Presently, there are two main types of flow batteries: zinc bromine and vanadium redox. The zinc bromine flow battery uses a solution of zinc bromide as an electrolyte, with an amine or complexing chemical added to stabilize the bromine evolved during charging. The vanadium redox type uses solutions of vanadium ions in two different oxidation states.

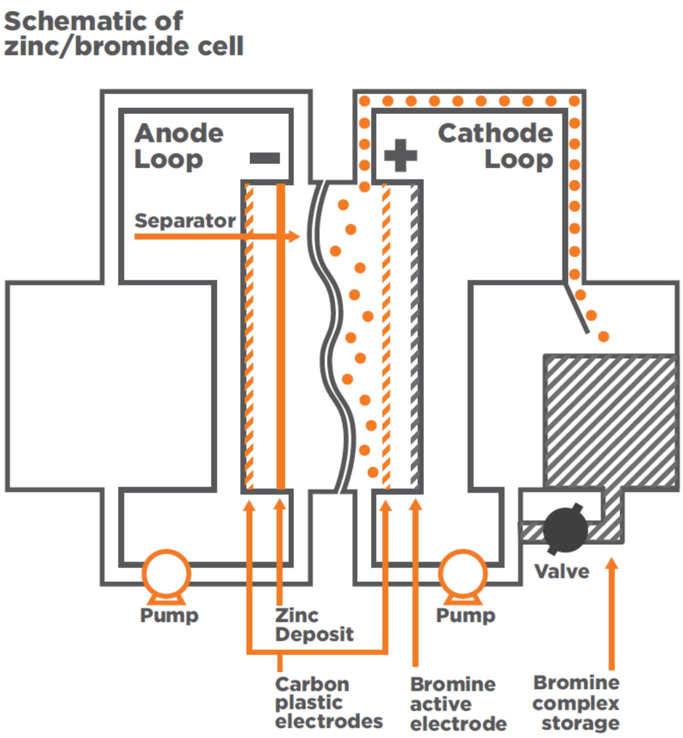

Figure 4: Schematic of a flow battery

[4] Species are atoms, molecules, molecular fragments, ions and so on that are being subjected to a chemical process.

2.1.7 Sodium-ion analogue batteries

Sodium-ion analogue battery storage systems are relatively new to the Australian market. They comprise a sodium chloride and hydrogen oxide electrolyte (i.e. salt water), manganese oxide cathode, carbon composite anode and synthetic cotton separator. The battery uses noncorrosive reactions at the anode and cathode to prevent corrosion of the materials. The water-based chemistry results in a non-hazardous, non-combustible product that is safe to handle and environmentally friendly. More information on sodium-ion analogue battery technology is given in reference [3].

2.2 Technical information and terminology

A wide variety of batteries are available in the market, and these technologies have a range of attributes. Table 1 lists emerging and established technologies, typical technical specifications of the batteries considered in this report.

Table 1: Typical battery chemistry parameters

Parameter → Technology ↓	Maturity level (developing or mature)	Suitable application (energy, power or both)	Life time / cycle life (Years / cycles)	Power density (Wkg^{-1} / kWm^{-3})	Energy density ($Whkg^{-1}$ / $kWhm^{-3}$)	Operational temperature (° C)	Self-discharge (%/day)	Cell voltage (V)
Lead-acid	Mature	Energy	3–15 / 2000–3000	75–300 / 90–700	30–50 / 73–82	−10 to 40	0.1–0.3	1.75–2.35
Advanced lead-acid	Developing	Energy	3–15 / 3000–6000	75–300 / 90–700	30–50 / 73–82	−10 to 40	0.1–0.3	2.30–2.45
Lithium iron phosphate	Mature	Both	3–15 / 3000–6000	230–340 / 1300–10 000	100–250 / 250–620	0 to 45	0.1–0.3	2.65–3.2
Lithium titanate	Developing	Both	3–15 / 3000–6000	230–340 / 1300–10 000	100–250 / 250–620	−10 to 50	0.1–0.3	2.55–3.1
Lithium nickel manganese cobalt oxide	Developing	Both	3–15 / 3000–6000	230–340 / 1300–10 000	100–250 / 250–620	−10 to 45	0.1–0.3	2.55–3.1
Zinc bromide	Mature	Energy	5–10 / 300–1500	50–150 / 1–25	60–80 / 20–35	10 to 45	0.1–1	0.17–0.3
Vanadium redox	Developing	Energy	10–20 / ~13 × 103	NA / 0.5–2	75 / 20–35	0 to 40	0.1–10	0.7–0.8
Nickel-cadmium	Mature	Energy	15–20 / 2300–2500	150–300 / 75–700	45–80 / <200	−40 to 45	0.2–0.6	0.9–1.2
Sodium-ion analogue	Developing	Energy	12 / 3000–6000	1.6 / 1.8	40/20	−5 to 40	0.83	3–5.9

Reproduced from United States Department of Energy data [4] and CSIRO data [1], [5] and [6]. Note that lithium batteries are all Li-ion types.

The actual performance obtained from examples of the batteries listed in Table 1 may vary outside the ranges indicated, depending on the design and quality of the batteries and their usage.

When considering the performance and limitations of battery technologies, an understanding of terminology is essential. More detailed information on battery terminology is given in reference [1]. More terminologies and their definitions are given below, but the three important and commonly specified parameters for batteries are voltage, power and energy. Basically, **energy** is defined as the measure of the ability to do useful work or produce a change over time. It is normally expressed in kilowatt hours (kWh) or as the capacity in ampere-hours (Ah). **Power** is defined as the rate at which energy is flowing or the rate at which work is being done. It is generally expressed in kilowatts (kW). Thus, a 10-kWh domestic battery system can theoretically provide 1 kW of power output continuously for 10 hours, or 10 kW of power for 1 hour.

Power density is the amount of power that a battery can produce per unit volume (W/dm^3 or W/l), whereas **specific power** is power per unit weight (W/kg). In contrast, the amount of energy stored for a given volume or mass is referred to as either **energy density** (Wh/l) or **specific energy** (Wh/kg).

Cycle life is the number of charge–discharge cycles a battery is capable of within a defined period. The **lifetime** of a battery is often denoted by the total number of cycles that a battery can deliver. **Battery life**, which is a measure of battery performance and longevity, is the amount of time a battery can run on a full charge. It is normally estimated by a manufacturer as the number of charge–discharge cycles that are possible before it reaches the end of its useful life. Additionally, batteries have a **self-discharge rate,** which is the percentage of internal battery discharge per day (%/day).

Operating temperature range denotes the temperature range, measured in degrees Celsius (°C), within which the battery technology needs to be kept for safe, reliable operation. Operating the battery outside its operational temperature range can significantly reduce performance and lifetime, and could increase the risk of incidents such as fire or explosion.

Voltage is the electric potential across the terminals of the battery. For batteries, this is from the negative (black) to the positive (red) terminals. The **charge voltage** is the corrected charge voltage of a battery. For example, the cell voltage during charging of a typical lead-acid battery cell typically ranges from 2.30 to 2.45 V. For example, a lead-acid car battery is generally made up of six cells in series to create a 12-V battery.

Round-trip efficiency is the ratio of energy put in during charging to the energy retrieved during discharging.

2.3 Safety, handling, storage and transportation requirements

2.3.1 General technology safety

Safety risks and handling methods specific to battery storage systems include those given in Table 2. Many of these concerns are warranted, since battery storage are classified as dangerous goods, but appropriate care and handling procedures markedly reduce the risk, taking it to manageable levels.

Safe handling advice for where to store battery storage systems is often outlined in the material safety data sheet (MSDS) provided for each battery (an MSDS is an important component of occupational health and safety). A general summary of these recommendations is given in Table 2.

Table 2: Issues and actions for safe handling of battery storage systems

Risk	Recommended action
Safety	
Explosion or fire	• Keep battery storage systems away from potential sparks or flames. • Instigate appropriate emergency response if fire is nearby or occurs as a result of battery malfunction.
Electrical shock	• Do not place metal or conductive objects on top of battery storage systems or touch across the terminals.
Handling	
Risk of injury from lifting or moving storage systems	• Use correct lifting procedures when moving battery storage systems.
Hazardous chemicals	• Wear protective clothing when dealing with battery storage systems. • Take appropriate action if a spill from the battery occurs.
Cascading battery cell failure	• Instigate appropriate shut down procedure and display signage.
Temperature fluctuations	• Do not freeze or overheat battery storage systems. • Perform extra monitoring in extreme temperatures.
Long-term storage	• Nickel metal hydride and nickel-cadmium battery storage systems are made to be charged frequently, because they gradually lose charge (over a few months). It is therefore good practice to charge battery storage systems before use, using a recommended charger and observing proper charging polarity. Improper charging can cause heat damage or even high-pressure rupture.
Arc, flash or burn	• Accidental short circuit for a few seconds will not seriously affect the battery. However, prolonged short circuits will cause high cell temperatures, which can cause skin burns. Sources of short circuits include jumbled battery storage systems in bulk containers, metal jewellery and metal-covered tables, metal tools or metal tie-down straps or belts used for assembly of battery storage systems into devices. • Do not open a battery. The negative electrode material may be pyrophoric (capable of igniting spontaneously in air). Should an individual cell from a battery become disassembled, spontaneous combustion of the negative electrode is possible. This is much more likely to happen if the electrode is removed from its metal container. There can be a delay between exposure to air and spontaneous combustion.
Storage	
Containment	• Store lead-acid battery storage systems in well ventilated locations under cover (dry conditions) in cool ambient temperature [7]. • Store flow battery storage systems in a secured, cool, dry, well-ventilated area [8]. • Store lithium battery storage systems in a cool, well-ventilated area. Elevated temperatures can shorten battery life [9]. • Never seal or encapsulate nickel metal hydride battery storage systems. Do not obstruct safety release vents on battery storage systems. Encapsulation (potting) of battery storage systems will not allow cell venting and can cause high-pressure rupture.
Battery short circuit	• Regular maintenance recommended (monthly). • Electrical and performance issues may occur due to water contact or variable temperatures.

Modified from references [4] and [10].

2.3.2 Transportation

Battery storage systems are classified as dangerous goods, and thus require adherence to specific transport regulations and procedures. Information regarding transportation of battery storage systems under their relevant classifications can be found in the latest edition of the *Australian Dangerous Goods Code* [11]. The next version of the Code (Version 7.4), which will be published in late 2015, includes new provisions and packaging instructions for lithium-ion battery storage.

Most land transportation requires a waste transport licence and a classification placard displayed on the vehicle [10]. The transport regulations for different types of battery chemistries are shown in Table 4. Note that, for air transport, the Civil Aviation Safety Authority, International Air Transport Association (IATA) and other governing aviation bodies are presently reviewing standards and procedures due to several incidents and narrowly avoided incidents involving battery storage systems (discussed in Section 2.6).

Lead-acid and nickel cadmium battery storage systems have been classified as a Class 8 Dangerous good: Corrosive substances (see Table 3 and Table 4). This classification is backed by extensive worldwide experience with these technologies, and understanding of the hazards that can occur during transportation. However, despite the growing prevalence of lithium battery storage systems, they are still classed as Class 9: Miscellaneous. This is mostly due to the fact that the understanding of transportation hazards for this technology is poor. There is still too little information about hazards and accidents that have occurred to enable robust standards and classifications to be made for the transportation industry and this technology. Once this information has been ascertained through detailed reporting and data collection, a more robust and accurate classification can be made.

Presently, the Australian Maritime Safety Authority National Standard for Commercial Vessels (NSCV) is being progressively introduced to replace the Uniform Shipping Laws Code. Battery safety requirements are beginning to appear in documentation from the NSCV [12]. In the development of such documentation, the following standards were consulted or referenced:

- *IEC 60092 – Electrical installations in ships*
- *ISO 10133 – Small craft – electrical systems – extra-low voltage direct current (DC) installations*
- *ISO 13297 – Small craft – electrical systems – alternating current (AC) installations*
- *AS/NZS 3000: Electrical installations standard (known as the Australian/New Zealand Wiring Rules)*
- *AS 1852 – International electrotechnical vocabulary*
- *AS 2676.1 – Guide to the installation, maintenance, testing and replacement of secondary batteries in buildings – vented cells*
- *AS 2676.2 – Guide to the installation, testing and replacement of secondary batteries in buildings – sealed cells*
- *AS 3011.1 – Electrical installations – secondary batteries installed in buildings – vented cells*
- *AS 3011.2 – Electrical installations – secondary batteries installed in buildings – sealed cells*.

There are strict requirements related to the ventilation of battery spaces to open-air decks of the vessel, the placement of battery spaces within the vessel and the use of battery storage systems as an emergency source of electrical power.

Since a large portion of Australia's import industry relies on shipping, further development of these practices and guidelines will affect Australia's domestic energy storage industry. Hence, the industry should be kept abreast of these changes to ensure that business models keep in line with regulation change. This will enable growth and stability for small to medium enterprises and the household consumer on the frontline.

Table 3: Class 8 and 9 dangerous goods classes

Class[a]	Description
Class 8 – Corrosives	Corrosives are substances which by chemical reaction degrade or disintegrate other materials upon physical contact.
Class 9 – Miscellaneous dangerous goods	Miscellaneous dangerous goods are substances, materials and articles which during transport present a danger and/or hazard not covered by other classes. This class includes, but is not limited to, environmental hazardous, transported at elevated temperatures, and miscellaneous articles.

[a] Classes 1–7 have been omitted for simplicity.

Table 4: Summary transport standards and requirements

Battery technology and classification	Land transport	Sea transport	Air transport
General	Battery storage systems of different chemistries may not be loaded onto the same pallet Dry battery storage systems are not classified as dangerous goods	None found	Battery storage systems being transported by air must be protected from short-circuiting with insulated packaging and tabs
Flooded lead-acid batteries **[Class 8]**	Land Transport (ADR/RID) Classification: Class 8 Required label: Corrosive UN N°: UN2794 Proper shipping name: BATTERIES, WET, FILLED WITH ACID New and spent batteries are accepted from all ADR/RID (European rule) if they meet the requirements of Special Provision 598. Vehicle must be equipped with one or two fire extinguishers for carriage of goods greater than 1000 kg [13] Transporter must have a specialised dangerous goods driver's licence [13] Passengers are not allowed [13]	Sea Transport (IMDG Code) Classification: Class 8 Required label: Corrosive UN N°: UN2794	Air Transport (IATA-DGR) Classification: Class 8 Required label: Corrosive Packing Group: II (Substances and preparations presenting medium danger) [11]
Valve-regulated lead-acid batteries only **[Class 9]**	Land Transport (ADR/RID, US Department of Transportation) UN N°: UN2800 Classification ADR/RID: Class 8 Proper shipping name: BATTERIES, WET, NON SPILLABLE Packing Group ADR: not assigned Label required: Corrosive ADR/RID: New and spent battery storage systems are accepted from all ADR/RID requirements provided the requirements of Special Provision 598 are met. ADR Special Provision 598 states	Sea Transport (IMDG Code) UN N°: UN2800 Classification: Class 8 Proper shipping name: BATTERIES, WET, NON SPILLABLE Packing Group: not assigned Label required: Corrosive If non-spillable batteries meet the requirements of Special Provision 238, they are exempted from the IMDG codes, provided that the batteries' terminals are	Air Transport (IATA-DGR) UN N°: UN2800 Classification: Class 8 Proper shipping name: BATTERIES, WET, NON SPILLABLE Packing Group: not assigned Label required: Corrosive If non-spillable batteries meet the testing requirements in Packing Instruction 872 and Special Provision A67, they are exempted from all the IATA-DGR codes, provided that the batteries' terminals are protected against

Battery technology and classification	Land transport	Sea transport	Air transport
	that: 'New storage batteries are not subject to the requirements of ADR when: a) they are secured in such a way that they cannot slip, fall or be damaged b) they are provided with carrying devices, unless they are suitably stacked, e.g. on pallets c) there are no dangerous traces of alkalis or acids on the outside d) they are protected against short circuit' Vehicle must be equipped with one or two fire extinguishers for carriage of goods greater than 1000 kg	protected against short circuits	short circuits
Lithium batteries **[Class 9]**	Australian Dangerous Goods Code applies an exemption from certain packaging requirements for used and damaged lithium battery storage systems under the following classification: • UN 3090 – lithium metal batteries • UN 3480 – lithium-ion batteries Vehicle must be equipped with one or two fire extinguishers for carriage of goods greater than 333 kg	The International Maritime Dangerous Goods Code has provisions for the transport of lithium battery storage systems	Most of the larger airlines now ban the transport of lithium batteries
Nickel-cadmium & nickel metal hydride batteries **[Class 8]**	Nickel cadmium battery storage systems are classified as a dangerous good and there are packaging requirements in the Australian Dangerous Goods Code. Vehicle must be equipped with one or two fire extinguishers for carriage of goods greater than 1000 kg	Nickel metal hydride battery storage systems are classified as a dangerous good for sea transport	None found
Zinc bromide flow batteries **[Class 8]**	None found	None found	None found

ADR/RID, Agreement on Dangerous Goods by Road/Regulations concerning the International Transport of Dangerous Goods by Rail; DGR, Dangerous Goods Regulations; IATA, International Air Transport Association; IMDG, International Maritime Dangerous Goods; UN, United Nations; US, United States.

Being classified as Class 9, lithium battery storage systems present a danger not covered by other classes. As understanding of the technology grows, they have been given the following specific assignments [11]:

- 3090 LITHIUM METAL BATTERIES (including lithium alloy batteries)
- 3091 LITHIUM METAL BATTERIES CONTAINED IN EQUIPMENT (including lithium alloy batteries)
- 3091 LITHIUM METAL BATTERIES PACKED WITH EQUIPMENT (including lithium alloy batteries)
- 3480 LITHIUM ION BATTERIES (including lithium-ion polymer batteries)
- 3481 LITHIUM ION BATTERIES CONTAINED IN EQUIPMENT (including lithium-ion polymer batteries)
- 3481 LITHIUM ION BATTERIES PACKED WITH EQUIPMENT (including lithium-ion polymer batteries).

Nickel-cadmium [14] sealed battery storage systems are considered to be ‘dry cell’ battery storage and are not subject to dangerous goods regulations for the purpose of transportation by the United States Department of Transportation (DOT), the International Civil Aviation Administration, IATA or the International Maritime Dangerous Goods regulations. However, the only DOT requirement for shipping nickel-cadmium battery storage systems is Special Provision 130, which states: ‘Batteries, dry are not subject to the requirements of this subchapter only when they are offered for transportation in a manner that prevents the dangerous evolution of heat (for example, by the effective insulation of exposed terminals)’. IATA requires that battery storage systems being transported by air must be protected from short-circuiting and protected from movement that could lead to short-circuiting. Nickel-cadmium battery storage systems are classified as a D006 hazardous waste because of the presence of cadmium. This waste code is assigned because of toxicity, not corrosiveness; these batteries do not meet the definition of a corrosive waste. More information concerning nickel-cadmium shipping, testing, marking and packaging is given in reference [15].

Flow battery storage systems and sodium-ion analogue battery storage systems can be transported ‘dry’ (i.e. dry cell). That is, the electrolyte can be removed for transportation, and in this form the battery storage systems are not subject to dangerous goods regulations for the purpose of transportation. However, for the zinc bromide flow battery, the electrolyte requires special transporting (Class 8), which then requires the battery modules to be filled with the electrolyte before use. Therefore, a zinc bromine electrolyte or a battery module filled with electrolyte, as well as a module that once contained electrolyte, must be handled, stored and transported as an item with a dangerous goods classification of 8 [16]. Further considerations are required; for example, a RedFlow zinc bromine battery module size of 8 kWh weighs about 225 kg (with 100 L electrolyte filled) and a dry module weighs 90 kg. The wet module needs to be stored between 5 and 45 °C in an upright position, including during transport. This places additional requirements for transportation of wet modules compared to dry modules.

According to Aquion Energy Inc. [17], their sodium-ion analogue battery is not regulated by the DOT as a dangerous good. The individual constituents in the battery are not regulated by DOT, so it is easier to transport than lead-acid and nickel-based battery storage systems. However, the battery stacks and modules must not exceed 15 degrees of tilt angle during transportation and placement. Aquion states that the battery storage systems should not be tipped for an extended period of time during shipping, and that this restriction must be communicated to the shipper before transport, to ensure compliance. The battery storage systems may be wrapped (United States shipment) or crated (shipments outside the United States). Should the battery system be stored or unused for an extended period, Aquion recommends removing all communication and power connections, to prevent unintended self-discharge and undetected ground faults. However, any grounding should be kept in place. Conditions for storage of the Aquion battery are temperature between –10 and 45 °C, and state of charge of less than 50%, to avoid permanent damage [18]. Although the electrolyte is nontoxic, noncorrosive sodium sulfate-based saltwater with a neutral pH, if it comes into contact with the eyes or skin, they need to be thoroughly washed with water.

2.3.3 Sample transport signage

Appropriate safety and hazard identification labelling and signage should be clearly displayed on trades vehicles and installations. Examples of such signage are shown in Figure 5.

Figure 5: Example safety and hazard identifications labels and signage. Class 6: Toxic substances, Class 8 Corrosive substances, Class 9 Miscellaneous dangerous substances and articles [19]

For the aviation industry, the example label shown in Figure 6 alerts cargo handlers of packages containing batteries, to ensure safe and secure shipping of hazardous materials. The labels are available for lithium-ion batteries, and include forbidden markings, inspection, and battery-specific Class 9 Hazard.

Figure 6: Transport and handling example label used in the aviation industry [20]

2.4 Installation, maintenance and warranty considerations

2.4.1 Installation

The performance of a battery energy storage system will depend on proper installation, operation and maintenance. For example, consider a combined solar PV-battery installation with energy storage. Before installing the solar PV system, an accredited designer should select and size the battery system (including battery type, capacity, cables, devices and material appropriate for the required application, taking into account geographic location) to suit the size of the solar PV panels, as well as the budget of the customer. For any stationary battery installations, the same procedures should be followed for correct sizing, budget, safety and performance. Accreditation for stand-alone stationary energy storage installations is limited; the industry needs to address this situation promptly because the uptake of these systems is on the rise.

Installation, operation and maintenance, safety, testing procedures, and decommissioning of the battery energy storage and of the electrical systems associated with solar PV installations should all be done according to the recommendation and instructions of the manufacturers. This is because the various battery chemistry types, systems and components can have different characteristics and operating parameters. Thus, each battery chemistry type has different requirements for handling, monitoring, operation and maintenance.

Two different types of accreditation are in place for design and installation of battery storage systems. A person can be an accredited designer, accredited installer, or both, as explained in Section 4 of this report. The context in which battery storage is used is important for safety considerations; therefore, it is essential to select and install the storage for the intended application.

Domestic and small commercial battery energy storage systems are now available in standard packages ranging from 2 kWh to more than 20 kWh in size (with some even expandable to 1 MWh). Customers can pick the size to suit their budget, solar PV capacity and load requirements of the premises. Apart from the price, other important parameters to consider are warranty period and cycle life. The battery storage systems generally come with a highly specific BMS, which is important for the safe operation and maintenance of the system.

When assessing the life of a battery and its warranty period, the performance of the technology must be considered. The cycle life, depth of discharge and round-trip efficiency (explained in Table 5) are factors important in determining the likely lifetime of a battery. A comparison of some currently available energy storage technologies is given in Table 5.

Table 5: Comparison of factors influencing lifetime of a battery for different technologies [1]

Technology	Depth of discharge[a] %	Cycle life[b]	Claimed lifetime/years	Claimed round-trip efficiency[c] %
Advanced lead-acid (UltraBattery)	40	4000	10	90–98
Lithium iron phosphate	50–90	3000–6000	5–10	89
Lithium cobalt oxide	50	800–1200	5–7	97
Lithium manganese oxide	90	5000–10 000	10–30	75–95
Lithium nickel cobalt aluminium oxide	50	10 000	18–25	95–98
Lithium nickel manganese cobalt oxide	80	4000–8000	7	95–98
Zinc bromide flow battery (Redflow)	100	500–2000	5–10	80
Sodium-ion analogue (Aquion Energy)	50–100	3000–6000	10–15	80–90

a Depth of discharge (DoD) is the amount of energy the battery has used. If the battery is 100% fully charged, the DoD is 0%. If a battery is 100% empty the DoD is 100%.
b Cycle life is defined as the number of complete charge–discharge cycles a battery can perform before its nominal capacity falls below 80% of its initial rated capacity.
c Round-trip efficiency is the amount of discharge, expressed as a percentage of the previous charging step.

The sizing of a battery system is important for its intended use. Correct sizing ensures that the electrical loads being supplied or the power system being supported are adequately catered for by the battery for the period of time for which it is designed. Incorrect battery sizing can lead to issues such as usage problems, permanent damage to battery cells from over discharge, and low load voltages.

Battery storage systems for domestic and commercial applications can be sized using a guideline set out in the available standards. For example, the IEEE standard 1030 2007 includes details for recommended practice for sizing lead-acid battery storage systems for stand-alone solar PV. The sizing process outlines the following steps:

1. Collect the site loads that the battery storage system needs to support.
2. Construct a load profile and calculate the required power (i.e. kW) and energy (i.e. kWh) for the battery storage system.
3. Select the battery storage type and determine the characteristics of the battery cell.

4. Select the number of battery cells to be electrically connected in series or parallel.

Free online software is available for calculating the appropriate size for battery and solar PV systems.[5]

Most storage systems comprise a number of cells, which are assembled into batteries. The batteries are then connected together into a pack or bank, with commonly used voltages of 12, 24, 48 or 120 V. Battery storage systems can be supplied as a single unit, but usually come as individual cells that are assembled into a complete battery pack onsite.

Battery manufacturers provide information about how long their products should last, and installers should design and install battery banks to comply with standards and maximise battery life. Standards relating to lead-acid battery storage systems for stationary purposes include:

- *AS 2676-1992 – Guide to the installation, maintenance, testing and replacement of secondary batteries in buildings*
- *AS 3011-1992 – Electrical installations — secondary batteries installed in buildings*
- *AS 4029-1994 – Stationary batteries — lead-acid*
- *AS 4086-1993 – Secondary batteries for use with stand-alone power systems*.

For installations where the battery is connected to a solar PV system that is grid connected, an inverter is required. Inverters convert DC power from batteries or solar modules into usable AC power, normally 240 V AC (single-phase) or 415 V AC (three-phase). Inverters are complex electronic devices and must be installed in relatively clean areas. The following standards should also be observed:

- *AS 4777-2005 – Grid connection of energy systems via inverters*[6]
- *AS/NZS 4763:2011 – Safety of portable inverters*
- *AS/NZS 5603:2009 – Stand-alone inverters – performance requirements*.

The battery storage system installation should be designed in accordance with the requirements of AS/NZS 4509.1, and the batteries should be located in accordance with the manufacturer's recommendations. Consideration should also be given to the following points:

- Localised heat sources (e.g. direct sunlight, generators, battery proximity to walls exposed to direct sunlight) should not be present.
- Extreme ambient temperatures should be avoided, because low temperatures decrease battery capacity and high temperatures shorten battery life.
- The battery bank location should preclude contamination of the natural environment, damage to equipment and injury to personnel in the event of electrolyte spillage.
- The battery bank should not be located near combustible material or near metal objects capable of falling across the battery terminals and causing the battery to short-circuit (i.e. arc, flash or burn).
- The size of the enclosure should allow for sufficient clearance to provide access for installation, maintenance, handling equipment and safety equipment.
- In New Zealand, the battery enclosure or stand shall protect the battery storage systems from damage due to seismic (earthquake) activity and it shall comply with NZS 4219.
- In Australia, the battery stand or supports shall comply with AS 1170.4.
- The supporting surface of the enclosure should have adequate structural strength to support the weight of the battery bank and its support structure.
- The enclosure should be resistant to the effects of electrolyte, either by the selection of materials used or by appropriate coatings. Provision should be made for the containment of any spilled electrolyte. Corrosive resistant trays in which the batteries sit should be capable of holding electrolyte equal to the capacity of at least one cell of the battery bank.
- Any enclosure doors should allow unobstructed exit.

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[5] The HOMER software is available at: http://www.homerenergy.com/software.html
[6] Revisions to this standard are imminent.

- All battery installations, including those for both vented and VRLA batteries, shall have natural or force ventilated enclosures.

2.4.2 Performance, maintenance and operation

The way in which a battery is used and maintained will have a significant effect on the battery lifetime and its performance. There are many different battery chemistries, each with its own particular care requirements. However, all battery types have an electrical state of health to maintain. Certain parameters must be monitored to achieve optimal operational safety and performance of a battery system. The following section discusses the key maintenance requirements of the different battery technologies.

2.4.3 General battery performance (applicable to all technologies)

One of the key questions for energy storage is how long it will last. The lifetime of the battery is strongly dependent on how it is used and maintained. To optimise your battery performance it is good to know the battery chemistry well, for example, lead-acid prefers a slow rate of charge and discharge in a single cycle per day. Alternatively, if the battery is used to smooth the intermittent generation from a solar PV panel and is operating continuously in a partial state of charge most days, this may decrease the lifetime of the battery. Further, if a battery is used only on rare occasions to supplement household use or as a back-up power source, then additional maintenance and precautions may be needed to ensure that the battery performs for its intended application.

A number of parameters that affect the lifetime of battery storage systems are described below. The combination of the effect of all of these factors dictates how long a battery will last for in operation.

Duty cycle

By far the most important factor in determining battery life is the duty cycle. This is how the battery will be used during operation. Applications that require fast charging or discharging to a high depth of discharge (DoD) will have shorter lifetimes than those set for slow charging or discharging to lower depths of discharge. The duty cycle depends on the type of application (e.g. domestic energy storage or utility power quality), with different applications having different duty cycles. Typically, the duty cycles of battery storage systems in operation are far more complex than those used by manufacturers to estimate battery lifetime.

Depth of discharge

DoD is related to the extent of conversion of the active materials within the battery. The lifetime of battery storage systems is strongly related to the DoD. The lower the DoD, the greater the lifetime and the number of cycles the battery can achieve. For example, a lead-acid battery with a DoD of 5% can provide close to 15 000 cycles at a given temperature and cycle rate. However, under the same conditions, a DoD of 90% would reduce the cycle number to about 600. The DoD a battery will experience in operation depends on the duty cycle and system set-up.

Charging level

The charging level of a battery can strongly affect its lifetime. For technologies such as lithium ion, reducing the charge cut-off voltage (i.e. the charging limit) can have the same effect as operating at a lower DoD (i.e. partially charging the battery), extending the lifetime. However, this comes at the cost of operating the battery at a lower capacity than its full rated value. Thus, the charging level for each individual technology must be optimised in the energy storage system to maximise the lifetime of the battery.

Charging and discharging rate

The rate at which the battery is charged strongly influences its lifetime. High charging and discharging rates can lead to an increase in cell temperature (see below). Generally, as long at upper temperature and voltage limits are observed (via a BMS), there is no harm to the battery.

Voltage limits

All battery storage systems have a characteristic voltage range in which the desired chemical reactions occur. The range depends on the battery technology type, but is limited by the points at which the desired and undesired reactions occur. Working outside of these ranges (i.e. over charging or discharging) causes unwanted chemical changes and thus shortens the lifetime of the battery. Typically, the overcharging or discharging process also increases the cell temperature and pressure, leading to additional problems. For some technologies, going outside the limits can even lead to the production of gas or explosion hazards.

Cell formation or conditioning

In a typical manufacturing process, the electrodes constructed are not in the optimal state for battery usage. To solve this, most manufacturers use a conditioning or formation process based on cycling to optimise the battery cells. The amount of cycles required to form the optimal electrodes depends on the battery type and chemical formulation. An incomplete formation step can lead to shorter lifetimes than expected.

Cell ageing

During cycling, physical morphological changes occur on the electrodes, in combination with the chemical changes. In many battery storage systems, these morphological changes are not reversed completely during the cycle; thus, they continue to build up during operation of multiple cycles. As a consequence, the battery lifetime can be shortened when sufficient morphological changes have occurred. The battery chemistry or type dictates the type of degradative morphological changes occurring.

Cell interactions

Cell voltages depend on the chemistry type, but typically range from 1 to 4 volts. Most consumers are aware that commercial battery storage systems come in sizes of 12 or 24 V or higher. To achieve this, multiple individual cells are strung together in a single package until the desired package voltage is reached. In these multicell battery storage systems, the placement of a bad cell (e.g. from manufacturing tolerances, variable temperature across the pack or lower capacity of the cell) can lead to detrimental effects or non-uniform ageing across all of the cells in the pack. Overall, this effect serves to decrease the battery lifetime and is difficult to identify in systems that are operating without expensive monitoring electronics.

System set-up

The configuration of an energy storage system using batteries will have a big impact on the battery lifetime. For example, a battery directly connected to an intermittent generation source (variable and high DoD) and expected to provide high power or energy (i.e. fast discharging rates) with no cooling system in place will have a short lifetime. In contrast, a system in which the battery units have been oversized (so that each cell experiences a low DoD), a cooling system has been installed to keep each cell at an optimal temperature, and intermittent generation is suitably buffered will have a longer lifetime. However, although the latter system has the best performance, the cost of such a system is far higher than that of the first system. Thus, the optimisation of the system for performance versus cost has an effect on the lifetime of a battery.

Chemical changes

Unwanted (also known as parasitic) chemical changes can occur in batteries alongside the desired chemical changes needed for battery operation. The rate at which these unwanted reactions occurs and the chemical products they form have a strong effect on the battery lifetime.

Storage or shelf time

Many battery storage systems are stored for extended periods of time before being used or, while in use, are required to be in standby mode for extended periods (e.g. backup power applications). This storage or standby time can affect some battery chemistries, causing unwanted chemical changes to occur that shorten battery life.

Depletion of active chemicals

Under the different conditions of pressures, temperature, duration of reaction (charging or discharging period) and so on, the active chemicals in battery storage systems can breakdown or combine in different ways. These reactions can significantly shorten battery life. A classic example of this is the formation of electrolyte breakdown products on lithium battery electrodes during the charging process. Typically, these products are formed on each cycle and continually deplete the electrolyte solution.

Quality of battery

The quality of a battery and the method of manufacturing greatly affect battery lifetime. In some instances, contamination of materials can exacerbate parasitic reactions. Also, contamination by metallic particles from cell manufacturing can lead to internal short circuits or additional degradative processes.

Temperature effects

The chemical reactions that occur in the battery (both the wanted and the parasitic reactions) depend strongly on temperature. Increasing the temperature of the battery during operation or storage periods serves to increase the rate of the chemical reactions occurring. However, at the same time, the degradative reactions also occur at a much higher rate, with the overall effect of reducing the battery lifetime. Most battery storage systems operate best at ambient temperatures of 20–25 °C.

Pressure

For batteries constructed in a sealed cell format, the increase in internal pressure can have detrimental effects on lifetime. High currents or high ambient temperatures will cause the cell temperature to rise. Overcharging also results in increased temperature, but can also cause the generation of gases, resulting in an even greater build-up in the internal pressure. This pressure build-up helps to increase the rate of chemical reactions occurring in the battery – not just the required chemical changes but also the unwanted changes that lead to degradation.

Mechanical stress

For some batteries, mechanical stresses are placed on the electrodes during the cycling process (e.g. the grids in lead-acid or flow batteries, or the crystal in lithium-ion batteries). Over the course of multiple cycles, these can lead to breakdown of electrodes and detaching of the conductive pathways to the terminal. Hence, the lifetime of the battery is reduced.

Passivation

Some of the detrimental parasitic chemical changes that occur in batteries can lead to the formation of insulating solid products which are deposited onto the electrode material interfaces (e.g. the lead sulfate in lead-acid cells). Over time, these build-up products reduce the available electrode area for the desired chemical reactions in the battery. This serves to decrease the cell's ability to deliver the current and increase the internal resistance of the battery. This effect contributes to the shortening of the lifetime of a cell. The rate at which this passivation occurs depends on battery chemistry type, duty cycle, DoD, temperature and so on.

Loss of electrolyte

Any reduction in electrolyte volume (through parasitic reactions, or venting or leaking of electrolyte) will lead to a shorter battery lifetime. In extreme events, significant loss of electrolyte can lead to rapid failure.

Venting

Some battery types have systems in place to allow excess gases produced to vent into the atmosphere. For technologies such as lithium ion, this can be a safety feature when gassing occurs due to irreversible breakdown of chemical components that lead to failure. Any venting leads to loss of electrolyte. For technologies such as sealed lead-acid batteries, which produce some gas as part of the reactions, this loss of gas reduces battery life.

Manufacturing tolerances

Battery life can be affected by variation in materials and cell configurations. Factors such as chemical composition can vary from supplier to supplier and batch to batch. If the change is significant enough, this can affect the lifetime of the battery. Dimensional changes in electrode or component geometries can also affect cell lifetime. For example, misalignments can lead to a short circuit, or smaller sizing of electrodes can lead to excess current being applied to the cell and uneven usage of material.

2.4.4 General battery maintenance and operation (applicable to all technologies)

The battery storage manufacturer’s instructions and recommendations for the operation and maintenance should be followed to achieve optimal battery life. The best way to avoid a safety incident or battery failure is to proactively check a battery system on a monthly basis (or as per manufacturer guidelines), and to have an accredited installer service the system annually. It is also important to display a monthly maintenance checklist and warning signage. In particular, such signage should indicate the type of battery chemistry being used for the storage system, because this can aid emergency workers in event of incidents.

Newer systems tend to come with their own monitoring software (and mobile phone apps) that can provide information on usage and battery status. Such information may include temperature, electrical current and voltage, capacity or energy, state of charge, state of health, and input and output power. These types of systems can aid in proper maintenance of the battery installations.

All battery storage systems have specific charge regimes and may require periodic equalisation charging. The equalisation charge may be controlled automatically by the system or may require the owner to connect to the grid or generator and battery charger at regular intervals (about once a month). No matter what maintenance scheduling is performed, all rechargeable battery storage systems have a limited life and will gradually lose their capacity to hold charge.

2.4.5 Specific maintenance and operation requirements for lead-acid batteries

Lead-acid batteries are generally classified by application and by construction. Deep-cycle batteries are used for various types of applications, including renewable energy storage and backup power supply. There are two common construction types: flooded batteries (wet) and VRLA batteries. In flooded batteries, the electrolyte is a solution of sulfuric acid and water that can spill out if the battery is tipped over. In VRLA batteries, the electrolyte is suspended in a gel or an absorbent fibreglass mat; hence, these batteries can be mounted in a variety of positions, with no danger of electrolyte being released.

Battery maintenance

Advice on battery maintenance is as follows:

- keep terminals clean and tight and, for lead-acid batteries specifically, ensure the electrolyte is kept above minimum levels; use only distilled water when topping up electrolyte levels
- neutralise any electrolyte spilt or splashed on the top of the batteries (e.g. with sodium bicarbonate for flooded lead-acid cells) and wash away with water at frequent intervals
- avoid creating a short circuit across the battery terminals; for example, ensure that metal tools or materials cannot fall onto the battery terminals or housing
- ensure that ventilation and cooling or air-conditioning systems are operational
- inspect battery storage systems on a regular basis in order to detect and correct potential problems before they can do harm; a typical inspection involves:
    - visual examination of the battery identifying cracks, dirt or corrosion
    - detection of leaked fluids and replacement of any damaged batteries
    - checking of battery cables and their connections

    - identifying loose or damaged parts, and replacing damaged or frayed cables
    - tightening of all wiring connections to the specification recommended by the manufacturer and ensuring there is good contact with the terminals
- where applicable, ensure water levels are correct and top-up regularly.

Charging

Advice on battery charging is as follows:

- charge batteries according to manufacturer recommendations, and after each period of discharge (note: lead-acid batteries do not have a memory effect and thus do not need to be fully discharged before charging)
- charge in well-ventilated areas or enclosures, and keep sparks or flames away from charging battery storage systems
- ensure charging voltage limits are accurate for the battery configuration and type; if the BMS does not have an in-built control for temperature compensated charge voltage, ensure that the correct charging voltage is used during charge process
- tighten all vent caps before charging
- do not overcharge the batteries – overcharging causes excessive gassing (water breakdown), heat build-up and battery ageing
- do not undercharge the batteries – undercharging causes stratification, which can lead to premature battery failure
- do not charge a frozen battery, and avoid charging at temperatures above 50 °C
- do not overcharge VRLA batteries – overcharging will dry out the electrolyte and damage the battery
- for flooded batteries, perform an equalisation charge periodically as recommended by the manufacturers, to reduce stratification and sulfation effects, which reduce battery capacity
- batteries that cannot support a charge are probably damaged and should be replaced.

Storage

Advice on battery storage is as follows:

- store and operate batteries in a cool, dry place; for every 10° C rise above room temperature (25° C) the battery life decreases by 50%
- store battery storage systems in a charged state; allowing batteries to stand at a low state of charge for extended periods will decrease capacity and lifetime
- if battery storage systems are stored for extended periods of time, charge them fully every 3–6 months; lead-acid batteries will self-discharge 5–15% per month, depending on the temperature of the storage conditions
- monitor battery voltage and specific gravity of the electrolyte regularly to verify charge status
- if battery storage systems are in storage, given them a boost charge when they show a 70% charge or less
- avoid locations where freezing temperatures are expected; freezing will irreparably damage a battery's plates and container
- avoid direct exposure to heat sources; temperatures above 25 °C accelerate the battery's self-discharge characteristics
- completely charge the battery and equalise the batteries before re-activating.

Handling

Advice on battery handling is as follows:

- check flooded battery storage systems regularly to ensure correct water level is maintained; add water after fully charging the battery, and use only distilled water
- do not let the plates get exposed to air as this will damage (corrode) the plates

- do not overfill the water level in the filling well to the cap of flooded batteries because doing so will cause the battery to overflow acid, causing a loss in capacity; it can also cause corrosive burn
- do not use water with a high mineral content; use distilled or deionized water only
- check that all vent caps are tightly in place
- when cleaning, do not allow any cleaning solution or other foreign matter to get inside the battery
- clean battery terminals and the inside of cable clamps using a post and clamp cleaner
- keep the area around battery storage systems clean and dry
- use correct lifting equipment and procedures when handling lead-acid batteries.

2.4.6 Specific maintenance and operation requirements for nickel batteries

The performance of nickel metal hydride battery storage systems can be greatly affected by their operation. For example, lifetimes can be reduced if the battery is significantly overcharged. Some overcharge of the battery is vital to ensure that all batteries are fully charged and balanced, but maintenance of full charge currents for extended periods once the battery has reached full charge can reduce the life of the battery. The lifetime can also be reduced if the battery is exposed to high temperatures because this increases the ageing processes occurring within the battery. High temperatures are a particular concern during charging because charge acceptance is reduced; also, identifying the transition from charge to overcharge is more difficult at higher temperatures. Overdischarge of the battery can shorten battery life, especially if this overdischarge is repeated routinely.

Maintenance of nickel batteries

Advice on maintenance of nickel batteries is as follows:

- performance can be improved by routine slow discharge to 0.9 V per cell, to help balance cell voltages in a pack and break up any large crystals forming in the cell
- cells in packs can become unbalanced during use and, as the pack is used further, these voltage differences continue to increase; once that cell is discharged, the pack must be stopped from discharging to prevent the cell from undergoing ‘cell-reversal’, which reverse-charges the cell and can damage it
- to rebalance cells that have become unbalanced, do one or both of the following monthly:
  - individually discharge each cell down to exactly the same voltage (balancing them)
  - slowly charge the pack at a rate that prevents the already charged cells from overheating but allows the other cells to become fully charged too (balancing them).

Charging

Successful charging balances the need for quick, thorough charging with the need to minimize overcharging, a key factor in prolonging life. In general, the nickel metal hydride battery is more sensitive to charging conditions than the nickel-cadmium battery. Undercharging can cause low service whereas overcharging can cause loss of cycle life. Nickel metal hydride batteries operate on an exothermic, hydrogen-based charging and oxygen recombination process. Precautions should be taken to avoid venting. Should venting occur, the vent gases must be properly managed. When the battery reaches overcharge (in which the bulk of the electrical energy input to the battery is converted to heat), the battery temperature increases dramatically. Battery pressure, which increases somewhat during the charge process, also rises dramatically in overcharge because gas is generated at a greater rate than the battery can recombine it. Without a safety vent, uncontrolled charging at this rate could result in physical damage to the battery.

Typically, a moderate rate (2–3 hour) is preferred for nickel metal hydride battery storage systems. The batteries are protected from overcharge by the BMS. Extremely fast charging (<1 hour) can affect battery cycle life and should be limited where possible. Charging at a 0.1 C rate for 12–14 hours is well suited for nickel metal hydride batteries. Finally a maintenance (or trickle) charge rate of less than 0.025 C is recommended. The use of small trickle charges helps to reduce the negative effects of overcharging.

Storage

Advice on storage of nickel metal hydride batteries is as follows:

- store battery storage systems
  - at a temperature between –20 °C and 30 °C
  - in open circuit and in a charged condition
  - in a clean dry protected environment to minimize physical damage to batteries
- for batteries intended for storage for extended periods of time (past the point where they are fully discharged), disconnect them from all electronics.
- when nickel metal hydride batteries are stored under load, small quantities of electrolyte can leak around seals or through vents and can lead to corrosion of batteries; although such occurrences are rare, it is best to electrically isolate the battery or disconnect it from electronics during extended storage.

In normal practice, stored battery storage systems should provide full capacity on the first discharge after removal from storage and charging as recommended by the manufacturer. Battery storage systems stored for an extended period or at elevated temperatures may require more than one cycle to attain pre-storage capacities.

Handling

Nickel metal hydride battery storage systems are safe; however, as with any battery, they should be treated with care. Issues in dealing with nickel-metal hydride batteries include the following:

- for devices with tightly sealed or waterproof battery compartments, hydrogen gas generation under normal or abusive conditions is a potential safety issue; therefore, appropriate venting of enclosures should be used, to prevent accumulation of dangerous levels of hydrogen gas
- if shorted, nickel metal hydride batteries can generate high currents that are sufficient to cause burns or ignition of flammable materials; hence, all flammable materials should be kept away from enclosures for such batteries, and care should be taken when handling them, to avoid electrocution hazards or risks
- the active materials in the negative electrode can ignite on exposure to air, and the electrolyte is corrosive and capable of causing chemical burns; thus, batteries should be kept intact and regular maintenance should be performed to ensure integrity of batteries.

2.4.7 Specific maintenance and operation requirements for lithium-ion batteries

As with all battery storage systems, lithium ion batteries require routine maintenance for optimal performance, and have a limited life and will gradually lose their capacity to hold charge (i.e. will age). This ageing is irreversible and, as the battery loses capacity, it will eventually lead to the end of the battery life. Lithium-Ion batteries continue to slowly discharge (self-discharge) when not in use or while in storage. Hence, they should not be left unused for extended periods of time. During periods of storage or no operation, the charge status of the battery should be checked every 6 months, and the battery should be charged or disposed of as appropriate.

Battery maintenance

Advice on maintenance of lithium-ion battery storage systems is as follows:

- routinely check the battery's charge status
- carefully monitor batteries that are approaching the end of their estimated life and replace when they have reached the end of life
- consider replacing the battery with a new one if you note either of the following conditions
  - the battery run time drops below about 80% of the original run time
  - the battery charge time increases significantly

- if a battery is stored or otherwise unused for an extended period, and the battery has no charge remaining when you check it, consider it to be damaged; in such cases, do not attempt to recharge or to use the battery, but instead replace it with a new battery.

Charging

Always follow manufacturer's instructions for charging of lithium-ion battery storage systems. Do not overcharge beyond the recommended limits and ensure that charging rates are consistent with those recommended by the manufacturer.

Storage

Advice on storage of lithium-ion batteries is as follows:

- charge or discharge the battery to approximately 50% of capacity before storage
- charge the battery to approximately 50% of capacity at least once every 6 months
- store the battery at temperatures between 5 °C and 20 °C.

Handling

Advice on handling of lithium-ion batteries is as follows:

- do not disassemble, crush or puncture a battery
- do not short the external contacts
- do not dispose of battery in fire or water
- do not expose a battery to temperatures above 60 °C
- keep the battery away from children
- avoid exposing the battery to excessive shock or vibration
- do not use a damaged battery
- if a battery pack has leaking fluids, do not touch any fluids; dispose of a leaking battery pack appropriately
- in case of eye contact with fluid, do not rub eyes; immediately flush eyes thoroughly with water for at least 15 minutes, lifting upper and lower lids, until no evidence of the fluid remains, and seek medical attention.

2.4.8 Warranties

Most battery storage systems warranties contain some standard conditions, including a period (typically 12 months) of free replacement for failure due to defects in material or workmanship, but not including failure caused by abuse, neglect or breakage. The warranty does not usually cover consequential damage or injury, freight, labour or administrative costs. It is usually non-transferable and may only apply to the original purchaser of the new product. In some cases, extended warranty is available at an extra cost.

All warranties explicitly clarify that the battery storage products have to be installed, used and serviced in accordance with the relevant product information and following all the manufacturer's operating instructions such as those defined in the product installation and operation manual. In some cases, it may be a specific requirement that the products have to be installed by a properly certified and licensed installer such as an installer accredited by the CEC.

Depending on the manufacturer, the warranty may also include performance criteria; for example, for meeting the minimum efficiency specified. To cover this performance warranty, however, the products will usually require exclusive service and maintenance from the supplier or the approved personnel who installed them. Some performance warranties reserve the right to conduct tests before considering any claim.

Often, the warranty specifies that manufacturers are entitled to refuse to honour the warranty in certain circumstances (regardless of how the circumstances arise). These situations include those where the product has:

- been handled, abused or neglected, or had modifications not in accordance with the relevant product information
- been incorrectly configured or used for purposes or in circumstances not conforming to the product specifications
- loose wiring or corroded terminal connections
- been frozen
- been improperly charged or left uncharged for extended periods of time
- been damaged due to external or environmental causes of any kind, fire, explosion, smoke, charring, lightning, hail, frost, snow or storms or pollution.

These situations are in addition to the general limits, such as damage due to malicious acts, lack of service or not being maintained in accordance with the relevant product information and written instructions issued by the manufacturer.

Some examples of different company's defects and performance warranty periods are shown in Table 6 for a range of different battery types.

Table 6: Typical supplier or manufacturer warranties for domestic and commercial battery storage systems

Supplier or manufacturer	Battery type	Defects warranty (Years)	Performance warranty (Years)	Source
Ecoult	Advanced lead-acid	1	3	[21]
Tesla	Lithium nickel cobalt aluminium oxide	10	Not specified	[22]
Bosch	Lithium nickel cobalt aluminium oxide	5 (can extend to 10)	5	[23]
BYD/Solar Australia	Lithium iron phosphate	5–10	5–10	[24]
Iron Edison	Lithium nickel manganese cobalt oxide	7	Not specified	[25]
Samsung	Lithium manganese oxide	2–5	7–10	[26], [27]
Redflow	Zinc-bromine flow	1	5 (assuming on full discharge per day)	[28]

It is important to note what is covered under the warranty for a given energy storage system (e.g. battery only, the whole system or specific components). For example, Bosch Power Tech provides warranty for the whole product or system, and will repair or replace the product or any part thereof if such products are faulty or defective, for a period of 5 years from the date of purchase. Some other installers or retailers provide different warranties for separate components in the energy storage system. For example, RFI Solar supplies a Samsung 3.6-kWh All-In-One Energy Storage System, which comes with 2 years' battery warranty, 5 years' power control system and 7 years' battery performance warranty.

All warranties are provided in addition to other rights and remedies held by a consumer under law. This means that the warranty cannot be excluded under the Australian Consumer Law or a state government's law. This situation means that the consumer is entitled to a replacement or refund for a major failure, and compensation for any other reasonably foreseeable loss or damages.

2.5 Disposal and recycling of battery storage systems

Battery storage systems can contain heavy or toxic metals such as nickel, cobalt, cadmium and lead, which can be harmful to the environment if disposed of in a landfill. In Australia, used rechargeable batteries are classified as a hazardous waste under the *Hazardous Waste Act 1989* because they can create environmental risks if disposed with general household waste or dumped illegally.

Recycling is the reclamation of materials that would ordinarily be considered waste. It reduces the amount of waste that goes into local landfills and of toxic chemicals that leach into river ways and streams. In the context of batteries, recycling can only occur at end of life of the battery. The main aim is to reduce the quantity of materials that end up in landfill and, for some types of batteries, prevent the release of toxic materials into the environment. Additionally, some materials used in the construction of batteries can readily be reclaimed and reused in batteries or other applications (e.g. copper metal from electrodes or terminals).

2.5.1 Lead-acid batteries

Due to its long history, the lead-acid battery has long-established recycling methods and regulations. Consequently, this technology has led the way in recycling. For example, the Australian automotive industry can be credited for organising the recycling of used car batteries. In Australia, 80–90% of all lead-acid batteries are recycled, whereas only one in six households recycles other battery types [29].

Lead-acid batteries have an established disposal and recycling process [7] and are considered a controlled waste in Australia [10]. Within Australia, a Waste Storage Licence and Waste Transport Licence is required in most Australian states and territories to handle more than 333 kg of lead-acid batteries [30]. After transportation, lead-acid batteries are recycled in one of the two lead refineries in Australia, or are sent overseas for recycling. It is critical that these batteries are disposed of through specialised processing companies, because the sulfuric acid electrolyte is extremely hazardous to humans and the environment.

A typical lead-acid recycling process is shown in Figure 7. Spent batteries are taken to recycling facilities, crushed and separated into components (lead, plastics and acid) to be further processed. Recycled lead is melted and refined for battery manufacturing and lead products. Recycled plastic is cleaned and used to make new lead-acid battery cases and other consumer products. The acid is collected in tanks for either direct sale or further neutralisation.

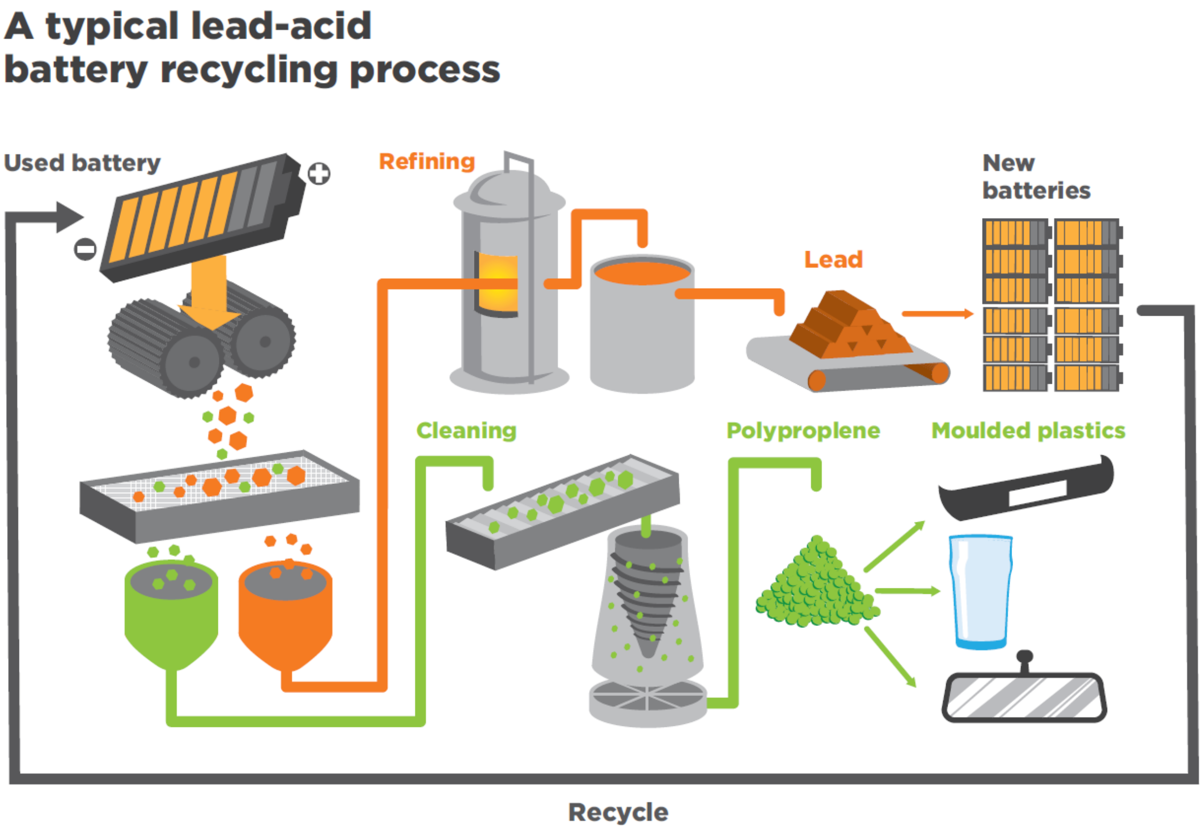

Figure 7: A typical lead-acid battery recycling process

2.5.2 Nickel-based batteries

Nickel-based battery storage systems are considered more environmentally friendly than other battery types. Currently, batteries with this chemistry are being recycled in Australia and overseas. The main material formed after recycling is nickel and cadmium metals, which is considered semitoxic and toxic respectively. Nickel-based batteries also contain electrolytes that can be hazardous in large amounts.

In Canada and the United States, nickel-based batteries (and other technologies) are recycled through the 'Call2Recycle' program [14]. Australia has a similar program organised through Planet Ark [31].

2.5.3 Lithium-ion batteries and other technologies

Most lithium-ion battery storage systems are not presently recycled in Australia; however, some recycling plants do operate overseas. A large percentage of Australian lithium-ion batteries are used for small consumer electronic products, such as mobile phones, tablets and laptops. The environmental impacts of recycling such portable lithium-ion batteries are still being researched [32].

For technologies such as flow batteries or sodium batteries, no established recycling process presently exists. Although these technologies contain many materials that can be reclaimed and reused, to date there has been no significant development of a recycling process or construction of a recycling plant for these technologies within Australia.

Should an environmental incident occur, the lack of clear performance criteria for safety could have devastating effects on the industry's integrity. Thus, industry, government, installers and users of stationary battery storage should consider a range of issues to ensure the ongoing environmental integrity of stationary battery systems:

- For lithium-ion batteries, the lack of standardisation among battery chemistries, and the changes in elements being used due to research for higher energy batteries have made evaluation of the recycled value of the components uncertain for lithium battery recyclers.
- Present and future lithium-ion battery chemistries under research and development (e.g. phosphate or manganese-based chemistries) have little or no high-cost metals such as cobalt or nickel. Thus, the value for recycling is limited to components such as copper current collectors and high-purity electrolytes. Hence, recycling in the long term may be mainly for ecological benefits and adherence to environmental laws.
- European legislation has already included the cost of recycling battery systems within the retail cost. The European Union battery directive requires producers of industrial batteries to recycle them. It is envisaged that domestic energy storage systems will be classified as industrial batteries, and therefore be included in the present ruling for the European Union.
- Some groups are advocating for the cost of lithium-ion recycling to be included in the cell purchase price within the Australian context.
- Regulations currently differ from state to state and country to country. In Australia, the Environment Protection Authority in each state is the recommended point of contact. There are a number of Australian recycling companies receiving spent lithium-ion cells, but since no recyclers are processing these cells locally, they are stored in a warehouse for shipping to one of only a few overseas recyclers.
- Lithium cobalt oxide batteries are currently recycled in countries such as South Korea, due to the high value of cobalt.
- Other lithium-ion battery components could also be recycled to recover high-value materials such as high-purity copper and aluminium, electrolytes (high-purity chemicals for reuse in new cells), highly processed carbons and casing materials (aluminium or steel). However, this is not presently undertaken, because the number of batteries of this type is not yet sufficient to make recycling economically viable.

The above list is given in the context of lithium-ion cells. However, the points raised are applicable to alternative battery technologies such as flow batteries and sodium batteries, which at present are not being recycled.

There is currently no Australian legislation or regulation (apart from the *Hazardous Waste Act 1989* act) obliging manufacturers and retailers to participate in responsible disposal of battery storage. Funding is limited, and there are no incentives for manufacturers, retailers or overseas suppliers to undertake responsible disposal.

Further information on the appropriate methods of disposal for battery storage in Australia can be obtained from the government agencies listed in Table 7.

Table 7: Relevant Australian government agencies for battery disposal

State or territory	Agency	Website
New South Wales	NSW Environment Protection Authority	http://www.epa.nsw.gov.au
Victoria	Victoria Environment Protection Authority Victoria	http://www.epa.vic.gov.au
Queensland	Department of Environment and Heritage Protection	http://www.ehp.qld.gov.au
Australian Capital Territory	Environment and Planning Directorate – Environment	http://www.environment.act.gov.au
Tasmania	Tasmania Environment Protection Authority	http://www.epa.tas.gov.au
Western Australia	Western Australia Environment Protection Authority	http://www.epa.wa.gov.au
South Australia	South Australia Environment Protection Authority	http://www.epa.sa.gov.au
Northern Territory	Northern Territory Environment Protection Authority	http://www.ntepa.nt.gov.au
Australian Government	Department of Environment	http://www.environment.gov.au

Adapted from reference [10]

For technologies such as lithium-ion, flow batteries and sodium batteries, there is no established method of collection, transport and recycling within Australia. There are also no regulations for collection, transport and recycling of such batteries (despite such regulations existing for lead-acid or nickel batteries). Agencies such as the Australian Battery Recycling Initiative (ABRI) – a recycling industry collaboration – are actively pursuing the development of these methods.

ABRI members include a number of key Australian battery manufacturers, recyclers, retailers, government bodies and environment groups. The goal of ABRI is to promote the collection, recycling and safe disposal of all battery chemistry types. ABRI and the CEC, with assistance from CSIRO and other members of the CEC's Energy Storage Integrity Working Group, are also developing new ABRI guidelines for battery recycling, as explained in reference [29].

ABRI and others are encouraging battery storage manufacturers, suppliers and government bodies to use consistent labelling for battery storage systems. A labelling scheme similar to that used in the aviation industry (see Figure 6) would be an acceptable example. This will help future battery recyclers to identify and prevent potential incidents. For example, there have been concerns about charged lithium-ion batteries mistakenly entering the lead-acid recycling process (in particular the 'crusher' process – see Figure 7). If this occurs, a fire or explosion could occur. With appropriate labelling, recyclers will be able to identify and mitigate such risks. For information about general battery collection, recycling and safe disposal, please see the websites listed in Table 8.

Table 8: Examples of collection, recycling and safe disposal companies

Battery type	Company	Website
Lead-acid, lithium-ion, nickel metal hydride, nickel-cadmium	MRI	http://www.mri.com.au
Lead-acid, lithium-ion, nickel metal hydride, nickel-cadmium	Battery World	http://www.batteryworld.com.au
Lead-acid, lithium-ion, nickel metal hydride, nickel-cadmium	Cleanaway	http://www.cleanaway.com.au
Lead-acid, lithium-ion, nickel metal hydride, nickel-cadmium	SITA Environmental Solutions	http://www.sita.com.au
Not applicable – general information	Australian Battery Recycling Initiative (ABRI)	http://www.batteryrecycling.org.au

2.6 Safety incidents involving battery storage systems

Of major concern to retailers, installers and consumers is safety and incidents where damage from batteries storage systems can be caused. In the context of energy storage for renewables, only limited data are available because this market is not yet mature. However, incidents from other markets such as aviation, vehicles and consumer electronics can help to identify potential issues and learning that can be applied to storage of renewable energy.

Information on safety incidents involving energy storage systems as a whole is rare, apart from a few known large-scale cases. These include the sodium sulfur battery fire at the Tsukuba's power plant in Japan, and the battery room fire at Kahuku in Hawaii [33]. However, a large amount of data is available on battery or battery pack incidents within the aviation industry, which has been best documented by the Federal Aviation Administration (FAA) in the United States. Table 9 shows data collected for battery safety incidents involving fire, extreme heat or explosion; the information is mainly derived from the FAA data and media reports. The list is not comprehensive, but provides some understanding of the level of safety risks in relation to different battery chemistries.

Table 9: Summary of energy storage incidents

Technology type	Number of incidents	Source	Methods of reporting (e.g. media, industry req. report)
Lithium (chemistry not specified)	6	Aviation	FAA, media
Lithium-ion	59	Aviation	FAA
Lithium-ion	1	Marine	NREL
Lithium-ion	25	Vehicles (EV and HEV)	Media
Lithium metal/primary	15	Aviation	FAA
Nickel-cadmium	6	Aviation	FAA
Lead-acid	40	Aviation	FAA
Nickel metal hydride	4	Aviation	FAA
Sodium-ion analogue	Not available	Not available	Not available

EV, electric vehicles; FAA, Federal Aviation Administration; HEV, hybrid electric vehicles; NREL, National Renewable Energy Laboratory.

The data in Table 9 include two thermal runaway incidents with lithium-ion batteries installed in modern aircraft and electric vehicles. In these incidents, lithium-ion batteries appear to dominate the safety risks, which is perhaps unsurprising, considering the proliferation of these batteries in recent years. The IATA's document '*Lithium batteries risk mitigation guidance for operators*' [34] estimates that upwards of one billion lithium batteries are transported by air annually, as either mail, cargo or in the baggage of passengers or crew. Further, according to the Underwriters Laboratories, the Consumer Product Safety Commission documented 467 reported incidents since March 2012 that identified lithium-ion cells as the battery type involved, with 353 of those being incidents involving fire and burn hazards [35]. This report collated data from consumer electronics, in addition to the data presented for aviation in Table 9.

However, not all battery safety incidents involve lithium-ion batteries. Of the 156 incidents reported by the FAA, only 59 were specified as involving lithium-ion batteries. In a number of cases, the battery type was not identified, but the others involved lithium metal or primary batteries, lead-acid batteries, ordinary dry cells, nickel-cadmium batteries or nickel metal hydride batteries. Most of these incidents involved cargo shipments either on or off the aircraft. There have also been many cases of fire before and after unloading, suggesting that the movement and vibration of these batteries greatly contributes to the risk of short circuit. New rules now govern the cargo carriage of lithium-ion batteries (see reference [36]), and some companies have banned the transportation of lithium batteries altogether. However, to put this into perspective, many more lithium batteries, particularly lithium-ion, are in use than any other type of battery. Also, as pointed out by the United States National Renewable Energy Laboratory in their 2012 report [37] on vehicle battery safety, there is a low probability of field failures arising from manufacturing defects that cause internal short circuits. This may be reassuring for manufacturers of portable electronics where only a single or a few cells are used. However, when making packs for larger systems (e.g. for energy storage), these failures can be difficult to detect and can potentially damage systems if not detected during the manufacturing process. This places a burden on manufacturers to detect such failures, and generally results in an increased cost of product. Consequently, worldwide research and development is continuing, to overcome these safety risks.

2.6.1 Recommendation for records of energy storage

The Australian domestic and small commercial battery storage industry is an emerging market, and there appears to be no common framework or best practice. Therefore, it is recommended that the battery storage (and solar PV) industry develop a best-practice initiative for their industry, to report energy storage installations and incidents.

It is also recommended that a recording process or database be put in place to allow:

- identification of the geographical locations where battery energy storage has been installed and their relevant systems parameters (e.g. chemistry type, system initial capacity in kWh, manufacturer model and serial numbers)
- reporting of installed system maintenance into a national database
- reporting of a system incident or near miss into a national database.

A potential process for reporting incidents may be implemented through the accredited installer. As consumers report to their accredited installer, the installer would report to a recognised industry body, which would maintain a record of all incidents and near misses on a national database. This process could then be regulated rather than industry controlled.

3 Battery storage installations

Battery installations are already occurring in Australia. However, accreditation and training pathways are not yet well established. Hence, there is a lot of uncertainty within the market about the management of the safety and quality control systems for these installations. This critical issue for the industry was raised by a number of people during interviews with industry stakeholders.

3.1 Introduction

Gathering information about battery installations in Australia's domestic market is challenging. Larger scale deployment details can be sourced from the Global Energy Storage Database [38], but there is no central database to identify domestic and commercial-scale deployments.

Solar installations are already performed by accredited installers, and there are data requirements for rebates and feed-in tariffs. Thus, information about the work undertaken is available on databases. In some cases, the installations also include storage, but information about storage is not being effectively captured. It is difficult to obtain installation data on energy storage systems (especially in domestic applications), because no accreditation or installation certificate is required, and therefore no paperwork and data entry requirements are in place.

The existing CEC accreditation and training scheme for solar PV includes some certification and training for energy storage attached to a PV system, both on and off-grid. However, the scope has mainly focused on the historical context of these installations in rural off-grid settings, and on the dominant technology of lead-acid batteries.

A more appropriate training, accreditation and regulation framework is now required, aimed at the burgeoning uptake of energy storage technologies, across urban and city landscapes. This will ensure that battery storage system installation data capture is also regulated.

More information is provided in Section 4 and Appendix A.

3.2 Suppliers and present deployments

A list of manufacturers and their country of origin for the energy storage technologies considered in this report is provided in Table 10. This list is not comprehensive, but includes major players in the stationary domestic storage market. In terms of large-scale deployments in Australia, Table 11 shows the types of energy storage deployed and related information.

Table 10: Manufacturers and their country of origin for respective battery energy storage technologies

Manufacturer	Location(s)
Lead-acid	
Century Yuasa (GS Yuasa Corporation)	Australia, China, Indonesia, Japan, Thailand, United States
Trojan	United States
Exide	Australia, United States
East Penn Manufacturing	United States
Panasonic	Japan
Battery Energy	Australia
Fusion	Australia
Bosch	Germany
Advanced lead-acid	
Ecoult / East Penn Manufacturing	Australia, United States
Furukawa	Japan
Nickel metal hydride	
GS Yuasa Company	China
Sanyo	Japan
Lithium iron phosphate	
BYD	China
Samsung SDI	Korea
Sony	Japan
SMA	Germany (Korean battery supplier)
Bosch	Germany (Japanese battery supplier)
Magellan Power	Australia (Korean battery supplier)
Sunverge	United States
Lithium manganese oxide	
Samsung	Korea
Lithium nickel manganese cobalt oxide	
Panasonic	Japan
BYD	China
Tesla	United States (Japanese battery supplier)
Sony	Japan
Lithium titanate	
Toshiba	Japan
Lithium nickel cobalt aluminium oxide	
Bosch	Germany
Saft	France

Manufacturer	Location(s)
Redox flow battery (vanadium flow)	
GEC	China
Hybrid flow battery (zinc bromine flow)	
Redflow	Australia
ZBB	Australia, United States
Sodium-ion analogue	
Aquion Energy	United States

Table 11: Larger-scale deployments of energy storage in Australia demonstrating different technology types [1]

Deployment	Technology type	Size (power)	Status	Application
AusNet 1-MW Thomastown Network Trial	Lithium-ion battery	1 MW	Operational	Electric energy time shift Grid-connected commercial (reliability and quality) Microgrid capability
Powercor 2-MW Grid Scale Energy Storage	Lithium-ion battery	2 MW	Contracted	Electric energy time shift Electric supply reserve capacity – non-spinning Frequency regulation
Mackerel Islands	Lithium-ion battery	325 kW	Operational	Onsite power Onsite renewable generation shifting Renewables energy time shift
RedFlow Adelaide	Zinc bromine flow battery	300 kW	Under construction	Electric bill management Electric supply reserve capacity – spinning Microgrid capability
MPower Solar PV Project Australia	Lithium-ion battery	800 kW	Contracted	Onsite renewable generation shifting Renewables energy time shift
Ausgrid SGSC – 40 RedFlow Systems	Zinc bromine flow battery	200 kW	Decommissioned	Stationary transmission/distribution upgrade deferral Grid-connected domestic (reliability) Renewables energy time shift
Ausgrid SGSC – 20 RedFlow Systems	Zinc bromine flow battery	100 kW	Decommissioned	Stationary transmission/distribution upgrade deferral Renewables energy time shift Grid-connected domestic (reliability)
Redflow, University of Queensland M90	Zinc bromine flow battery	90 kW	Decommissioned	Renewables energy time shift Renewables capacity firming
King Island Renewable Energy	Hybrid lead-acid battery/electrochemical capacitor	3 MW	Operational	Renewables capacity firming Onsite renewable generation shifting

Deployment	Technology type	Size (power)	Status	Application
Integration Project	(UltraBattery)			Electric supply reserve capacity – spinning
Hampton Wind Park	Hybrid lead-acid battery/electrochemical capacitor	1 MW	Operational	Ramping Voltage support
Global Change Institute M120	Zinc bromine flow battery	120 kW	Operational	Onsite renewable generation shifting Load following (tertiary balancing) Renewables energy time shift
University of Technology Sydney	Zinc bromine flow battery	25 kW	Under construction	Renewables capacity firming
CSIRO, ZBB Experimental	Zinc bromine flow battery	100 kW	Decommissioned	Electric bill management Renewables energy time shift
Magellan GPSS – SWR	Lithium iron phosphate battery	25 kW	Operational	Load following (tertiary balancing) Voltage support Black start
TransGrid iDemand	Lithium polymer battery	100 kW	Under construction	Electric energy time shift Onsite renewable generation shifting
Ausgrid SGSC – ZEN 60-kW Battery Energy Storage System	Lithium-ion battery	60 kW	Decommissioned	Electric energy time shift Distribution upgrade due to solar Renewables capacity firming
King Island Renewable Energy Expansion VRB	Vanadium redox flow battery	200 kW	Offline/under repair	Renewables capacity firming Onsite renewable generation shifting
ZECO Energy	Lithium iron phosphate battery	33 kW	Operational	Electric supply capacity Microgrid capability

3.3 Standards

3.3.1 Standards and regulations

Australian standards for energy storage and connection to the electricity network are limited and incomplete. This is understandable, considering that this a rapidly growing market with emerging technologies. There are some standards for mature or established technologies, and the connection of inverters to the electricity network. For example, there are standards for lead-acid batteries (AS 4029) and nickel-cadmium batteries (AS 3731), and for their applications as secondary batteries for use with stand-alone power systems (AS 4086 & AS/NZS 4509). However, some of these standards are outdated (up to 22 years old) and only consider specific cases (i.e. off-grid and stand-alone), whereas current use of these technologies has expanded to much broader applications. Standards relating to inverters and grid connection of energy systems via inverters are also outdated (AS 4777 and AS/NZS 5603). However, these standards have been redrafted and are currently being revised; they are suited mainly for domestic and commercial low-voltage installations.

The standards available cover a variety of grid and off-grid connections, vehicle-to-grid connections, demand response and so on. The gap analysis conducted as part of this study identified a number of research documents relating to the response to lithium-ion fire hazards. These documents indicated that determined action in response to fire hazards is ongoing, and that most guidelines to date have been written using data from lithium-ion cell incidents in portable devices, rather than large installations of stationary battery storage systems.

For the domestic battery storage market, there is a need to develop new standards that cover installation, smart communication, training and maintenance, transportation, safety and emergency guidelines, and requirements for environmental safety and recycling.

3.3.2 Australian standards

This section provides tables representing the standards that currently apply to each of the four most commonly installed battery technologies: lead-acid (Table 14), lithium-ion (Table 15), nickel-based (Table 16) and flow batteries (Table 17). The tables cover each aspect of the life-cycle management of these technologies. The key colours for the standards tables are described in Table 12, and Table 13 describes the column headings for each of the standards described in Tables 14–17.

Cross-referencing between chemistries shows overlapping relevance of standards in some cases; however, an applicable standard may only have partial significance for a particular technology. Lithium-ion chemistries have the smallest number of applicable standards to date.

Table 12: Key for standard battery storage matrix

Key	Indication
(red)	No Australian or known international standard has been developed
(grey)	Battery standard does not apply to this chemistry
(blue)	Standard details and specifications relate to this battery chemistry

Table 13: Description of column headings in Tables 14–17

Column heading	Description of standards
TRANSPORT	Safe transportation; for example, packing, hazards, transport class, allowable transport methods
HANDLING	Safe handling of batteries; for example, weight lifting methods, personal protection
HAZARDS	Specifications related to each battery chemistry
SITE LOCATION	Safe install location, taking into consideration the specific hazards of energy storage parameters, such as battery chemistry and electrical risks
SYSTEM DESIGN	General overall system design comprising a number of individual component blocks, and how they interconnect functionally and safely; for example, battery cells, inverter, cabling and enclosure
BATTERY ENCLOSURE VENTILATION	Individual design parameters specified for the safe ventilation requirements unique to the specific battery chemistry
CELL/BATTERY/PACK	Technical and safety parameters of cell or battery packs for best practices when designing for an operational storage system
INVERTER	Design, operational, functional and safety performance specifications
WIRING/CABLING/PROTECTION	Design rules specifying standards to ensure safe connection, routing, physical and electrical connection and interconnection practices of all electrical wiring
MAINTENANCE TESTING AND PERFORMANCE	Safety or operational performance requirements of storage components and systems
SIGNAGE	Content and placement of hazard, safety and operational signage in the vicinity of storage system installations
SYSTEM DOCUMENTATION	Specifications for the accompaniment of operational and technical instruction documentation with manufactured or custom-built systems
RECYCLING/DISPOSAL	Present best practices for recycling or disposal of each battery chemistry

Table 14: Lead-acid standards

LEAD ACID STANDARD			TRANSPORT	HANDLING	HAZARDS	SITE LOCATION	SYSTEM DESIGN	BATTERY ENCLOSURE VENTILATION	CELL / BATTERY / PACK	INVERTER	WIRING / CABLING / PROTECTION	CONTROL SYSTEMS	MAINTENANCE TESTING PREFORMANCE	SIGNAGE	SYSTEM DOCUMENTATION	RECYCLING / DISPOSAL
NO CURRENT STANDARD												■				
Material Safety Data Sheet			■	■	■									■		■
UN2800 2012	Transport, Batteries Wet, Non Spillable Lead Acid		■	■	■											
UN3480 2013	Transport, Lithium Ion Batteries not packed with, or installed in equipment															
UN3481 2013	Lithium Ion Batteries Contained in Equipment															
AS 3011 - 1 & 2 1992	Electrical installation - secondary batteries in buildings	1 Vented					■	■	■		■					
	Electrical installation - secondary batteries in buildings	2 Sealed					■	■	■		■					
AS/NZS 3000 2014	Electrical installations	Wiring rules									■			■		
AS 4029.1 1994 AS4029.2 2000 AS 4029.3 1993	Stationary batteries - Lead-Acid	1. Vented							■				■			
	Stationary batteries - Lead-Acid	2. Sealed							■				■			
	Stationary batteries - Lead-Acid	3. Pure lead positive plate							■				■			
AS 2676 1 & 2 1992	Guide to the installation, Maintenance Testing and Replacement of secondary batteries in buildings	1. Vented		■	■			■	■		■		■	■	■	
	Guide to the installation, Maintenance Testing and Replacement of secondary batteries in buildings	2. Sealed		■	■			■	■		■		■	■	■	
AS 4086.1 1993	Secondary batteries for use with stand-alone power systems	General requirements							■				■			
AS 4086.2 1997	Secondary batteries for use with stand-alone power systems	Installation and maintenance			■			■			■		■	■		
AS 3731 1 & 2 1995	Stationary batteries - Nickel-Cadmium	1. Vented														
	Stationary batteries - Nickel-Cadmium	2. Sealed														
AS/NZS 4509.1 2009	Stand-alone power systems	Safety and installation						■		■	■		■	■	■	
AS/NZS 4509.2 2010	Stand-alone power systems	System design					■			■	■			■		
AS 4777.1 2005	Grid connection of energy systems via inverters	Installation requirements								■						
AS 4777.2 2005	Grid connection of energy systems via inverters	Inverter requirements								■						
AS 477.3 2005	Grid connection of energy systems via inverters	Grid protection requirements								■						
AS 2401.1 1994 AS 2401.2 1995	Battery charges for Lead Acid batteries Domestic	1. Vented			■						■		■			
	Battery charges for Lead Acid batteries Domestic	2. Sealed			■						■		■			
AS 4044 1992	Battery chargers for stationary batteries				■											
AS/NZS IEC/TR 61000.2.8:2009	Electromagnetic compatibility (EMC)-Environment-Voltage dips and short interruptions on public electric power supply systems with statistical measurement results						■									
AS 1852.603-1988	International Electrotechnical Vocabulary - Generation and Distribution of Electricity - Power System Planning and Management						■									
NCC 2015	Building Code of Australia, (From May 2015 renamed National Construction Code)					■										

Table 15: Lithium-ion standards

LITHIUM ION STANDARD			TRANSPORT	HANDLING	HAZARDS	SITE LOCATION	SYSTEM DESIGN	BATTERY ENCLOSURE VENTILATION	CELL / BATTERY / PACK	INVERTER	WIRING / CABLING / PROTECTION	CONTROL SYSTEMS	MAINTENANCE TESTING PREFORMANCE	SIGNAGE	SYSTEM DOCUMENTATION	RECYCLING / DISPOSAL
NO CURRENT STANDARD																
Material Safety Data Sheet																
UN2800 2012	Transport, Batteries Wet, Non Spillable Lead Acid															
UN3480 2013	Transport, Lithium Ion Batteries not packed with, or installed in equipment															
UN3481 2013	Lithium Ion Batteries Contained in Equipment															
AS 3011 - 1 & 2 1992	Electrical installation - secondary batteries in buildings	1 Vented														
	Electrical installation - secondary batteries in buildings	2 Sealed														
AS/NZS 3000 2014	Electrical installations	Wiring rules														
AS 4029.1 1994 AS4029.2 2000 AS 4029.3 1993	Stationary batteries - Lead-Acid	1. Vented														
	Stationary batteries - Lead-Acid	2. Sealed														
	Stationary batteries - Lead-Acid	3. Pure lead positive plate														
AS 2676 1 & 2 1992	Guide to the installation, Maintenance Testing and Replacement of secondary batteries in buildings	1. Vented														
	Guide to the installation, Maintenance Testing and Replacement of secondary batteries in buildings	2. Sealed														
AS 4086.1 1993	Secondary batteries for use with stand-alone power systems	General requirements														
AS 4086.2 1997	Secondary batteries for use with stand-alone power systems	Installation and maintenance														
AS 3731 1 & 2 1995	Stationary batteries - Nickel-Cadmium	1. Vented														
	Stationary batteries - Nickel-Cadmium	2. Sealed														
AS/NZS 4509.1 2009	Stand-alone power systems	Safety and installation														
AS/NZS 4509.2 2010	Stand-alone power systems	System design														
AS 4777.1 2005	Grid connection of energy systems via inverters	Installation requirements														
AS 4777.2 2005	Grid connection of energy systems via inverters	Inverter requirements														
AS 477.3 2005	Grid connection of energy systems via inverters	Grid protection requirements														
AS 2401.1 1994 AS 2401.2 1995	Battery charges for Lead Acid batteries Domestic	1. Vented														
	Battery charges for Lead Acid batteries Domestic	2. Sealed														
AS 4044 1992	Battery charges for stationary batteries															
AS/NZS IEC/TR 61000.2.8:2009	Electromagnetic compatibility (EMC)-Environment-Voltage dips and short interruptions on public electric power supply systems with statistical measurement results															
AS 1852.603-1988	International Electrotechnical Vocabulary - Generation and Distribution of Electricity - Power System Planning and Management															
NCC 2015	Building Code of Australia, (From May 2015 renamed National Construction Code)															

Table 16: Nickel-based standards

NICKEL BASED STANDARD			TRANSPORT	HANDLING	HAZARDS	SITE LOCATION	SYSTEM DESIGN	BATTERY ENCLOSURE VENTILATION	CELL / BATTERY / PACK	INVERTER	WIRING / CABLING / PROTECTION	CONTROL SYSTEMS	MAINTENANCE TESTING PREFORMANCE	SIGNAGE	SYSTEM DOCUMENTATION	RECYCLING / DISPOSAL
NO CURRENT STANDARD												■ (red)				
Material Safety Data Sheet			■	■	■									■		■
UN2800 2012	Transport, Batteries Wet, Non Spillable Lead Acid			■	■											
UN3480 2013	Transport, Lithium Ion Batteries not packed with, or installed in equipment															
UN3481 2013	Lithium Ion Batteries Contained in Equipment															
AS 3011 - 1 & 2 1992	Electrical installation - secondary batteries in buildings	1 Vented					■	■	■		■					
	Electrical installation - secondary batteries in buildings	2 Sealed					■	■	■		■					
AS/NZS 3000 2014	Electrical installations	Wiring rules									■			■		
AS 4029.1 1994 AS4029.2 2000 AS 4029.3 1993	Stationary batteries - Lead-Acid	1. Vented														
	Stationary batteries - Lead-Acid	2. Sealed														
	Stationary batteries - Lead-Acid	3. Pure lead positive plate														
AS 2676 1 & 2 1992	Guide to the installation, Maintenance Testing and Replacement of secondary batteries in buildings	1. Vented		■	■			■	■		■		■	■	■	
	Guide to the installation, Maintenance Testing and Replacement of secondary batteries in buildings	2. Sealed		■	■			■	■		■		■	■	■	
AS 4086.1 1993	Secondary batteries for use with stand-alone power systems	General requirements							■				■			
AS 4086.2 1997	Secondary batteries for use with stand-alone power systems	Installation and maintenance			■			■			■		■	■		
AS 3731 1 & 2 1995	Stationary batteries - Nickel-Cadmium	1. Vented							■				■			
	Stationary batteries - Nickel-Cadmium	2. Sealed							■				■			
AS/NZS 4509.1 2009	Stand-alone power systems	Safety and installation						■		■	■		■	■	■	
AS/NZS 4509.2 2010	Stand-alone power systems	System design					■			■	■			■		
AS 4777.1 2005	Grid connection of energy systems via inverters	Installation requirements								■						
AS 4777.2 2005	Grid connection of energy systems via inverters	Inverter requirements								■						
AS 477.3 2005	Grid connection of energy systems via inverters	Grid protection requirements								■						
AS 2401.1 1994 AS 2401.2 1995	Battery charges for Lead Acid batteries Domestic	1. Vented			■						■		■			
	Battery charges for Lead Acid batteries Domestic	2. Sealed			■						■		■			
AS 4044 1992	Battery charges for stationary batteries												■	■	■	
AS/NZS IEC/TR 61000.2.8:2009	Electromagnetic compatibility (EMC)-Environment-Voltage dips and short interruptions on public electric power supply systems with statistical measurement results						■									
AS 1852.603-1988	International Electrotechnical Vocabulary - Generation and Distribution of Electricity - Power System Planning and Management						■									
NCC 2015	Building Code of Australia, (From May 2015 renamed National Construction Code)					■										

Table 17: Flow battery standards

FLOW BATTERY (ZINC-BROMIDE) STANDARD			TRANSPORT	HANDLING	HAZARDS	SITE LOCATION	SYSTEM DESIGN	BATTERY ENCLOSURE VENTILATION	CELL / BATTERY / PACK	INVERTER	WIRING / CABLING / PROTECTION	CONTROL SYSTEMS	MAINTENANCE TESTING PREFORMANCE	SIGNAGE	SYSTEM DOCUMENTATION	RECYCLING / DISPOSAL
NO CURRENT STANDARD																
Material Safety Data Sheet																
UN2800 2012	Transport, Batteries Wet, Non Spillable Lead Acid															
UN3480 2013	Transport, Lithium Ion Batteries not packed with, or installed in equipment															
UN3481 2013	Lithium Ion Batteries Contained in Equipment															
UN1760 2015	Corrosive Liquid, n.o.s (contains Zinc bromide)															
AS 3011 - 1 & 2 1992	Electrical installation - secondary batteries in buildings	1 Vented														
	Electrical installation - secondary batteries in buildings	2 Sealed														
AS/NZS 3000 2014	Electrical installations	Wiring rules														
AS 4029.1 1994 AS4029.2 2000 AS 4029.3 1993	Stationary batteries - Lead-Acid	1. Vented														
	Stationary batteries - Lead-Acid	2. Sealed														
	Stationary batteries - Lead-Acid	3. Pure lead positive plate														
AS 2676 1 & 2 1992	Guide to the installation, Maintenance Testing and Replacement of secondary batteries in buildings	1. Vented														
	Guide to the installation, Maintenance Testing and Replacement of secondary batteries in buildings	2. Sealed														
AS 4086.1 1993	Secondary batteries for use with stand-alone power systems	General requirements														
AS 4086.2 1997	Secondary batteries for use with stand-alone power systems	Installation and maintenance														
AS 3731 1 & 2 1995	Stationary batteries - Nickel-Cadmium	1. Vented														
	Stationary batteries - Nickel-Cadmium	2. Sealed														
AS/NZS 4509.1 2009	Stand-alone power systems	Safety and installation														
AS/NZS 4509.2 2010	Stand-alone power systems	System design														
AS 4777.1 2005	Grid connection of energy systems via inverters	Installation requirements														
AS 4777.2 2005	Grid connection of energy systems via inverters	Inverter requirements														
AS 4777.3 2005	Grid connection of energy systems via inverters	Grid protection requirements														
AS 2401.1 1994 AS 2401.2 1995	Battery charges for Lead Acid batteries Domestic	1. Vented														
	Battery charges for Lead Acid batteries Domestic	2. Sealed														
AS 4044 1992	Battery chargers for stationary batteries															
AS/NZS IEC/TR 61000.2.8:2009	Electromagnetic compatibility (EMC)-Environment-Voltage dips and short interruptions on public electric power supply systems with statistical measurement results															
AS 1852.603-1988	International Electrotechnical Vocabulary - Generation and Distribution of Electricity - Power System Planning and Management															
NCC 2015	Building Code of Australia, (From May 2015 renamed National Construction Code)															

3.3.3 Gaps between Australian and international standards

Table 18 summarises the gaps identified between Australian and international standards from Tables 14–17.

Table 18: Gaps between Australian and international standards

Requirement for standard	Summary	Existing relevant international standards	Existing relevant Australian standards	Additional comment / recommendation	Potential benefit of energy storage in Australia
Whole network system communication					
Grid system communication Distribution automation Distribution management systems Substation automation Transmission of information	Given the elemental nature of the national electricity grid and the use of different equipment and varying levels of communication sophistication, there is a need for the industry to reach agreement on the core communication protocols and data security to be applied across the smart grid in Australia	IEC/TR 62357 IEC 61970-1 IEC 61968 IEC 62351 IEC 61869 series IEC 61850	None known	Adapt international standards for Australian market application	Battery energy storage used as domestic or grid based would have to communicate with the whole network system
Gaps and standards Controlling voltage and frequency					
Electromagnetic compatibility	Ensure that all future elements of the smart grid are designed and operated in such a manner as to ensure electromagnetic compatibility with the existing electricity grid	IEC 61000 series CISPR	Yes	Adapt international and Australian standards for present Australian market application	Battery storage may benefit the grid by controlling voltage and frequency variations, and reducing electromagnetic interference
Physical future grid connection – smart grid, including storage					
Interconnection protocols	Future application of the smart grid will require that any equipment connected to the grid is consistent with the core communication, data security and electromagnetic compatibility requirements of the smart grid	IEC 60904 IEC 62446 IEC/TS 62257	None	Adapt international standards for Australian market application	

Requirement for standard	Summary	Existing relevant international standards	Existing relevant Australian standards	Additional comment / recommendation	Potential benefit of energy storage in Australia
Distributed generation	Decentralised generation of electricity via co-generation and tri-generation systems creates a need for the development of high-level protocols for smart grid technologies designed to manage the interaction of these systems with the grid network	IEC 60904 IEC/TS 62257 IEC 62446	None	Adapt international standards for Australian market application	
System safeguards	If developed to their full potential, smart grids will increase the interdependencies of the discrete elements of the national electricity grid, potentially increasing the risk of power interruptions. Successful management of this issue will probably require network-wide application of wide-area measurement systems, and system integrity protection schemes enabled by new monitoring hardware (e.g. grid sensors) It is envisaged that this element would also extend to the testing (i.e. design and operation) of condition monitoring equipment used for transformer monitoring, geographic information system monitoring, overhead line monitoring and circuit breaker monitoring	IEC 61869 series (some parts still under development)	Possibly AS 4777	Adapt international standards for Australian market application	
Operation of microgrids	Smart grid functionality provides an opportunity to use the surplus energy generated by microgrids (networked small distributed generation) during peak periods of load demand; however, for this potential to be realised, it is essential that the electrical and communications architecture of the microgrids is compatible with that of the national electricity grid		AS 4777 (parts 1–3) AS 6100.3.100	Review existing Australian standards regarding specific smart grid requirements	

Requirement for standard	Summary	Existing relevant international standards	Existing relevant Australian standards	Additional comment / recommendation	Potential benefit of energy storage in Australia
Connection of microgrids to the national grid	Operation of smart grids affords an opportunity to tap into the power generated by microgrids or renewable energy		AS 4777 (parts 1–3) AS 6100.3.100	Review existing Australian standards regarding specific smart grid requirements	Battery storage will be a component of any future smart grid Battery storage will be part of the Smart Grid and will have different applications depending on the co-generation or tri-generation system Battery storage would be a component of the Smart Grid and if the grid was interrupted the battery storage would have to be disconnected Battery storage will be part of the Smart Grid and will have different applications depending on the renewable energy generation
Terminology and vocabulary					
Smart grid terminology	The development of all smart grid standards will require the adoption of a common vocabulary and terminology for all elements of a smart grid	None, but definitions are included in variety of IEC standards	None	Develop standard for Australian market applications	Battery storage vocabulary (chemistries, size, C-rates and hybridisation) needs to be standard across the grid network
Design, planning and performance					
Battery storage design	Standards will be required to ensure the performance characteristics of battery storage with a primary focus on the safe operation, location, electrical integrity and communication of these devices	None	Possibly AS 4777	Adapt elements from AS 4777 for electrical installation procedures for Australian market application	Detailed battery storage design with the emphasis on which chemistry to use for application/location will be very important
Location and installation					
Battery storage installation Battery storage location Battery storage training and maintenance	Poor installation and maintenance of this infrastructure has the potential to create substantial public risk (in terms of shock and fire risk) or reduce the economic utility of upstream investments in areas such as dynamic load control and system monitoring	None	Possibly AS 4777	Adapt elements from AS 4777 for electrical installation procedures for Australian market application	Correct battery storage installation, location, training and maintenance will ensure safety, operational and economic advantages are fulfilled

Requirement for standard	Summary	Existing relevant international standards	Existing relevant Australian standards	Additional comment / recommendation	Potential benefit of energy storage in Australia
Storage technology					
Battery storage	The use of battery storage (voltage and frequency control) connected to the high-voltage grid network and smart grids using small battery storage located downstream of high-voltage transformers during peak periods of localised network demand will require standards that ensure the safe operation, electrical integrity and communication of these networks	None	None	Develop standards for Australian market application	Battery storage used for any application at any point of the grid network will require battery (chemistry) technical standards
Electric – mobility					
Battery storage from electric vehicles	Using battery energy stored in electric vehicles connected to the grid during peak periods of demand (i.e. vehicle-to-grid) brings requirements different to those required for non-electric vehicle battery storage systems There is likely to be a need to develop a standard that stipulates the performance characteristics of electric vehicle batteries and power systems to be used for vehicle-to-grid connections, to ensure this infrastructure meets minimum thresholds for safety, battery durability and cyclic stability of electricity	ISO 6469-1 IEC 61982 IEC 62619	None	Adapt international standards for Australian market application	

AS, Australian Standard; CISPR, International Special Committee on Radio Interference; IEC, International Electrotechnical Commission; ISO, International Organization for Standardization
Information from: Standards Australia, *The Australian standards for smart grids – standards roadmap*, June 2012 [39]

Best practice around battery energy storage is performed in some industries for selected technology types. For example, best practice is used for transportation of lithium-ion batteries in the aviation sector, probably due to the international standards that govern this industry. However, for domestic and small commercial stationary energy storage, there is a lack of guidance and consistency for safe selection and management of batteries. This is key, because energy storage is seen as an enabling technology in the future electricity system.

3.4 Installation and operation of energy storage systems

Important aspects of safety include how a battery energy storage system is installed, or used and maintained. Also important are the quality and reliability of the different components within the system, and how well they integrate within the system. Thus, to support industry growth, appropriate certification of battery technology components and system should be implemented. Similar compliance requirements already exist in other industries (e.g. solar PV, and building and construction material industries), and these requirement must be met before products can be imported, sold or used in Australia. The rest of this section outlines suggested requirements.

3.4.1 Electrical requirements

This section outlines the electrical connection requirements for domestic and commercial energy storage systems, and the relevant Australian standards and regulations. It covers the following aspects:

- types of voltages
- cable selection and wiring
- voltage drop calculations
- cable protection (including overcurrent protection)
- grid connection
- maintenance.

Types of voltages

Electricity at the domestic household power point is called alternating current (AC). Batteries and solar panels produce direct current (DC). In a typical domestic or small commercial system of solar panels and batteries, the solar array will produce DC power, which is then converted to AC by the solar inverter (as shown in Figure 1). The DC power generated by the solar panels will then be in a form compatible with the AC mains power coming into the household or business from the grid.

A battery system connected to solar panels also uses DC. The batteries are usually connected to the AC mains power in a similar way to that used for solar PV panels. Thus, an inverter converts DC power from the batteries to AC power. This makes the system suitable for connection to the grid, and allows the batteries to charge and discharge depending on the household usage.

Most battery storage systems comprise of a number of cells, assembled into batteries. The batteries are then connected together into a package or bank, with commonly used voltages of 12, 24, 48 or 120 V DC. Battery storage systems can be supplied as a single unit, but usually come as individual cells that are assembled into a complete battery pack onsite.

Two types of voltage are commonly found on energy storage systems: extra low voltage (ELV) and low voltage (LV). By definition, ELV cannot exceed 50 V AC or 120 V ripple-free DC, as defined in AS/NZS 3000, clause 1.5.7(a). LV exceeds ELV, but not beyond 1000 V AC or 1500 V DC, as defined in AS/NZS 3000.

Cable selection and wiring

For all battery installations, cabling must be wired to AS/NZS 3000 specifications. Under this standard, cables should be sized such that the maximum load demand of the circuit does not exceed the current-carrying capacity of the cable. When determining the size of the cables, provision should be made for foreseeable changes to the external environment (e.g. the installation of thermal insulation in ceiling spaces and walls). Additionally, cables should be suitable for the highest and lowest local ambient temperatures. The maximum permissible conductor operating temperatures for several cable types is provided in AS/NZS 3000. The standard also dictates the minimum cross-sectional area for different conductor materials and types of wiring system.

In general, when selecting cables and the method of connection in accordance with AS/NZS 3000, the following factors must be taken into account:

- cable length and installation surroundings
- material of the conductor and its insulation
- number and shape of the wires forming the conductor
- cross-sectional area of the conductor
- number of conductors connected together (e.g. parallel or junction)
- temperature attained by terminals in normal service
- prevention of entry of moisture, and siphoning of water through any cable or wiring enclosure.

Comprehensive data tables and examples for selecting cables based on the above factors are provided in AS/NZS 3000. For example, Table C9 in that standard lists the maximum number of single-core sheathed cables that may be installed in conduit for different cable types.

In accordance with AS/NZS 3000, cables should be installed such that there is no undue mechanical stress on any joints or connections. Appropriate tools (e.g. crimping devices for crimp joints) should be used during installation and should be insulated where practical. Soldered connections should be able to withstand mechanical stress and temperature rise under fault conditions. Conductor colour identification (by sleeving or other means) should be implemented as per AS/NZS 3000.

AS/NZS 3008.1 specifies a method for cable selection for working voltages up to and including 0.6/1 kV 50 Hz AC. The standard covers calculations for cable current-carrying capacity, voltage drop and short-circuit temperature rise for typical Australian installation conditions. Comprehensive tables and examples are provided to assist with these calculations. The current-carrying capacity for DC cables can be determined from AS/NZS 3008.1, because the heating effect for DC currents is equivalent to the root mean square value for AC currents.

Voltage drop calculations

AS/NZS 3000 specifies that the voltage at the battery terminals should not impair the safe functioning of the electrical equipment. The voltage drop between the point of supply and any point in the installation must not exceed 10% of the nominal voltage at the point of supply. In the context of domestic energy storage, this means that:

- cable losses between the PV array and the battery bank should not exceed 10%
- cable losses between the battery bank and any DC load should not exceed 10%.

AS/NZS 3008.1 provides extensive details to assist with calculating voltage drop for AC cables up to 0.6/1 kV. However, voltage drops for DC currents (i.e. those flowing from the battery) cannot be calculated using AS/NZS 3008.1. Instead, AS/NZS 1125 can be used to determine the maximum DC resistance of a conductor, and therefore calculate DC voltage drops.

The voltage drop of a cable is given by:

$$V_d = \frac{2 \times L \times I \times \rho}{A}$$

where L = route length of cable (m)
I = electrical current (A)
ρ = resistivity of copper wire ($\Omega/m/mm^2$) e.g. copper wire $\rho = 0.0183$
A = cross-sectional area of cable (mm^2)

The value for electrical current used in the above equation should not exceed either the current-carrying capacity of the cable or the current rating of any circuit protective devices, noting that the current-carrying capacity of the protection device should be lower than that of the cable.

Protection devices

Overcurrent protection devices, such as fuses or circuit breakers, prevent damage to equipment or cables caused by overcurrent (i.e. a current that exceeds the rated current). Overcurrent can be caused by overloading the circuit, a short circuit or a ground fault. The protection devices should be selected based on the electrical current rating of relevant equipment or cables, or both (see AS 3008 for more details).

For energy storage systems, overcurrent protection must be installed in each positive conductor, except where one side of the battery bank is earthed (ground). In the latter case, only the unearthed (ungrounded) conductor requires overcurrent protection. It is normal practice to either fuse the positive conductor and earth (ground) to the negative, or fuse all conductors.

Standards and regulations, including AS 4509 (stand-alone power systems safety and installations), require the following:

- High rupturing capacity fuses[7] or circuit breakers should be installed to protect all ELV subcircuits, and these circuits must be capable of being electrically isolated without the use of tools (i.e. by means of a switch or quick-disconnect fuse near the batteries). Any circuit breaker used in DC circuits must be rated for the appropriate DC voltage and be non-polarised.
- Battery fusing should preferably not be in the same enclosure as the battery bank. If the fusing is in the same enclosure, then it should be either a minimum of 500 mm away from the batteries or 100 mm below the top of the batteries. Alternatively, a vertical partition can be placed between the battery bank and the fuse to keep the fuse close to the battery bank but isolated from it.
- Terminals should be shrouded to prevent battery shorting and to ensure safe separation between live terminals.
- Any exposed cabling should be protected from ultraviolet light and mechanical damage (e.g. using run in conduit).

AS/NZS 5033 requires that a DC isolation or disconnection device be installed adjacent to the PV array. When installed correctly, these isolators can be beneficial. Their primary purpose is to provide a means to isolate the PV array from the inverter so that it can be safely serviced. However, there have been concerns about fire hazards relating to (solar PV panels) isolators [40] being poorly installed or substandard equipment being used.

When an energy storage system is installed and connected to a PV array, this concern applies in the same way. It is also important that when any part of the battery storage system protection devices are subject to harsh outdoor conditions, the equipment is of high outdoor tolerance with a recognised ingress protection rating (i.e. greater than IP56). Standards and regulations around weather protection of the isolators may be required to address these concerns.

[7] A high rupturing capacity fuse is one that has a certain current tolerance before becoming open circuit.

Grid connection

Standards for the grid connection of energy systems via inverters are covered by the AS 4777 series. This series of standards specifies requirements for installation, inverters and grid protection for inverters.

Maintenance

Energy storage manufacturers should provide a maintenance schedule and other necessary information to optimise the life and efficiency of the system, and to reduce risk of personal injury (see Section 2.4 for further details). Maintenance services can be carried out by a suitably qualified accredited installer.

3.4.2 Physical installation requirements

There is debate about where battery storage should be located in the home. This debate centres on battery safety and the actions that should be taken in the event of an incident. The discussions have recently increased because of growing interest in the use of battery storage systems in the urban environment, and the projected predominance of lithium-ion technologies, which present unique hazards.

A popular location for battery storage systems is the garage area, if such an area is present. However, a wide range of scenarios may confront an installer, and even where there is a garage area, it may not be suitable for a battery installation because of its design and construction. For example, if the garage is contained under the same roof space as the living areas but without a suitable, fire break partition, the risk of an incident encroaching on the living areas in increased. Hence, it may be necessary to use a different location, or to modify either the dividing wall or system enclosure.

Standards encompassing the installation of lead-acid battery storage systems are already in place. In conjunction with the Australian building code, such standards have provided guidance to installers of battery systems until now. However, the fast uptake and developments in the technology of lithium battery storage systems pose new risks and dilemmas about the selection of ideal locations for installations of sizeable capacity. The locations need to be practical and economic for the installation, while still ensuring safety.

The following basic guidelines are suggested for lithium-ion battery storage systems, which are particularly applicable to installations approaching commercial-scale capacities:

- Platforms and enclosures constructed of aluminium or steel are recommended, because they can contain potential fires and more efficiently regulate heat.
- Fireproof enclosures must contain any fire while also incorporating venting to prevent pressure build-up.
- Battery storage systems should be accommodated in a space that can be sealed and that can safely vent gases into the atmosphere away from people and living spaces, because toxic organic compounds are formed when the cell is venting. The toxic gases can be denser than air; thus, there should be no open access to the lower regions of the enclosure. Ideally, the enclosure should be lockable in the event of a venting or fire incident. This can be accomplished with an interlock device that triggers during an incident, or with a fixed lock that is always secured. If the latter is used, then a system to alert when an incident has taken place should be incorporated (e.g. an alarm).

3.5 Emergency response requirements

Depending on the technologies, there will be different safety requirements in response to an incident. For established battery chemistries, there are clear and understood actions to take in an emergency situation. For the emerging technology of lithium, the appropriate steps to take in response to an incident are less clear. This section presents the results of the literature search related to the particular chemistries. The most suitable emergency response may also depend on the situation, size and conditions of the incident.

3.5.1 Lead-acid batteries

Lead-acid batteries have a well-known chemistry. Because of the hazardous materials at risk of exposure (i.e. sulfuric acid, which can cause severe burns, and lead, which can cause cumulative effects and harm for humans and the environment) there is a need for various precautions and actions [41] [42] [43].

Fire or explosion risk – lead-acid batteries

- Lead-acid batteries generally burn with difficulty. However, should a fire occur, it is advised to extinguish with an agent suitable for surrounding combustible materials (carbon dioxide or halon).
- Hydrogen gas may be flammable or explosive when mixed with air, oxygen or chlorine. Avoid open flames, sparks and other sources of ignition near battery.
- Extinguish fire. Cool exterior of battery if exposed to fire to prevent rupture.
- Do not use water on fires where molten metal is present.

Chemical exposure or spill – lead-acid batteries

- The acid mist and vapours generated by heat or fire are corrosive. Use National Institute for Occupational Safety and Health-approved self-contained breathing apparatus and full protective equipment operated in positive-pressure mode.
- Sulfuric acid is highly corrosive. Any spills from the battery should be neutralised with sodium bicarbonate and washed away with plenty of water.
- Ventilation requirements should be followed, as set out in Australian Standards AS 2676 and AS 3011. This includes a rate of ventilation of at least 0.1 m/s of air velocity and maintenance of the average hydrogen concentration by volume in a battery room or enclosure below 2%.
- Hydrogen gas and sulfuric acid vapours are generated upon overcharge and polypropylene case failure.

Electrical risk – lead-acid batteries

- Do not allow metallic materials to simultaneously contact negative and positive terminals of cells and batteries.
- Do not use water on fires where molten metal is present.

3.5.2 Lithium-ion batteries

Lithium battery storage systems are an emerging technology, and multiple chemistries are included in this category. The chemistry the system comprises may have implications for the best way to manage an incident. The breadth of types of lithium battery may also explain why there are many different (and sometimes contradictory) methods for treating a potential incident [44] [45] [46] [47] [48] [49].

Fire or explosion risk – lithium-ion batteries

- Lithium-ion cells contain flammable electrolyte; thus, they have a high energy density and potential for fire or explosion.
- If a fire occurs adjacent to stored lithium-ion cells and battery packs, they must be protected from relatively modest overheating, otherwise they may begin to vent and ignite, spreading the fire more rapidly than would be expected for normal combustibles.
- For a 'vent with flame' incident originating in one individual cell, it is suggested to cover or submerse the cell in sand to suppress the fire.

- Once the fire has spread to a larger area of the battery bank, the use of sand alone may not be sufficient; instead, the use of an inert and cooling gas, such as argon, is presently the best practice.
- Do not use water on lithium battery storage systems, because they contain their own oxygen source and will go on burning until that oxygen is exhausted.
- At fire scenes where large quantities of lithium-ion cells have been involved, emergency services personnel must make decisions regarding movement of undamaged batteries or cells, with an understanding that as cells are uncovered, moved or damaged during this procedure, they may potentially undergo thermal runaway reactions and vent, or they may ignite. Similarly, the potential for rekindles will be high at such fire scenes, and these scenes will require more extended monitoring than normal fire incidents.
- In the event of thermal runaway, even after the fire is extinguished, the battery storage systems can continue to generate tremendous amounts of heat for extended periods of time and can reignite fumes, hampering rescue efforts. Some national and international government departments and agencies are working together to educate firefighters and rescue workers to identify these issues in vehicles and grid storage systems, and in how to respond to battery fires.
- There has been some suggestion that water be used as a cooling agent to prevent heat propagation from burning cells to neighbouring cells when dealing with lithium-ion, as opposed to primary lithium batteries. Care should be taken to prevent water coming into contact with burning cells. Also, burning cells should be allowed to extinguish themselves, or should be extinguished using sand or argon gas.

  It is strongly recommended for fires involving primary batteries NOT to use water. However, if water is used, the following cautions apply:

  - Cool the cells or batteries adjacent to the ones that have caught fire to maintain low temperature.
  - On active batteries, avoid the electrical hazard that may be present.
  - In case of risk of mixes between primary lithium metal batteries and lithium-ion rechargeable batteries, avoid the use of water but use abundant dry media, as recommended above. Request additional information about firefighting tools from the battery manufacturer.
  - Treat any waste water by confining the effluent or the contaminated material and collecting it for further for appropriate treatment as a hazardous waste (water). Collect the waste water and transfer it to properly labelled containers.
  - Dispose of waste water in accordance with local waste management legislation and emissions regulations.

Chemical exposure or spill – lithium-ion batteries

- Safety is a concern in emerging lithium-ion battery technology; thus, it is important to understand that cells contain both the oxidiser (cathode) and fuel (anode) in a sealed container. By-products of combustion, if it occurs, may be toxic.
- Most of the metal oxide electrodes are thermally unstable and can decompose at elevated temperatures, releasing oxygen, which can lead to thermal runaway. If allowed to react chemically in an electrochemical cell, the fuel and oxidiser convert the chemical energy directly into heat and gas. Once started, this chemical reaction is likely to proceed to completion because of the intimate contact of fuel and oxidiser, limiting the ability to control or extinguish it.
- Gas generation in lithium-ion cells under abuse conditions (e.g. overcharge, overdischarge, operation at temperatures above safe rated, puncture or crushing, thermal runaway or short-circuiting) has an indirect effect on safety by producing sufficient pressure and gas volume to convert the flammable solvents into aerosols, which are released into the surrounding environment during cell venting. The venting potential of lithium-ion cells has some similarities with aerosol products, which typically use a flammable propellant. Vents can be used as a safety mechanism as

they open in response to an increase in cell pressure. Releasing this pressure prevents damage to the cell inside the battery case and prevents related risks from exposure to these materials.

- In the context of lithium battery fires, water should not be used as a firefighting medium because it can react with chemical compounds being formed during the battery fire and can worsen the situation.

Electrical risk – lithium-ion batteries

As is clear from the points above, there are a wide variety of issues to consider when trying to extinguish lithium-ion battery fires. At present, there is no consensus about the best method to accomplish this. The literature suggests using sand, liquid nitrogen, water mist, lithium chloride or foam, or suggests doing nothing. Each of these methods has advantages and disadvantages. Hence, further research is required to provide clarity about the best way to suppress a domestic fire involving lithium-ion battery storage systems.

3.5.3 Flow batteries

Compared to other battery storage types, there is less concern about the risk of fire with flow batteries (specific to this example, based on a zinc bromine electrolyte). However, there is more concern about the chemical exposure to the battery materials [8].

Fire or explosion risk – flow batteries

To extinguish a fire involving flow batteries, the response will depend on the cause of surrounding fire. Media including water, foam or dry agent are acceptable for extinguishing a fire without posing a risk of reaction with the battery materials.

In case of fire where flow batteries are present:

- Evacuate the area and contact emergency services.
- Toxic gases may be evolved in a fire situation. Remain upwind and notify those downwind of the hazard.
- Wear full protective equipment, including self-contained breathing apparatus, when combating fire.
- Use water-fog to cool intact containers and energy storage areas.
- Select extinguishing media based on the cause of the surrounding fire.
- The batteries will not react adversely to water, foam or dry agent-based extinguishers.
- Prevent contamination of drains or waterways.
- Note that the Hazchem Code is 2W.

Chemical exposure or spill – flow batteries

- Chemical hazards identified may include harm by inhalation, burns and high toxicity to aquatic organisms and the environment.
- In response to cleaning up an electrolyte leak (e.g. in a zinc bromide flow battery) personal protective equipment including a respirator, goggles and gloves should be worn.
- Prevention of contamination of drains and waterways is advised.

3.5.4 Nickel-based batteries

Nickel-based battery storage systems are a technology that is less used today, generally due to the toxicity of the materials. There are also varying data on the most appropriate method to extinguish a fire involving a nickel-based battery. The information given here was collected from different manufacturer MSDSs [50] [14] [51] [52].

Fire or explosion risk – nickel-based batteries

In case of fire where nickel metal hydride batteries are present:

- Burning batteries are likely to burn themselves out. However, appropriate extinguishing media includes carbon dioxide, dry chemical, soda ash, lime, sand or foam.
- There is some suggestion that any class of extinguishing medium may be used for nickel-cadmium batteries or their packing material.
- Possible methods for extinguishing include use of a smothering agent such as METLX, sand, dry ground dolomite or soda ash, or flooding the area with water.
- Most fires involving nickel metal hydride batteries can be controlled with water. The water may not extinguish burning batteries, but it will cool the adjacent batteries and control the spread of fire.
- When water is used directly on exposed and burning nickel metal hydride batteries, hydrogen gas may be produced; it is recommended that water is unsuitable for this reason.
- Firefighters should wear self-contained breathing apparatus.

Chemical exposure or spill – nickel-based batteries

- Burning nickel metal hydride batteries can produce toxic fumes, including oxides of nickel, cobalt, aluminium, manganese, lanthanum, cerium, neodymium and praseodymium.
- In a confined space, hydrogen gas can form an explosive mixture. In this situation, smothering agents are recommended.
- Exposure to temperatures of above 100 °C can cause evaporation of the liquid content of the potassium hydroxide electrolyte, resulting in the rupture of the cell.
- Nickel metal hydride cells (if non-sleeved) may generate short circuits, causing release of alkaline electrolyte mist or liquid. This electrolyte reacts with zinc aluminium, lime and other active materials to release flammable hydrogen gas.
- Prevent release of spilt battery materials to soil, drains, waterways or ground water as they are highly toxic to aquatic life.

3.5.5 Electrical hazards for batteries

Battery storage systems (regardless of their different chemistries) have inherent electrical hazards and are always likely to have a live voltage. It is not possible to isolate batteries; thus, any risk of contact with the terminals (with a metal object) will draw current. Given the electrical risk, in the event of a fire, it is best to use an extinguishing media such as carbon dioxide or dry powder.

3.6 Conclusion

It is clear from this section that there is a lack of knowledge on the various energy storage technologies. In turn, this means that information is lacking on how to care for and operate such technologies in a safe manner in the domestic and small commercial context. There is a need for industry to develop best practice for these systems in general, and for specific situations. For example, consensus is lacking on how best to extinguish a lithium fire in the event of an incident. Emergency response teams will have little experience of dealing with incidents like these, especially in urban locations. Hence, there is a need for education of such teams, and for installations to be sited in an appropriate location and to have relevant warning signage (in particular, making it clear what type of battery chemistry is being used).

Section 6 provides recommendations relevant to battery installations, with a particular focus on safety.

4 Accreditation and training

Battery technologies have inherent risks; therefore, the system design and installation is critical, to ensure that the product and operating environment are as safe as possible. Accreditation and training mechanisms are one way to govern this. Presently, there is limited regulation of training for energy storage system design and installation. Another way to improve safety in the industry is through a certification process for the quality and reliability of different components and their compatibility within an energy storage system. Industries such as solar PV, building and construction already have certification requirements that products and workers must meet before they can be imported or sold, or can operate in Australia.

There is clearly a need for accreditation and training for the design and installation of domestic and commercial battery storage installations. This section of the report reviews present battery accreditation and training schemes for Australia, with an emphasis on storage safety.

Certain safety aspects will depend on the context in which battery storage is used; therefore, information needs to be tailored to particular circumstances. There is a lack of agreed training requirements for energy storage systems, both in Australia and globally. The CEC offers an accreditation guideline for designers and installers in the solar PV sector. Something similar is needed for the energy storage industry, with separate accreditation for the design and for the installation of different system types (grid-connection, battery endorsement and stand-alone energy storage). The accreditation certification would also need to be specific for particular battery types (e.g. lead-acid or lithium). An international example is the German Energy Storage Association's safety guidelines for lithium-ion domestic battery storage systems [48].

4.1 Accreditation for design and installation

The CEC currently oversees accreditation for the design and installation of solar PV (including battery storage), whether connected to the electricity grid or in a stand-alone power system. The CEC is a nationally recognised peak body that represents Australia's clean energy sector. This industry association comprises more than 400 member companies operating in the fields of renewable energy and energy efficiency. The present accreditation pathway for solar PV (& battery storage) is shown in a simplified diagram in Table 8.

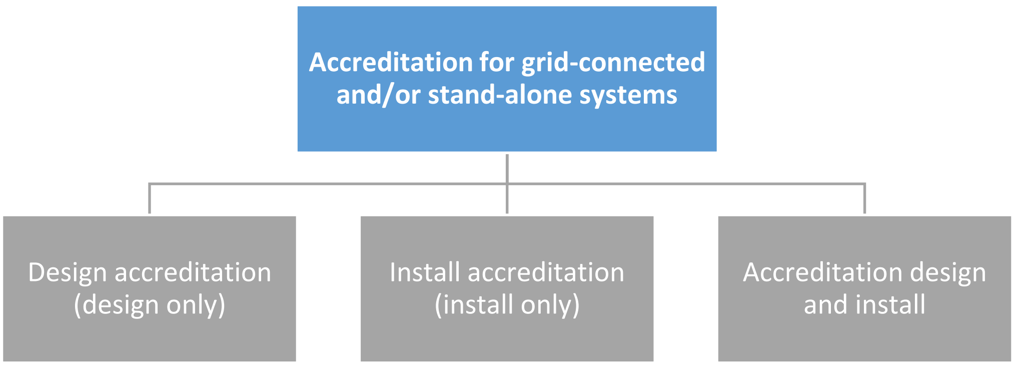

Figure 8: Present CEC accreditation pathway for solar PV (and battery storage systems)

Accreditation (similar to the CEC's solar PV requirements) could be for installation, design or both. The following definitions clarify these roles:

- **Accredited designer** – a person who is accredited by the CEC to **design** grid-connected, endorsed battery storage systems or stand-alone battery storage systems (or both), and holds all relevant qualifications.
- **Accredited installer** – a person who is accredited by the CEC to **install** grid-connected, endorsed battery storage systems or stand-alone battery storage systems (or both), and holds all relevant qualifications.

The Clean Energy Regulator[8] stipulates that, if a small generation unit (including solar PV panels, wind turbines and hydro systems) is to be eligible for a small technology certificate, it must be designed by a CEC accredited designer and installed by a CEC-accredited installer. As outlined above, accreditation can include grid-connected solar PV and storage, and stand-alone solar PV and storage; also, it can cover either design or installation. Additionally, the CEC has further endorsements for wind, micro-hydro and grid back-up organisms.

Presently, the CEC has over 4000 accredited installers. It works with relevant industry associations and the Australian training and educational community at university and TAFE (tertiary and further education) levels to develop and certify training courses and systems. The CEC maintains lists of accredited installers and registered training organisations (RTOs).[9]

Approved training providers develop and conduct training according to nationally recognised competency standards, and are registered with an Australian RTO. RTOs are available in all states across Australia; a list of RTOs can be found on the CEC website.[10] At present there are only two RTOs providing accreditation training courses for solar PV grid-connect with battery storage.

According to the CEC accreditation training pathway (i.e. UEE11), the following modules are required for grid-connected accreditation:

- *Solar PV Design* – has no prerequisites
- *Solar PV Install* – must hold unrestricted electrical licence
- *Solar PV Design and Install* – must hold unrestricted electrical licence.

A person who has obtained full or provisional accreditation from the CEC for the design or installation (or both) of stand-alone power systems, solar grid-connected PV or solar PV grid-connected with battery backup or other acknowledged grid-connected system will, according to the CEC website [53]:

- be eligible for government incentives such as small technology certificates and feed-in tariffs
- be listed on the solar accreditation website
- be able to keep up to date with changes in the industry
- have access to expert technical advice and effective dispute resolution services
- follow a recognised code of conduct for installers
- have access to a restricted technical support website run by the CEC.

By choosing an accredited installer, the PV system that customers receive and have installed should be of high-quality, safe and reliable. A reliable installation that fulfils customer expectations requires both careful design and correct installation practice. Compliance with relevant standards, state health and safety regulations is also necessary. Accredited installers must comply with the following standards, where applicable:

- *AS/NZS 3000 – Electrical wiring rules*

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[8] www.cleanenergyregulator.gov.au, accessed 11 August 2015
[9] RTOs are training providers registered by Australian Skills Quality Authority or a state regulator to deliver vocational education and training services. RTOs are recognised as providers of quality-assured and nationally recognised training and qualifications.
[10] www.solaraccreditation.com.au

- *AS/NZS 5033 – Installation and safety requirements for solar PV arrays*
- *AS/NZS 4509.2 – Design of stand-alone power systems*
- *AS/NZS 1170.2 – Structural design for wind*
- *AS 4777.1 – Installation of grid connection of energy systems via inverters*
- *AS/NZS 1768 – Lightning protection.*

Standards and regulations are discussed further in Section 3 of this report.

CEC accreditation [53] does not accredit applicants for any LV work. All LV work must be completed by an appropriately licensed electrical tradesperson in accordance with the relevant Australian standards and legislation.

4.2 Battery energy storage

Under CEC guidelines [53], installation of a grid-connected battery backup system shall be performed by a person with CEC grid-connected install accreditation with battery backup endorsement, or a person(s) with CEC grid-connected install accreditation and CEC stand-alone install accreditation.

Although there is accreditation for the design and installation of battery energy storage with solar PV and a battery backup endorsement for grid-connect accredited installers or designers, there is currently no specific accreditation for battery or energy storage only. Having these courses would enable the creation of a separate accreditation scheme that would not require the applicant to be solar PV accredited.

The installation of battery storage has additional safety risks, including electric shock hazard, energy hazard and chemical hazard, which the accredited designer and installer should be aware of. Given the safety considerations highlighted for battery storage (including the diversity of electrical and chemical characteristics across technologies), it is recommended that a special accreditation scheme for installation of battery storage be established. This should encompass components such as:

- stand-alone battery systems (generic and specific battery types)
- grid connection compliant with, at the very least, the standards and regulations highlighted in Section 3.

Additional endorsement could include installation with multiple generation sources (including and beyond solar PV). Authoritative bodies such as E-Oz or Skills Service Organisations may wish to investigate and develop suitable training packages, to create a nationally recognised training and accreditation scheme for battery storage installation.

An appropriate legislative or regulatory framework is needed to ensure the integrity of the industry and its smooth growth. Thus, establishing the training requirements for installers and designers to be accredited is crucial. Collaboration with RTOs to provide and assess these qualifications would also be useful.

4.3 Product certification

Due to the inherent risk associated with battery storage systems, the products and equipment should comply with standard and certification for a given application and region. CEC does provide information relating to which product standards need to be certified and can be found on their website.[11] Presently the CEC require national certification testing to be performed by a test laboratory approved to certify solar PV panels to the relevant standards. This approval process provides accredited designers and installers with a list of products that they know meets the required standards and are acceptable to use. These certifications would need to extend to the inverters and batteries for a domestic or commercial storage installation.

[11] http://www.solaraccreditation.com.au/products/inverters.html

4.4 Conclusion

Most of the present accreditations are designed for Australia's solar PV systems rather than for battery energy storage systems. There is an insufficient accreditation and training to help designers and installers to gain qualifications specific to the installation of energy storage systems. Hence, the Australian industry needs a battery energy storage accreditation scheme, similar to that of the CEC's solar designer and installer accreditation scheme.

As the battery energy storage industry relating to renewable energy application is relatively new, a limited number of designer and installers have adequate accreditation and training. This is particularly true for the emerging lithium-ion battery technologies. Also, there is a need for accreditation and training to encompass safety protocols, and signage related to warnings and battery chemistry type. The issue is complicated by the wide variety of aspects to consider, plus the continuous development of the many different technologies, components and regulations.

There is a need to investigate and develop specific energy storage system installation training packages for use in a nationally recognised accreditation scheme. Agencies such as E-Oz or Skills Service organisations could take on this role and fill existing gaps. This would enable a safe and smooth widespread adoption of energy storages with all the multiple facets and scales of the systems, whether on or off the grid, for any applicable generation source or load type. Skills updating or refresher course should also be set up to provide continuous professional development and keep up with the best practices for the industry from a global perspective.

Also, the storage industry needs to develop an installer checklist – to help educate and ensure safe best practices when installing of domestic and small commercial battery storage systems. Appendix A provides a suggested guide for battery storage system installation.

Section 6 provides recommendations relevant to accreditation and training.

5 Identification of key gaps in the market

We used a gap analysis to identify the key challenges in the energy storage market that require further assessment. The domestic and commercial battery storage industry may perform below its future potential if it does not make the best use of existing resources, or if it forgoes investment in education, training, standards and technologies.

5.1 What is a gap analysis?

A gap analysis makes it possible to assess whether the present practices in the field are adequate and to identify areas that need attention. The analysis identifies the required actions and high priorities for a newly developing industry, by comparing the actual performance of the industry against its potential or desired performance. This helps the industry to meet its long-term objectives while being profitable, mature and safe. Figure 9 shows that the 'gap' represents the actions required to improve the industry's performance to its desired level.

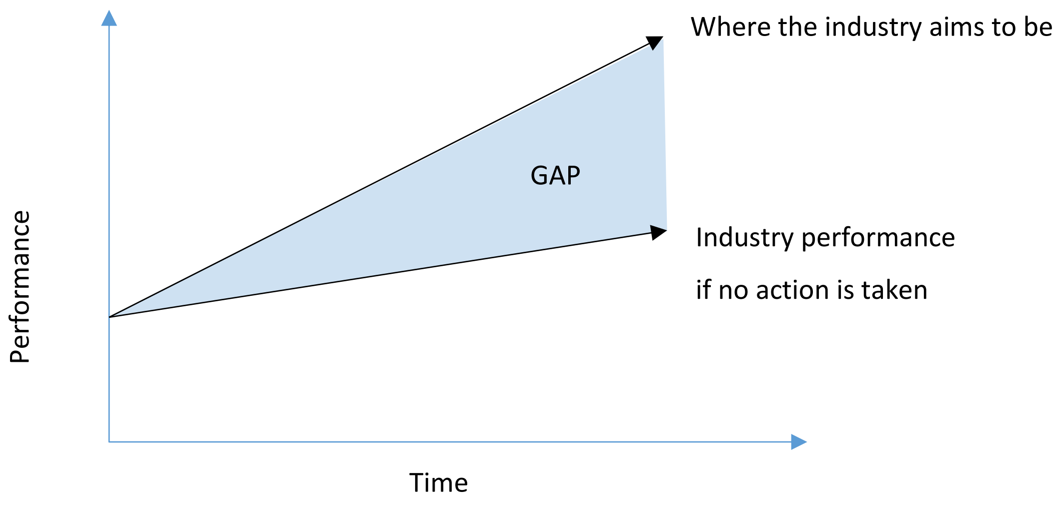

Figure 9: Gap analysis diagram

5.2 Methodology and assessment criteria

In undertaking a gap analysis of Australian energy storage safety, we used a traffic light criteria system, as shown in Table 19. The system defines the present coverage and effectiveness that can be used to describe various industry practices. It was used to identify specific problem areas where present energy storage safety practices are ineffective and require action.

The analysis aimed to assess whether present practices are effective for a variety of battery storage technologies (lead-acid, lithium-ion, sodium-ion analogue, nickel-based and flow technologies). The areas evaluated were grouped as follows:

- **Consumer education** – Is the general public aware of the battery storage technology and its capabilities and performance? Are they aware of the advantages and disadvantages of each technology, especially with regards to safety risks?

- **Best practices** – Has the industry (or government agency) created best practices for battery storage technology? There is a need for a benchmark for safe practices, including installation and maintenance, specific to the storage technology. Best practices are generally designed and implemented to reasonably assure operational and organisational success; they usually include safety and service margins additional to those of standard practices.
- **Designer accreditation** – Is there an accreditation scheme for the designer to design the battery storage system for domestic and small commercial grid or off-grid battery energy storage systems? An accredited designer is a person (typically an engineer) who is accredited to design grid-connected battery storage systems or stand-alone battery storage systems. Note, this may or may not include installer accreditation (see Section 4).
- **Installation accreditation** – Are installers able to install a battery storage system that complies with safety requirements? Is there an accreditation scheme to effectively oversee this? An accredited installer is a person who is accredited to install grid-connected battery storage systems or stand-alone battery storage systems (see Section 4).
- **Technology standards** – Are there comprehensive and effective standards relating to the transport, storage and maintenance of the battery technology? Are MSDSs available?
- **Installation standards** – Are there comprehensive and effective standards and building codes relating to the various aspects (electrical connection, physical enclosure, signage and so on) of the battery technology? (see Section 3.3)
- **Installation, maintenance and incident reporting** – Is there a requirement to report information such as the location of installation, maintenances schedules and incidents? Are records available? (see Section 2.4)
- **Warranties** – Do warranties cover defects and performance for the battery storage system. Also, do they outlines any manufacturer service or maintenance instructions that must be followed to not void the warranty? (see Section 2.4)
- **Recycling and disposal** – Are there established programs for recycling and disposal for the battery technology? Are these programs suitable and effective? Heavy (toxic) metals in many battery technologies are classified as a hazardous waste and must be dealt with appropriately to minimise risk. (see Section 2.5)

5.3 Results

Each of the practices outlined in the above section were evaluated for each battery storage technology, and the results are indicated using the traffic light system described in Table 19. The results of the gap analysis, based on the information collated and identified in this study, are provided in Table 20.

Table 19: Gap analysis traffic light criteria

Colour	Coverage
✓	Effective
o	Partially effective
X	Ineffective

Table 20: Safety performance gap analysis

Evaluation → / Technology ↓	Consumer education	Best practices	Designer accreditation	Installation accreditation	Technology standards	Installation standards	Reporting, maintenance & incident reporting	Warranties	Recycling and disposal
Lead-acid	✓	✓	✓	✓	✓	✓	o	o	✓
Lithium-ion	✓	x	o	o	o	o	o	o	x
Nickel-based	o	o	o	o	o	o	X	o	x
Flow	x	x	o	o	o	o	X	o	o
Sodium-ion analogue	x	x	o	o	o	o	X	o	o

Table 20 clearly identifies the industry gaps in battery storage safety performance. In general, lead-acid battery storage systems are well covered by effective practices. This is understandable, given that lead-acid batteries are a relatively mature technology and have widespread use in Australia. However, the reporting of installation, maintenance and incidents could be improved (for lead-acid and all other battery technologies).

Critical gaps identified (i.e. areas where present practices are ineffective) include:

- consumer education for sodium-ion analogue and flow technologies
- best practices for lithium-ion, sodium-ion analogue and flow technologies
- maintenance and incident reporting for sodium-ion analogue, nickel-based and flow technologies
- recycling and disposal methods for lithium-ion and nickel-based technologies.

The above gaps must be addressed to minimise the risk posed by emerging energy storage technologies, and thereby improve the safety performance of the industry as these technologies become more prevalent.

This report has identified appropriate avenues to assist the safe integration of emerging energy storage technologies in Australia. In general, further research is required in some areas, together with improvements to standards, regulations and procedures for installation and maintenance.

Section 6 makes recommendations about how the identified gaps could be addressed.

6 Conclusions and recommendations

This report has provided an overview of the safety performance of six energy storage technologies that are likely to affect the Australian market: lead-acid, lithium-ion, nickel-cadmium, nickel metal hydride, sodium-ion analogue and flow batteries. It has identified appropriate avenues to assist the safe integration of the emerging energy storage technologies in Australia, and areas where there is a need for further research, or improvements to standards, regulations and procedures for installation and maintenance.

There are seven key findings from this study. On the basis of these findings, we have developed recommendations to improve the safety performance and industry approach for domestic and small commercial energy storage in Australia.

Optimising the practices for energy storage technologies in Australia will facilitate the continued growth of this industry, and encourage further uptake of emerging renewable technologies in the future.

6.1 Key findings

1. **There is a lack of knowledge on the variety of energy storage technologies, and thus on how to care for and operate them in a safe manner in the domestic and small commercial scale context**.
   As the battery storage industry is relatively new, there is limited knowledge across the different technologies available – in particular for the emerging lithium-ion battery storage systems – and the various safety considerations for each technology. Although battery storage is a low-risk technology, it is important that systems are installed and maintained by an accredited installer, and that industry best practice is developed. Best practice around energy storage is performed in some industries for selected technology types; for example, transportation of lithium-ion batteries in the aviation sector. However, there is a lack of guidance on the selection and management of appropriate and safe domestic and small commercial stationary energy storage. Also, at present there are no established reporting processes or formal record keeping for energy storage installations and incidents, and thus no way to assess the scope or resources required to assist industry.
2. **There is currently no consensus on the appropriate method to extinguish a lithium battery storage fire in the event of an incident.**
   Present suggestions for extinguishing a lithium battery fire include use of sand, liquid nitrogen, water mist, lithium chloride or foam, or to simply do nothing. Each of these methods has advantages and disadvantages. There is a need for further research to identify the appropriate method for dealing with such an incident, and the appropriate response may vary depending on the size of the incident and conditions involved.
3. **There is insufficient accreditation and training to support and provide qualifications for designers and installers of energy storage systems.**
   Present accreditation in the industry are designed for Australia’s solar PV systems, rather than for battery energy storage systems. There is insufficient accreditation and training for designers and installers related specifically to energy storage systems. This is particularly relevant for the emerging lithium-ion battery technologies. The training and accreditation needs to cover safety protocols, and signage related to warnings and battery chemistry types.
4. **Emergency response teams (fire brigade, police and ambulance) have limited education about the issues related to an energy storage technology in the event of an incident.**
   When emergency response teams are called to respond to an incident (e.g. fire, electrical shock or chemical exposure), relevant safety signage needs to be on display and the response team needs to take into account the location of the battery system.

5. **There is a lack of standards for battery storage system disposal and recycling (except in the case of lead-acid batteries).**
   Battery storage systems can contain heavy or toxic metals such as nickel, cobalt, cadmium and lead, which can be harmful to the environment if disposed of in a landfill. In Australia, used rechargeable batteries are classified as either a hazardous waste or a dangerous good, which means that they can create environmental (and safety) risks if disposed of incorrectly. Whole-of-life recycling practices are often overlooked when procuring and installing a battery energy system. Consumers, designers and installers should have awareness and consideration of these.
6. **Australian standards for battery energy storage and connection to the electricity network are incomplete.**
   The lack of comprehensive standards is understandable in this rapidly growing market with emerging technologies. For the domestic storage market especially, there is a need to develop standards that incorporate installation, smart communication, training and maintenance, transportation, safety and emergency guidelines, and requirements related to the environment and recycling. A number of standards are available for mature or established storage technologies, and for the connection of inverters to the electricity network. However, some of these standards are outdated and only consider specific cases, whereas actual use of these technologies has expanded to much broader applications. Developing Australian standards aligned to international ones could help to create world-leading advances.
7. **Stationary energy storage installations and incidences are insufficiently reported.**
   Relatively few incidents have been reported. However, rather than reflecting a low number of incidents, this may simply reflect the lack of records or reporting process requirements that are in place to capture such incidents, and the relatively low numbers of present installations.

6.2 Recommendations

The following recommendations are considered as essential steps toward preparing for the anticipated energy storage uptake in the Australian domestic and commercial battery storage markets.

1. **Improve awareness of and access to information on the variety of battery energy storage technologies and their appropriate operation and care among consumers (general public), designers (engineers and electrical tradespeople) and installers (electrical tradespeople).** See Section 2.3 and 5.3 for more information.

2. **Research and identify the best methods for lithium-ion battery storage system recycling, and establish a lithium-ion battery recycling initiative.** Further detail can be found on Lithium-ion batteries and other technologies in Section 2.5.3.

3. **Research and identify the best methods to safely (passively) extinguish domestic and small commercial scale lithium-ion battery storage fires.** Challenges and current practise are explored in Section 3.5.2, Lithium-ion batteries.

4. **Align Australian and international standards, and improve local regulatory and building codes relevant to battery energy storage systems.** See Section 5.2, Methodology and assessment criteria for further details and gap analysis.

5. **Establish a set of best practices specific to the battery storage industry, including development and upkeep of an installation, maintenance and incident-reporting database for energy storage systems in Australia.** See Section 2.6.1.

6. **Develop training and nationally recognised accreditation pathways for designers and installers, specific to domestic and small commercial scale energy storage systems.** See Section 4, Accreditation and training.

7 Abbreviations

Abbreviation	Meaning
ABRI	Australian Battery Recycling Initiative
AC	alternating current
AS	Australian standard
BMS	battery management system
CEC	Clean Energy Council
CSIRO	Commonwealth Scientific and Industrial Research Organisation
DC	direct current
DOT	Department of Transportation (United States)
ELV	extra low voltage (i.e. voltages up to 50 V AC and 120 V DC)
SELV	separated or safety extra low voltage
EPA	Environment Protection Authority
FAA	Federal Aviation Authority
IATA	International Air Transport Association
IEC	International Electrotechnical Commission
IP	ingress protection
ISO	International Organization for Standardization
kW	kilowatt (unit of power)
kWh	kilowatt hour (unit of energy)
LV	low voltage
MSDS	material safety data sheet
NSCV	National Standard for Commercial Vehicles
NZS	New Zealand standard
PV	Photovoltaic
RTO	registered training organisation
VRLA	valve-regulated lead-acid (commonly known as a sealed or maintenance-free battery)

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Appendix A – Suggested installer checklist

This appendix provides a suggested battery storage installer checklist. It focuses on lead-acid and lithium ion battery technologies because these are the most likely technologies to be adopted in the near future. This checklist was requested by the focus group and is based on the present Australian standards.

All battery storage

All battery storage	Check ✓
All battery storage is installed in a dedicated battery room, enclosure or restricted access area; this area is: • mechanically sound • suitable for the local environmental conditions • designed to prevent the formation of 'gas pockets' • in a domestic dwelling not in a habitable room (as defined by the National Construction Code 2015) • not in direct contact with the floor of the enclosure or room.	☐
The storage system is installed in such a way that it is **NOT** exposed to direct sunlight at any time, or partially exposed (which would create temperature differentials across the batteries).	☐
All battery terminations and interconnect cable connections have been checked for tightness.	☐
All electrical cables, isolators and fuses are correctly rated and sized for operating and fault conditions.	☐
There are no exposed electrically 'live' parts on any installed equipment.	☐
All battery cell interconnects and terminals are covered and protected against accidental short circuit.	☐
All 'live' cables have been tested for electrical leakage to earth.	☐
Electrical wiring is routed so as to be protected from any physical damage or mechanical stress and exposure that could cause corrosion.	☐
Installation activities have not caused any damage to any cable insulation.	☐
All low and high voltage electrical wiring has been installed in accordance with AS/NZ 3000, and equipment is certified correctly for Australian use.	☐
Unearth conductors in battery banks (including multiple strings) are protected by overcurrent circuit breakers or fuses.	☐
Battery banks have a means of isolation. Such isolation has been checked and tested.	☐

Battery storage warning signs (i.e. ‘DANGER – Risk of battery explosion’ and ‘DANGER – Harmful voltage’) are permanently fixed outside the battery room, enclosure or area in a prominent position, and are appropriate for the battery chemistry type. ☐

All other appropriate signage is displayed; for example, shut down procedure, emergency contact details, emergency response procedures, maintenance and operation procedures, ‘Warning – Spark hazard’, ‘electrolyte Burns’, battery voltage and short circuit fault current warning. ☐

Voltage, current and power throughput have been verified and are within the design specification for intended use and load profile. ☐

Metering is installed to monitor the battery voltage. ☐

Visual and audio alarms and warning notifications have been tested correctly. ☐

All commissioning tests and results have been documented. ☐

Lead-acid specific

All crimp lugs have been fitted using an appropriate tool. ☐

Batteries are installed on a timber platform (to reduce short circuit risk and hazardous gas production if a battery were to leak acid). ☐

The clearance and ventilation of equipment and arc-producing devices is in accordance with manufacturer’s installation guidelines or relevant standards, including AS4086.2 and AS4509.2. ☐

The enclosure is constructed of corrosive-resistant materials. ☐

Personal protective equipment and electrolyte containment is provided, including spill kit, eye protection, gloves and eye wash water. ☐

Lithium-ion specific

Platform and enclosure is constructed of aluminium or steel (to minimize risk of fire). ☐

Batteries are in a sealable enclosure with pressure activated venting, ducted to the open atmosphere away from living spaces or areas occupied by people and animals (see habitable rooms in ‘all batteries’, above). ☐

Enclosure base is sealed from the atmosphere. ☐

Battery management system has been verified as operating correctly, including logging data. ☐

Documentation

All documentation relevant to a system installation should be provided to the customer and kept on-site for use by maintenance personnel.

A system user manual that includes a short description of the function and operation of installed equipment. ☐

A system performance estimate. ☐

A list of supplied equipment. ☐

A list of any alarms installed and the action required. ☐

Equipment manufacturers' documentation and handbooks for all equipment supplied. ☐

Equipment and workmanship warranties. ☐

A copy of the shutdown procedure and any electrical safety warnings. ☐

Maintenance procedure(s) and schedule timetable. ☐

Battery maintenance record logbook. ☐

Commissioning records and this checklist for the installation. ☐

Record of installation personnel details. ☐

Manufacturer's warranty information. ☐

System electrical wiring connection diagram. ☐

Customer verbally instructed on managing their storage system and provided with all of the above documentation. ☐

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