Battery Energy Storage Systems

Guidance Report

Australian Energy Council Limited

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→ **The Power of Commitment**

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Executive Summary

The transition to renewable energy generation requires energy storage solutions to preserve the current system resilience, ensuring that supply matches the demand needs within Australia. The progressive advancement and development of battery chemistry and technology has resulted in the global uptake of grid-scale Battery Energy Storage System (BESS) facilities. There have been a number of larger BESS installations in the past decade; most notably, the South Australian Hornsdale and Victorian Big Battery facilities. Although these grid-scale applications of batteries are advantageous, there have been several self-heating, thermal runaway and other incidents which have highlighted hazards and risks which need further consideration.

The Australian Energy Council (AEC) are aware of these issues and engaged GHD to develop guidance material associated with grid-scale BESS facilities, with a focus on lithium-ion and vanadium chemistries.

The scope of this project is to produce a high-level risk assessment and develop guidance material which captures the findings from the following activities and engagements completed:

– A high-level literature review, reviewing battery chemistries, thermal runaway and events which have occurred over recent years, and key reference documentation utilised (e.g., Acts, Regulations, Standards, and other existing guidance).
– Interviews with five (5) stakeholders who are involved in the lifecycle of BESS facilities.

With various thermal events occurring over recent years, good learnings have been translated into good practices which are noted in this study. The main emphasis of this guidance material is on the good practices whilst noting Legislation, Acts, Regulations, Standards, and other guidance material that are emerging or being currently utilised.

This guidance material developed considers the following areas:

– Site selection, facility orientation, and facility configuration
– Safety case approach
– Emergency management planning
– Environmental offsite effects

This guidance material also utilises good principles drawn from a broader range of industries and facets of society that are applicable to energy storage facilities. From this, it is proposed that BESS facilities are classified into “types” based on their storage capacity and have varying assessments based on this classification. The proposed “type” based classification is shown:

1. **Type 1:** Less than 50 MWh
2. **Type 2:** Between 50 MWh and 250 MWh
3. **Type 3:** Between 250 MWh and 1,500 MWh
4. **Type 4**: Greater than 1,500 MWh

Based on the literature reviewed and learnings from the stakeholder interviews, the risk profile of BESS facilities is dependent on several factors, similar in some respects to the way risk evolves in other high hazardous industries. Figure 7 illustrates the proposed approach to assess grid-scale BESS facilities, building upon the “type” based classification scheme above.

A supporting high-level risk register is also provided, identifying a few preliminary risk scenarios utilising literature findings, previous incidents and based on the interviews with stakeholders engaged as part of this work. The risk register aims to primarily capture key risks associated with lithium-ion batteries (specifically lithium-ion phosphate formulations) and vanadium redox flow batteries as they represent a significant cross-section of the current types of BESS facilities present.

This guidance is an important step along a path of evolving knowledge and good practice for the expanding energy storage scale and associated developing technology. All of this is essential for the societal journey to safely achieving more sustainable energy.

This report is subject to, and must be read in conjunction with, the limitations set out in Section 1 and the assumptions and qualifications contained throughout the report.

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1. Introduction

1.1 Background

Technical innovation, accelerated closure of coal-fired power generation plants, government policies, as well as society's growing environmental conscientiousness has seen a rapid uptake of renewable energy generation. The *2022 Integrated System Plan*, released by the Australian Energy Market Operator (AEMO), highlights that the forecasted withdrawal of approximately "8 gigawatts (GW) of the current 23 GW of coal-fired generation capacity by 2030" [1] will introduce complexities within the National Electricity Market (NEM).

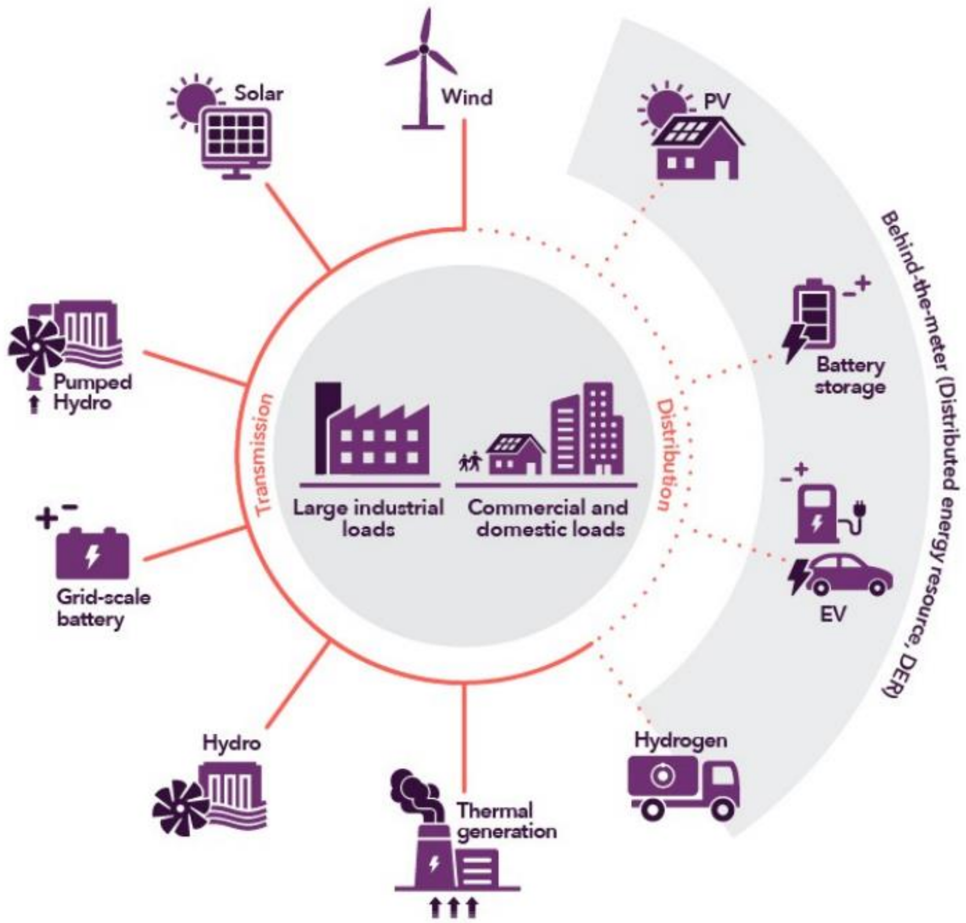

Figure 1 Power system interactions between grid and behind-the-meter energy supply (Figure 4 in ref [1])

As solar, wind, and other renewables transition into becoming primary energy resources, it will become increasingly complex to preserve the current system resilience. The intermittent nature of renewables requires energy storage solutions, with enhanced diversity and strategic redundancy, to ensure that supply matches the demand needs (by volume and timing) of renewable-based electricity in Australia.

The advancement in battery chemistry and associated technology, combined with decreasing costs of supply, has seen the global growth and uptake of grid-scale battery energy storage system (BESS) facilities (shown as a contributor to transmission networks in Figure 1). The development of batteries for energy storage is expected to significantly increase in the next decade, going from a global capacity of about 11 Gigawatt hour (GWh) in 2017 to 100 - 167 GWh or even 181 - 421 GWh[1], in 2030 [2].

[1] As specified within the International Renewable Energy Agency (IRENA) report, this represents a scenario where the "stationary battery storage increases relatively in response to meet the requirements of doubling renewables in the global energy system by 2030" [2].

There have been a number of BESS installations in the past decade; most notably, the South Australian Hornsdale and Victorian Big Battery facilities are two of the larger sites globally. There are currently a number of grid-scale BESS facilities under construction and a multitude of projects which are soon to begin or have been confirmed [3].

Despite the many advantages that electrochemical storage present, from an asset and public safety perspective there have been numerous self-heating and thermal runaway incidents associated with Li-ion batteries [4] [5] [6]. These events have increased the awareness of thermal risks associated with Li-ion BESS installations, and have highlighted that there are 'unknown unknowns' associated with large-scale electrochemical storage. With BESS facilities, the number of electrical connections and piping couplings required increases with the number of battery cells and modules. Until recently, there has been minimal variation in battery cell size, and with modular design components of a set size, it is inferred that the number of failure points will tend to increase linearly with the size of the facility. Therefore, larger facilities are likely to have more failures than smaller ones and, if not designed properly, these failures can escalate to other nearby cells, modules and beyond. This is starting to change as proponents, regulators and equipment manufacturers are actively embracing recent learnings alongside continual technological and scientific advances.

Logically, larger facilities need more comprehensive safety control systems, and more detailed siting and layout assessment than smaller facilities to achieve similar risk levels. Various stakeholders are seeking a consistent and mature approach to implement the safety controls system to achieve well defined and acceptable risk levels.

The Australian Energy Council (AEC) are cognisant of these issues and how the accelerated pace towards a low emissions future, although positive, poses challenges. Currently representing "20 major electricity and downstream natural gas businesses operating in the competitive wholesale and retail markets [7]," the AEC secretariat represent a team of energy analysts, economists, and public policy advocates. Members have recognised that the experience and knowledge associated with managing conventional power stations is not wholly transferrable to new energy generation and storage facilities. Utilising the AEC's extensive network, GHD has been commissioned to produce preliminary guidance material to initiate and facilitate collaboration amongst its member organisations towards a harmonised leading practice approach for grid-scale BESS facilities in Australia.

1.2 Purpose of this guidance material

These recent battery thermal and explosion events have highlighted to the AEC the potential issues associated with current operational grid-scale BESS facilities as well as those planned within the AEMO's pipeline of new facilities.

The purpose of this engagement is to provide the AEC with informed guidance material associated with grid-scale (or commonly referred to as large-scale) battery energy storage facilities which will aim to capture the hazards and risks associated with the life cycle of a BESS facility. Due to the accelerated pace of battery chemistry development, the guidance material presented primarily focuses on lithium-ion based chemistries, with supporting commentary on vanadium redox flow batteries. This report summaries GHD's findings from:

- **The literature review.** The literature review completed examines the evolution of battery chemistry, issues such as thermal runaway, and provides a summary of recent grid-scale BESS incidents. From this, GHD reviewed the potential environmental and societal implications and identified potential gaps and opportunities moving forward, thus informing the guidance material
- **Review of relevant** standards, acts, regulations, and available guidance material
- **Interview sessions** with five (5) relevant stakeholders, identifying how these parties currently form part of the consultation and/or approvals processes needed for the development, operation, and decommissioning of grid-scale BESS facilities
- **Broader industry knowledge of good practice**, and harmonised approaches of identifying and managing safety, utilising the well-established fundamental principles and approaches from other industries and sectors, such as the rail and transport industries, the power sector, oil and gas, dams, and nuclear

From these findings, this report articulates suggested key elements required for guidance material associated with grid-scale BESS facilities. A supporting high-level risk assessment provides a summary of the potential safety, health, environment, and quality issues identified during the aforementioned reviews and interviews. This was subsequently translated into a guidance flow-chart to assist future stakeholders with implementing a consistent, risk-informed approach to grid-scale BESS facilities.

1.3 Scope and limitations

The scope of this project is to (1) produce a high-level risk assessment and (2) develop guidance material which captures the findings from the following activities and engagements completed:

– Literature review
– Relevant standards, acts and regulation review
– Findings from interviews with relevant stakeholders
– Existing guidance material review

The stakeholders interviewed are summarised in Table 1.

Table 1 Stakeholders interviewed for development of guidance material

Stakeholder	Stakeholder Type	Role / Team
Contemporary Amperex Technology Co., Limited (CATL)	Original Equipment Manufacturer (OEM)	Technical Team members
Country Fire Authority (CFA)	Fire authority	Risk and fire safety specialist and advisor
The Victorian Energy Safety Commission, also commonly referred as Energy Safe Victoria (ESV)	Regulator	General Manager Electrical Safety, Head of Risk, and members from different groups
Queensland Government, Environmental Services and Regulation, Department of Environment and Sciences (DES)	Government regulator	Member of Environmental Services and Regulation team
Fluence Energy	OEM	Health, Safety, Environment and Quality (HSEQ) Australasian Lead

This engagement represents a valuable step in assisting AEC in their journey towards creating a more formalised guidance material and meeting their objective of promoting consistency and synergy between the various stakeholders involved in the lifecycle of grid-scale BESS facilities.

Due to the proprietary nature of the some of the information, GHD relied upon publicly accessible information, as well as what was shared during the stakeholder interviews. Within the constraints of the project, GHD have identified recurring themes and areas of importance. Given the evolving nature of battery chemistry, technology trends and market participants this document represents preliminary guidance that should continue to be considered for further development and periodically reviewed with key stakeholders which the AEC subsequently identify.

The following is excluded from the scope of this engagement:

– Prediction of future battery chemistry trends. Although this guidance material briefly discusses other batteries chemistries (refer to Section 3.1), it is unknown whether these, or other battery chemistries, will complement or replace the existing, common Li-ion chemistries currently utilised. This guidance material aims to provide a considered, holistic approach for grid-scale BESS facilities, focusing primarily on the considerations and risks associated with Li-ion batteries and also vanadium redox flow batteries.
– Development of guidance material associated with residential battery modules or community-scale BESS.
– Development of guidance material associated with use of combined energy storage systems. An example of this includes sites which have battery and hydrogen energy storage systems; these combination storage facilities have recently been referred to as renewable energy hubs [8]. Although these facilities will broadly present a similar cross-section of risks, there are other factors such as the production and storage of hydrogen which need to be taken into consideration and is beyond this scope of works.
– As the diversity of applications of energy storage is increasing, the reliability requirements of some applications may affect the design, i.e., critical communications and detailed classification of grid scale BESS facilities as critical infrastructure. Some of these evolving demands or compliance requirements may go beyond the general good practice requirements developed and will need to be considered within guidance materials moving forward. These considerations have been raised in this guidance, but detailed discussion has been excluded from this scope.

– At a high level, the guidance provided within this document is aligned with the National Electricity Rules. However, detailed assessment is required to validate this, which is outside the scope of this engagement.
– Philosophical and larger questions about BESS systems. These include:
  - Whether BESS facilities are environmentally sustainable
  - Whether a BESS is the right type of energy storage solution
  - Heritage land site considerations during the siting optimisation exercise prior to BESS construction
  - Any specific site location issues, including visual or other amenity considerations in urban and local environments
  - Any specific State regulatory requirements
– Development of consequence, likelihood, and risk rating descriptors for the high-level risk register. As the aim of the risk register is to provide an initial draft pre-populated risk register for use. It is assumed that organisation will review the risk register and transfer these risks to their respective templates and rank accordingly, in doing so the users will also consider any further specific project and organisation specific matters as is usual in conducting risk assessments.

1.4 Assumptions

The following assumptions were made as part of this engagement:

– Interviews and consultations
  - As part of this engagement, several interviews and consultations were required with various State regulators, Original Equipment Manufacturers (OEMs), and other authorities as listed in Section 1.3. To effectively liaise with each, it was necessary for AEC to assist GHD with identifying key personnel. Where needed, GHD suggested interviews with stakeholders which GHD have previously engaged with, or have current contacts
  - In addition to the above, follow up contact with participants for matters requiring clarification was anticipated. At the time of writing GHD has yet to receive further feedback from those interviewees where follow up queries subsequent to the interviews were made.
  - Some of the information provided by stakeholders within these interview sessions is commercially sensitive information. As such, all recordings or annotated notes will not be accessible without permissions from the AEC or the interview participants. All recordings will be destroyed by GHD following the completion of this engagement
– The energy storage market is rapidly growing, with new battery technology constantly emerging, as well as regulatory approaches that are maturing. Whilst efforts were made to get the most recent information, there will likely be emergent information and approaches in addition to these findings over the next few years. This may supersede or amplify the importance of some of the information provided within this guidance and material which is referenced
– The location of grid scale BESS facilities is dependent on many factors associated with their intended utilisation in high voltage transmission networks. Each intended location will require its own independent assessment, which may reveal additional considerations not addressed by this guidance material.

2. How was this guidance material developed?

A number of Acts, Regulations, Standards, and guidance materials are currently available to instruct, or where compliance criteria are not clearly defined, assist with the development of grid-scale BESS facilities. Some guidance material, such as the Clean Energy Council's (CEC) *Best Practice Guide: Battery Storage Equipment* [9], previously sought to engage industry associations involved in this field to provide an "agreed minimum standard" to be upheld in Australia. However, the accelerated pace of development, in combination with the time and involvement required to update Acts, Regulations, Standards, and guidance materials, has seen widely relied upon material in need of review and updating for this expanding field.

This guide has been developed to assist the AEC in their objective to promote consistency and synergy between the various stakeholders involved in the lifecycle of grid-scale BESS facilities. As discussed in Section 1.3, this document represents a preliminary step towards the development of further, comprehensive guidance, and is primarily focused on Li-ion chemistries. Unlike the CEC guide which aims to present safety hazards associated with different "types" of storage (i.e., battery module, pre-assembled battery system equipment and pre-assembled integrated battery energy storage system equipment), this guidance draws on the growing trend of increasing site storage capacity and is focused on assisting in differentiating and categorising the minimum assessment requirements for these grid-scale installations.

To gain an understanding of the key issues and concerns, recurring themes, and developments across a spectrum of remits, GHD completed a literature review (Section 3) and interviewed five (5) organisations (see Table 1 for stakeholders who participated in this engagement). It should be noted that GHD utilised existing industry connections to contact the CFA and ESV, while AEC reached out to the remaining participants. These stakeholder consultations were held in an interview-style arrangement, with GHD facilitating the interviews which were approximately an hour in duration. To assist these conversations, GHD prepared a list of questions (refer to Appendix B) which was used as a basis for each consultation. It was recognised that there was a need to have differing prompts due to the spectrum of organisations and the respective remits of the interviewees.

In the event where participants were unable to answer questions or needed to consult other members within their organisation to verify responses, GHD provided the questions following the interview. However, no further responses were further received during this engagement.

The findings from the literature review and the interview process were subsequently consolidated within a high-level risk register. It is recognised by GHD that there is existing guidance material available (CEC *Best Practice Guide* [9]) and the purpose of this register is not to replicate this material. Instead, the register provided within Appendix D, aims to capture risks which have importance for good practice design features of the facility, including quality, environmental, operability, and end-of-life considerations.

As this guidance material is meant to be utilised by multiple organisations, which would all have different risk management processes (thus, different risk matrices and descriptors), the risk register provided does not aim to develop consequence, likelihood and risk rating descriptors. Rather, it provides an initial pre-populated risk register which organisations can then transfer into their respective templates and rank accordingly. Alternatively, as the AEC progresses the development of this risk assessment, organisations who are members of the AEC should socialise this register and define the likelihood, consequence, and risk descriptors.

Finally, GHD present preliminary guidance (Section 5) recommendations which drawn upon fundamental principles such as recognised good safety approaches, emerging standards and codes, and leading regulatory requirements.

It is expected that this material is distributed and reviewed with other AEC members to further develop and subsequently refine prior to publication. Compliance with this guide does not replace or substitute compliance with existing Acts, Regulations, Standards, and other statutory obligations.

3. Literature review

This literature review aims to provide a summary of the material drawn upon to synthesize the grid-scale BESS guidance material. The sources which formed part of this review were determined based on current relevance (e.g., UL 9540A which is used to demonstrate propensity of thermal runaway propagation) and material which interview participants acknowledged played a role in their decision-making process. It has been acknowledged that battery penetration into the energy storage sector has "outstripped our actual knowledge of the risks and hazards associated with them [10]". Therefore, in addition to the above, this review also aims to identify areas of interest, concern and gaps within existing literature based on fundamental risk understanding.

As this field is evolving, with many concurrent efforts underway to manage existing battery chemistries, technologies and understanding of how to manage the lifecycle of BESS facilities develops, it is acknowledged that the sources used to inform this guidance material may be revised or become outdated in the short-term future. This literature review aims to distil the information reviewed into practicable elements, the learnings of which can be transferrable as grid-scale BESS facilities advance.

The review is divided into the following sections:

– A summary of the evolution of battery chemistry (Section 3.1)
– Grid-scale BESS facility thermal runaway events (Section 3.2)
– Grid-scale BESS facility Occupational Health and Safety (OH&S) considerations (Section 3.3)
– Grid-scale BESS facility Environmental considerations and implications (Section 3.4)
– Other areas of consideration (Section 3.5)
– Key observations from reference material (Section 3.6).

As lithium-ion chemistry, specifically lithium iron phosphate (LFP) is the dominant battery chemistry used in grid-scale BESS facilities, Section 3.2 to Section 3.6 primarily focuses on this. However, issues identified in Section 3.4 provide commentary on areas which are specific to vanadium redox flow (VRF) batteries. Furthermore, Section 3.5 posits other areas of concern which would be applicable across a spectrum of battery chemistries.

3.1 A brief summary of the evolution of battery chemistry

The advancement in battery chemistry and associated technology combined with decreasing costs, has resulted in grid-scale BESS facilities becoming a viable means of promoting the accelerated uptake of renewable energy options. Of the available types of energy storage devices, batteries are considered desirable due to the ability to connect in series and / or parallel to increase power capacity or adapt to requirements of specific applications [11].

Optimal battery chemistry is being sought after, with multiple efforts underway to progress existing formulations [12]. The following provides a high-level summary of battery chemistries which have been used in grid-scale BESS applications or have been expressed as potential alternatives during stakeholder consultations.

Table 2 provides an overview of the advantages and potential hazards and disadvantages associated with each chemistry discussed within this section.

Table 2 Battery chemistry overview

Battery chemistry	Advantages	Disadvantages and hazards
<u>Lithium-ion</u> Li-ion chemistries are diverse. Nickel-Manganese-Cobalt and Iron Phosphate formulations are commonly used within BESS facilities	– Energy efficiency >90% [13] – High energy density, ranging between 100-265 Watt hours per kilogram (Wh/kg) – Wide availability and cost effective – Due to high energy density, footprint of land required for facility is comparatively lower than other low energy density formulations	– Potential for thermal runaway (greater for Nickel Manganese Cobalt (NMC) formulation). Most electrolytes are flammable. This has been evidenced and is further discussed in Section 3.2. – Limited temperature performance window (i.e., not compatible with extreme cold or hot conditions) – Compatibility issues

Battery chemistry	Advantages	Disadvantages and hazards
		– Reactive and hazardous in off-nominal conditions – Previous incidents of failures of safety systems during electrical surges – Potential for explosion from gas accumulation of gases produced in a fire
Lithium-ion polymer battery	– Reduction, or in some cases elimination, of thermal runaway potential – Greater energy density than non-polymeric Li-ion chemistries – Due to high energy density, footprint of land required for facility is comparatively lower than other low energy density formulations	– Costly and therefore grid-scale applications may not yet be viable from a commercial perspective
Vanadium redox flow battery	– Better safety and efficiency with long life cycle – Easily able to scale up energy storage capacity – Longer expected operational performance and life in comparison to Li-ion batteries, – Broad temperature operation envelope, operating between -20 °C and 50 °C [14] – Elimination of cross-contamination risks in comparison to other existing flow batteries as the same material is used in both half cells – Lack of combustible materials used for construction	– Low energy density in comparison to Li-ion formulations, therefore large facility footprint is required [15] – Potential for vanadium electrolyte to be released into the environment if there is a loss of containment event
Sodium-ion battery	– Moderate energy density, with research underway to achieve densities of up to 200 Wh/kg – Abundant element in comparison to lithium – Non-flammable chemistry (however, flammability is dependent on exact compositions)	– Electrolyte solvation issues

Lithium-ion batteries

Li-ion present fundamental advantages over other chemistries, making them the current favourable battery chemistry utilised for grid-scale energy storage solutions:

– Li has the lowest reduction potential of any element, allowing Li based batteries to have the highest possible cell potential

– Li is the third lightest element and has one of the smallest ionic radii of any single charged ion

– The monovalent charge reduces Li-ion mobility.

These factors allow Li-based batteries to have high gravimetric and volumetric capacity and power density. Commonly used battery chemistries in grid-scale BESS facilities are Li-ion Nickel-Manganese-Cobalt (NMC) or Li-ion Iron Phosphate (LFP) formulations [16]. As an example, LFP batteries now have energy densities which range between 100 and 265 Wh/kg which is significantly greater than the 90 Wh/kg density quoted a decade ago [16]. Equipment manufacturers, such as Tesla, have transitioned from NMC batteries to LFP batteries, largely due to the LFP's reduced thermal runaway propensity at higher operating temperatures, as well as other characteristics like increased battery life [17] [18].

Other Li-ion chemistries and formulas, such as Li-ion polymer batteries are being investigated as certain formulations are quoted to achieve greater safety (e.g., reduction or elimination of thermal runaway), increased energy density, material stability within a greater operating envelope, and an enhancement in overall performance.

Issues such as thermal runaway, and desires to develop safer options without compromising performance, has promoted further research and development into investigating alternate chemistries (which may or may not be lithium based) for grid-scale BESS applications.

Vanadium redox flow battery

An attractive alternative currently being trialled globally is the use of vanadium redox flow (VRF) batteries. The energy in these batteries is stored in a liquid vanadium electrolyte and the change in valence of the vanadium ions facilitates the movement of protons through the membrane, charging and discharging the battery [19]. A schematic of the redox flow battery is provided in Figure 2.

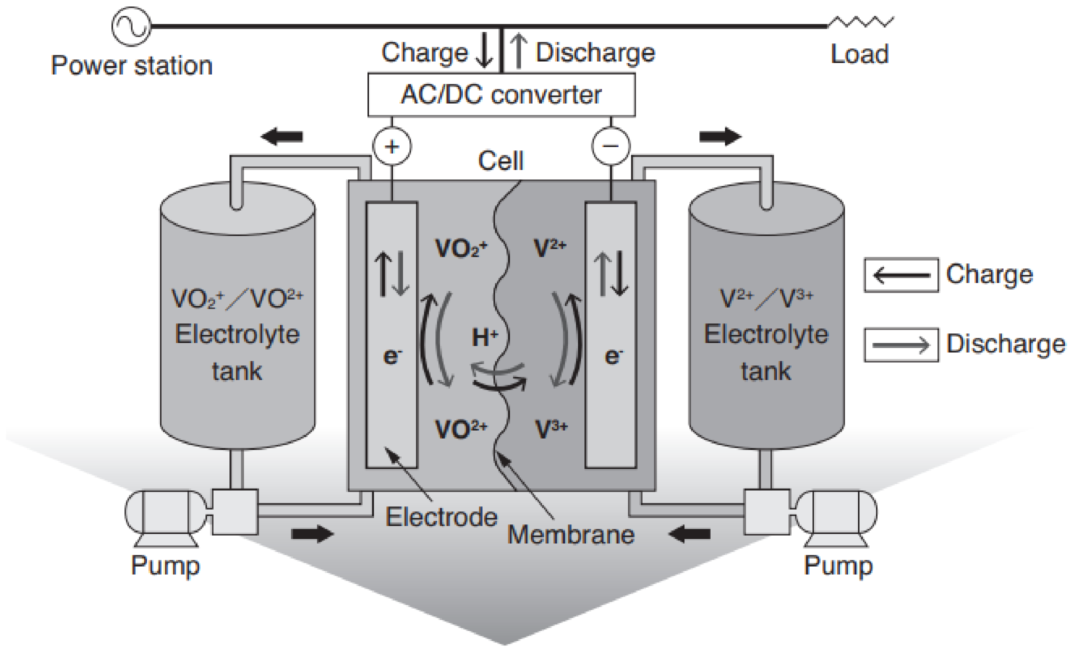

Figure 2 Principle and configuration of the vanadium redox flow battery (Figure 2 in ref [19])

Sumitomo Electric recently brought online one of the world's largest VRF BESS in northern Japan [20]. This project builds upon an existing 15 Megawatt (MW) / 60 Megawatt hour (MWh) VRF system commissioned in 2015 in Hokkaido (in partnership with Hokkaido Electric). Another project which was commissioned in 2022 is the Dalian Rongke Power VRF system in Dalian. The first phase of the project has a capacity of 100MW / 400MWh, and the second phase will see the site operate at full capacity of 200MW / 800MWh [21] .

The advantages conferred with this technology with regards to grid-scale BESS applications include, but are not limited to, the following [22]:

– Easily able to scale up energy storage capacity.
– Longer expected operational performance and life in comparison to Li-ion batteries,
– Consistent performance, with a broad temperature operation envelope, making it a candidate for regions which experience temperatures approximately between -20 °C and 50 °C [14]
– Elimination of cross-contamination risks in comparison to other existing flow batteries as the same material is used in both half cells.
– Lack of combustible materials used for construction.
– Low likelihood of fire (dependent on the electrolyte composition).

Although the all-vanadium redox flow battery is a promising technology for grid-scale energy storage, the comparatively low energy density compared to Li-ion batteries, combined with the stability of vanadium electrolyte solutions outside of their operational envelopes makes it a less favourable choice in some respects.

Sodium ion battery

Another battery chemistry which may be an alternative candidate to Li-ion based batteries are sodium-ion (Na-ion) batteries. Similar to VFR batteries, Na-ion batteries present many advantages compared with Li-ion batteries. Although explicit announcements regarding use of Na-ion batteries for grid-scale BESS applications has not been sighted, it is known that they are or will be utilised in other applications. CATL's first-generation Na-ion battery has an energy density of approximately 160Wh/kg per single battery cell, and in 2021 it was announced that there were plans to use these for electric vehicle applications [23]. This battery technology is an appealing alternative, given its environmental abundance, non-flammable nature, and reduced susceptibility to temperature changes relative to Li-ion batteries [24]. However, as the comparatively lower energy density and issues encountered with electrolyte stability at certain voltages [25] are seen as two disadvantages associated with the Na-ion batteries.

3.2 Grid-scale thermal runaway events

3.2.1 Thermal runaway

Despite the many advantages associated with electrochemical energy storage, there have been numerous self-heating and thermal runaway incidents at grid-scale BESS facilities over the past decade. Therefore, there is a growing concern that more thermal events will occur as the demand increases for the construction and use of grid-scale energy storage facilities globally.

As defined by Sauer [26], a thermal runaway incident is “where one exothermal process triggers other processes, finally resulting in an uncontrollable increase in temperature. This can result in the destruction of the battery or, in severe cases, in fire.” The critical aspect of escalation to a thermal runaway event is if the initiating event or fault results in enough heating to lead to a reaction where the rate of heat generation exceeds the rate of heat loss – a self-supporting exothermic reaction [27].

While thermal runaway is a possible consequence of a variety of failure modes, it can be broadly categorised into the following groups [28]:

– Electrical abuse (e.g., overcharging / discharging)
– Thermal abuse (e.g., overtemperature)
– Mechanical abuse (e.g., external impact)
– Existing, latent defect (e.g., electrolyte leaks, faulty components).

With respect to Li-ion batteries, extensive studies have been conducted to understand the mechanistic pathways which promote thermal runaway events. This knowledge can then be used to develop effective mitigation measures to either eliminate or reduce such occurrences. A study by Feng et al. [29] aimed to summarise such mitigation strategies and provided a time-sequence system level map to illustrate to readers how mitigation measures could interrupt the various thermal runaway pathways identified. This is provided as Figure 3.

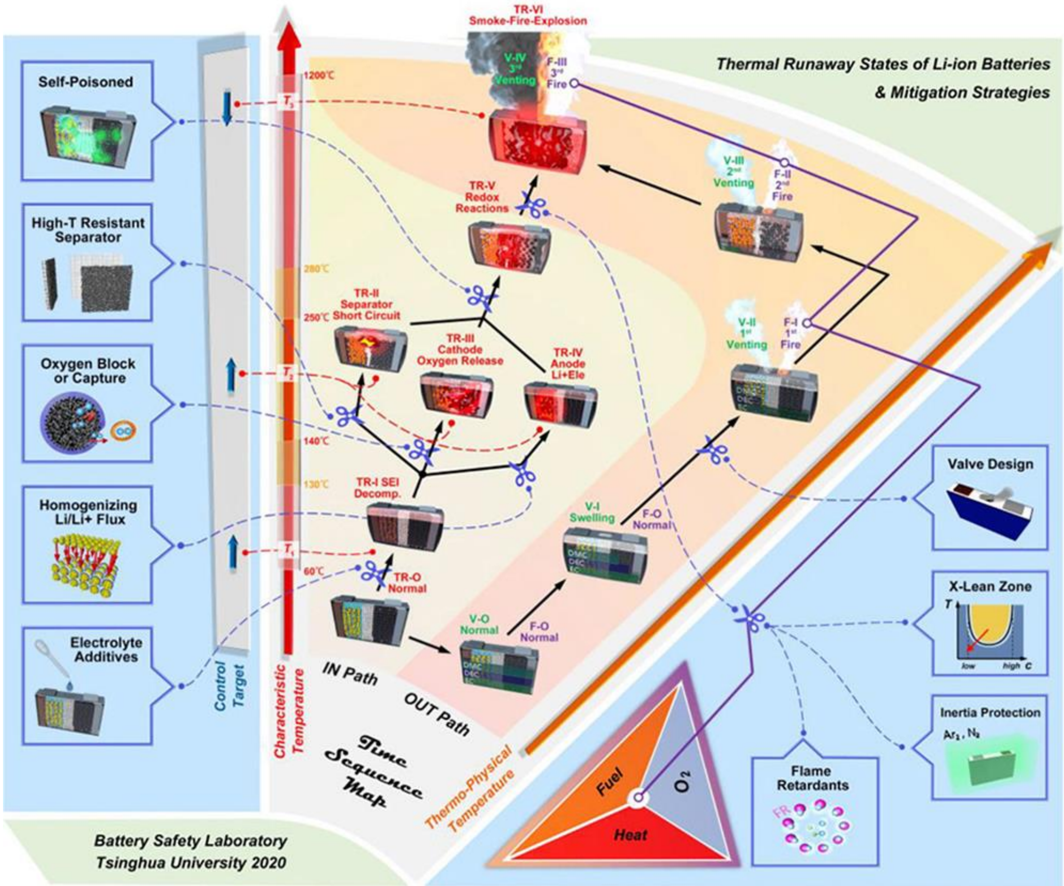

Figure 3 *Thermal runaway states of a Li-ion cell and correlated mitigation strategies (Figure 3 within Feng et. al [29])*

Controls for thermal runaway and fire include, but are not limited to, the following [30]:

- Additives to be mixed with or replace the flammable solvent.
- A separator that is fire resistant with thermomechanical stability and ion-transport resistance.
- Current Interrupt Devices (CID).
- Positive Temperature Coefficient devices.
- Safety or pressure vent.
- Remote monitoring of voltage, current, and resistance for abnormal results.
- Gas detection sensors.
- Appropriate cooling of battery system.
- Calorimeter to measure internal heat generation.
- Minimum prescribed separation distances between battery units.
- Thermal insulation within a battery unit.
- Fire suppression systems – water-based suppression was considered effective against propagation of battery fires [16] by allowing cooling of neighbouring battery modules to prevent escalation of thermal runaway events.

It is important to note the temperature triggering a self-sustaining exothermic reaction varies between Li-ion batteries as it is dependent on a range of factors, such as the electrolyte used. Thus, the mitigation strategies and design controls should be assessed on a case-by-case basis.

Bodies such as the CEC have documented detailed control measures within their BESS *Best Practice Guide* and accompanying risk assessment, in addition to the list presented above [9]. Separately, OEMs and proponents responsible for BESS facility site operations have been building upon this existing material or completing other risk assessments (such as Failure Mode Effectiveness and Criticality (FMECA) analysis) to determine appropriate control measures[2].

Managing fires in battery modules poses a particular threat as there is the potential for fires to spread to other modules, emit toxic or flammable gases, with the potential to cause an explosion [31].

3.2.2 Past grid-scale BESS thermal runaway events

Despite our collective understanding of thermal runaway propagation and the various mechanistic pathways it can follow, there are still gaps being identified. A review of highly publicised grid-scale BESS incidents within the past decade demonstrates this, and the iterative improvements being made as a result of the learnings. A high-level overview is provided in Table 3, noting that this is not an exhaustive list.

Table 3 Overview of recent BESS fire events

Date	Event	Facility Size	Location	Comments
2017 to present	Multiple events	Various facility sizes	South Korean BESS facilities	More than twenty (20) fires due to BESS facilities have occurred in South Korea since August 2017. In response to these incidents, a fire investigation committee was formed to review each event, analyse the root causes and distil the findings as part of an incident report. The report, which was released on 11 June 2019 concluded that there were four major cause categories for the BESS fires [32]: – Insufficient battery protection systems against electric shock – Inadequate management of operating environments – Faulty installation (due to human error) – Insufficient integration of the protection and management system of the BESS
April 2019	Battery fire	2 MW / 2 MWh	Arizona Public Service McMicken BESS facility	After an extensive independent investigation [16] [33], it was found that the following were contributing factors which led to the explosion: – Internal defect within the LG Chemical batteries (Li-NMC) which initiated an “extensive cascading thermal runaway event” – Lack of thermal barriers between battery cells – Storage container design did not allow the vapour and gases produced during the incident to vent, leading to a build-up of flammable / explosive gases within the container – Inadequate emergency response plan which did not instruct personnel how to extinguish the fire or specify the entry procedure
April 2021	Battery fire	4 MW / 8 MWh	Yurika Bohle Plains, Townsville, Queensland BESS facility	Yurika managed the site and on 8 April 2021 a fire was reported at the BESS. Specific details of the incident have not been publicly communicated. Publicly available information is that Tesla powerpacks were initially installed at the facility and the fire occurred during commissioning [34].
July 2021	Battery fire	300 MW / 450 MWh	Moorabool, Victoria Big Battery BESS facility	The Tesla Megapack batteries were of a Li-NMC chemistry [35] It was stated by Energy Safe Victoria that the probable root cause of the thermal escalation event was a leak in the internal coolant system of the Tesla Megapack 1.0 design in combination with unmapped SCADA systems during the commissioning.

[2] These have been sighted as part of separate confidential engagements GHD has been involved in or have completed as part of other engagements. Although specifics cannot be shared within this document, key mitigations are embedded within the list above.

Date	Event	Facility Size	Location	Comments
				The event started in one megapack and escalated to another, and thermal radiation from this fire damaged two adjacent megapacks.
September 2021 & February 2022	Overheating incident	400 MW / 1,600 MWh Phase I & Phase II	Monterey County, California Moss Landing BESS facility	Li-ion battery modules, which formed part of Phase I of the Moss Landing BESS, were operating above their operational temperature limit. Vistra Energy communicated that the safety features of the facility responded as expected: targeted sprinkler systems were triggered for the impacted modules and personnel were made aware of the operational limit exceedance [36]. Following investigation, in January 2022 it was reported that the overheating of the battery was not the cause of the incident. Rather, it was possibly due to a fan bearing causing smoke which triggered the water system. Due to faulty couplings, the water system improperly sprayed the battery racks which led to overheating of the batteries [37]. In early 2022, Phase II was taken offline. It was reported that a sprinkler system released water onto the battery racks, similar to what occurred in Phase I [38].
April - August 2022	Multiple events	Multiple facilities	Various BESS facilities	Three BESS fires occurred in the US in California and Arizona. The first in California was contained to a single battery module due to the correct function of the safety systems [39]. The second was an explosion of a BESS in a caravan park attached to a solar system in California. There were no injuries reported but nearby structures were severely damaged [40]. The final was in Arizona, a BESS unit was smouldering and required intervention to provide ventilation [41]. The causes of the incidents had not been reported.
September 2022	10 battery packs catch fire	182.5 MW / 730 MWh	Monterey County, California Elkhorn BESS facility	Initial reports suggest that the first event appeared to be a repeat of the incident which occurred in September 2021 [38] (described two rows above). A second incident occurred in September causing a highway closure due to possible hazardous gas releases during a fire incident [42], [43].
October 2022	Battery fire	25 MW / 50 MWh	Hainan, China	A fire occurred during commissioning at a 100 MW photovoltaic project at a sea salt farm. The battery was allowed to burn itself out while being monitored by firefighters [44].

McMicken BESS incident

Following the McMicken BESS fire the Det Norske Veritas (DNV) led investigation revealed that although the fire suppression system had worked as intended it was "not capable of preventing or stopping cascading thermal runaway in a BESS" [16]. Despite the fire suppression system being designed and operated with the governing requirements at the time of the incident, this event demonstrated that requirements need to be tailored to BESS facilities and cannot simply be taken, replicated, and applied without accounting for site specific considerations and technological differences.

Victoria Big Battery incident

The Victoria Big Battery (VBB) thermal runaway incident which occurred on 30 July 2021 saw two Tesla Megapacks heat damaged and two megapacks heat affected to various extents during testing and commissioning activities. This thermal event escalated beyond the confines of one Megapack and impacted adjacent Megapacks to various degrees, some of which were located approximately three metres away, as shown in Figure 4. An incident report published on the Victorian Big Battery website states that the Tesla Megapacks present at the site during the initial commissioning period passed the UL9540A test. As quoted in the report "In addition to cell and module level tests, Tesla performed unit level tests to evaluate, among other faire safety characteristics, the potential for fire propagation from Megapack-to-Megapack [45]."

This demonstrated that thermal runaway of one unit could have a greater reach not previously considered. An investigation led by ESV stated that the probable root cause of the event was "a leak within the Megapack cooling system that caused a short circuit that led to a fire in an electronic component [46]". Tesla have since updated their Megapack configuration (MP2XL) and now use LFP chemistry, along with a revised design of the modules. Their UL9540A testing of the latest units indicates no thermal event propagation potential of suitably spaced Megapacks.

Figure 4 Victoria Big Battery fire incident [47]

Moss Landing incidents

There have been three incidents at the Moss Landing Energy Storage facility located California; two of which were associated with the system owned operated by Vistra Energy (400 MW / 1,600 MWh) BESS and the other associated with the Elkhorn Battery (182.5 MW / 730 MWh) which was commissioned in April 2022. An investigation into the Vistra Energy BESS Phase I thermal event found that due to faulty couplings, the water system improperly sprayed the battery racks which led to overheating of the batteries. The corrective actions from this incident included "sealing gaps between the floor levels containing battery racks to prevent water leaking from one down to the other, testing all heat suppression equipment thoroughly and reviewing the programming of the Very Early Smoke Detection Apparatus (VESDA) [36]." A similar incident occurred for Phase II.

The cause of the Elkhorn BESS fire is currently being investigated. Unlike the Vistra Energy fires, this incident led to the partial closure of a highway and local residents were advised to take shelter and close windows due to the risk of exposure to hazardous materials [43].

In summary:

These events highlight that there may still be further understanding to be developed of how the overall battery systems design and implementation, general facility design (including orientation and inter module spacing), and external factors influence the initiation and propagation of battery thermal runaway events. Although there is literature demonstrating how battery modules are assessed with Computational Fluid Dynamic (CFD) modelling [29], whole of site analysis with respect to consequences from thermal runaway have not been sighted as part of this engagement. However, Airflow Sciences Corporation [48] have recently demonstrated capability to model BESS facilities to assist “authorities and utilities making crucial decisions about evacuations, site design, and BESS unit locations, and [how] they can play a vital role in a site’s risk mitigation planning.” Thus, due to the growing complexity and size of BESS facilities, there is a need to view each facility on a case-by-case basis and is further discussed in Section 5. .

3.3 Occupational, Health and Safety (OH&S) considerations

Guidance material on the OH&S considerations for residential, small commercial buildings and community scale battery energy storage applications is widely available. For example, Worksafe Queensland provides high-level guidance on the safety implications of incorrect installation and the need to have competent workers to install BESS, "safe work practices" in place, as well as compliance with relevant legislation, rules, and standards [49]. The Department of Mines, Industry Regulation and Safety Building and Energy (DMIRS) of Western Australia provides a guide for electrical contractors, that also provides guidance on some OH&S matters. However, specific guidance which focuses on OH&S of permanent or transient workers within grid-scale BESS facilities was not sighted during this review.

3.4 Environmental considerations and implications

3.4.1 Environmental impact during normal operations

There are few environmental impacts from the normal operations of a Li-ion BESS. In urbanised areas, large scale BESS facilities may have a nearby 'heat island' effect on its surrounds, however, little information is available in the public literature. Specifically, the BESS units and associated power equipment produce heat while operating; this coupled with solar radiation could increase the ambient temperature in and around the BESS facility. Therefore, heat pollution may be a potential side effect on the facility as well as adjacent areas during normal operations. It should be noted that this localised heat island effect could be higher than that of typical low and medium density urban locations, however studies have not been conducted for this exercise and representative thermal modelling for an entire site (including a case study) was not sighted during this review.

Noise emissions during normal operation are currently being considered by stakeholders and their impact on residential receptors located in close proximity to BESS facilities [50] [51]. As an example, ACEnergy, a utility-scale solar farm BESS provider, have listed potential noise control strategies within their publicly available assessment findings. These include:

– "Ensuring inverter units are fitted with suitable manufacturer noise reducing kits
– Configuring battery storage container air conditions units to maximise noise shielding in the direction of residential receptors. This will include the construction of four-side acoustic barriers around the air conditions units internally lined using sound absorbing materials
– Construction of localised acoustic barries around the proposed inverter units combined with an independent acoustic barrier"

Due to the continuous operation of BESS facilities and the modular nature of the facilities, it has been recommended that noise levels are assessed for (1) different modes of operations and (2) at different times (e.g. daytime and night-time).

3.4.2 Environmental impact during and following a fire event

Unlike normal operations, significant environmental impacts may be possible in the event of the Li-ion BESS fire. This impact is magnified given the extent of the fire, and the time and resources it takes to extinguish. The two primary impacts include:

– Fire water runoff generated during the control of a fire, impacting local flora and fauna and contaminating soil, groundwater and/or surface water.
– Air emissions produced during combustion.

The Victorian CFA have recommended within their guidance material that "infrastructure is provided for the containment and management of fire water runoff…[and] may include bunding, sumps and/or purpose-build impervious retention facilities." A reference to Australian Standard (AS) 4681-2000 Section 7.3.9 *Control of run-off* is provided as a recommended resource to review. Although not required, CFA state that the site water management plan "may" include information on the containment and disposal of contaminated fire water.

While water runoff can generally be contained using a robust site drainage design, air emissions cannot be contained to the site, and can extend to a distance downwind of the site. Thus, is the potential for people in the vicinity of a BESS facility fire to be exposed to hazardous gases such as asphyxiants and irritants [52]. This occurred during the Elkhorn BESS facility fire in September 2022, prompting a nearby highway closure to minimise exposure to possible hazardous gases [43]. Following draft review, Synergy have stated that their local first responders will apply water spray downwind of a fire to minimise transfer of smoke particulates beyond the site.

Although the gases released are dependent on the battery chemistry [16], gases that may be emitted include:

– Fluorine [53]
– Hydrogen
– Carbon monoxide
– Carbon dioxide
– Methane
– Ethylene
– Propylene
– Nitrogen oxides
– Hydrogen Cyanide
– Hydrogen Fluoride

The fire risk profile of VRF BESS facilities is significantly lower than Li-ion as mentioned in Section 3.1. This is dependent on the electrolyte composition, specifically the degree of hydration. Therefore, when considering the use of VRF batteries, fire risk should still be reviewed.

3.4.3 Environmental impact due to loss of containment event

There is also potential for environmental impact if there is a loss of containment from Li-ion BESS, such as loss of containment of refrigerant, loss of containment of coolant, and/or loss of containment of oil from transformers on site. Depending on the amount lost, all three scenarios identified have the potential to pollute groundwater and runoff into local water mains if adequate protection measures are not in place. As there are a spectrum of refrigerants and coolants which may be utilised for these systems, in conjunction with the quantities varying between battery module size and overall site configurations, and various safety mechanisms in place to detect leaks, detailed literature on these loss of containment scenarios were not sighted as part of this review.

Comparatively, VRF BESS facilities hold more electrolyte with pipework, pumps, and other infrastructure like traditional process plant operations. Although some VRF battery developers claim that the electrolyte they have proprietarily developed is non-toxic [54], other sources state that the addition of sulphuric acid or hydrochloric acid which make up the electrolytic composition, as well as the vanadium itself, are toxic and corrosive [55]. Furthermore, another concern is the fumes which could be released during a loss of containment event of the electrolytic solution.

3.4.4 Environmental impact during decommissioning

From a reliability perspective, battery modules will be a key item requiring replacement throughout the operational life of the facility. It is likely that individual battery modules will be decommissioned progressively, with the potential to replace these decommissioned modules with improved, compatible equivalents which may possess greater energy storage capacity. This could occur sequentially rather than an entire facility battery upgrade as it is relatively easy to isolate and disconnect battery racks from the overall module, and likewise modules from the overall battery pack, and then replace with an updated component.

Key areas of concern when considering the disposal of battery modules (or battery racks which are housed within the modules) include (1) sustainability, (2) potential for environmental discharges, and (3) the fire risk. Normally, there is some state of charge within the battery cells at decommissioning. There is latent chemical reactivity of the battery cells to oxygen or water (i.e., an oxidising agent), so adequate care is needed in the removal, handling, and disposal of the cells.

There are a growing number of recycling facilities for processing lithium and other chemistry batteries overseas. In Australia, the amount of lithium recycled is comparatively low but is likely to improve due to growing sustainability impetus and due to the increase in price of lithium. Approximately 92% of the lithium battery material can be recycled, thus there is a driver to recycle this material so it can be utilised again. OEMs such as Tesla [56] [57] and CATL [58] recycle their batteries, and independent facilities, like Ecobatt in Australia recycle lithium batteries [59]. Apart from some specific suppliers, in general there needs to be more specific guidance regarding the disposal and recycle processes, as each will have unique attributes.

With respect to VRF batteries, the electrolytic solution can be reused with minimal documented degradation. Unlike Li-ion battery facilities, if the capacity of a VRF BESS is looking to be upgraded, the infrastructure which will be replaced as part of the decommissioning process will mainly include the electrolytic tanks [10], piping and, if needed, pumps. The Australian Battery Recycling Initiative (ABRI) have assessed the vanadium flow battery recycle potential [60], noting that vanadium, acid, and plastics could be recovered in the process.

During the literature search, the following discussion points were not sighted and have been put forward here for further consideration:

– As battery chemistry and technology evolves, it is likely that the overall large energy storage sites will increase in power output and storage capacity. The overall power systems could be expanded from a modularity perspective, i.e. adding extra modules like the Neoen Hornsdale facility, so the disposal would likely still be at the modular level, but in greater quantities.
– Owners and regulators may eventually require OEM providers to further articulate broader asset management plans which provided detailed decommissioning considerations for proponents responsible for site operations. Key aspects may include decommissioning of components within battery modules; the battery module itself; and how the site design influences the decommissioning process. If these processes are not well developed or adequately communicated, it is possible that there may be environmental effects from disposal and landfill of spent batteries as the battery cells leach into the surrounding areas (unless the disposal locations are sealed and capped appropriately).

3.5 Other areas of consideration

In addition to the above, GHD have highlighted other areas of consideration which are pertinent to BESS facilities given their growing capacity and land footprint. Inadvertent interactions (such as mobile plant, vehicle-to-vehicle, or vehicle-to-person) and interaction with the general public during construction, commissioning, and operation are important factors which need to also be considered for BESS facilities. This section focuses on areas which are currently maturing and want to use this guidance material as an opportunity to begin stakeholder conversations around these matters.

3.5.1 Deliberate acts of physical damage

For numerous reasons, some members of the public may not like a BESS facility at a particular location. There are many avenues for complaint and protest and in most cases, objections remain civil and peaceful. However, there are some individuals or groups in the community that may want to escalate objections or wish to cause disruption with the potential to take their objections further by physically damaging a facility with an act of sabotage. Typically, good stakeholder management appropriate for the project will often manage this range of risks.

One control is the use of secure boundary fences for safety and deliberate acts, especially given the potential for BESS facilities to be remote and unmanned.

A more difficult protective consideration is the risk from gun fire, either deliberate or accidental. Recently in the United States (North Carolina) there have been some shootings of electrical substations, on 3 December 2022, with investigations being undertaken by the US Federal Bureau of Investigation. [61] FBI has stated that the damage led to a power outage to 45,000 customers with a state of emergency being declared.

More recently on 17 January 2023, there have been reports of damage to a third substation. This third apparent act of damage did not cause any disruption to electrical supplies. It is also being investigated by the FBI. [62]

Due to the differences in Australian ownership and usage of guns, it is generally considered that the risk profile for a gunfire event in Australia is lower than that in the United States, but it is not a (near) zero risk. Like other infrastructure around Australia, the growing presence of BESS facilities will naturally attract a full spectrum of behaviours (potentially ranging from graffiti and vandalism to terrorism), similar to that of rail and other infrastructure facilities.

Australia utilises Crime Prevention Through Environmental Design (CPTED) approaches [63], and there is a range of guidance material which is used in other industries. Currently, GHD have not sighted explicit incorporation of CPTED into BESS designs and operation, apart from the usual aspects of buffer zones, warning signs, security fencing and surveillance systems typical of power facilities. Physical damage to Li-ion cells is a known mechanism for a thermal runaway event. It is unlikely to be practical and/or cost effective to eliminate all of the potential of damage due to a deliberate act.

However, like rail, aviation and other facilities and infrastructure, consideration of simple methods or design features, either in the BESS modules themselves or with the site layout and physical provisions should be undertaken as part of the design to reduce the risk so far as is practicable.

3.5.2 Cyber vulnerability

As a follow on from physical methods of damage, there is the potential for cyber vulnerability to achieve similar outcomes, and even broader ranging events. As seen recently in the media, there have been multiple cyber security breaches of various organisations, with some breaches severely disrupting services such as Colonial Pipeline cyberattack [64].

Although the scope of this guidance material is to review other areas (see Section 1.3) cyber security and vulnerability considerations should be given to existing and future BESS facilities moving forward. In 2021, Kharlamova et al. [65] flagged that there is a lack of extensive review on battery cybersecure design and operation. As discussed, there are several interconnected parts which, if attacked, may render the whole system inoperable.

An example provided is the potential for a false state of charge estimation, providing a false command which could be detrimental to operations. A graphical summary of the types of cyber threats is provided as Figure 5.

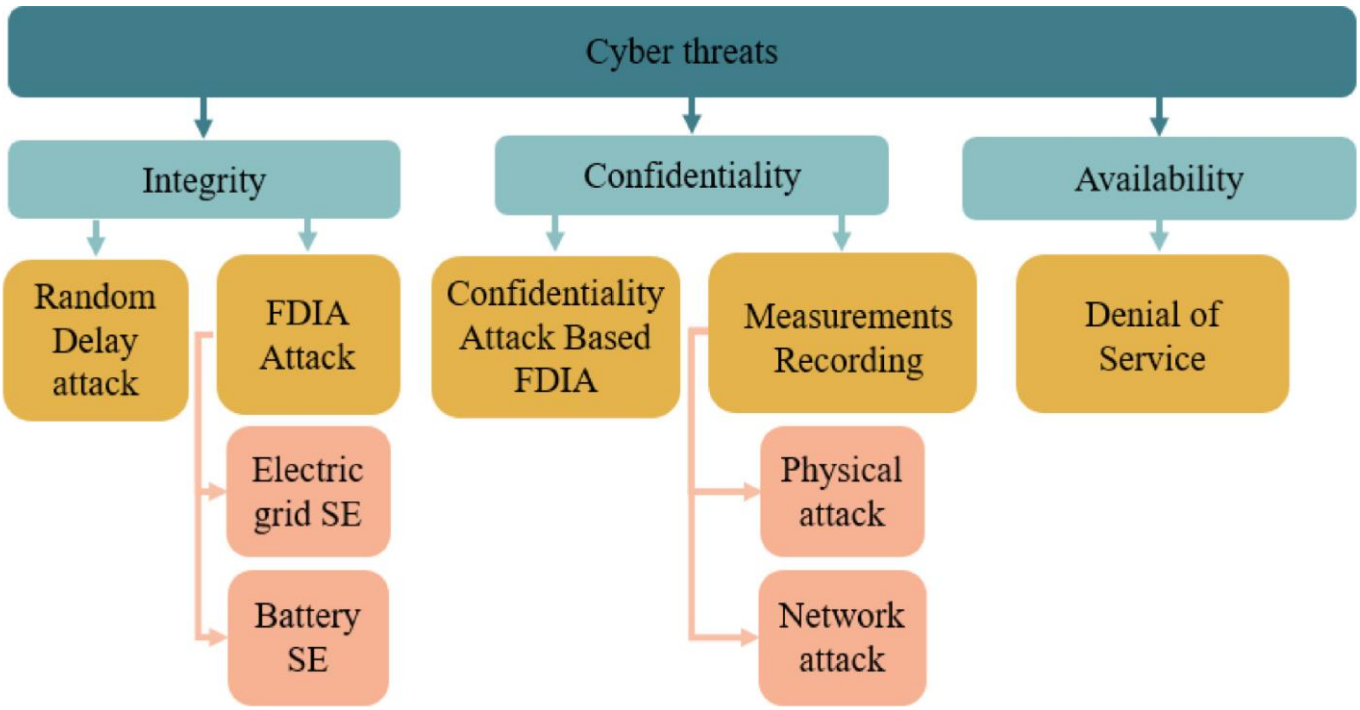

Figure 5 Classification of cyber threats for the BESS (Figure 2 of ref [65])

Kharlamova et. al provide a comprehensive review of cyber security considerations for grid-scale BESS facilities, demonstrating that this is a plausible area based on the precedents set from other cyber and terrorist attacks.

The recent increase in the size and number of battery facilities poses unique issues. The convergence of new battery chemistry, remote internet-based energy management technology, high response control systems and diverse facility locations have not historically been seen anywhere around the world. In the near-term future, many larger facilities (over a gigawatt hour in capacity) and possible multi-stacked arrangements may exist. This presents a new range of threat scenarios. These threats could manifest in primary, secondary and tertiary safety risks to Australians.

Where:

– Primary safety threats are associated with the on-site facility / systems
– Secondary safety threats are the localised, off-site area
– Tertiary safety threats are associated with the broader grid effects from power outages or instabilities.

BESS facilities can be unmanned, particularly if they are in isolated areas, and operated remotely. Networked systems can be vulnerable to bad actors with the potential to trigger unwanted events. As a technology grows in its presence in society, the profile of cyber hacking interest in this technology also increases. Cyber security should be a consideration when managing threats to BESS facilities as there is the potential for a range of consequences from a loss of control.

There is a growing awareness amongst regulators who are exploring how cyber security pertains to their jurisdictions. This is a growing area and the growing dependency on grid-scale energy storage requires further jurisdictional scrutiny for safety and grid performance. Regulators should be coordinating more globally about this for better consistency, and energy storage system providers will need to provide more substantial evidence of the cyber security their systems do (or do not) have.

3.5.3 Land value impacts

Although land planning requirements are currently in place, guidance on how community growth around existing BESS facilities is being considered has not been sighted. As population growth continues, concerted efforts are being made to further develop existing suburbs, or to create new estate packages. This development will see the reclassification of land, such as the transition from peri-urban locations into urban as residential property expansion continues. Battery facilities, like the Victoria Big Battery, are currently installed in rural locations, as these facilities generally require a large amount of land, depending on type and energy storage requirements. As the population begins to migrate further out, it is possible that existing BESS facilities may affect land values.

Conversely, as technology progresses and the footprint required to produce a comparable amount of energy reduces, there is also potential to construct a BESS facility within existing residential areas, which may also impact land values.

Thus, considerations for the land requirements will also need to be included in planning new communities and expansions. Questions such as ‘will the risk profile of properties surrounding the BESS facility be impacted?’ need to be considered moving forward. Considerations for locating BESS facilities in existing communities will need to include fire risks, and natural environment, noise, visual and other amenity impacts.

3.6 Key observations from reference material

The development, construction, and subsequent operation and reliance on grid-scale BESS facilities has outpaced the development of Acts, Regulations, Standards, and other guidance materials used to inform such ventures to date. The material relied upon by constructors and designers, regulators, and operators is region specific; therefore, the list of documents discussed within this section is not exhaustive.

An example of the diversity of Standards and notable guidance material relied upon globally for BESS is illustrated by Figure 6, extracted from Ampace Technology Energy Storage Solution material.

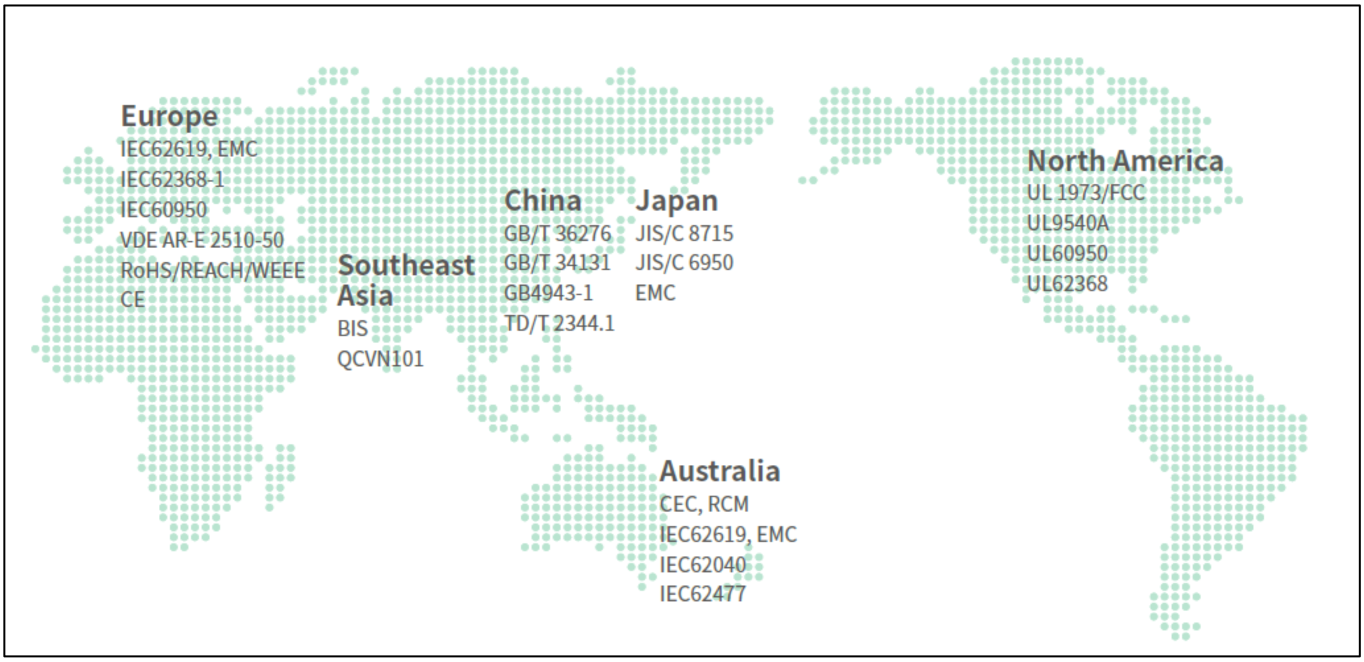

Figure 6 High level list of global standards used for BESS

Table 4 provides a summary of the key findings during review of relevant source material. Due to time limitations, the review was focused on some of the materials which were identified as references by stakeholders interviewed or from prior engagements associated with BESS facilities. It is noted that the references are not exhaustive, and there are many other relied upon resources available.

Table 4 Summary of reference documentation

Title	Key observations
Australian Acts, Regulations and Standards	
Work Health and Safety Act 2011	The WHS Act states the following for duty of designer: “The designer must ensure so far as is reasonably practicable, that the plant, substance or structure is designed to be without risks to the health and safety of persons.” Therefore, under the WHS Act, persons who control or manage workplaces are obligated to ensure the health and safety of people ‘so far as is reasonably practicable’ (SFAIRP). This legislation requires consideration of risk control measures and safe systems of work, which for BESS facilities may relate to: – Housekeeping, including vegetation management – Maintenance activities (vehicle, plant, and equipment) – Security – Emergency considerations (egress, ease of evacuation)
AS/NZS ISO 14001:2016 Environmental management systems - Requirements with guidance for use	The ISO standard describes environmental management systems for organisations with a systematic approach. The standard describes environmental management from planning through to performance evaluation. The standard may relate to BESS facilities in relation to environmental aspects such as:

Title	Key observations
	– Emissions and releases to land or water – Waste generation and raw material requirements – Considerations to be included during planning Emergency preparedness and response
AS/NZS ISO 45001:2018 Occupational health and safety management systems - Requirements with guidance for use	The ISO standard describes requirements for OHS management systems which could apply to operators, contractors, and visitors to site etc of BESS facilities. The standard may relate to BESS facilities in relation to: – Hazard identification process requirements Defining OHS objectives
AS/NZS ISO 9001:2016 Quality management systems – Requirements	The ISO standard describes the requirements for a quality management system that can apply to any organisation to improve its overall performance. This standard may relate to BESS facilities in terms of: – Risk-based thinking and employing preventative action – Ensuring the facility abides by the required policies and standards – Determining the required knowledge and competence of workers General quality assurance requirements for BESS facilities
National Standard for Construction Work [NOHSC:1016 (2005)]	The national standard defines the requirements "to protect persons from the hazards associated with construction work". This could apply to BESS facility installations during the construction phase or during maintenance or upgrade activities as the client or designer of a construction project.
AS/NZS 5139:2019 Electrical installations - Safety of battery systems for use with power conversion equipment	AS/NZS 5139:2019 details the general installation and safety requirements for BESS. This standard applies to battery systems with a nominal voltage between 12 V D.C and 1500 V D.C, with a rated capacity equal to or greater than 1kWh and no more than 200kWh. It outlines potential hazards related with BESSs and other associated battery systems, and details installation methods to minimise the risk of these hazards. Key observations include: – Standard discusses installation and safety requirements for BESSs connected with power conversion equipment (PCE) but does not specifically include PCE itself in their requirements – The standard provides a detailed overview of installation and commissioning requirements but not decommissioning – Sufficient clearance from the BESS for safe egress is given to be "no less than 1 metre" – Mentions that the installation of pre-assembled integrated BESS must take into account spacing requirements between multiple BESS and other associated equipment but does not identify what these requirements are – The standard has in-depth detail about pre-assembled battery systems but lacks large-scale battery systems (it does briefly mention requirements for parallel battery system). The standard makes comments on "larger installations" but does not provide any further detail about them.
AS/NZS 4681:2000 The storage and handling of Class 9 (miscellaneous) dangerous goods and articles	– AS/NZS 4681:2000 details the safety requirements for Class 9 dangerous goods and articles. Although it provides a detailed information on storage and handling of dangerous goods, there is minimal information on batteries. There is no information available on lithium-ion batteries (there is limited information on the storage and handling of lithium batteries), vanadium redox flow batteries, or sodium-ion batteries.
AS 2067:2016 Substations and high voltage installations exceeding 1kV A.C.	– Applicable if the rated AC/DC voltage is greater than 1 kV – AS 2067 states that for equipment with a rating above 1 kV a minimum ground safety clearance of 2,440 millimetres is required
AS/NZS 1170.2:2021 Structural Design Actions – Wind Actions	– Wind and seismic loading on facilities, and tolerable design thresholds
Victorian Dangerous Goods (Storage and Handling) Regulations 2012	Regulations 54 and 55 of the Dangerous Goods (Storage and Handling) Regulations 2012 may be required depending on the nature and quantity of material on site.

Title	Key observations
	– Regulation 54/55 states that “An occupier of premises where dangerous goods are stored and handled in quantities that exceed the relevant quantities specified” will request written advice from the relevant emergency services authority to reduce the risk of a catastrophic scenario by reviewing or altering the design of the fire protection system and through an emergency plan.
International Standards and guidance	
ISO 22320:2018 Security and resilience – Emergency management – Guidelines for incident management.	The ISO standard describes guidelines for incident management and is applicable to any industry that is involved in responding to incidents of any type or scale. This standard details a general incident management structure and process which may be applicable to BESS facilities.
UL 9540A Battery Energy Storage System Test Method	UL 9540A is a test standard which is utilised to develop data on the fire and deflagration hazards from thermal runaway and its propagation. The standard aims to systematically assess thermal runaway and propagation in energy storage system at cell, module, unit, and installation levels. It is being utilised globally by original equipment manufacturers, such as Tesla [66] and CATL [67], as a means of demonstrating that thermal runaway is improbable (within the testing parameters used) The data from the testing may be used to design fire protection methods to mitigate against the hazards generated Key observations include: – The testing requirements for batteries in the for UL 9540A unit level fire test analysis is not necessarily tested at ambient temperatures analogous to environmental temperatures in Australia. – As provided by Synergy following the draft AEC BESS report review, if cell-to-cell propagation test is passed, then the module-to-module test is not required. If module-to-module propagation test is passed, then unit-to-unit test is not required. Therefore, there may not be any testing to confirm module-to-module or unit-to-unit propagation will not occur in the event thermal runaway propagates beyond a cell. The increased temperature and wind speed at the locations of Australian sites may negatively affect the likelihood of thermal runaway.
UL 9540 Energy Storage System Requirements	UL 9540:2020 sets out the requirements for energy storage systems used for receiving and storing energy in a form that can be converted to electrical energy to power a local / area electric power system. The standard provides an assessment of the compatibility and safety of individual parts of the energy storage system (e.g., power conversion system, battery system, etc.). Key observations include: – Includes hazardous fluid control (e.g., toxic vapours, spills) – Includes general information on fire protection, suppression, and propagation for energy storage systems (ESS’s) – Includes large scale fire testing for electrochemical type ESS (Note: Test requirements are found in UL 9540A) and is required for certification in Australia – Requirements (including testing and evaluation) for batteries, electrochemical capacitors, hybrid battery-capacitor systems or flow batteries used in electrochemical ESS are found in UL 1973. – The standard identifies that a Leakage Test, Strength Test, and Hydrostatic / Pneumatic Test are required for ESS that contain hazardous fluid. The test procedure and acceptable results are also given. – Requirements for installation and maintenance are given but the standard provides minimal information on decommissioning requirements.
NFPA 855 (2020) Standard for the Installation of Stationary Energy Storage Systems	NFPA 855 is a standard for installation of “Stationary Energy Storage System” and a 2023 version is being produced and outlines “the minimum requirements for mitigating the hazards associated with ESS”. The standard includes information on operations and maintenance as well as commissioning and decommissioning of units. It currently covers different types of chemistries and configurations. Key observations include:

Title	Key observations
	– The standard does not focus on large scale installations – Minimum separation distances are described as "3 feet" The 2023 version should be reviewed when available
IEC 62933-5-1:2021 Electrical energy storage (EES) systems - Safety considerations for grid-integrated EES systems - General specification	Part 5-1 of IEC 62933 specifies safety considerations regarding EES systems integrated with the electrical grid. It outlines the potential hazards, consequences, and safeguards associated with EES systems. An example of the main risk scenarios for lithium-ion batteries is available in Annex A. No other specific information can be found on large-scale battery facilities. The standard also includes system testing for various EES system malfunction scenarios. A set of guidelines and manuals that should be considered is also outlined in the standard.
IEC 62933-5-2:2020 Electrical energy storage (EES) systems - Safety requirements for grid integrated EES systems - Electrochemical based systems	Part 5-2 of IEC 62933 outlines the safety requirements for people, surroundings, and other living beings for electrochemical energy storage systems. This standard is applicable for the entire lifecycle of BESS. This part of the standard includes a general risk analysis for BESS. Protective considerations to reduce risk are outlined in the standard. Specific preventative measures are found in IEC 62933-5-1. Operation and maintenance of BESS is also outlined, including design revisions and end of service life management. Annex B includes hazard considerations specific for Lithium-ion batteries, and Vanadium redox flow batteries. Annex C includes large-scale fire testing on BESS, referencing UL 9540A
Other guidance material	
Design Guidelines and Model Requirements – Renewable Energy Facilities (2022)	Facilities that support the generation of electricity in Victoria include wind energy facilities, solar energy facilities and battery energy storage systems. These facilities are the focus of this guideline. CFA recommends the adoption of a risk management process, in line with AS/ISO 31000- 2018: Risk Management Guidelines, to identify and address fire risk at renewable energy facilities. Within the guidance material, CFA reviews: – The site firewater requirements – Inter-module distances, and – Water run-off requirements. CFA recommend containment be provided as per AS 4681-2000: *The storage and handling of class 9 dangerous goods* (Section 7.3.9: Control of run-off). In the event of a fire, suppression water will contain potentially toxic substances. CFA design guide recommends that water runoff needs to be managed through the inclusion of physical infrastructure including, for example, bunding, sumps and/or impervious water retention facilities, with an equivalent capacity to the fire protection system provided on-site These guidelines advocate a holistic approach to fire and emergency risk management. Where the facility includes a battery energy storage system or other significant quantities of dangerous goods, a request for emergency services written advice under Regulations 54 and/or 55 of the Dangerous Goods (Storage and Handling) Regulations 2012 may be required. The quantity of dangerous goods must be determined for the purposes of requesting emergency services written advice. For lithium-ion based battery energy storage systems, the net weight of the lithium-ion battery cells (rather than the gross weight of the battery enclosure/container) must be provided.
Clean Energy Council (CEC) reference material (2018)	The CEC, with support and guidance various industry associations, produced a guide and accompanying risk register to develop a "best practice guide" which stipulates the minimum safety requirements for Lithium BESS facilities within Australia. The best practice guide presents different methods to address hazards and provides a list of applicable standards to review as part of this process. However, as noted within the disclaimer, this document was current at the time of publishing and the standards referred to within the guide, and also within the risk register, have either been revised or are now updated given the fast-paced nature of battery development since 2018. The risk register separates the risks based on the battery configuration (e.g., battery module or preassembled battery system), and provides base control measures to incorporate. As guidance, each risk indicates the relevant clause /

Title	Key observations
	section of standards to review for compliance. A total of sixty-two (62) hazards were identified. Key observations include: – The guide mentions the emerging concerns associated with cyber security risk but does not address any of these issues. This, alongside other malicious intent activities, is subsequently not captured within the risk assessment – The guidance seems to be location and size agnostic, not differentiating between how to approach risk given these differences – Lack of end-of-asset life and decommissioning considerations within the risk register
New York Battery Energy Storage System checklist	This checklist is primarily used to assist with field inspections of residential and small commercial battery energy storage systems. Although this document is applicable to energy storage systems in New York, it provides a step-by-step approach to approaching inspection activities. This may be relevant during the development of commissioning checklists. As this is outside the scope of this engagement, it is recommended that this checklist is reviewed when further detailed guidance is developed.

3.6.1 Case Study: Gaps identified in reference material following the Victoria Big Battery fire

Drawing on the discussions following the Victoria Big Battery incident in Victoria, Australia, it was found that grid-scale BESS facilities fall outside the definition of a Major Electricity Company (MEC) under the Energy Safety Act 1993; as they are assumed to fall within the definition of complex electrical installation. The result currently is that there was (and is) currently no formal requirement for an electricity safety management scheme and safety case demonstration to be provided for entities operating BESS facilities. ESV encourages voluntary submissions of electricity safety management schemes. Furthermore, there currently is no clear expectation as to what constitutes evidence of a safe BESS facility design for reference by ESV.

In a technical findings report issued by Fisher Engineering [68], Victorian Big Battery facility design general arrangement showed that the clearances between Megapack containers is 2,400 millimetres. Since it is unknown what maintenance practices were planned to be conducted on site, it is suggested a pragmatic consideration includes ability of vehicles (e.g., utility vehicle or site-specific small vehicles) to traverse site.

For areas of the site or equipment which have voltage greater than 1kV, AS 2067 prescribes minimum safety clearances.

In addition to these issues identified, the following was also found:

– At the time of the incident, there was no legal requirement to inform the CFA of the battery composition
– From a quality assurance perspective, downstream proponents are reliant on the guarantees provided by the OEM and their affiliate organisations
– Although a version of UL9540A[3] was relied upon to demonstrate that thermal runaway would not occur and to justify that thermal escalation to other megapacks was improbable, a thermal runaway incident occurred. The Fisher Engineering report noted that the wind conditions for the certification were 30 to 40% of the prevailing wind conditions at the time of the incident [68].

The Fisher Engineering report also noted that there were gaps in the commissioning procedure, electrical fault protection devices and thermal roof design. Tesla has implemented several procedural, firmware and hardware mitigations to address these gaps to existing Megapacks at that time, as well as for future installations.

[3] GHD has reviewed the Fisher Engineering report on the Victoria Big Battery fire (released in 2022) [68] for further information regarding testing stipulated within UL9540A

4. Discussion

4.1 General findings

As demonstrated from the literature review and high-level review of reference material above, the growth and integration of grid-scale BESS facilities had outpaced the development of Acts, Regulations, Standards (both local and international) and other guidance available. Recent thermal events, such as the case study example provided in Section 3.6.1, have reinforced this, as well as highlighting to various stakeholders that their remits and responsibilities needed to be assessed and redefined. Recent efforts by stakeholders have addressed these gaps to some extent. Although beyond the scope of this engagement, it was noted that each State within Australia has differing regulatory requirements, reinforcing the need for the development of harmonised guidance material.

Key features of a more harmonised approach are emerging, whereby stakeholders who are involved in differing stages of the grid-scale BESS facility lifecycle, are involved in the update, revision, and development of Acts, Regulations, Standards, and other guidance material moving forward, this approach is positive and is consistent with the proactive approach and support being led by the AEC.

Whilst it was found that there is significant research effort directed to engineer an optimal and safe battery chemistry, it was found that there is not as much research focused on determining the influence of facility wide factors (such as site selection, facility orientation, battery stacking arrangements, and centralised versus decentralised storage) on thermal events.

The current guidance is mostly location and facility size agnostic and as a result does not provide guidance on how to approach safety and risk to consider those differences. It is noted that the CFA guidance material briefly addresses these factors (refer to Section 5.3.1 of CFA document [69]) by asking the following: “Does the proposed layout of the site impact fire risk? Is the fire service infrastructure safely accessible? Are there hazards or infrastructure that may impact safe evacuation?”

The sources reviewed provided detailed mechanistic pathways, with supporting mitigation measures, that could be utilised to decrease the likelihood of thermal runaway from occurring or further propagating. From our discussions, these events and their potential facility wide implications present a major concern to multiple stakeholders given the Victoria Big Battery incident. However, current standards, such as UL9540A, do not necessarily simulate conditions which are representative of the conditions within Australia and also within the facility itself (e.g., microclimate formations due to heat island effects).

This, again, reinforces the need for further research and development in the assessment of facility-wide risks. CFA’s guidance implicitly addresses this need, recommending that a Fire Safety Study is conducted in accordance with NSW Planning's *Hazardous Industry Planning Advisory Paper 2: Fire Safety Study Guidelines* [70] and that risk is approached in line with AS/ISO 31000- 2018: Risk Management Guidelines.

There is minimal guidance on the process and consequences associated with decommissioning such facilities based on the resources sighted. As grid-scale BESS facilities are a relatively new development, with major facilities less than a decade old, information regarding decommissioning of large capacity sites is not currently publicly available. The CEC’s guidance material briefly addresses this process, and a risk is provided within the pre-populated risk register. UL 9540:2020 *Energy Storage System Requirements*, a standard which is utilised by OEMs, provides requirements for installation and maintenance activities, but does not include detailed decommissioning information.

Similar to the installation, operation and maintenance of a BESS site, decommissioning represents is a key stage within the lifecycle of a BESS, and therefore further information needs to be developed and provided. Due to the likely variability in battery chemistry composition in the near future, the increase in storage capacity, as well as the possibility of sequentially decommissioning battery modules rather than a whole-of-site decommissioning process, further instruction is required by OEMs. Areas such as environmental implications (including recycling), OH&S and potential to replace current battery modules with greater capacity modules need to be further developed.

Other considerations, such as environmental impacts from loss of containment events (a key consideration for VRF batteries with large quantities of vanadium electrolyte) were not thoroughly documented in the resources reviewed. Based on learnings from other industries, loss of containment can lead to groundwater contamination and result in runoff if there are inadequate containment measures associated with the design. Similarly, literature on malfeasant activity (in the form of deliberate physical damage to a facility or via cyber-attack) and potential influence on land value were not sighted. As briefly explored in Section 3.5, these are other relevant areas which need to be considered during the planning and operation of grid-scale BESS facilities. Although the scope of this engagement is primarily focused on thermal, OH&S and environmental risks, it is important to note that given the growing size of these facilities, the risks associated with these other associated matters should be considered when assessing installations.

Lastly, from an OH&S perspective, the literature search result indicated a gap in efforts (i.e. there is an opportunity) regarding the need to incorporate human factors within the design. This is a critical aspect of other high-risk industries with large facilities, such as rail, aviation, and oil and gas, which stipulate that human factors need to be considered (through various assessments) for a safer, more useable and understandable design.

While the above areas present opportunities for future areas of focus, it is important to note that emerging and updated material, such as the 2022 edition of the CFA guidelines, NFPA 855:2020 *Standard for the Installation of Stationary Energy Storage Systems*, UL9540:2020 (and associated testing standard UL9540A) have helped considerably in the journey towards a consolidated, safety-informed approach in the development of grid-scale BESS facilities.

4.2 Stakeholder interview summary

All interviewees acknowledged that collaboration is needed to proactively bridge gaps continuously being identified with BESS facilities. Furthermore, interviewees expressed that national harmonisation is desirable, noting that this may be difficult to achieve.

It was acknowledged that the CEC's Best Practice Guide involved regulatory and manufacturer engagement at the time of development. However, it has not been updated since 2018 and draws upon standards which are now either outdated or no longer applicable. There are also a number of ways to demonstrate compliance within the support CEC risk register, making it difficult to enforce. Therefore, the guidance cannot be relied upon for further BESS developments but may provide a good starting point for safety considerations.

Although beyond the scope of this engagement, ESV expressed the need to fundamentally review existing legislation to ensure that accountability and anomalies in the current Acts and Regulations are addressed. A major issue identified by ESV is the absence of an Australian Standard for large energy storage battery facilities. Efforts are being made to expedite the creation and subsequent release of an appropriate standard, however as an interim measure, technical guidance will represent an iterative update of the existing CEC guidance.

From the interviews, it is understood that ESV are in the process of developing technical guidance material and recognise that the CFA guidance material is one of the few resources which addresses the requirements for fire management at a BESS facility (as per stakeholder interviews). It was conveyed that the technical guidance material that ESV are developing will touch on fire systems and fire suppression, but it will likely not be prescriptive. ESV communicated that the expectation will be that a "rigorous" risk assessment process is undertaken, mirroring the risk-based approach within the CFA guidance.

Discussions with CFA representatives revealed that the guidance material has undergone four updates to capture changes and new initiatives within the BESS industry and Li-ion chemistry development. CFA representatives communicated that the organisation is trying to get a national position on BESS to achieve consistency and are seeking feedback from international fire safety specialists to further enhance their guidance. The following issues were identified:

– Water supply
– Access, bushfire, and firefighter safety
– Separation distances between batteries as well as separation distances between batteries and other utilities on site.

The Victoria Big Battery incident demonstrated the importance of all the above issues, where radiant heat impact was observed between two banks of batteries which were approximately 2.4 metres apart (a bank of battery contains four (4) megapack units). Similar to ESV, CFA expressed the need for an Australian Standard for batteries, explicitly mentioning the installation process. Additionally, when asked about the implications of stacking arrangements, CFA mentioned that although stacking has not directly been taken into consideration in their guidance, the need to complete a risk assessment (including a fire safety study) and comply with AS 2419 *Fire Hydrant Installations* would capture risks. It was agreed that this may be an issue in the next decade due to urban pressures.

CFA have also consulted with WorkSafe New South Wales about the classification of grid-scale BESS facilities as Dangerous Goods facilities. If this occurs, then will allow more legislative purview about what needs to be introduced into these facilities.

From an OEM's perspective, members of the technical team at CATL stated that they are looking into double layer battery module solutions. With regards to centralised or decentralised utilities for battery modules, CATL expressed that the preference was to keep utility support systems decentralised as it promotes better consistency. The greatest risk currently being faced by CATL within the Australian market is demonstrating that thermal runaway potential is minimal given the Victoria Big Battery incident. In conjunction with the mitigation measures integrated into the design, CATL are looking to address these risks by in-house battery chemistry research and development.

A Health, Safety, Environment and Quality representative from Fluence Energy reinforced the concerns expressed from the interviews with CFA and ESV, regarding:

– Growing desire to fit greater storage capacity in a given parcel of land.
– Proper access and egress within the facility, noting that for some facilities there is only one access gate, posing potential safety issues during emergency situations
– Entrapment issues given the limited space between battery module rows.

Similar to feedback provided by CFA, Fluence Energy recognised that there is not enough guidance provided for the installation of grid-scale BESS facilities. It was also noted that from contractor management perspective there are differing licencing requirements across States, which may delay installation and construction activities.

Lastly, a representative from the Queensland Government (Environmental Services and Regulation, Department of Environment and Sciences) stated that there are currently no Environmentally Relevant Activities (ERAs) with the Environmental Protection Regulation 2019 that are specifically for batteries. Some of the electricity generating facilities do already utilise battery technology. There may be bespoke conditions that are within their approvals that deal with the risks. However, environmental issues are not broadly get assessed. This is assessed on a case-by-case basis.

From an environmental management perspective, BESS facility owners need to demonstrate through modelling during the application that there would be no nuisance / amenities related impacts. However, thermal modelling and microclimate formations is currently not considered.

In summary:

– Regulatory authorities and other stakeholders recognise that their jurisdictional presence and involvement in future energy storage facilities needs to be further defined, with clear guidance on when they should be involved in the BESS facility engagement process.
– Existing legislation needs to undergo a fundamental change as technology progresses. Similarly, the existing CEC guidance is difficult to utilise given the innumerable ways to demonstrate compliance. Guidance material (both technical and non-technical) needs to be to unambiguous and well-defined to prevent this from occurring again.
– A risk-based approach is preferred, assessing each facility on a case-by-case basis. By doing so, the specificities, such as battery chemistry consideration, fire water requirements, and broader site selection and configuration, can be justifiably presented to relevant stakeholders.
– It is likely that battery stacking will be required, given the interest already being expressed to OEMs. This needs to be investigated moving forward and incorporated as a scenario or future consideration in all guidance materials, and eventual Standards.
– Further involvement from HSEQ and environmental stakeholders is needed to further develop guidance in these areas. Early involvement is key as it may dictate site selection and facility design.

- The material relied upon by constructors and designers, regulators, and operators is region specific. Based on the feedback received from stakeholders interviewed, there is no definitive standard to refer for holistic guidance on BESS facilities
- Although UL9540A is relied upon, it was expressed that further simulation work is not completed by OEMs. Results from such modelling may be requested by regulators and may be mandatory moving forward.

5. Guidance material

5.1 Purpose of the guidance material

The purpose of the guidance material is to provide a high-level, risk-informed approach to assess grid-scale BESS facilities. Based on the learnings summarised in Section 3 and Section 4 of this report, the degree of assessment required for a grid-scale facility is dependent on the battery chemistry, proposed site location and layout, the storage capacity of the facility, as well as the neighbouring receptors.

To adequately assess facilities and the complex interdependencies it possesses, the approach taken is to categorise BESS facilities into different “types” based upon energy storage capacity. This principle is used in the major hazard facility classification process, and it is considered a practical way to delineate energy storage systems. This will also promote a consistent assessment approach associated with different “types” of facilities moving forward.

The guidance material in this document considers the following areas:

– Site selection, facility orientation, and facility configuration
– Safety case approach
– Emergency management planning
– Environmental offsite effects.

This guidance is designed to assist the AEC in their journey towards the development of further, comprehensive guidance material. While this guidance can be applied to differing battery chemistries, the facility “type” categorisation is primarily for Li-ion and VRF BESS facilities. The principles noted can be translated across to different battery chemistries and technologies, but it is recommended that the “type” thresholds and recommended assessments are reviewed prior to finalisation of guidelines.

5.2 Grid-scale BESS facility guidance

Based on the literature reviewed and learnings from the stakeholder interviews, the risk profile of BESS facilities is dependent on a number of factors. These include:

– The battery scale: Is the battery for grid-scale applications?
– The battery type: What is the battery chemistry? What type of technology (e.g., redox) is being utilised?
– The energy storage capacity: How much electrical energy can the grid-scale facility store?

This parallels the way risk evolves in other high hazardous industries as the type of material storage as well as the quantity changes the overall safety and assessment requirements of the site.

Figure 7 illustrates the proposed approach to assess grid-scale BESS facilities, capturing the interdependency of the above factors.

Although the scope of this engagement is to provide guidance for grid-scale BESS facilities focused primarily on Li-ion BESS and VRF BESS, shaded in grey are a number of matters that it is expected will require consideration and review as these resources are used in future. These include:

– Residential and community-scale BESS’s
– Other battery types (including chemistries and technologies)
– Further assessments which many be required for Type 1 and 2 categories.

The guidance is meant to be challenged and further developed by AEC members. Therefore, it is expected that this flowchart will be revised as more stakeholder input is incorporated.

The range of stored energy is categorised into four (4) types:

1. ***Type 1:*** *Less than 50 MWh*

   Typically containerised energy storage system
2. ***Type 2:*** *Between 50 MWh and 250 MWh*

   Typically on a modular basis typically delivered in containers
3. ***Type 3:*** *Between 250 MWh and 1,500 MWh*

   Energy storage facility that requires a larger footprint, with battery modules arranged in bank (cluster) or island formations
4. ***Type 4****: Greater than 1,500 MWh*

   Energy storage facility that requires a larger footprint, with battery modules arranged in bank (cluster) or island formations. Land constraints may become an issue given the larger storage capacity required

Type 1 and Type 2 represent smaller scale facilities, while Type 3 and Type 4 represent larger facilities requiring more detailed and further assessments. The aim of this guidance is not to be prescriptive (i.e., detailing the specific sections, parts and/or clauses of legislation. Acts, Regulations, Standards, and other guidance material). Rather, this guidance is meant to be a resource highlighting key areas for consideration.

As expressed throughout this report, this field is evolving and prescribing specific requirements would likely yield only temporarily beneficial guidance given that subsequent updates to supporting references will continue to evolve. This guidance distils the findings and presents, at a high-level, what should be completed for each Type category presented.

Although assessments such as 'critical infrastructure and cyber security assessment", "detailed safety in design and human factors assessment' are only noted for Type 3 and Type 4 BESS facilities, this guidance is meant to be challenged and further developed by AEC members. Therefore, it is expected that this flowchart will be revised as more stakeholder input is incorporated. As depicted within the figure, Type 3 and Type 4 facilities require a coordinated and collaborative assessment process that involves all stakeholders, including regulators.

5.2.1 Key guidance steps

In addition to the flowchart provided below, suggested key intermediary steps to support facility development, safety documentation, engagement, and approvals. This will support the risk identification, assessment process and potential safety case required for the specific facility

1. Articulating the battery energy storage opportunity and key project drivers.
2. Proposed power and capacity characteristics of the facility, including any foreseeable expansions to the size, capacity and footprint of the battery facility
3. Proposed site location, defining the facility size (i.e., layout and projected land use) and configuration.
4. Research local jurisdictional requirements (Council, State and Federal requirements)
5. Identify and consult key regulators and stakeholders, with considerations given to neighbouring community engagement
6. Amenity and environmental assessment
7. Initial discussions based on requirements with the regulators. It is suggested at early design stage to incorporate key requirements (tolerable safety and environmental criteria) into key contractual documents
8. Develop a checklist of compliance needed from relevant Legislation, Acts, Regulations, Standards, and guidelines. Initiate early risk assessment process, assessing risks against tolerability thresholds, and commencing SFAIRP approach. Ensure these are clearly outlined in contract documents to key suppliers and contractors.
9. Outline and communicate key risk and safety documentation requirements to OEM providers
10. Develop a communications plan for key stakeholders
11. Develop initial safety case documentation with independent specialists and internally
12. Develop suitable detailed engineering design and confirm the safety documentation. Outline conformance to key tolerability requirements

13. Submission of key documentation for assessment.

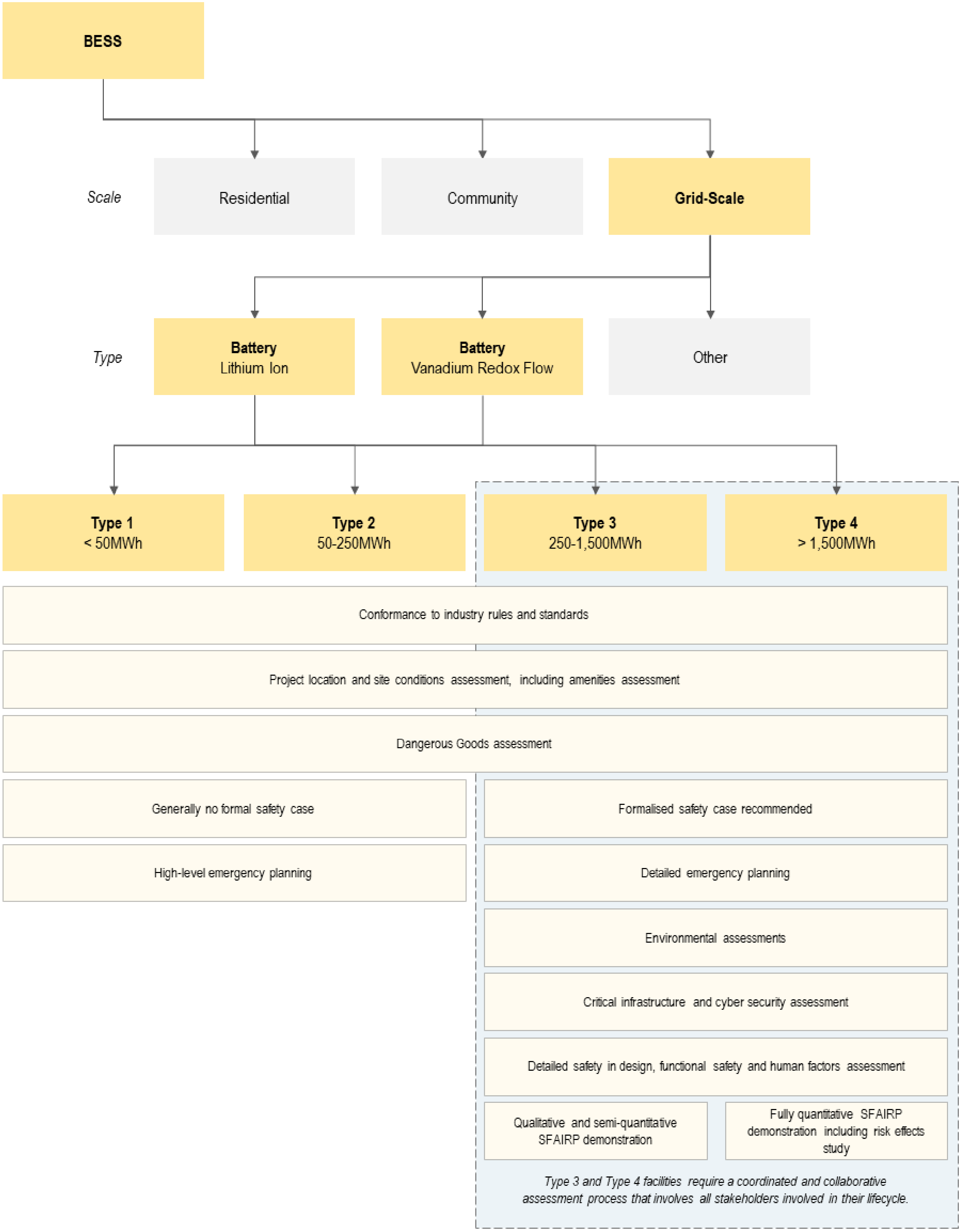

Figure 7 BESS guidance flowchart

5.3 Site selection, orientation, and configuration

Site selection is a key step in the development of grid-scale BESS facilities. As expressed by CATL, a major limiting factor for BESS facilities is temperature. High temperatures result in faster battery degradation, as the battery will have a consistently higher operating temperature. Furthermore, humidity may influence performance, with the potential for condensation during operation if greater than a specified percentage.

However, as mentioned in Section 4.1, little consideration has been given to the shape and/or alignment of BESS modules on a site. Appendix C provides a detailed overview of:

– The meteorological conditions that should be reviewed as part of the BESS facility design.
– Guidance on separation distances between battery modules, referring to existing guidance provided by Standards and/or other guidance material.

As larger facilities are proposed, appropriate site selection and site alignment will become a more important consideration. For an individual site and BESS configuration, wind patterns may impact performance of some of the battery modules from time-to-time due to downwind heat plume/heat island effect.

Following the Victoria Big Battery thermal runaway event, publicly available information was utilised to produce preliminary thermal models of the facility. Two simulated examples are shown in Figure 8 and Figure 9. The modelling conditions used for these figures is summarised in Table 5.

Table 5 Modelling conditions used for Figure 8 and Figure 9

Modelling conditions	Figure 8	Figure 9
Ambient temperature	35°C	35°C
Wind speed	Calm conditions	20 km / hr
Wind angle	-	Wind is parallel to the long face of the facility layout

During calm and light wind conditions, the air discharged by the BESS modules rises vertically away from the site; the simulation illustrates that each module cooling system is effectively operating independently (as generally designed).

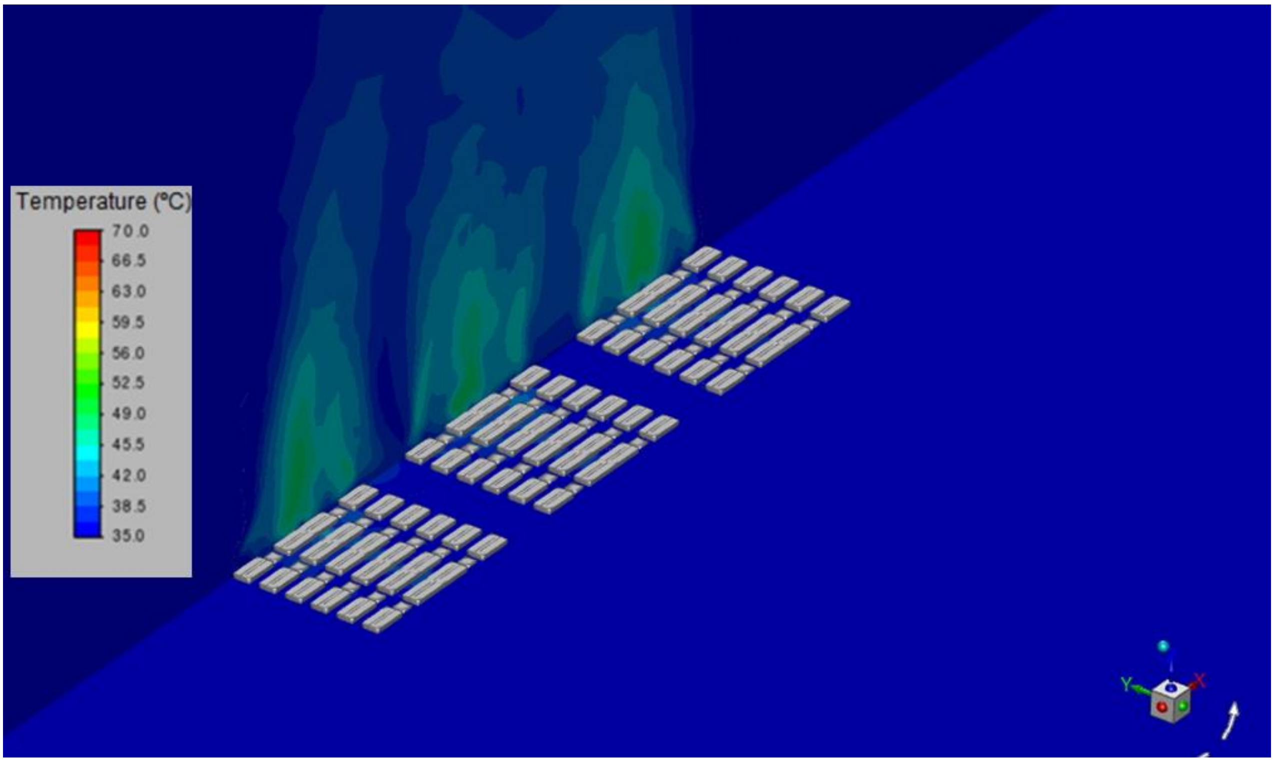

Figure 8 CFD simulated heat plumes from a BESS showing thermal contours of air temperature (35°C calm wind conditions)

For a 20 km/h (at 10 m reference height) wind aligned with the long axis of the BESS site, modules located near the downwind side of the site can be exposed to elevated ambient air temperatures. The thermal contour slice illustrates that some of the Megapack units in the centre of the facility reach have the potential to reach temperatures between 60°C and 70°C on a 35°C day and is above the operational envelope of Tesla Megapacks.

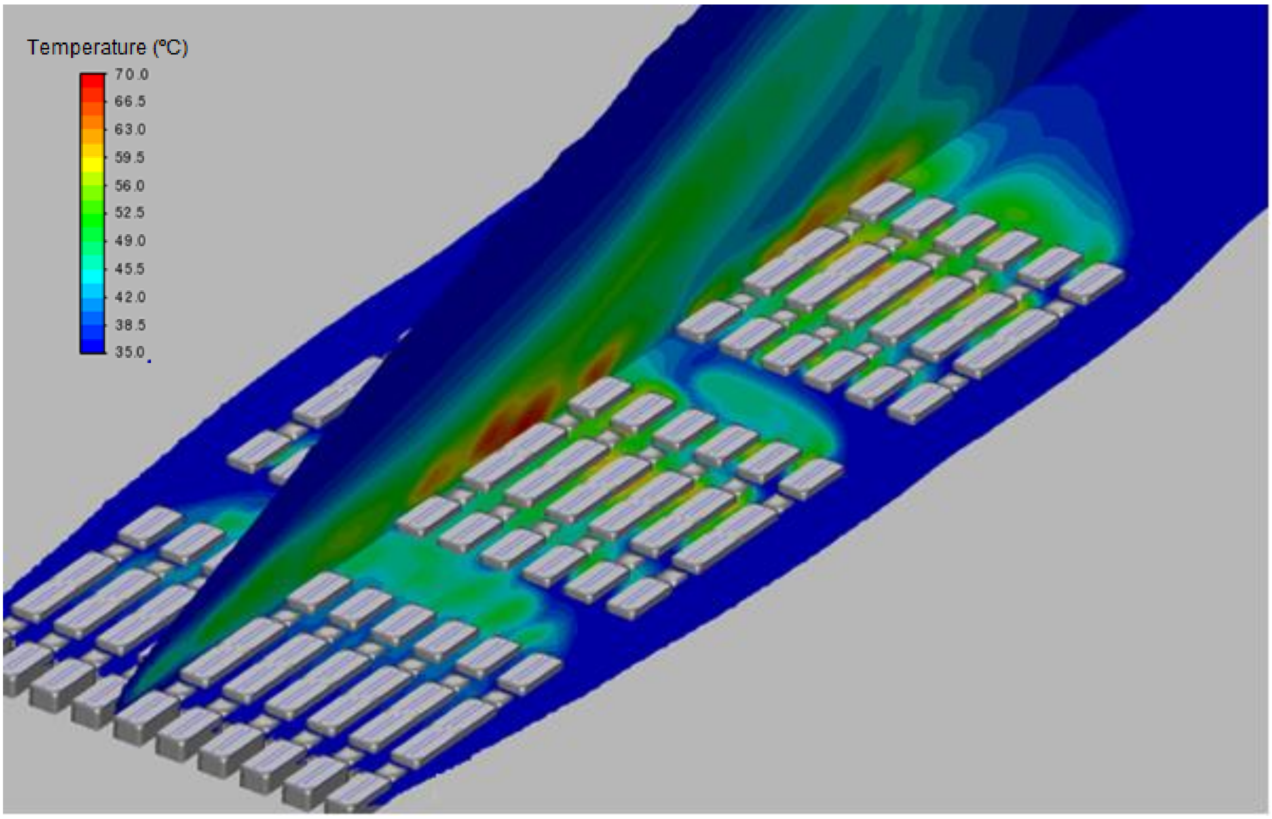

Figure 9 ***CFD simulated heat plumes from a BESS showing thermal contours of air temperature (20 km/h with BESS long face aligned wind conditions)***

For the simulations shown, local ambient temperatures near individual modules inside the site could be 10 to 15 C higher than the upwind ambient. Thus, it is possible that module performance derating could ensue as a result of inappropriate site selection and facility orientation given the prevailing meteorological site conditions.

The inter-module spacing used in the model approximates the distances between modules at the Victoria Big Battery site. Despite complying with the required specifications at the time of design and construction (some of which are discussed in Appendix C), Figure 9 demonstrates that the pathways between modules can potentially exceed 50 °C, presenting O&HS risks.

As demonstrated by these simulations, larger facilities (Type 3 and Type 4) require complex modelling to inform risk assessments and safety case developments.

In addition to the above considerations, it is also important to understand noise issues. Differing modes of operation (e.g., normal operations, during commissioning, etc.) may have differing emissions which can impact nearby residents. Observationally, noise assessments appear to be in their infancy for these types of facilities. OEMs, regulators, and operators should utilise the well-developed principles from other environmental impact study areas and apply this to BESS facilities.

5.4 Safety case development

For larger facilities (classified as Type 3 and Type 4), regulators may need demonstration that the equipment selection and facility design meet acceptable safety levels on-site and off-site. Typically, facilities must demonstrate safety to a level So Far As Is Reasonably Practicable (SFAIRP).

If a SFAIRP safety argument were to be provided to a regulator for larger grid-scale BESS facilities, the discussion would need to clearly demonstrate the rationale for selection and exclusion of available options. An interesting example would be the selection of the Li-ion battery chemistry. It is well known that the NMC-aluminium formulations have a higher propensity for thermal runaway than LFP chemistry batteries. In this case, the regulator would expect a convincing argument for the selection of an NMC formulation (or another similar chemistry with similar susceptibility). Suitable arguments may centre around better safety management systems and containment versus cost differences in chemistry, or the availability of materials.

Similarly, for layout and orientation, SFAIRP demonstration would need to address the potential compromise between facility space and layout, available safety systems and thermal capabilities of the modules (taking into consideration heating, ventilation, air conditioning, etc.) with the level of risk. For aviation and nuclear industries, high integrity safety systems (such as functional safety systems) are utilised to offset the intrinsic risk nature of specific events. If OEM suppliers can provide suitable information, or provide certification against 62619, the battery management systems (BMS's) do need to operate with multiple layers of protection, due to the large number of BMS units, and thermal runaway potential. Larger energy storage systems could also utilise high integrity systems as part of a SFAIRP argument. The typical outline of a safety case process to demonstrate SFAIRP is shown in Figure 10.

Smaller facilities could complete appropriate aspects outlined but to a lesser degree. A simpler SFAIRP demonstration could be contained in the smaller facility documentation.

As quoted from the Safe Work Australia *Guide for Major Hazard Facilities: Preparation of a Safety Case*

"*The development of the safety case outline will generally require the operator to:*

– *Understand what processes and systems are required by Chapter 9 of the [Work Health and Safety] WHS Regulations*
– *Understand the purpose of the safety case*
– *Identify what information will be required to prepare the safety case*
– *Identify any existing information that might be used to meet these requirements*
– *Carry out a comparison or analysis which evaluates the existing information against the requirements and determine what extra information is required to prepare the safety case (gap analysis or similar)*
– *Determine how to obtain the extra information*
– *Plan to evaluate how well the major hazard facilities meets the requirements of Chapter 9 of the WHS Regulations, and how to establish what actions, systems or processes are required to meet any deficiencies*
– *Write the safety case outline*."

The typical risk studies which form part of a safety case demonstration are summarised in Table 6.

Table 6 Summary of risk studies which may form part of a safety case demonstration

Assessment Type	Comments
Project risk assessment	Captures broader risk considerations associated with the lifecycle of the project. It is expected that stakeholders regularly update the project risk assessment.
Hazard Identification (HAZID)	Completed to identify the range of hazards applicable to the site/project
Hazard and Operability Study (HAZOP)	Completed to identify hazards and operability issues applicable to the site/project.
Safety and Operability Study (SAFOP)	Completed to identify hazards and operability issues applicable to the electrical aspects of a site/project. Conducted for electrical systems from power through to end points.

Assessment Type	Comments
Control Hazard and Operability Study (CHAZOP)	A CHAZOP is used to assess the control system for critical issues and unsafe failure modes. It represents a modified hazard and operability study to assess the control systems or safety systems associated with the project undergoing review.
Layers of protection assessment (LOPA)	Significant risk scenarios arising from the HAZOP, SAFOP and CHAZOP undergo a LOPA. The aim to determine if functional safety (safety integrity levels) are required for certain safety or environmental functions.
Failure Modes, Effects (and Criticality) Analysis FMEA/FMECA	FMEA and FMECA are completed to identify failures modes which may potentially cause product or process failure. While a FMEA is qualitative, a FMECA offers a degree of quantitative input taken from sources of known failure rates.
Quantitative and Semi-quantitative Risk and consequence modelling	Completed to assess the consequences and risks associated with basic site layout configurations and distances, as well as demonstrating the overall facility effect on the safety of onsite personnel and offsite population. Risk and consequence modelling is important in the identification and quantification of risks inside and outside the boundaries of a hazardous facility. It is generally conducted for a new hazardous facility development or when there are material changes to storage within an existing site.
Fault Tree analysis	Completed to assess how systems fail using deductive, Boolean logic to identify methods to reduce risk, thus determining event rates for safety incidents or specific system level failures.
Event Tree analysis	Completed to assess the probabilities of certain outcomes from an initiating event, using a forward, top-down, Boolean logic approach.
Reliability, Availability and Maintainability Study (RAMS)	Completed to assess how various system component and sub-component failures can contribute to an overall system failure. This study is then used to determine and confirm the reliability against key targets.
Reliability Block Modelling	By representing the system as a series of blocks, reliability block modelling is used to determine the critical components of that system. The failure rates of equipment (at the componentry and sub-componentry levels), design and safety configurations, operating philosophies and maintenance strategies can be quantitatively assessed and the impact to the system performance can be found. The system can then be assessed against defined reliability and safety criteria.
Computational Fluid Dynamic modelling	Modelling the heat plumes generated by the facility, and determining intra- and inter-site effects (i.e., adjacent module effects), along with interactions with local natural and built environment.

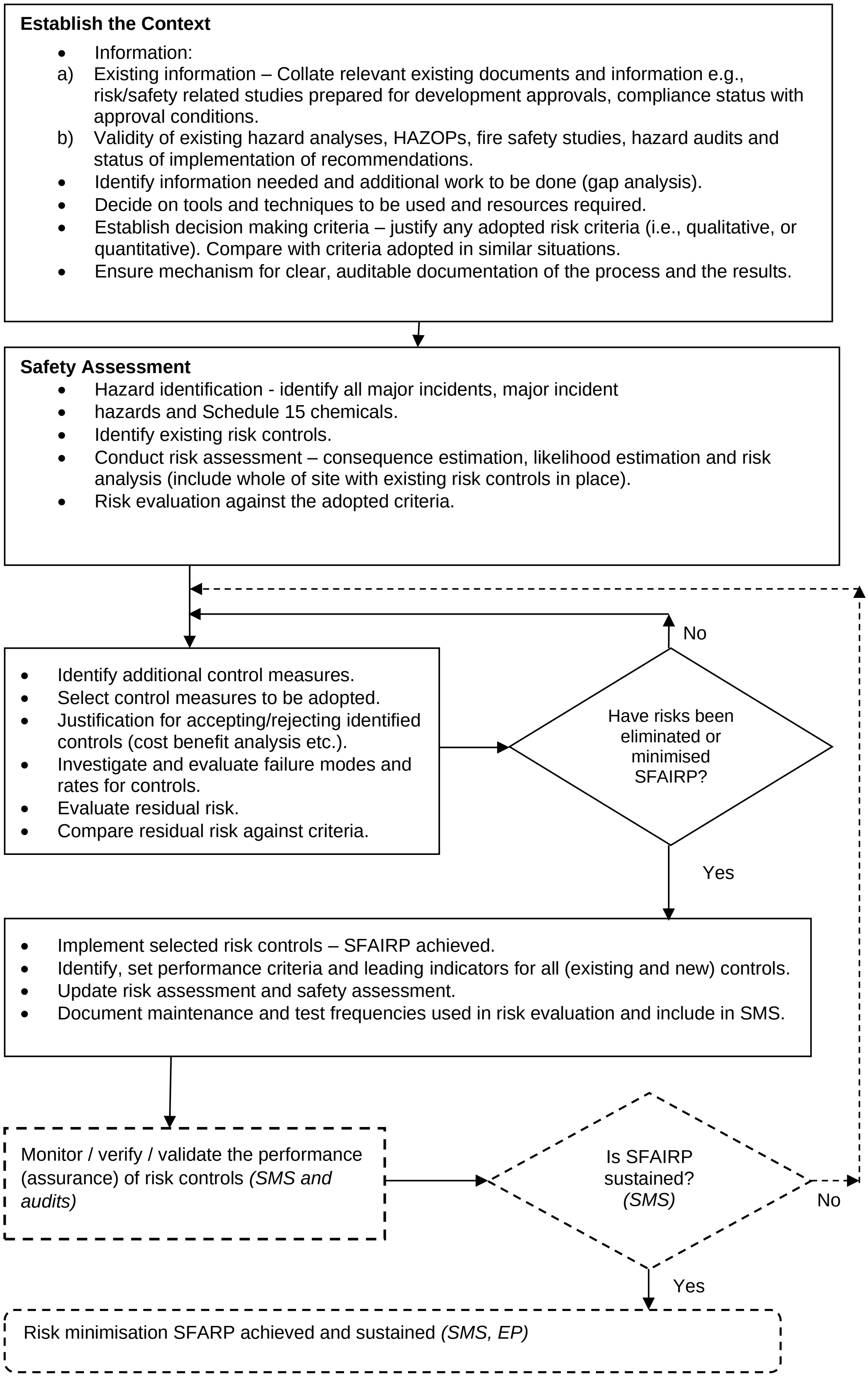

Figure 10 Flowchart for the development of a safety case outline (Figure 9 of ref [71])

5.4.1 Human factors

In addition to the list above, Human Factors assessment may be required. Human Factors engineering and assessments are used within multiple industries, such as rail, aviation, oil and gas, to assess how people and the built systems interact [72] [73]. As BESS facilities get larger in size, the range and nature of Human Factors issues are likely to increase. From the literature and material reviewed to date as part of this engagement, there is no explicit instruction to complete a Human Factors assessment for grid-scale BESS facilities.

There are a range of ergonomic and anthropometric considerations for people to safely and effectively carry out various tasks on energy storage facilities. Factors such as frequency of tasks, complexity of tasks, weight of materials and equipment carried, distances, and consequences of errors all need to be considered in a Human Factors assessment.

For larger energy storage facilities, a Human Factors assessment may be valuable to undertake, given the interdependency of facility layout with maintenance and operational needs. Some of the issues to consider through the lens of a human factors assessment might include:

- *Movement of larger equipment across the site*: Larger equipment may need to be carried over longer distances to complete routine activities. Thus, better tools (e.g., lighter), lifting equipment and transport systems may be required to assist personnel in executing their tasks.
- *Compatibility of module spacing with required activities*: Spacing between battery modules (i.e., between rows of battery modules) needs to be compatible with the range of maintenance equipment required for the site. Furthermore, consideration must be given to egress between battery module rows during operational and maintenance task, such as inspections, cleaning, and filter checks.
- *Achieve site reliability and maintenance objectives:* Complete FMECA and Reliability, Availability and Maintainability (RAM) assessments to evaluate whether the overall site reliability and maintenance objectives can be realistically achieved, and the nature of operational and maintenance requirements by personnel are understood and appropriately managed.
- *Local heat effects and microclimate formation:* Microclimate formation as a result of localised hot zones may be present across the site. Therefore, work related heat stress out on the site may be an issue, giving rise to the need for heat stress work cycle calculations and assessment. These hot zones, or localised heat islands, may be exacerbated during hotter months.
- *Specialised activities on site:* Larger or unique facilities may require special activities to be undertaken by operational and maintenance staff.
- *Visibility:* Limited visibility of workers in and amongst the facility units may also need to be considered in terms of worker safety and communications.

The extent of Human Factors assessment will be dependent on the complexity and scale of the grid-scale BESS facility. For larger, more complex facilities, a Human Factors Integration Plan (HFIP) and Early Human Factors Assessment (EHFA) is advisable. The EHFA is designed to accelerate consideration of Human Factors issues, risks and opportunities by design leads, thereby setting the expectations and activities for Human Factors integration within the design program. A HFIP then defines the integration of Human Factors issues, providing appropriate assurance procedures to guide these activities.

For smaller, simpler facilities, a basic Human Factors assessment alongside the Safety in Design register may suffice. As noted for other areas of consideration, this will need to be reviewed on a case-by-case basis.

5.5 Emergency management plan

A detailed, site-specific emergency management plan (EMP) for grid-scale BESS facilities is essential to ensure that the facility is prepared for an emergency incident. This is to minimise damage sustained to the site, ensuring the safety of onsite personnel, emergency responders and the community, and minimising any period of disruption to operations and supply.

As detailed by the CFA [69]:

"*An EMP details the structures, procedures, resources, training for managing emergencies. EMPs **must be specific** to the infrastructure, operations and location of facilities, and informed by a sound risk management process. An Emergency Management Plan may also assist employers to meet their obligations under the OH&S Act in providing a workplace that is safe and without risks to heath.*"

Credible scenarios need to be considered for emergency plan formulation. Some prompts to review include the following:

- Is it plausible or probable for a single or multiple battery modules to catch fire or explode?
- What are the credible hazards and risks present for the BESS facility being reviewed? This includes fire scenarios (internal and external initiators)
- For cyber hacking, is it possible for multiple units to drive to full or zero power with loss of control function?
- Is there potential for frequency control and ancillary services (FCAS) malfunction and consequent grid instability issues?

In line with CFA, it is recommended that the EMP is consistent with the requirements within AS/NZS 3745 *Planning for emergencies in facilities*. Furthermore, it is recommended that the EMP is updated to reflect any subsequent amendments to this standard [74] [75].

AS/NZS 3745 outlines key components to include within an EMP, as summarised in Figure 3.1 of AS/NZS 3745.

In Section 10.1.2 of CFA's guidance material details mandatory elements to be included within EMPs for all renewable facilities, specifying that they must cover construction and operational phases for the site. There are also additional mandatory requirements for BESS facilities. Furthermore, CFA details other optional, but highly recommended, contents which they expect within EMPs. The CFA guidance represents the current leading practice and should be utilised as it builds upon the principles within AS/NZS 3745 and the learnings from the Victoria Big Battery incident.

Consideration should be also given to modifying the mandatory and optional contents within EMPs based on the facility 'types' outlined earlier. This will need to be further discussed with the CFA and other stakeholders to ensure alignment of stakeholder expectations.

5.6 Environmental offsite effects

The regulatory approvals and compliance, and ongoing management of environmental offsite effects required for BESS facilities will be dependent on facility location and jurisdiction. It is important to note that specific regulations and requirements may vary depending on the jurisdiction, and the facility operator should consult with relevant authorities to ensure compliance.

The following steps are generally involved:

– *Environmental Impact Assessment (EIA)*:

  An EIA is typically required to assess the potential environmental impacts of the facility, including impacts on air and water quality, neighbouring wildlife and habitats, and human health. The EIA will also identify mitigation measures to minimise these impacts.

– *Development Application and Approval:*

  The facility will need to obtain development approval from the relevant local, State, or Federal government, which will involve assessing the facility's compliance with relevant planning and environmental regulations. Identify the key documents needed for each approval and application.

– *Environmental Management Plan:*

  An EMP will need to be developed and implemented, outlining the measures that will be taken to minimise the environmental impacts of the facility, such as air and water pollution control, waste management, noise management and biodiversity conservation.

– *Licensing and Permits*:

  The facility will need to obtain any necessary licenses and permits for its operations, such as air, water consumption and discharge permits, noise management and comply with relevant regulations.

– *Monitoring and Reporting:*

  Regular monitoring of the facility's environmental performance will be required (air, water, noise and solid waste), and the facility will need to report this information to the relevant authorities. This may include water in retention ponds or dams.

– *Community Engagement:*

  It is important to engage with local communities and stakeholders to keep them informed about the facility's operations and potential impacts and address any concerns they may have. A stakeholder management plan is best developed early in a project and undertaken at key points throughout the project phases.

– *Decommissioning Plan:*

  A plan for the decommissioning of the facility will also need to be prepared and approved.

Some detail on the key offsite effects would include:

– Bushfires and ember attacks
– Fugitive air emissions from single module or other for the credible scenario failures
– Refrigerant, coolants, and/or electrolyte releases
– Volatiles from any hydrocarbons utilised for operational and maintenance requirements
– Washdown chemicals
– Adequate pondage for fire water. Demonstrate site discharge water is separate from local catchments and waterways.
– Noise emissions (in some areas, noise barriers may be required where the facility is closely sited to urban areas)

For larger facilities, thermal emissions monitoring may be required, especially if there is interaction with nearby solar farms or other facilities that may have a cumulative effect or be affected by the energy storage facility.

5.7 Supporting risk register

A number of preliminary risk scenarios were identified, utilising literature findings, previous incidents and based on the interviews with stakeholders engaged as part of this work. As discussed in Section 3.1, battery chemistry and technology are rapidly advancing to maximise performance capabilities while upholding safety. Therefore, this risk register aims to primarily capture key risks associated with Li-ion (specifically, LFP) batteries and VRF batteries as they represent a significant cross-section of the current types of BESS facilities present.

Although the risks identified may be applicable to other battery chemistries, there are also distinctive risks (e.g., chemistry specific risks, unique facility configuration), that need to be added. As such, the risk register provided (refer to Appendix D) is a preliminary assessment tool.

This risk assessment represents a hazard identification study (HAZID), capturing related risks, their causes, and resultant consequences. Furthermore, the register details standard control measures and proposes additional controls measure which may or may not be needed based on the facility needs. As the aim of the register is to provide a pre-populated list of hazards (and associated controls, consequences, and controls), it is assumed that organisation will transfer these risks their respective templates and utilise organisational-specific likelihood and consequence descriptors to rank the risks accordingly. Thus, these areas of the risk register have been left unfilled.

The risk register aims to categorise the risks identified into different 'risk categories':

- Design
- Effluent
- Environmental
- Environmental / Hazardous Material
- Equipment
- Occupational, Health and Safety
- Project
- Security.

This is not an exhaustive list, and stakeholders should continue to add to or amend the risk categories as required.

The typical methodology expected to be applied when reviewing and updating the pre-populated register is illustrated in Figure 11.

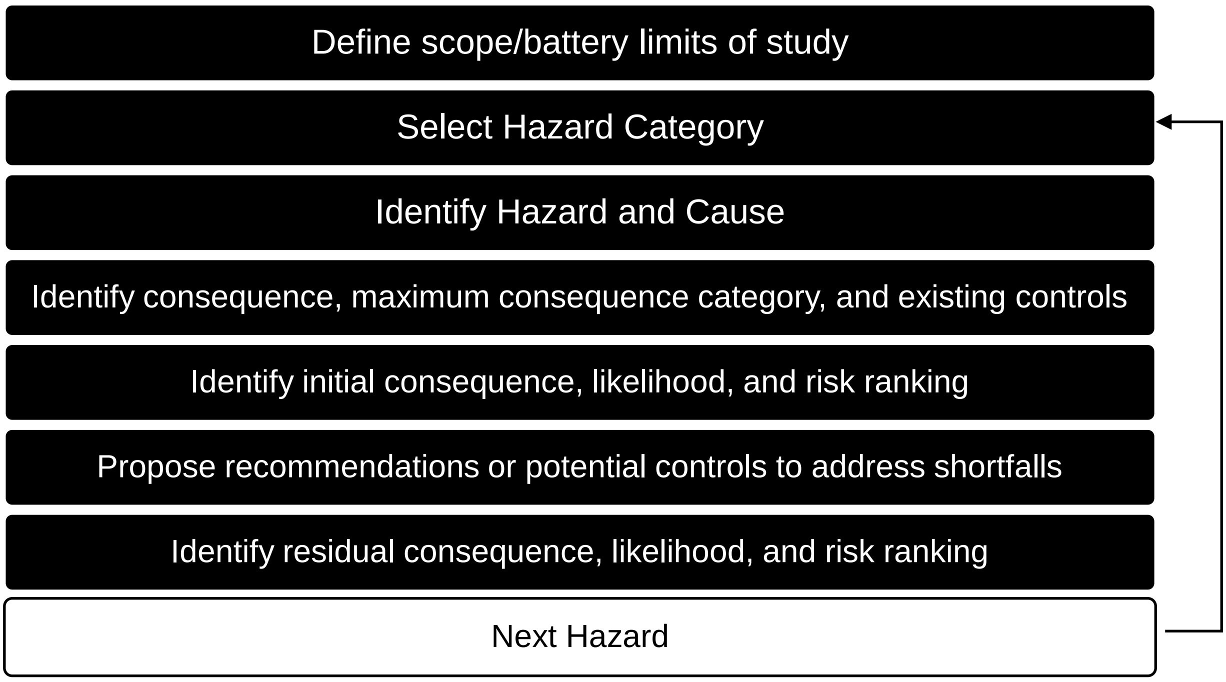

Figure 11 Flowchart for HAZID study

This register aims to complement the existing risks within the CEC's Best Practice Guide risk register by capturing other issues of concern, including cyber security, visual amenities, noise and importance of stakeholder engagement. The guidance provided in Appendix D focused on principles which exist in Acts, Regulations, Standards and current supporting guidance, and does not detail which clauses / parts of standards need to be reviewed for each risk identified.

As discussed throughout this report, the rapid pace of development of this technology will result in these references being superseded or outdated. Where applicable, currently relevant Acts, Regulations, Standards, and guidance are listed as current control measures. But the overriding purpose of the register is to capture the forward momentum in societal stakeholder thinking with regards to energy storage safety - which may not yet be formally and explicitly captured in existing reference material.

A total of forty-one (41) risks were identified. A legend within the register is provided to distinguish between risks which are Li-ion- or VRF-specific risks or are applicable to both types of BESS facilities. There is a comments column within the risk register which provides additional information, such as past events, to support the risk relevance.

As with other previous investigations and available material, the risk register captures that there are multiple scenarios or pathways by which uncontrolled energy release can occur, escalating to thermal runaways and fire events. This is not dissimilar to other liquid fuel storage facilities; the primary difference being the way in which the energy release occurs. Table 7 outlines key features of comparison between hydrocarbon facilities of a similar size.

Table 7 Comparison between hydrocarbon storage facility events with BESS facility events

Area	Hydrocarbon storage	Lithium battery unit	Vanadium battery flow cell
Fire and explosion	For fire and explosion events: - Vapour - Heat and/or ignition source - Fuel	For fire and explosion events: - Stored energy within the BESS - Presence of short circuit or exposing the lithium-based chemistry to water or oxygen	Due to the intrinsic properties of the flow batteries, the cells do not go thermal. However, it is possible that an energy release from the aggregate collection of cells is enough to initiate fires in associated adjacent equipment, albeit less frequent
Size	Standalone large singular tank or multiple large tanks (i.e., tank farms)	Currently is constrained by container modular sizes, which are then arranged / configured into battery banks or islands, limiting escalation	Larger assembly due to lower energy density (compared to lithium)
Infrastructure	Pumps and pipework present	Electrical cable work	Pumps and pipework present to move electrolyte Electrical cable work
Energy density	Generally higher energy density due to the energy density of liquid hydrocarbons prior to oxidation and large quantity of liquid fuel present (major hazard facility level)	Moderate energy density with reactive lithium chemistry	Low energy density with a low volatility liquid.
Toxicity	Dependent on the nature of the liquid fuel. Release is harmful to aquatic life, the environment and is an irritant	Combustion products can have toxic off-gases (detailed in the risk assessment) and toxic firewater runoff	Toxic electrolyte which, depending on the chemistry, is harmful to aquatic life, the environment and is an irritant

6. Conclusions and opportunities

As we transition towards renewable sources for energy generation, our dependency on energy storage grows to uphold current network resilience. The global uptake of grid-scale BESS facilities has been rapid; with two of the world's largest facilities currently in Australia. Although beneficial, events such as the Victoria Big Battery fire in 2021 and other global grid-scale incidents, demonstrated that further work is required in conjunction with existing requirements. Australia is largely dependent on overseas manufactured equipment for energy storage systems.

This guidance report consolidates learnings from the literature review, findings from stakeholder consultations, and broader industry knowledge to present a preliminary guide to approaching assessment of grid-scale BESS facilities moving forward. Refer to Section 5.2 to view the BESS guidance flowchart and Section 5.2.1 for supporting intermediary steps.

Although the scope of this engagement was limited to review of grid-scale BESS facilities, specifically Li-ion and VRF, additional guidance needs to be developed for:

– Other battery chemistries and battery technologies
– Residential-scale battery energy storage
– Community-scale battery energy storage
– Energy storage systems involving a combination of storage types, for example battery and hydrogen energy storage systems (referred to as renewable energy hubs).

6.1.1 Key considerations moving forward

Similar to all documentation, this guidance is an evolving document. From this engagement, multiple stakeholders have conveyed that other technical guidance is being developed. It is recommended that the AEC engages with other stakeholders to assist in the development of guidance material that aims to support or complement the upcoming developments. Key considerations include:

– The likely growth in physical size and capacity of BESS facilities

  As this will likely occur in the near- and medium-term future, there needs to be harmony and consistency between States on the regulatory assessment.

– Promoting consistency as this helps set broader expectations from international suppliers.

  This includes the likes of CATL, Tesla, LG Energy Solution and many other OEMs. Australia has an opportunity to influence further international thinking about the safety of energy storage systems. This also helps Australia's sovereign reputation as well as our international presence on the BESS front.

– Classification as critical infrastructure.

  Although beyond the scope of this engagement, it is recognised that with the increased dependence on various forms of energy storage there may be a need to classify them as critical infrastructure. This categorisation of the infrastructure must be suitably incorporated at the very early stage of the BESS design lifecycle. Thus, certain reliability criteria are required early on in the design.

– Resource constraints

  As Australia transitions away from the traditionally segregated energy and distribution sectors, State regulators may experience resource constraints as traditional participants in the energy sectors are largely funding their activities. There is a need for State-by-State regulator resourcing and skill to assess BESS facilities. Therefore, owners of complex installations (such as BESS facilities) should provide funding moving forward.

– Combining energy storage mediums

  As we continue to grow in our dependence on energy storage systems, new innovative approaches in storage technology, including combination of storage mediums, will become more prevalent. For these systems, thought must be given to the development of combined threshold classifications.

– Safety-case thinking

> Whilst certification at the unit and module level is important, it should still be viewed as an important component of safety case thinking, but not to replace the SFAIRP argument.

This guidance represents an opportunity for stakeholders in Australia to influence the future requirements and assessments of grid-scale BESS facilities. It will be in the interests of the AEC, associated members, and regulators in Australia to continue its collaboration and also engage with and participate in international forums and bodies to influence revisions to existing standards and the development of future standards.

Australia is actively progressing along the risk development curve of energy storage and is one of the nations at the forefront of facility size and knowledge on the global level (e.g., Victoria Big Battery and the South Australian Hornsdale facilities). We can therefore leverage our knowledge and influence the global trends during the safety management maturation of these facilities, which will be advantageous to all involved.

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Appendices

Appendix A

Abbreviations

Table 8 Abbreviations table

Term	Definition
AC	Alternating Current
ACCC	Australian Competition and Consumer Commission
AEC	Australian Energy Council
AEMO	Australian Energy Market Operator
AFAC	Australasian Fire and Emergency Service Authorities Council
AHJ	Authority Having Jurisdiction
AS	Australian Standard
BESS	Battery Energy Storage System
BMS	Battery Management System
CATL	Contemporary Amperex Technology Co., Limited
CEC	Clean Energy Council
CFA	Country Fire Authority
CFD	Computational Fluid Dynamics
CHAZOP	Control Hazard and Operability Study
CID	Current Interrupt Devices
CPTED	Crime Prevention Through Environmental Design
DC	Direct Current
DELWP	Department of Environment, Land, Water and Planning
DES	Department of Environment and Sciences
DMIRS	Department of Mines, Industry Regulation and Safety Building and Energy
DNV	Det Norske Veritas
EES	Electrical Energy Storage
EHFA	Early Human Factors Assessment
EIA	Environmental Impact Assessment
EMP	Environmental Management Plan
ERA	Environmentally Relevant Activities
ESA	*Electricity Safety Act* 1998
ESMS	Electrical Safety Management Schemes
ESS	Energy Storage System
ESV	The Victorian Energy Safety Commission, also commonly referred as Energy Safe Victoria
FCAS	Frequency Control Ancillary Services
FDIA	False Data Injection Attack
FMEA	Failure Modes and Effects Analysis
FMECA	Failure Mode Effect and Criticality Analysis
GW	Gigawatt
GWh	Gigawatt hour
HAZID	Hazard Identification
HAZOP	Hazard and Operability Study

Term	Definition
HFIP	Human Factors Integration Plan
HIPAP	Hazardous Industry Planning Advisory Papers (NSW Planning)
HSEQ	Health, Safety, Environment and Quality
ICNIRP	International Commission on Non-Ionising Radiation Protection
IRENA	International Renewable Energy Agency
ISO	International Standards Organization
kV	Kilovolt
LFP	Lithium iron phosphate
LGA	Local Government Areas
Li-ion	Lithium-ion
LOPA	Layers of Protection Assessment
MEC	Major Electricity Companies
MHF	Major Hazard Facility
MW	Megawatt
MWh	Megawatt hour
Na-ion	Sodium ion
NEM	National Electricity Market
NFPA	National Fire Protection Association
NMC	Li-ion Nickel-Manganese-Cobalt
NSW	New South Wales
NZS	New Zealand Standard
OH&S	Occupational Health and Safety
OEM	Original Equipment Manufacturer
QFES	Queensland Fire and Emergency Services
QLD	Queensland
RAMS	Reliability, Availability and Maintainability Study
SAFOP	Safety and Operability Study
SCADA	Supervisory Control and Data Acquisition
SFAIRP	So Far As Is Reasonably Practicable
UGL	UGL Limited
UL	Underwriters Laboratories
V	Volt
VBB	Victoria Big Battery
VESDA	Very Early Smoke Detection Apparatus
VRET	Victorian Renewable Energy Targets
VRF	Vanadium Redox Flow
Wh/kg	Watt hours per kilogram
WHS	Work, Health and Safety

Appendix B

Interview questionnaire

The following questions / discussion items were used by the GHD team during interviews with relevant stakeholders. Refer to Section 4.2 to review the main findings from each interview.

General questions:

– Have there been any issues within your jurisdiction associated with currently operating BESS facilities?
– Have you been consulted as part of BESS facility installations / commissioning processes to date? If so, in what capacity? Have there been any discussion about decommissioning these sites in the future?

Regulator specific questions:

– What are the current acts and regulations that cover grid-scale BESS regulation?
– What have been the key challenges associated with BESS regulation?
  - Gaps and ambiguities in the current regulations
  - Gaps and potential opportunities in roles and responsibilities
  - Is there a plan for consistency of regulation across the States? What about globally?
– Are there any thoughts of adopting international regulations in Australia? If so, what are these and which elements are of interest?
– Are there any plans to add new regulatory requirements?
– How are you made aware of and what is the process of assessing new BESS facilities
– Do you envisage that different scale facilities would/should have different regulations applied? [GC]
– What are the regulatory requirements for dealing with a fire at a BESS facility?
– Are there any separation distances you require between a BESS facility and other sites/residences? If so, what are they? Is there a particular Standard or guideline? If not, how should BESS facility owners demonstrate suitable buffer distances?

OEM specific questions:

– What are the regulations that you are becoming most aware of internationally? If so, what are these?
– What are the current / future requirements around BESS fires and explosions?
– Without releasing commercial in-confidence information, how does your BESS handle thermal runaway incidents? What do you do to prevent thermal runaway? Do the thermal management systems have redundancy capacity?
– Is there undue reliance on particular standards which may be restrictive (e.g., UL9540A)?
– Are there any plans to change the configuration of battery packs? For example, will they be stackable (double, triple)? Centralised vs. decentralised utilities for the modules (fire systems, cooling)
– What do you perceive as best current practice in the HSE space for BESS [GC]?
– What do you perceive as emerging / future practice in the HSE space for BESS [GC]?
– What are the greatest risks you face? What are you doing about these?
– In the event of a BESS fire, are there any specific requirements or operations that a site operator or emergency responder must be aware of? Is the response to a fire the same for all different BESS types?
– What measures can be implemented to prevent fire spread throughout a BESS site?
– What climatic conditions may cause operational limitations?
  - How much testing of BESS modules has been carried out in climatic conditions similar to Australia?
– Is downwind thermal heat plume considered when providing BESS modules for a particular site?

General concluding questions:

– What would you like to be done differently?
  - Are there aspects of BESS facilities that concern you?
  - Are there concerns about future trends of these batteries and associated facilities?
  - Are the current locations, configurations, site footprints, general design, etc. of these facilities of concern?

– Will the public be consulted in preparation for BESS installations? Will this be fed into future guidelines? For example, land that is currently being used may become residential areas which could impact land valuation later on (i.e., urban pressures)?

Appendix C

Site selection requirements and considerations

C-1 Meteorology

C-1-1 Wind

Consideration of wind loading impacts should be undertaken prior to selecting a BESS site. AS/NZ 1170.2:2021 *Structural design actions Part 2: Wind Actions* [76] is a key source of guidance. The northern Australia coast is dominated by cyclonic wind conditions, stretching at least 50 km inland and up to 100 km along parts of the Western Australian coast between 20 ° and 25 ° latitude, as shown in the wind region map in Figure 12, extracted from AS 1170.2 (Fig 3.1(A)).

Along with resistance to wind loading, depending on the site, consideration of BESS module flying debris impact resistance should be undertaken. Thermal runway events can occur should battery cells become physically damaged. AS/NZ 1170.2:2021 (Section 2.5.8) provides guidance, however, individual OEM suppliers should be consulted.

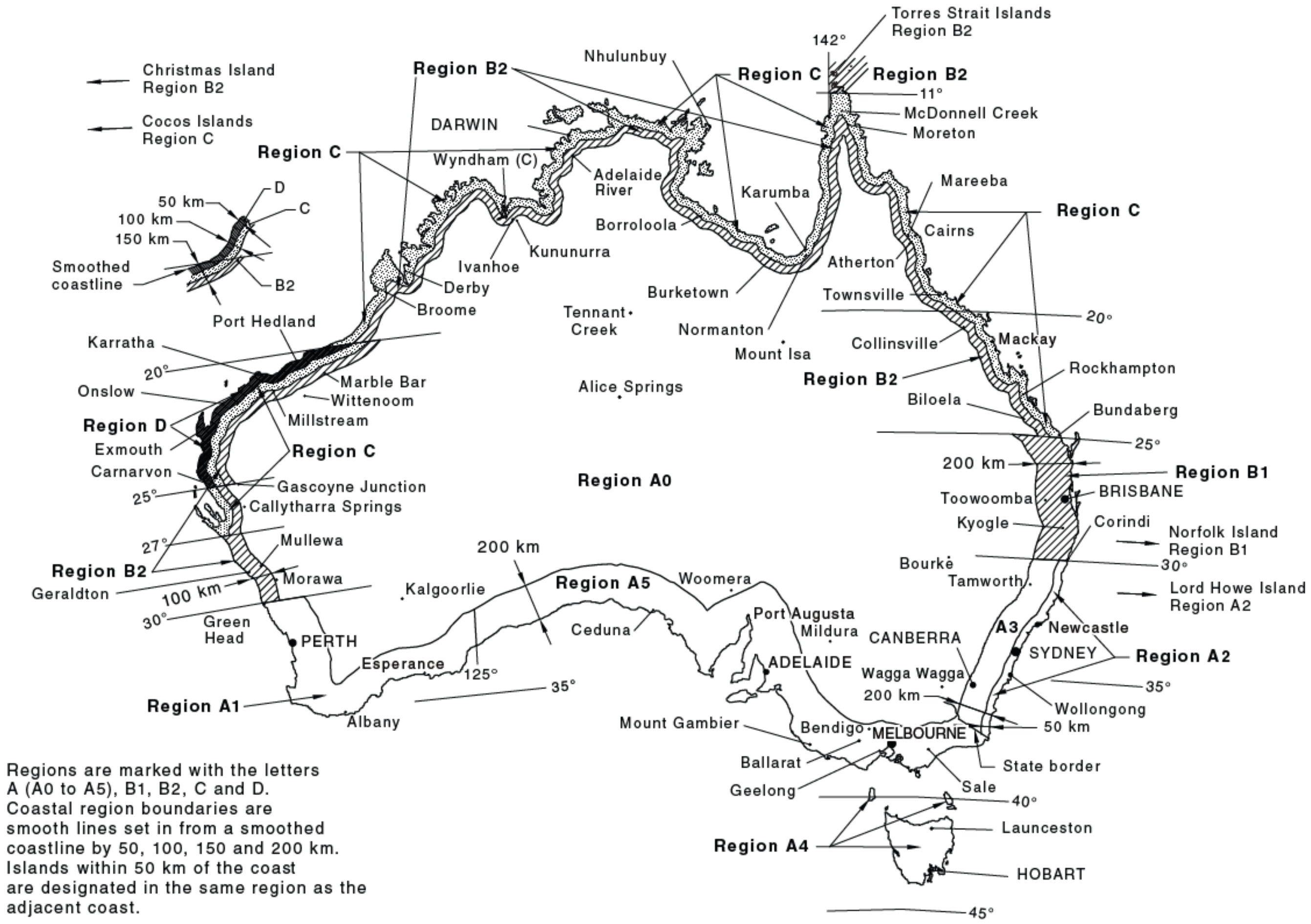

Figure 12 Australian wind regions as defined in AS 1170.2 (Figure 3.1 (A)). Source: AS 1170.2:2021.

"On a broad scale, Australia is dominated by westerlies in southern parts of the continent and easterlies (trade winds) in the northern parts. On regional and local scales wind speed and direction are affected by terrain, vegetation and meteorological factors such as the monsoon regime, tropical cyclones, sea/mountain breezes, frontal systems and convective activity."[4](BoM, 2023)

Some examples of wind rose for four locations throughout Australia are shown in Figure 13. Annual 3 pm has been selected as afternoons and evenings are more likely to be the times of greater BESS demand.

[4] **http://www.bom.gov.au/climate/maps/averages/wind-velocity/** Accessed 15/01/2022 @ 5:26 pm.

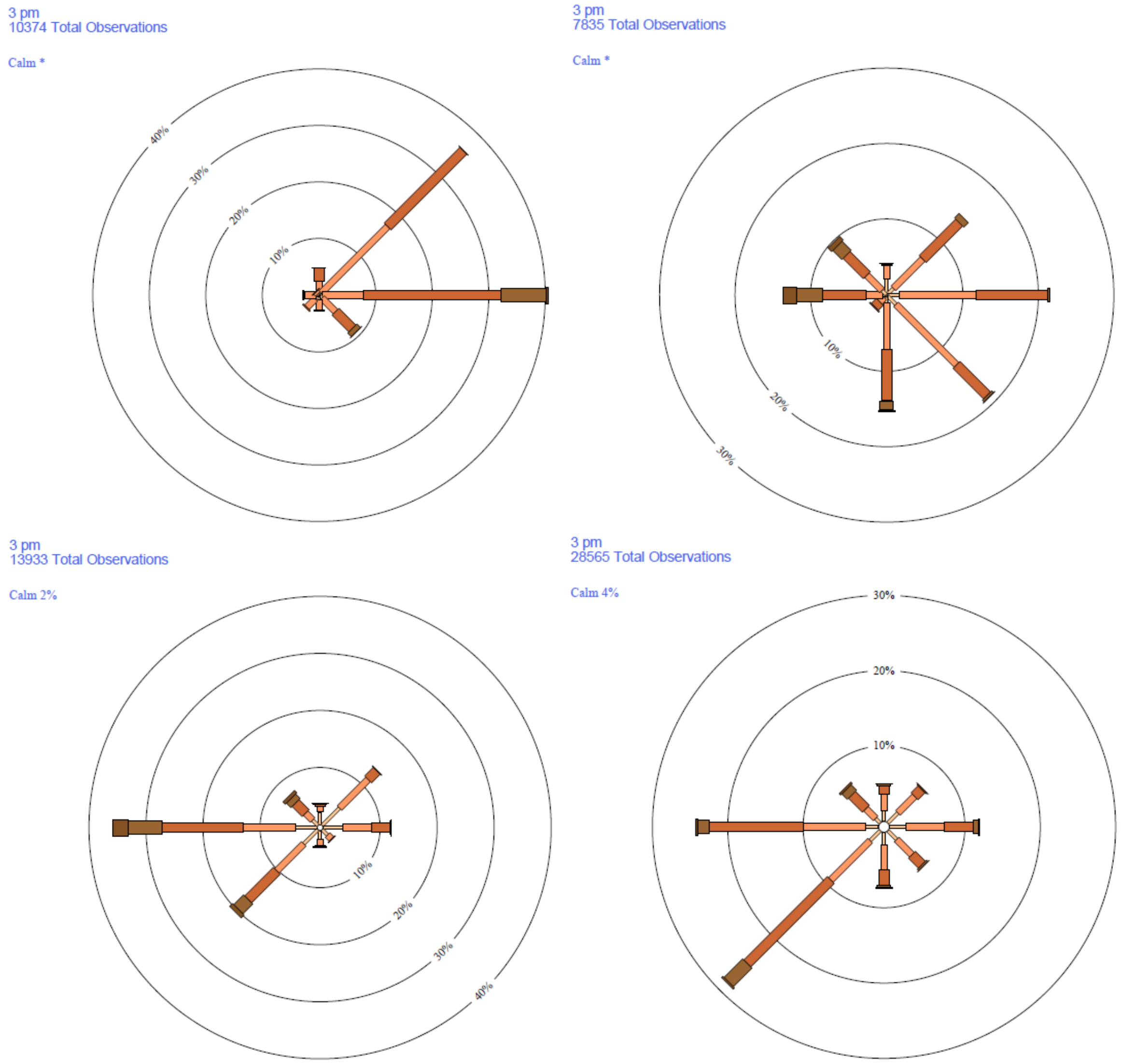

Figure 13 ***Comparison of 3 pm annual wind rose plots. Source: BoM (2023). From top left clockwise: Gladstone (Qld), Nowra (NSW), Perth (WA) and Latrobe Valley (Vic)***

C-1-2 Temperature

Commercially available BESS scale batteries will generally be manufactured with the greatest sales market in mind. Sales to the United States of America will be utmost in mind. However, in terms of climate, the United States is generally a cooler climate. A comparison of average annual mean temperatures of Australia and the United States is shown in Figure 14. About half of the Australian mainland has an average temperature greater than 21 °C. This compares to less than 10 percent of the United States.

When viewing the areas of highest solar radiation in Australia, shown in Figure 15, areas of highest solar radiation, best suited for solar arrays, also correspond to the areas of Australia with average temperatures greater than 21 °C.

Elevated temperature does not prevent a BESS module from operating as in-built cooling mechanisms will prevent overheating, with one such mechanism being a de-rating of available output/input power. Therefore, the total number of unaffected operational hours should be considered when selecting a site. Paradoxically, highest energy demand, and therefore greatest chance of a BESS supplying to the grid is more likely when air temperatures are greatest. Whole of BESS expected life can be affected by elevated temperatures, with battery life reduced when cell ambient temperature exceeds 35 °C [77] [78].

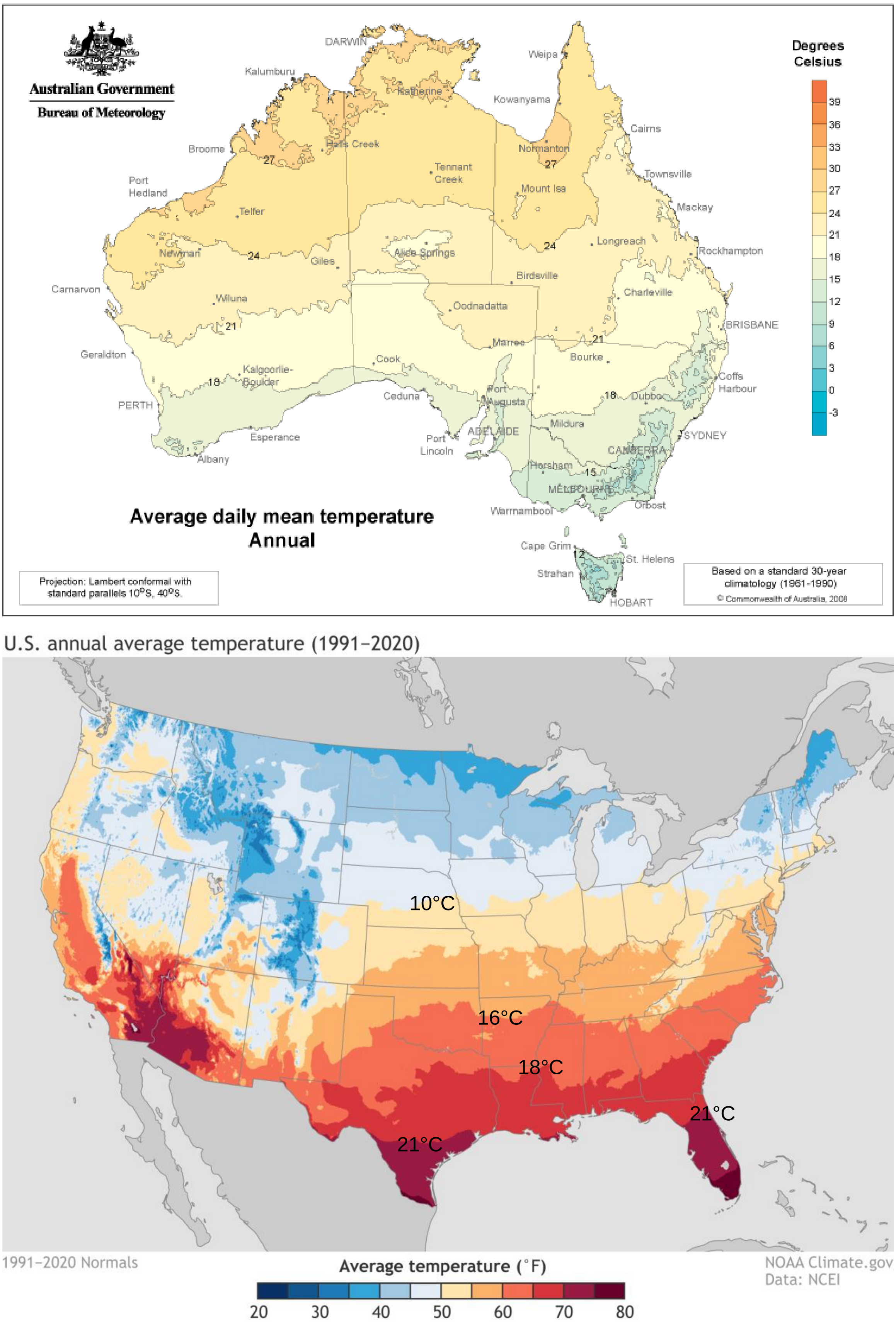

Figure 14 ***Annual average temperatures maps for Australia (top) and United Stated (bottom). NB. 50°F = 10°C, 60°F ≈ 16°C, 70°F ≈ 21°C.***

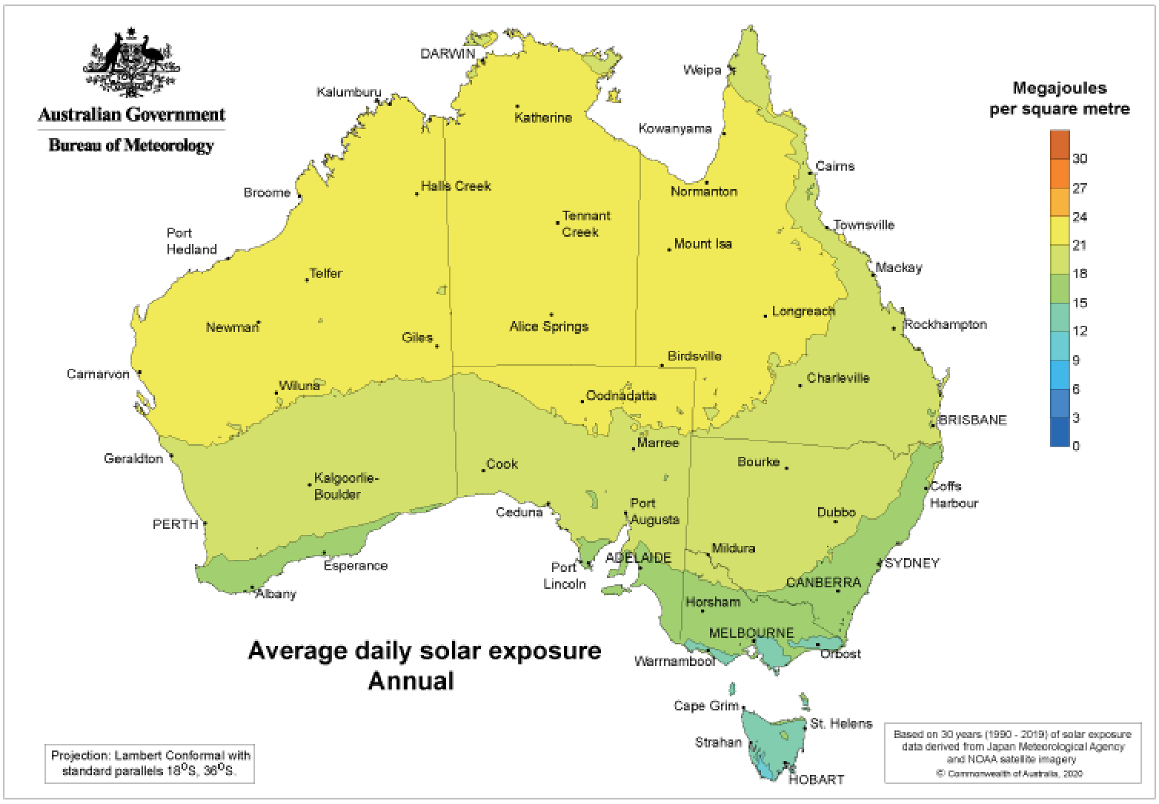

Figure 15 ***Annual average daily solar radiation map for Australia***

C-2 Separation distances

Separation distances between module and site are provided in at least two of the reviewed Standards/Guidelines.

C-2-1 NFPA 855

NFPA 855 (2023) [79] provides specifications relating to clearance to exposures and separation distances.

A minimum 0.9 m (3 ft) separation distance is required between groups or modules and other modules and walls, with each module having a maximum allowable energy storage capacity of 50 kWh. This spacing and/or maximum energy rating can be changed subject to acceptable fire and explosion testing results.

Combustible vegetation needs to be cleared and controlled within 3 m (10 ft) of any BESS.

Sensitive exposure areas such as, but not limited to, public ways, buildings, stored combustible materials, high piled stock require a separation distance of at least 3 m (10 ft) from the BESS. However, there are provisions that do allow this distance to be reduced, such as freestanding fire barriers, but the reduction does not allow a separation distance smaller than 0.9 m (3 ft).

NFPA 855 refers to the Authority Having Jurisdiction (AHJ) as the organisation, office or individual responsible for enforcing the requirements of a code or standard or for approving equipment, materials, an installation design or an operating procedure.

C-2-2 CFA renewable energy facility design guidelines

The CFA has published a set of design guidelines for various renewable energy facilities, including BESS facilities. [69] In some areas these guidelines are more conservative than NFPA 855, but in other areas less prescriptive.

For example, the CFA stipulates a minimum 10 m combustible vegetation separation distance (fire break) for BESS facilities. This is to prevent radiant heat from a (bush/grass) fire impacting on the BESS.

Unlike NFPA 855, CFA does not prescribe a distance between battery modules, but instead refers to a separation distance informed by radiant heat output that will prevent spread between modules.

In Victoria, the CFA is not required to be notified of a renewable energy facility planning application. However, applications may be sent to CFA for their comment. Therefore, as defined in NFPA 855, the CFA would not be an AHJ, and their guidelines may not be enforced.

Appendix D

High-level supporting risk register

Project:	**Project No.:**		*Vanadium redox flow battery related risks*
Title: AEC BESS Guidance Risk Register	**Client:**		*Lithium-ion battery related risks*
Revision: DRAFT	**Document Date:** 30/01/2023		*Risks related to both vanadium redox flow batteries and lithium-ion batteries*

Hazard I.D.	Project Area	Hazard Description	Cause	Consequence	Standard Control Measures	Risk Owner	Initial Risk Rating			Potential Control Measures And Actions	Responsibility	By When	Decision / Status	Residual Risk Rating			Comments / references
							Consequence	Likelihood	Risk Rating					Consequence	Likelihood	Risk Rating	
1	Environmental	Flammable gases	Production and accumulation of flammable gases in battery enclosure with ignition resulting in fire or explosion and thermal runaway	- Damage to BESS - Escalation of event (i.e. propagation to neighbouring BESS modules) - Injury to onsite personnel - Injury to surrounding populations (neighbouring industries, residents) - Bushfire, damage to environment - Heat radiation to the transformer. Transformer overheats and fails.	- Designed to Industry Acts and Standards (Occupational Health and Safety Act, AS/NZS ISO 14001:2016, AS/NZS ISO 45001:2018, UL1973, UL9540) including deflagration control (pressure sensitive vents and sparker system) - Compliance with applicable requirements from NFPA 855 and UL9540A - Vegetation management / clearance around BESS - Site specific emergency response and management plan - Multiple access and egress points on site to allow fire authority to access the fire water tank					- Include remotely accessible flammable gas monitoring to detect presence of flammable gases - Include appropriate signage and site manifest to identify hazardous chemical hazards associated with the contents of BESS - Consider and confirm unintended consequences of a noise wall if it is implemented, including accessibility to and from site, accumulation of hazardous gases and confinement of heat within the site ("heat island effect")							Arizona fire 2019 Victorian Big Battery fire 2021
2	Environmental	Toxic gases	Thermal runaway in BESS (including initiation) leading to production and dispersion of toxic gases	- Injury to onsite personnel - Injury to surrounding populations (nearby industrial area or residential) - Impacts to local flora and fauna	- Designed to Industry Acts and Standards (Occupational Health and Safety Act, AS/NZS ISO 14001:2016, AS/NZS ISO 45001:2018, UL1973, UL9540) - Compliance with applicable requirements from NFPA 855 and UL9540A - PPE for emergency response team and onsite personnel - Site specific emergency response and management plan - Selection of appropriate battery chemistry - Design of battery modules to slow and limit rate of gas generation					- Include remotely accessible flammable gas monitoring to detect presence of flammable gases - Include appropriate signage and site manifest to identify hazardous chemical hazards associated with the contents of BESS - Incorporate presence of toxic gases being generated from the BESS into site Emergency Response Procedures, including appropriate exclusion zones, PPE for Emergency Responders, and communications required to neighbouring industries and local residents - Confirm what toxic materials (type and volume) are produced from the BESS and ask the vendor to provide information on products of combustion - Determine the potential toxic hazard impact zone around the BESS using suitable air dispersion modelling with consideration of wind speeds and directions - Prepare information for community of the potential hazards to residents of toxic gas dispersion from the BESS, once dispersion modelling is complete - Consider and confirm unintended consequences of a noise wall if it is implemented, including accessibility to and from site, accumulation of hazardous gases and confinement of heat within the site ("heat island effect")							Toxic gases from recent PG&E (California) fire were HCN, CO, and trace amounts of HF Toxic gases can be generated due to the incomplete combustion of gases generated during the initial thermal runaway phase
3	Environmental	External fire	External thermal source (e.g. fire at neighbouring facility or bushfire) resulting in overheating of BESS	- Damage to BESS leading to disruption of power supply - Damage to power supply infrastructure causing disruption of power to community - Hardware failure - Heat radiation to the transformer. Transformer overheats and fails. - Potential for escalation to a thermal runaway event (and propagation between units)	- Vegetation Management / clearance around BESS (Asset Protection Zone with landscaping treatment, fencing and retaining constructed from fire resistant materials) - Access and egress suitable for prevention activities and firefighting - Housekeeping/maintenance to remove debris build up - Fire water requirements meet required guidance (e.g., CFA guidance material) - Other buildings within the BESS facility compound are designed for adequate fire protection - Site specific emergency response and management plan - Procedure/ controls for correct storage of any chemicals/ combustible materials brought onsite, to be away from units (if applicable) - All equipment clearances in accordance with AS2067 - Selection of appropriate battery chemistry - Design of battery modules to slow and limit rate of gas generation - Bushfire risk assessment					- Confirm fire water supply requirements to manage a BESS fire and determine the fire system scope of work (e.g., onsite tank, water main, etc.) - If a noise wall is required for the site, reconsider the size of the Asset Protection Zone to ensure it is sufficient - If a noise wall is required for the site, ensure noise wall material is fire resistant - If a noise wall is required for the site, determine the thermal radiation consequences for the site inside the noise wall - Include a procedure to shut down BESS during conditions where fire can spread externally into site (e.g. bushfire) as part of standard operating protocols - Position and design air conditioning vents on site buildings and BESS cabinets to prevent debris build up and fire propagation - Investigate designing louvres and shields on air intakes to batteries - Consider and confirm unintended consequences of a noise wall if it is implemented, including accessibility to and from site, accumulation of hazardous gases and confinement of heat within the site ("heat island effect") - Use of non-combustible materials for all adjacent hardware & equipment							
4	Environmental	External fire	Bushfire in the local bushland resulting in ember attack	- Ember attack ignites exposed cables - Damage to BESS leading to disruption to power supply - Damage to power supply infrastructure causing disruption of power to community - Potential for escalation to a thermal runaway event (and propagation between units)	-Non-combustible elements used for construction - Site specific emergency response and management plan - Procedure/ controls for correct storage of any chemicals/ combustible materials brought onsite, to be away from units (if applicable) - Fire water requirements meet required guidance (e.g., CFA guidance material) - Other buildings within the BESS facility compound are designed for adequate fire protection - Insulation around battery module to limit heat effects - Bushfire risk assessment					- Confirm fire water supply requirements to manage a BESS fire and determine the fire system scope of work (e.g., onsite tank, water main, etc.) - If a noise wall is required for the site, ensure noise wall material is fire resistant - Include a procedure to shut down BESS during conditions where fire can spread externally into site (e.g. bushfire) as part of standard operating protocols - Use of non-combustible materials for all adjacent hardware & equipment. - Complete Computational Fluid Dynamic modelling of the whole BESS facility							

BESS
Hazard Identification (HAZID) Register

Hazard I.D.	Project Area	Hazard Description	Cause	Consequence	Standard Control Measures	Risk Owner	Initial Risk Rating			Potential Control Measures And Actions	Responsibility	By When	Decision / Status	Residual Risk Rating			Comments / references
							Consequence	Likelihood	Risk Rating					Consequence	Likelihood	Risk Rating	
5	Environmental	External ambient conditions / environment	Extreme temperature (e.g. hot day) or humidity resulting in overheating of BESS **Note:** *A noise wall around the facility may increase the hazard through the potential for a "heat island"*	- Damage to BESS leading to disruption of power supply - Degradation of equipment - Hardware failure - Reduction in BESS operating life - Deteriorating insulation leading to injury to personnel - Unable to comply with derating and regulatory requirements - Potential for escalation to a thermal runaway event (and propagation between units)	- Design BESS units for worse case site ambient conditions with appropriate IP rating - BMS to shut down BESS if temperature exceeds high temperature threshold - Fire water requirements meet required guidance (e.g., CFA guidance material) - Other buildings within the BESS facility compound are designed for adequate fire protection - Site specific emergency response and management plan - Selection of suitable battery chemistry					- Complete Computational Fluid Dynamic modelling of the whole BESS facility - Confirm fire water supply requirements to manage a BESS fire and determine the fire system scope of work (e.g., onsite tank, water main, etc.) - Consider and confirm unintended consequences of a noise wall if it is implemented, including accessibility to and from site, accumulation of hazardous gases and confinement of heat within the site ("heat island effect") - Selection of low noise fans and ventilation system design							
6	Environmental	Severe storm event during operation (lightning)	Lightning strike to BESS unit	- Damage to BESS leading to loss of ancillary services (e.g., monitoring) - Potential for escalation to a thermal runaway event (and propagation between units)	- Vegetation Management / clearance around BESS - Dual redundancy - Lightning protection study, and appropriate lightning protections applied - Site specific emergency response and management plan												
7	Environmental	Severe storm event during operation (flooding)	Flash flooding inundating BESS facility, leading to: - ground instability - high water levels (potential to submerge BESS units)	- Limited access to site - Damage to BESS, with the potential to initiate a thermal runaway event depending on the extent of the flooding	- BMS to shut down BESS if temperature exceeds high temperature threshold - Site location considers flood regions and incorporates suitable facility design height - Site specific emergency response and management plan					- Conduct flood modelling of BESS site to determine potential impact zones and design drainage to mitigate the effects - Determine impact of flooding at substation including expansion on the BESS site (e.g. water runoff across site) and design drainage to mitigate the effects - Complete geotechnical studies to ensure stable ground conditions for light and heavy vehicles including in heavy rain / flooding events and seismic events							
8	Environmental	Storm water or local flooding during construction	Flooding inundating construction site, leading to: - ground instability - high water levels (potential to submerge BESS units)	- Limited access to site, delaying commissioning - Environmental impact - Local erosion, scouring, sediment flowing offsite - Onsite impact - ground conditions	- Civil design to comply with relevant standards - Design of temporary works to manage erosion control - Weather monitoring - Environmental inspections - Flood mapping of area - Site location considers flood regions - Construction management plan					- Conduct flood modelling of BESS site to determine potential impact zones and design drainage to mitigate the effects - Schedule construction in dry season to reduce the likelihood of environmental impacts from site drainage - Complete geotechnical studies to ensure stable ground conditions for light and heavy vehicles including in heavy rain / flooding events and seismic events							
9	Environmental	High winds during bushfire event	Windy conditions at BESS facility in combination with fire, resulting in ember propagation and attack	- Generation of microclimate around BESS facility - Potential for escalation to a thermal runaway event (and propagation between units) - Damage to surrounding BESS facility infrastructure	- Vegetation Management / clearance around BESS - BMS to shut down BESS if temperature exceeds high temperature threshold - Other buildings within the BESS facility compound are designed for adequate fire protection - Compliance with AS1170.2 - Site specific emergency response and management plan - BESS module design to withstand ember attack and external heat with insulation					- If a noise wall is to be implemented, ensure it is compliant with Australian Standards for wind loading - activation of site spray system if exists.							
10	Environmental	Seismic event	Earthquake causing ground instability	- Damage to BESS units - Damage to BESS facility infrastructure	- Set back distances from falling objects (trees or powerlines) - Designed to AS1170.4 - Site specific emergency response and management plan					- Complete geotechnical studies to ensure stable ground conditions for light and heavy vehicles including in heavy rain / flooding events and seismic events							Dependent on location
11	Environmental	Dust ingress to BESS	- Inadequate IP rating - Accumulation of dust within BESS module, resulting in overheating or electrical fault, potentially leading to thermal runaway	- Damage to BESS leading to loss modules - Potential for thermal runaway, explosion / fire, leading to: -> Injury to onsite personnel -> Injury to surrounding populations (neighbouring industries, residents) -> Bushfire	- Ventilation system - Maintenance strategy - IP rating of the ventilation system - BMS to shut down BESS if temperature exceeds high temperature threshold - Vegetation Management / clearance around BESS - Design includes two measures for explosion mitigation (sparker system and deflagration panels in roof) - Fire water requirements meet required guidance (e.g., CFA guidance material) - Other buildings within the BESS facility compound are designed for adequate fire protection					- Confirm current containment requirements for fire water used in fighting a BESS fire (e.g., implement holding tank and treatment for contaminated water) - Ensure all fire hazards are considered within a Fire Safety Study, including appropriate preventative and mitigative controls to ensure all hazard requirements are met - Thermal and airflow detectors							This scenario is dependent on the quality and number of independent layers of protection.
12	Environmental	Noise	Noise produced by BESS impacting nearby residents and community	Reputational impacts	- Complete noise modelling - Construction of a noise wall (if needed) - Suitable noise specification with supplier					- Undertake noise modelling to determine if a noise wall is required to reduce noise impacts to nearby residential areas - Consider and confirm unintended consequences of a noise wall if it is implemented, including accessibility to and from site, accumulation of hazardous gases and confinement of heat within the site ("heat island effect") - Utilise low noise fan and ventilation system design							Applicable to all BESS facilities

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13	Effluent	Contaminated fire water	Fire at BESS requiring use of fire water	Potential runoff of contaminated fire water into the environment resulting in environmental damage	- Civil design to comply with relevant standards - Fire water requirements meet required guidance (e.g., CFA guidance material)					- Determine the extent of contamination of water used to fight fires and any potential environmental impacts if released - Confirm current containment requirements for fire water used in fighting a BESS fire (e.g., implement holding tank and treatment for contaminated water)							Experience from VBB fire (2021) that a BESS module fire requires 6hrs fire water (TBC) and the fire water was not contaminated Consider CFA guidance for relevant criteria for fire water runoff in Victoria.
14	Equipment	Internal thermal source (i.e., within the battery module)	Thermal event within a battery module due to various reasons including, but not limited to, the following: - Internal coolant leak - SCADA system offline during commissioning - Short circuit - Leakage of water to below cells resulting in damage and thermal runaway - Internal cell defect (e.g. manufacturing error)	- Damage to BESS leading to module loss - Heat radiation to the transformer. Transformer overheats and fails - Potential for thermal runaway, explosion / fire, leading to: -> Injury to onsite personnel -> Injury to surrounding populations (neighbouring industries, residents) -> Bushfire	- OEM QA procedures, SAT and FAT data - Maintenance strategy - BMS to shut down BESS if temperature exceeds high temperature threshold - Design includes two measures for explosion mitigation (sparker system and deflagration panels in roof) - Fire water requirements meet required guidance (e.g., CFA guidance material) - Other buildings within the BESS facility compound are designed for adequate fire protection - Designed to Industry Standards (UL1973, UL9540, AS2067) - Compliance with applicable requirements from NFPA 855 and UL9540A - Complete mapping of the supervisory control and data acquisition (SCADA) system to the control system and provide full data functionality and oversight to operators					- Confirm fire water supply requirements to manage a BESS fire and determine the fire system scope of work (e.g., onsite tank, water main, etc.) - If a noise wall is required for the site, reconsider the size of the Asset Protection Zone to ensure it is sufficient - If a noise wall is required for the site, ensure noise wall material is fire resistant - If a noise wall is required for the site, determine the thermal radiation consequences for the site inside the noise wall - Include a procedure to shut down BESS during conditions where fire can spread externally into site (e.g. bushfire) as part of standard operating protocols - Position and design air conditioning vents on site buildings and BESS cabinets to prevent debris build up and fire propagation - Investigate designing louvres and shields on air intakes to batteries - Consider and confirm unintended consequences of a noise wall if it is implemented, including accessibility to and from site, accumulation of hazardous gases and confinement of heat within the site ("heat island effect") - Use of non-combustible materials for all adjacent hardware & equipment. - Thermal imaging camera(s) included in O&M toolkit, allowing for monitoring of system in event of suspect behaviour. - Ensure all fire hazards are considered within a Fire Safety Study, including appropriate preventative and mitigative controls to ensure all hazard requirements are met							
15	Equipment	Electrical equipment fault	Fault in AC and DC electrical equipment in BESS resulting in arc flash	Injury to onsite personnel	- Designed to relevant standards (arc flash rating, isolations) - Live equipment procedures					- Conduct an Arc Flash study as part of BESS cabinet design for arc flash containment - Implement suitable operational procedures for LOTO, switching, etc. This includes procedures for substation operation during construction / commissioning of BESS interface							
16	Equipment	Contact with underground utilities and step and touch voltages	BESS installation earthing and connection to existing earth mat	Injury to personnel from step and touch potential	- Designed to applicable electrical Standards to minimise touch and step potential - Lift plan for lifting of BESS equipment over live BESS modules during construction, operation, replacement and decommissioning					- Develop and follow suitable lift plan for lifting of BESS equipment over live BESS modules during construction, operation, replacement and decommissioning - Implement suitable operational procedures for LOTO, switching, etc. This includes procedures for substation operation during construction / commissioning of BESS interface							
17	Equipment	Earth fault on the DC systems	- Insulation failure - Water ingress battery failure - Equipment fault	Damage to BESS leading to disruption of power supply	- Earthing Standards covered in battery storage (AS5139, AS3000) - Vegetation management / clearance around BESS					-Implement suitable operational procedures for LOTO, switching, etc. This includes procedures for substation operation during construction / commissioning of BESS interface							
18	Equipment	Fire in diesel generator unit (if applicable)	Diesel leak resulting in ignition and fire in the diesel generator unit	Heat radiation impact to adjacent structures	- Integrally bunded tank within the diesel generator unit - Low quantity of diesel stored (Less than 1000 L). - Storage faculty is classified as minor under AS 1940 and no segregation is required. - Adjacent building are non-combustible material					- Recommend compliance with the minor storage provisions of Section 2.3 of AS1940 for diesel storage and refuelling - For less than 1,000 L separation from buildings is unrestricted but 1.5 m from structures is recommended for access purposes							
19	Equipment	Communication panel	Electrical fault in communications panels	Fire in panel and potential loss of communication equipment fire growth into the room and adjacent equipment.	- Use of fire detection - Staff available near site for quick response if remote communication becomes unavailable - Switch gear is fail safe and can be operated manually - Room is constructed from non-combustible materials (low fuel load) - Low energy equipment in the communications panel.												
20	Equipment	Fire Protection & VESDA Panels - Control Room	Electrical fault in panels	Fire in panels, loss of fire protection system equipment, impaired fire suppression capabilities	- Use of early smoke detection and gas suppression to mitigate fire risk before damage can occur to the system - Equipment should be rated to withstand and detect fire in its vicinity - Fire system circuit is design as fail safe - Extra low voltage panel wiring												

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21	Equipment	External impact	- External impact (e.g., vehicle) to high voltage equipment, BESS units, or surrounding infrastructure, due to fatigue, speeding, loss of vehicle control, inadequate road condition	- Equipment damage - Damage to BESS leading to module loss. Depending on the extent of impact, there is potential for thermal runaway, - Potential for injury to onsite personnel	- Safety rails and bollards - Fencing around site - Not many vehicles required/expected during operation and maintenance - Minimum compliance with AS2067, AS3000 and other requirements - Site speed limit - Steel frame of module					- Implement dedicated walkways and crossing points to reduce risk of vehicle interactions with pedestrians - Implement site speed limit to reduce risk of vehicle interactions with pedestrians and collisions with BESS and associated equipment							
22	Equipment	Failure during maintenance	Error in maintenance of BESS	- Cell failure, loss of performance - Potential for thermal runaway, explosion / fire, leading to: -> Injury to onsite personnel (if present) -> Injury to surrounding populations (neighbouring industries, residents) -> Bushfire	- Trained, competent, and qualified staff - OEM maintenance procedures - Fire water requirements meet required guidance (e.g., CFA guidance material) - Other buildings within the BESS facility compound are designed for adequate fire protection - Designed to Industry Standards (UL1973, UL9540, AS2067) - Compliance with applicable requirements from NFPA 855 - Site specific emergency response and management plan					- Confirm fire water supply requirements to manage a BESS fire and determine the fire system scope of work (e.g., onsite tank, water main, etc.)							
23	Equipment	Dropped objects during construction	Dropped loads during installation due to poor load placement or lifting failure (live batteries dropped during construction or replacement)	- Equipment damage - Injury to onsite personnel	- Lift and construction sequencing plan which details lifting of BESS equipment over live BESS modules during construction, operation, replacement and decommissioning - Constructability and maintainability assessment and plan for the BESS site, to ensure adequate provision for future work activities on the site - Compliance with applicable requirements from NFPA 855												Although this risk specifically refers to live batteries being dropped on site, this is risk is applicable to all grid-scale BESS facilities which require lifting equipment at heights
24	Equipment	Dropped objects during operation and maintenance	Dropped loads during operation and maintenance due to poor load placement or lifting failure	- Equipment damage - Injury to onsite personnel	- Lift plan which details lifting of BESS equipment over live BESS modules during construction, operation, replacement and decommissioning - Constructability and maintainability assessment and plan for the BESS site, to ensure adequate provision for future work activities on the site - Compliance with applicable requirements from NFPA 855												Although this risk specifically refers to live batteries being dropped on site, this is risk is applicable to all grid-scale BESS facilities which require lifting equipment at heights
25	Emergency	Accessibility	- Inadequate spacing between BESS module rows (e.g. only - Restricted BESS facility access / egress routes for emergency evacuation and responders	- Injury to onsite personnel - Emergency responders unable to reach BESS as spacing between battery banks is insufficient for vehicle movement	- Specification includes access requirements for maintainability and emergency response purposes - design of two separate paths of egress - Layout review (in a later project stage) once the preferred supplier has been awarded - Minimum compliance with AS2067, AS3000 and other requirements - Compliance with applicable requirements from NFPA 855 - Engage with local fire authorities and other emergency services during layout design and site commissioning process					- Conduct a hazardous area assessment to determine the locations of release points in relation to potential ignition sources - Consider and confirm unintended consequences of a noise wall if it is implemented, including accessibility to and from site, accumulation of hazardous gases and confinement of heat within the site ("heat island effect")							
26	Occupational, Health and Safety	Accessibility	- Inappropriate layout of BESS area - Inadequate spacing between BESS module rows	- Injury to personnel (e.g. ergonomics) - Two way foot traffic not possible when completing checks and maintenance with one battery module cabinet door open due to current spacing requirements	- Layout review (in a later project stage) once the preferred supplier has been awarded - Minimum compliance with AS2067, AS3000 and other requirements - Compliance with applicable requirements from NFPA 855 - Inclusion of OH&S team during layout review discussions '- Low physical maintenance design of facility												
27	Occupational, Health and Safety	External ambient conditions / environment	BESS facility microclimate due to BESS operation in conjunction with hot ambient conditions (>40DegC)	- Injury to personnel (heat exhaustion and/or heat stroke)	- Site specific OH&S plans												
28	Occupational, Health and Safety	Contact with HV equipment	Personnel contact with damaged battery module	Electrocution leading to injury or fatality	- Review of OEM BESS safeguards to prevent high voltage exposure in various abuse conditions (e.g. battery modules sealed within enclosures in sub-groups) - Isolation and earthing on switchgear, boards and inverters - Provide interlocks on HV electrical equipment to minimise contact with HV electrical hazards - Develop an Energy and Isolation Standard for the site to minimise contact with HV electrical hazards												

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29	Environmental / Hazardous material	Contact with coolant	BESS damage resulting in leaked battery coolant (e.g., due to mechanical damage) which does not escalate to thermal event	Leaked battery coolant leading to - Skin irritation - Environmental release and impact	- PPE when working in vicinity of battery units (gloves, protective clothing) - Containment of leaks and spills - Compliance with EPA guidelines - Site specific emergency response and management plan					- Ensure BESS units are stored per storage precautions recommended by OEM - Ensure the emergency response procedure includes a plan to evacuate the area in the case of a gaseous or liquid loss of containment - Include in the emergency response plan the requirement to minimise the exposure to hazardous gases by the use of respiratory protection - Determine the maximum volume of coolant that can be released in any credible loss of containment scenario and design suitable containment							
30	Environmental / Hazardous material	Hazardous material - refrigerant	BESS damage resulting in leaked refrigerant (e.g., due to mechanical damage)	Skin irritation or frostbite (if exposed to liquid refrigerant)	- Battery modules stored outside (adequate ventilation) - PPE when working in vicinity of battery modules - Site specific emergency response and management plan - Determine volume of refrigerant per battery module					- Include in the emergency response plan the requirement to use self-contained breathing apparatus (SCBA) in the case of a refrigerant leak							
31	Environmental / Hazardous material	Hazardous material - decomposition products	BESS damage during fire resulting in release of toxic/corrosive decomposition products (i.e. refrigerant decomposition chemicals)	Exposure to toxic/corrosive decomposition products impacting - Onsite personnel - Nearby residents	- Battery modules stored outside (adequate ventilation) - PPE when working in vicinity of battery modules - Site specific emergency response and management plan - Limited volume of refrigerant per battery module					- Include in the emergency response plan the requirement to use self-contained breathing apparatus (SCBA) in the case of a refrigerant leak - Determine volume of potential decomposition products							Item 2 talks about toxic combustion products. This issue is talking about decomposition of refrigerant (not combustion) that results from overheating of BESS. Decomposition products include HF, halogens, halogen acids, and possibly carbonyl halides
32	Environmental / Hazardous material	Hazardous material - electrolyte	BESS damage resulting in release of flammable electrolyte (hydrocarbon + $LiPF_6$)	Leaked electrolyte leading to: - ignition of vapours - irritation to eyes and skin	- Possibility of release of electrolyte is very remote (not much is in free liquid form but rather contained in electrodes) - Cells are in sealed steel compartments able to contain liquid from a number of cells (to be confirmed)					- Ensure the emergency response procedure considers leaked (or suspected leaked) electrolyte - use of PPE, ventilation of area, cleaning spills using dry absorbent material							PPE includes: air purifying respirator, safety goggles, gloves, protective clothing
33	Security	Unauthorised access from members of the public	Intentional access to site with no malicious intent (e.g. protestors)	Injury to members of the public	- Security fencing - CCTV and monitoring - Site security plan for the BESS site (e.g. mobile patrol, monitoring etc.)					- Confirm site security can be monitored using humans (control room) or technology (CCTV / AI) CPTED assessment and design of BESS facility							Applicable to all grid-scale BESS facilities
34	Security	Unauthorised access from members of the public	Intentional access and damage to BESS (e.g. sabotage, theft)	Damage to BESS and injury to onsite personnel	- Security fencing - CCTV and monitoring - Secure battery unit cabinets design - Locked control room - Site security plan for the BESS site (e.g. mobile patrol, monitoring etc.)					- Confirm site security can be monitored using humans (control room) or technology (CCTV / AI)							Applicable to all grid-scale BESS facilities
35	Security	Cyber attack	Intentional cyber attack of BESS facility, resulting in multiple, targeted thermal runaway events, or events that cause grid stability issues	- Damage to BESS leading to module loss - Heat radiation to the transformer. Transformer overheats and fails - Potential for thermal runaway, explosion / fire, leading to: -> Injury to onsite personnel (if present) -> Injury to surrounding populations (neighbouring industries, residents) -> Bushfire	- Conformance to the Security of Critical Infrastructure Act - User authentication (e.g., two factor) and site security protocol / verification - Regular cyber auditing (including routine system penetration testing) - Configuration of appropriate systems architecture (e.g., distributed, segmented, centralised) - Encrypted, secure communications - Software updates and regular backups					- Assess degree of impact from loss of operation as per Section 10 of Security of Critical Infrastructure Act (*https://www.cisc.gov.au/critical-infrastructure-centre-subsite/Files/register-critical-infrastructure-assets.pdf*) - Complete cyber security training for staff - Network and software penetration testing							Applicable to all grid-scale BESS facilities
36	Project	Lack of stakeholder engagement / consultation	Non-acceptance from community and stakeholders due to: - Disruption of local habitat - Environmental damage - Noise - Safety concerns	- Project delays resulting in financial impacts, disruption to operations - Protests - Reputational impacts	- Community consultation - Stakeholder management plan including communication/education to community about overall benefit of facility and proactively clear misconceptions on safety/environmental impacts - Early engagement with relevant regulatory authorities (e.g. fire authorities, land planning authorities, electrical etc.)												Applicable to all grid-scale BESS facilities

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37	Design	Stacked battery units	- Limited land space available for BESS facility construction due to land value increases, movement to peri-urban locations - Creative approach to get more storage capacity within the same footprint	- Inadequate ventilation of the battery units due to stacked configuration - Increase in heat island effect, increasing local microclimate conditions - Damage to unit on ground level - Unable to access stacked units for maintenance without working at heights permit. This may present ergonomic issues - Potential for thermal runaway, explosion / fire, leading to: -> Injury to onsite personnel (if present) -> Injury to surrounding populations (neighbouring industries, residents) -> Bushfire						- Advanced thermal and fire modelling - Advanced ventilation approaches - Advanced battery chemistry and design suitable for such arrangements - Advanced insulation and fire protection systems -> Fire detection (including, VESDA, IR and thermocouples) -> Fire suppression (investigating feasibility and benefit of centralised suppression) - Rack and module isolation systems							
38	Design	Transport	- Damage during loading or unloading of battery unit into or out of shipping container (assuming brought in from overseas)	- Discharge of energy - Release of coolant, refrigerant, other hazardous materials, leading to short circuit - Damage to the battery cell or wiring structure leading to short circuit - Damage to the exterior of the battery module	- OEM inspection and testing program prior to shipping to site - OEM transportation guidance - Inspection and testing program in place which details the inspection measure required upon unloading the battery modules at site - Transportation insurance					- Advanced battery design, and module protection							
39	Effluent	Vanadium electrolyte	Loss of containment of electrolyte from Vanadium Redox Flow grid-scale BESS facility as a result of: - leaks from associated infrastructure (e.g., piping) - failure of the electrolyte tanks - during maintenance activities	- Discharge of potentially toxic and corrosive electrolyte into the environment - Exposure to toxic/corrosive electrolyte impacting - Onsite personnel - Nearby residents	- Site containment measures, such as bunding to AS1940 or equivalent, implemented to prevent spread - PPE when working in vicinity of cells - Site specific emergency response and management plan - Qualified personnel conducting maintenance - Monitoring of tank levels, pressure and other criteria to either directly or indirectly indicate loss of electrolyte												Applicable to VRF BESS facilities. Long duration flow batteries will require storage of large volumes of chemicals that will likely trigger screening thresholds for hazards analysis and require consideration for handling and storage of corrosive materials
40	Environmental	Internal fire External fire	Production and accumulation of toxic and/or flammable gases	- Environmental impact - Exposure to onsite personnel and potentially offsite population	- Dangerous goods legislation - MSDS - Toxicity and handling requirements - Thermal monitoring												Applicable to VRF BESS facilities. Dependent on electrolyte composition and associated physical/chemical properties