Tillbridge Solar

Tillbridge Solar

PEI Report Volume II Appendix 3-3: Outline Battery Fire Safety Management Plan

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1. Introduction

1.1 Background

Tillbridge Solar Ltd (hereafter referred to as 'the Applicant') has commissioned AECOM to prepare this Outline Battery Fire Safety Management Plan for a proposed Battery Energy Storage System (BESS) that will be constructed as part of the Tillbridge Solar scheme (hereafter referred to as the 'Scheme'). The Scheme comprises the installation of solar photovoltaic (PV) generating panels and on-site energy storage facilities within Lincolnshire and associated infrastructure for connection to the national grid at Cottam sub-station in Nottinghamshire. The Scheme would allow for the generation, storage, export and import of electricity.

The Applicant will have regard to feedback received during the statutory consultation and update the OBFSMP as appropriate. An updated plan will be produced for the Scheme and submitted with the application. It is proposed that the OBFSMP will be secured through a Requirement in Schedule 2 of the Development Consent Order (DCO). This will stipulate that a Battery Fire Safety Management Plan will be submitted to and approved (in consultation with the Fire and Rescue Service (FRS) and HSE) by the relevant planning authorities prior to the commencement of the works for the BESS. This plan will be substantially in accordance with the OBFSMP.

1.2 Technical Terms and Definitions

The following technical terms and definitions have been used in the document and/or reference documents and will form the basis of understanding (refer to Table 1-1).

Refer to upfront chapters of the Preliminary Environmental Information Report (PEI Report) for definitions of general terms.

Table 1-1: Technical Terms and Definitions

Term	Definition
Battery Energy Storage System (BESS)	Batteries with associated infrastructure to store, import and export electricity to the national grid.
BESS Enclosure	Cost-effective and modular, normally containerized solution, containing the BESS. Containers can be stacked and combined to increase the overall storage capacity, and are easily transported
Cell	Refers to the Li-ion unit that provides a source of electrical energy by direct conversion of chemical energy.
Developer	Individual, association, corporation, or other legal entity that owns, operates, or proposes to construct, own, or operate, a project. I.e., Tillbridge Solar Ltd
EMC	Electromagnetic Compatibility
EMS/BMS	Energy Management System/Battery Management System
Energy Storage System (ESS)	Device or group of devices assembled that is to convert the electrical energy from power systems and store energy in order to supply electrical energy at a later time when needed
Fire Suppression System	Active fire prevention system placed inside the battery enclosure

Term	Definition
FM Global	Factory Mutual (FM) Global is an American mutual insurance company specialising in loss prevention for large corporations in the Highly Protected Risk property insurance market sector.
FPA	The Fire Protection Association (FPA) is the UK's national fire safety organisation who work to identify the dangers of fire and help their clients reduce fire-related risks.
FRS	Fire and Rescue Service
Heating and Cooling System	System which regulates temperature and humidity within the BESS enclosure.
Installer	Individual or company in charge of BESS installation
Inverter	Inverters are required to convert the DC electricity collected by the PV modules into alternating current (AC), which allows the electricity generated to be exported to the National Grid.
LEL/LFL	Lower Explosive Limit / Lower Flammable Limit
Manufacturer	Company commissioned to manufacture the Scheme's BESSs.
Tier 1 manufacturer	Tier 1 manufacturers are direct suppliers of the final product. In this report they are the suppliers of the BESS, delivering the BESS enclosures as ready to go module
Maximum parameters	These defines the worst-case extent of design elements of the Scheme, or factors arising from them, for example maximum fire load depending on the selected battery technology.
Module	Compact module that integrates several Li-ion cells.
Mitigation	Measures including any process, activity, or design to avoid, prevent, reduce, or, if possible, offset any identified significant adverse effects on the environment.
NFCC	UK National Fire Chiefs Council
NFPA	The National Fire Protection Association (NFPA) is an international non-profit organisation devoted to eliminating death, injury, property and economic loss due to fire, electrical and related hazards.
Off-Gassing	The event in which the battery cell case vents due to a rise in internal pressure.
Operator	Individual/s in charge of day to day operations within the BESS
Rack	Composed of several modules in series, including their management system.
The Scheme	Tillbridge Solar.
SNC	Sodium Nickel Chloride cells
On-site substations	Compound containing electrical equipment to enable connection to the national grid.
National Grid Cottam Substation	The substation at Cottam Power Station located south of Cottam village, Nottinghamshire owned and operated by National Grid and where the Grid Connection Cable will connect to.
Temporary construction compound	Any working area defined for the purpose of storage of plant, materials, or equipment or for the use of welfare and site management.
Transformers	Transformers control the voltage of the electricity generated across the Principal Site before it reaches the On-site substations.

2. Scheme Description

2.1 Introduction

This report presents an Outline Battery Fire Safety Management Plan for the BESS[1] proposed for the Scheme.

As stated in **PEI Report Volume I Chapter 1 Introduction**, the Scheme comprises two distinct sections. These sections are:

- 'The Principal Site', which is the location where ground mounted solar photovoltaic (PV) panels, electrical sub-stations and energy storage facilities will be installed; and
- 'The Cable Route Corridor', which will comprise the underground electrical infrastructure required to connect the Principal Site to national transmission system at Cottam Power Station.

The Principal Site is located to the south of Harpswell Lane (A631), to the west of Middle Street (B1398) and largely to the north of Kexby Road and to the east of Springthorpe. The Principal Site covers an area of approximately 1,400ha and is located entirely within the administrative area of West Lindsey District Council. The Principal Site will be connected to Cottam National Grid sub-station located at the decommissioned Cottam Power Station in Cottam on the Nottinghamshire border.

2.2 General Arrangement

The Scheme will consist of the following components:

- Solar PV panels (also known as solar modules);
- Solar stations (invertor, transformer and switchgear);
- Battery Energy Storage System (BESS);
- Battery Direct Current (DC)/DC convertors;
- On-site cabling;
- On-site sub-stations;
- Solar farm control centre;
- Equipment storage;
- Fencing, security and lighting;
- Site access and access tracks;
- Surface water drainage; and
- Electricity connection to National Grid via Cable Route Corridor. The Tillbridge circuit will be connected to an existing free bay at Cottam sub-station.

Refer to **PEI Report Volume I Chapter 3 Scheme Description** for a detailed description of the components of the Scheme.

[1]At this stage, BESS Technology is assumed based on a lithium-ion chemistry technology or Sodium Nickel Chloride.

During the construction phase, one or more temporary construction compound(s) will be required as well as temporary roadways to facilitate access to all land within the Scheme Boundary.

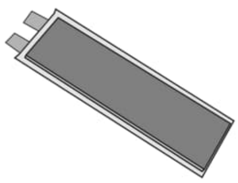
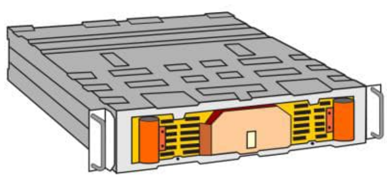
The Scheme will include BESS as an associated development and is primarily required for the operation of the solar PV panels. The BESS is designed to provide peak generation and grid balancing services to the electricity grid by allowing excess electricity generated either from the solar PV panels, or imported from the electricity grid, to be stored in batteries and dispatched when required. There are a number of different designs for the BESS that will be explored as part of the iterative design process. Batteries will likely be in individual enclosures. The precise number of individual battery storage containers will depend upon the level of power capacity and duration of energy storage that the Scheme will require; investigations are ongoing to determine this.

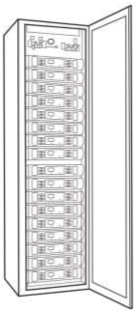
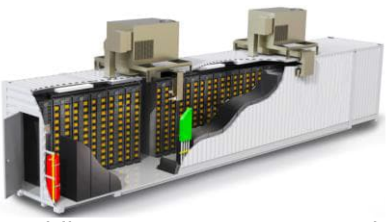
The exact locations of the BESS, transformers, and dedicated switchgear are yet to be determined, but it is anticipated that the BESS is DC-coupled. This means they will be spread across the Principal Site and located alongside the Solar Stations. This concept considers minimal system and cable losses between the components.

The footprint for each battery energy storage container would be around 12.2m in length x 2.5m in width x 4m in height. An illustrative battery container is shown below.

It is known that the BESS's will consist of a compound and battery array. Table 2-1: BESS Design Parameters outlines the limits of the design parameters for the BESS, which will allow flexibility and optimisation of the Scheme moving forward.

Table 2-1: BESS Design Parameters

Scheme Component	Applicable Design Parameters
Cell  *Typical Pouch Cell (Ref. 2).*	The batteries selected for use on the Scheme will be from tier 1 manufacturers and will utilise lithium-ion chemistry and/or Sodium Nickel Chloride. Cell design will be certified to UL 1973 and tested to UL 9540A unit or installation level for BESS designs.
Module  *Typical Enclosed Module (Ref. 2).*	Battery modules are comprised of multiple cells, the module design will contain fully tested passive protection / phase change materials and integrate a liquid cooling system when lithium-ion cells are used. For Sodium Nickel Chloride technology, the liquid cooling system is not necessary. In all cases, the module design will be certified to UL 1973 and tested to UL 9540A unit or installation level for BESS designs.

Scheme Component	Applicable Design Parameters
Rack  *Typical Rack (Ref. 2).*	 *6 MW Leighton Buzzard (Ref. 4).* There are a wide range of BESS battery rack designs. Rack design will have been tested to UL 9540A unit or installation level. Passive protection, ventilation and integrated suppression system designs for lithium-ion battery systems will have been validated during large scale testing (UL and / or 3rd party fire & explosion testing stipulated in NFPA 855 (2023)
BESS Enclosure  *Mobile Energy Storage Container (Ref. 4).*  *Sodium Nickel Technology for Energy Storage Application (Ref. 26)*	The BESS enclosure will have multiple racks with direct access either from the ends or side of the enclosure depending on the manufacturer. Typically, construction will be in the form of modified 20-foot / 40-foot ISO shipping containers OR modular premanufactured containers classified as cabinet systems (NFPA 855) / enclosures. The BESS enclosure design will be tested to UL 9540A unit or installation level and will either integrate a gas exhaust / ventilation system performance tested through full scale fire & explosion testing or comply with NFPA 69 explosion prevention standards. Complimentary deflagration vent designs should meet NFPA 68 standards. Per current manufacturer recommendations, BESS enclosures using Sodium Nickel Chloride (SNC) technology would be 20' high cube containerized solution with 64 battery ST523 for medium voltage applications.
Operational Office / Warehouse Building	A Solar Farm Control Centre will be included within the Scheme. It will consist of: • Central Control Room where all operational data of the whole plant will be controlled and monitored; • Central CCTV and security control of the whole plant including access gates to fenced areas; • Welfare facility for staff and subcontractors; • Parking area for staff and visitors; and • Own power supply including emergency power supply The Scheme will require spare parts for operation over time. Storage will be provided for spare solar PV panels, trackers, inverters, 400V/33kV

Scheme Component	Applicable Design Parameters
	transformer, switchyard, BESS, CCTV and metrological stations spare parts, as well as extra spare cable reels. Storage of BESS and their components involve risks that have been studied in this report proposing possible mitigation measures.
Energy Storage System equipment	Equipment located within or in close proximity to the BESS enclosure. Typical equipment examples are transformers, switchgear, power conversion system (PCS) or inverter, and other ancillary equipment.
Substations (adjacent to BESS)	The substations will consist of electrical infrastructure such as the transformers, switchgear and metering equipment required to facilitate the export of electricity from the Principal Site to the National Grid. The substations will operate at 400kV/33kV and there will be two substations on-site. Each substation compound would have a footprint of around 120m in length x 106m in width x 10m in height.
Fire Water Storage Tanks	Fire water storage tanks dedicated for firefighting operations only, water provision will be designated for the cooling of adjacent BESS or ESS equipment. Tanks can be integrated above or below ground. Volume of the tanks will be agreed with the FRS and be validated by an Independent Fire Protection Engineer based upon BESS internal suppression system performance capability from significant scale fire & explosion testing. UK NFCC guidelines stipulate tanks should be located a minimum of 10 metres away from BESS or ESS equipment and should be capable of delivering no less than 1,900 litres per minute for at least 2 hours. The firefighting water requirement will be fully assessed at the detailed design stage based upon BESS fire & explosion test data by an independent Fire Protection Engineer and water storage volumes will be agreed with Lincolnshire FRS. They must be easily accessible to FRS vehicles and their siting should be considered as part of a risk assessed approach that considers potential fire development/impacts. Outlets and connections should be agreed with Lincolnshire FRS. Any outlets and hard suction points should be protected from mechanical damage (e.g. through use of bollards).

3. Purpose and Scope

The scope of this Outline Battery Fire Safety Management Plan covers the life safety and property protection fire safety requirements of the BESS at the Scheme.

The purpose of the Outline Battery Fire Safety Management Plan is to demonstrate that the location of BESS within the Scheme does not give rise to a significant increase in fire risk and that any risk that does exist can be addressed by ensuring that the Scheme is constructed, operated and decommissioned in accordance with an appropriate Outline Battery Fire Safety Management Plan.

Principal Site emergency response requirements are currently being discussed with the local authorities and Lincolnshire FRS. This information will be considered to complete the Battery Fire Safety Management. Once information is available it will be updated and secured via DCO requirement.

4. Building Regs, Safety Standards and Guidelines

4.1 General

The following standards and regulations are updated as of the date of preparation of this report.

This Outline Battery Fire Safety Management Plan will be kept up-to-date if relevant legislation / guidance is introduced that triggers a change to the Battery Fire Safety Management Plan, or if there is a change to the Scheme (development or process) itself.

4.2 Building Regulations – BESS Fire & Explosion protection

NFPA 855 (2023) currently provides the most comprehensive guidelines for BESS design and site installation specifications. BESS design structural integrity must be demonstrated through full scale fire & explosion testing or by integrating NFPA 69 (Explosion prevention) and NFPA 68 (Explosion protection through deflagration venting) features.

4.3 Safety Standards

The minimum safety standards proposed by this Outline Battery Fire Safety Management Plan for this Scheme have been divided into group categories shown in Table 4-1. This list is non-exhaustive and based on experience from other projects of a similar nature for life safety purposes.

Table 4-1: Applicable Safety Standards

Group Category	Standard	Year	Description
Electrical Installation	BS 7671	2018	Requirements for electrical installations.

Group Category	Standard	Year	Description
			Institute of Engineering and Technology (IET) wiring regulations.
Fire Detection and Alarm	BS EN 54	-	All parts
	BS 5839-1	2011	Fire detection and fire alarm systems for buildings. Code of practice for design, installation, commissioning and maintenance of systems in non-domestic premises.
	BS 6266	2011	Fire protection for electronic equipment installations.
	BS EN 60079-29-3	2014	Part 29-3. Gas detectors. Guidance on functional safety of fixed gas detection systems.
Firefighting	BS 9990	2015	Non automatic firefighting systems in buildings. Code of practice
Automatic Fire protection	BS 5306-0	2020	Fire protection installations and equipment on premises. Guide for selection, use and application of fixed firefighting systems and other types of fire equipment.
	BS EN 12845	2015	Fixed firefighting systems. Automatic sprinkler systems. Design, installation and maintenance.
	NFPA 855 + NFPA 68 + NFPA 69	2020 2018 2019	NFPA 855: Standard for the Installation of Stationary Energy Storage Systems NFPA 68: Standard on Explosion Protection by Deflagration Ventin NFPA 69: Standard on Explosion Prevention Systems
	BS EN 14972-1	2020	Fixed firefighting system. Water mist Systems. Design, installation and maintenance.
	FM Global Property Loss Prevention Data Sheet 2-0	2021	Installation guidelines for automatic sprinklers
Product Safety General	BS EN 62619	2017	Secondary cells and batteries containing alkaline or other non-acid electrolytes. Safety requirements for secondary lithium cells and batteries, for use in industrial applications.
Product Safety Inverters	BS EN 62109-1	2010	Safety of power converters for use in photovoltaic power systems. General requirements.
	BS EN 62109-2	2011	Safety of power converters for use in photovoltaic power systems. Particular requirements for inverters.
	BS EN 62477-1	2012	Safety requirements for power electronic converter systems and equipment. General

Group Category	Standard	Year	Description
	BS EN IEC 62368-1	2020	Audio / video, information and communication technology equipment. Safety equipment.
Product Safety EMC	BS EN IEC 61000-6-1	2019	Electromagnetic compatibility (EMC). Generic standards. Immunity for residential, commercial and light-industrial environments.
	BS EN 61000-6-3	2007	Electromagnetic compatibility (EMC). Generic standards. Emission standard for residential, commercial and light-industrial environments.
Energy Storage Systems	BS EN IEC 62933-1	-	Electric Energy Storage (ESS) systems. Part 1. Vocabulary.
	BS EN IEC 62933-2-1	2018	Electrical Energy Storage (EES) systems. Part 2-1 Unit parameters and testing methods- General Specification.
	BS EN IEC 62933-5-2	2020	Electrical Energy Storage (EES) systems. Part 5-2 Safety requirements for grid integrated EES systems. Electrochemical-based systems.
	10209302-HOU-R-01	2020	DNV GL McMicken Battery Energy Storage System Event Technical Analysis and Recommendations.
	OAPUS301WIKO	2017	DNV GL Considerations for ESS Fire Safety
	DNVGL-RP-0043	2017	DNV GL Recommended Practice: Safety, Operation and Performance of Grid-connected Energy Storage Systems
	FM DS 5-33	2020	FM Global Datasheet. Electrical Energy Storage Systems.
	NFPA 855	2023	Standard for the Installation of Stationary Energy Storage Systems.
	EPRI 3002022540	2021	EPRI BATTERY STORAGE FIRE SAFETY ROADMAP: EPRI's Immediate, Near, and Medium-Term Research Priorities to Minimize Fire Risks for Energy Storage Owners and Operators Around the World
Transport	BS EN IEC 62281	2019	Safety of primary and secondary lithium cells and batteries during transport.
Fire & Rescue Service	-	2007	Water UK National Guidance Document on the Provision of Water for Firefighting
Product Safety General	RC61 (RiscAuthority)	2014	Recommendations for the storage, handling and use of batteries. Published by the FPA

Group Category	Standard	Year	Description
	RC62 (RiscAuthority)	2016	Recommendations for fire safety with photovoltaic panel installations. Published by the FPA.

In addition, the following UN and UL tests (refer to Table 4-2) are proposed to be considered in which the reactions of batteries to different risk situations have been examined.

Table 4-2: UN and UL Tests

Standard	Test	Description
UL Standards and Tests		
UL 9540A	Test Method for Evaluating Thermal Runaway Fire Propagation in Battery Energy Storage Systems	-
UL 1642	Standards for Lithium Batteries	-
UL 1973	Batteries for Use in Stationary and Motive Auxiliary Power Applications	-
IEC Standards		
CEI/IEC 61960		Provides a description of standard cell designations. This standard also provides procedures for assessing cell performance under a variety of conditions, such as various temperatures, various discharge rates, and after extended cell cycling.
CEI/IEC 62133		Addresses safety requirements for rechargeable cells and batteries.
IEC 62281		Safety requirements for rechargeable cells and batteries during transport

5. Risk Assessment and Emergency Response Planning

5.1 General Risk Assessment information

The site owner during design development, as well as the operator during exploitation, will work closely with the FRS to provide all relevant information on BESS and site design features to inform all necessary hazard and risk analysis studies and assist in the development of comprehensive Risk Management and Emergency Response Plans (RM&ERP). The final BESS design for the Scheme will include this RM&ERP.

Information will be supplied as early as possible in the detailed design stage to allow an initial appraisal of the BESS to be made. This information will be provided to the FRS (directly or via the Local Authority Planners), with appropriate evidence provided to support any claims made on performance, and with appropriate standards cited for installation.

Such information should also be made available to FRSs for inclusion in Site Specific Risk Information (SSRI) records.

BESS hazards for first responders and site operatives once a fire has started, depend on the BESS design but are typically defined as: fire, explosion, chemical hazards, carbon monoxide, carbon dioxide, hydrocarbon gases, and hydrogen. Full PPE should be worn, and operations should not generally be conducted within any identified blast exclusion zones (close proximity to doors and deflagration vents).

NFPA 855 (2023) does define some basic emergency response protocols for any BESS design:

- Potential debris impact radius is defined as 100 feet / 30.5 metres i.e., this is a typical explosion risk safe exclusion zone radius as modelling and previous BESS incidents typically show 25 metres to be maximum radius.
- Automatic building evacuation area is defined as 200 feet / 61 metres from the affected BESS container.

NFPA 855 (2023) also defines five BESS hazard categories – hazards are assessed under both normal operating conditions and emergency / abnormal conditions:

- Fire & explosion hazards
- Chemical hazards
- Electrical hazards
- Stored / stranded energy hazards
- Physical hazards

At the detailed design stage for the Scheme, risk assessment tools will be utilised together with detailed consequence modelling to provide a comprehensive site operations and emergency response safety audit. Typical BESS risk assessment tools are list below:

- Failure Modes and Effects Analysis (FMEA)
- Hazard and Operability Analysis (HAZOP)
- Hazard Mitigation Analysis (HMA)
- Fire Risk Analysis (FRA)
- Explosion Risk Analysis (ERA)

Some example BESS and site design information which should be shared with the FRS to establish a risk profile for first responders, are listed below:

- Battery chemistry integrated into BESS – can provide fire & explosive risk profile.
- Battery form factor (e.g., cylindrical, pouch, prismatic).
- Battery energy Wh / KWh – confirmation of new vs second life cells.

- Battery module cooling system details (e.g., liquid cooling design, air cooling design) – cooling system capability assessment to stop or reduce battery cell thermal runaway propagation.
- Battery module vent or gas exhaust specifications.
- Battery module KWh energy + number of cells contained in the module + battery circuitry details (number of cells in series vs number of cells in parallel).
- Direct suppression system details – module or rack level integration.
- Rack design – number of modules & KWh energy, spacing between modules, passive protection features, gas exhaust features, electrical isolation functions, heat or thermal runaway sensor integration, etc.
- Rack configuration – spacing to adjacent racks, number of racks in BESS, spacing to walls, doors, gas vents and roof.
- Type of BESS design e.g., container or cabinet, gas exhaust / ventilation features, deflagration vent design features, BESS enclosure level fire protection & suppression system details (proof of testing with BESS design + test data), additional fire or explosion protection features i.e., thermal barriers.
- EMS / BMS data monitoring capabilities and incident response integration capacity.
- Number of BESS containers/cabinets on site.
- Size and MWh capacity of each BESS unit.
- BESS and ESS equipment spacing; spacing to other equipment, boundaries, vegetation, roads or access routes, fire hydrants / water tanks, site building structures, etc.
- Access routes, observations points, turning areas, FRS equipment & assets, water supply locations & capacity, drainage, and water capture design.
- Definition and frequency of BESS equipment testing and maintenance requirements.

Digital provision of safety information and procedures must be provided to site operatives, first responders & Subject Matter Experts (SMEs) during BESS incident response – hard copy printed materials must be available onsite (location agreed with FRS). As a minimum content should include:

- Digital emergency response plans.
- Remote emergency shutoff procedures.
- SDS / Hazardous material documentation.
- Maps or design drawings.
- Gas detection capabilities; could include multi-sensor data metrics e.g., Carbon Dioxide (CO_2), Carbon Monoxide (CO), Hydrogen (H_2), VOC off gas + overpressure + local temperatures.
- Fire protection system data e.g., temperature, alarming, suppression status, etc. – establish discharge warrantee clauses, emergency BESS venting procedures, discharge times, impact on ventilation and detection systems, etc.

- ERP training drills for site operatives + FRS engagement (site familiarisation + training drills) + SME engagement (fire protection experts or battery experts)
- Other documentation as required by specific BESS project i.e., local response stipulations, contact information for nominated response personnel, community contacts, etc.

5.2 Emergency Planning requirements (based on UK NFCC guidelines)

A Risk Management Plan shall be developed by the Owner through the DCO and at detailed design stage which, as a minimum, provides advice in relation to potential emergency response implications including:

- The hazards and risks at and to the facility and their proposed management.
- Any safety issues for firefighters responding to emergencies at the facility.
- Safe access to and within the facility for emergency vehicles and responders, including to key site infrastructure and fire protection systems. Establish response times and site arrival protocols.
- The adequacy of proposed fire detection and suppression systems e.g., water supply on-site.
- Natural and built infrastructure and on-site processes that may impact or delay effective emergency response i.e., firefighting water runoff capture.

An Emergency Response Plan (ERP) will be developed to facilitate effective and safe emergency response and should include as a minimum:

- How the fire service will be alerted + incident communications & monitoring capabilities.
- Facility description, including infrastructure details, operations, number of personnel, and operating hours.
- Site plan depicting key infrastructure:
    - Site access points, internal roads, agreed access routes, observation points, turning areas, etc.
    - Firefighting facilities (water tanks, pumps, booster systems, fire hydrants, fire hose reels etc).
    - Water supply locations & capacity.
    - Drainage and water capture design & locations.
- Details of emergency resources, including fire detection and suppression systems and equipment; gas detection; emergency eye-wash and shower facilities; spill containment systems and equipment; emergency warning systems; communication systems; personal protective equipment; first aid.
- Up-to-date contact details for facility personnel, and any relevant off-site personnel that could provide technical support during an emergency.
- A list of dangerous goods stored on site.

- Site evacuation procedures.
- Site operation Emergency Management protocols - 4 phases: discovery, initial response / notification, incident actions, resolution & post incident actions / responses
- Emergency procedures for all credible hazards and risks, including building, infrastructure and vehicle fire, wildfires, impacts on local respondents, impacts on transport infrastructure.
- The operator will develop a post-incident recovery plan that addresses the potential for reignition of the BESS and de-energizing the system, as well as removal and disposal of damaged equipment.

5.3 Environmental impact assessment and mitigation measures

Suitable environmental protection measures should be provided for BESS sites. This should include systems for containing and managing firefighting water runoff. Internal BESS water based fixed suppression systems will ideally have a separate water containment system because water runoff is likely to contain higher levels of pollution.

Sites located in flood zones must provide details of flood protection and / or mitigation measures.

6. Mitigation and Control Measures

6.1 General

This section details the possible methods used to mitigate the potential residual risks of fire event leading to the spread of heat and uncontrolled fire with associated emissions through the project cycle. The Scheme will minimise fire risk using life safety features that are listed, minimum code requirements as well as recommended industry practice (property protection) throughout the project lifecycle.

The priority of the risk mitigation approach must be:

- Inherently fire safety design measures.
- Guards and protective devices such as BESS disconnection and shutdown controls.
- Information and training for end users.

The battery system mitigation measures adopted in the Battery Fire Safety Management Plan, which is to be approved subject to requirement 7 of the Development Consent Order, will reflect the latest BESS safety codes and standards applicable at that stage. Mitigation measures will be discussed and coordinated with local FRS.

At the same stage, a Failure Modes and Effects Analysis (FMEA) of the BESS will be conducted to lay the foundation for predictive maintenance requirements and compliment the fault indicator capabilities of the BMS data analytics system.

Comprehensive Hazard Mitigation Analysis (HMA) will be conducted by a BESS specialist independent Fire Protection Engineer following NFPA 855 (2023) guidelines and recommendations.

Additional risk assessments likely to be conducted at the detailed design stage are Fire Risk Analysis (FRA), Explosion Risk Analysis (ERA), Hazard and Operability Analysis (HAZOP). BESS 3rd Party risk analysis is sometimes automatically provided by Tier one BESS manufacturers and / or BESS integrators.

For the development of this outline battery fire safety management plan, the fire and explosion risks have been studied for bothlithium ion batteries and SNC (sodium nickel chloride) batteries integration into BESS systems. A preliminary risk analysis using one of the many available methods can be found in Appendix A. The mitigation measures below refer to the risks identified in that section taking into account the differences between the battery technologies.

A summary of the mitigation measures at every stage of the BESS lifecycle for the hazards and risks proposed by this Outline Battery Fire Safety Management Plan, along with the person responsible for providing the mitigation, are shown in Table A-7: Proposed List of Risk Mitigation Methods (Ref.12). These measures have been developed from the standards cited in section 4 Building Regs, Safety Standards and Guidelines, the good practices observed in previous projects and BESS's suppliers' guidelines.

The following key pillars have been considered in the development of the risk mitigation and control measures foreseen for the BESS:

- Cell manufacturing and installation
- Fire compartmentation
- Fire detection
- Fire suppression
- Ventilation
- Drainage

The mitigation measures pertaining to each area are described in more detail below.

6.2 Cell manufacturing, transport, installation and decommissioning

At the assembly line, visible and detectable defects, such as dropped, or physically damaged modules shall be immediately replaced. There are several possible defects during cell manufacturing that may escape this visual inspection such as contaminant's introduction, electrode defects, components misalignment or welding defects. To deal and mitigate these defects several manufacturing quality control techniques must be applied including undertaking reliability tests (such as charge/discharge cycles, resistance measurements or X-ray) to ensure that the equipment is distributed without damage or defects as this could lead to internal short circuits or battery fires at a later stage. In other to minimise battery defects, among other measures, batteries shall be manufactured in controlled dry rooms. The manufacturer shall have a quality control certificate. The developer shall ensure that the BESS are acquired from manufacturers providing a fully UL 9540 compliant BESS as per NFPA 855 with battery system and fire protection system tested according to UL 9540A.

The BESS will likely be shipped as a module with batteries already installed. The developer shall require that the manufacturer or transportation company follows preventive actions to avoid risks of shock, vibration etc.

The storage sites shall be safe places with restricted access to reduce the probability of shock or other external aggression occurrence, designed in compliance with NFPA 855. It is also important to assure that during the storage phase the temperature of the environment external to the battery system and modules is lower than the maximum recommended by the manufacturer.

During operation, a maintenance plan shall be planned and kept across all stages of the battery lifecycle.

Transportation and removal should be neutral stages for the Li-ion batteries, in the sense that transportation/removal means moving the battery from the factory to the location where it is going to be installed and from here to somewhere else. These stages will be carried out by trained personnel with the adequate equipment to maintain the original characteristics of the batteries. Safety regulations and supervision during these phases are essential procedures to maintain the safety conditions. The most common procedures for moving the battery enclosure are road and sea transportation. The latter is more commonly used for long distance journeys.

Once the batteries have reached the end of their useful life, de-installation and transport to the recycling and waste treatment points or to the new use destination if it is possible to repurpose the batteries, shall follow the same conditions and mitigation measures as for the transport and installation of BESS equipment in the Scheme.

6.3 Fire compartmentation and fire service accessibility

Site access

UK National Fire Chiefs Council BESS planning guidance draft document stipulates that suitable facilities for safely accessing and egressing the site should be provided. Designs should be developed in close liaison with the local FRS as specific requirements may apply due to variations in vehicles and equipment.

This should include:

- At least 2 separate access points to the site to account for opposite wind conditions/direction.
- Roads/hard standing capable of accommodating fire service vehicles in all weather conditions. As such there should be no extremes of grade.
- A perimeter road or roads with passing places suitable for fire service vehicles.
- Road networks on sites must enable unobstructed access to all areas of the facility.
- Turning circles, passing places etc size to be advised by FRS depending on fleet.

The BESS areas shall be designed to integrate firefighting water tanks located at least 10 metres from the nearest BESS enclosure, ideally upwind from the prevailing wind direction so that they are less likely to be impacted by smoke in the event of fire.

Compartmentation

In order to protect the BESS enclosures from exterior risks, they shall be provided with impact protection to prevent damage to battery enclosures by vehicles or construction equipment, as well as including Damage Limiting Constructions (DLC).

The vicinities of the BESS enclosures shall be designed to minimise the risk of fire and structural damage; therefore, BESS shall be installed on a non-combustible surface such as concrete. In addition, the BESS enclosures shall be separated by a distance of at 6m unless UL 9540A testing and / or 3rd Party Fire & Explosion testing has established closer spacing is safe. BESS enclosures will have an internal fire resistance rating of 1 - 2 hours (according to NFPA 855 and FM Global Datasheet 5-33).

The Scheme shall be provided with enclosed wiring and buried cabling, except where required to be above-ground for grid connection, to protect from damage and prevent a fire or cable failure from spreading to any of the battery systems.

If possible, internal BESS monitoring data should be accessible to the fire service, access to information (e.g., temperature and gases) shall be provided digitally for first responders.

BESS container gas exhaust vents and deflagration panels must direct flaming or toxic gases away from site personnel or first responders in line with NFPA 68 and EN 14797, doors cannot be used as deflagration vents.

6.4 Fire detection

The lithium-ion BESS fire and gas detection system will comply with NFPA 855 (2023) and NFPA 69, this means that smoke, fire and gas detection equipment will be installed. New BESS multisensor equipment in development which measures combinations of air temperature, hydrogen, VOCs, overpressure, shock & vibration, and moisture ingress will also be considered if fully tested with the BESS design. The gas detection systems will have external BESS beacon and audible alert facility.

The final fire detection design will be validated by an independent Fire Protection Engineer and must be approved by the FRS.

In case of using SNC technology for the BESS, a smoke detection system and gas detection system shall be installed .

6.5 Fire suppression

A dedicated automatic water-based system will be provided within each BESS container designed to control or fully suppress a fire, without the intervention of the Fire & Rescue Service. The suppression system must be capable to operate effectively in conjunction with a gas exhaust / ventilation system to minimise deflagration risks.

The BESS fire suppression systems will conform to NFPA 855 (2023) guidelines, and the suppression system will be tested to UL 9540A latest standard or significant scale 3rd Party fire & explosion testing. Fire suppression system performance will be benchmarked against free burn testing. An independent Fire Protection Engineer specialising in BESS will review all UL 9540A test results and any additional fire and explosion test data which has been provided and validate the suppression system design. System design and water supply requirements must be fully agreed with the FRS.

If the BESS system is designed to safely burn out without internal fire suppression systems, UL 9540A heat flux test data will establish safe distances between containers and ESS equipment and additional 3rd Party fire & explosion testing will be required to demonstrate that structural integrity is maintained and toxic gas emissions to the closest receptors are below PHE guidelines. An independent Fire Protection Engineer specialising in BESS will review all UL 9540A test results and any additional 3rd Party fire and explosion test data which has been provided.

If the BESS system is designed to safely burn out to remove the risk of stranded energy in the battery systems, then full scale free burn testing will have been conducted to demonstrate that loss will be safely limited to one container without the intervention of the Fire & Rescue service.

A post-incident recovery plan shall be developed that addresses the potential for reignition of ESS, as well as removal and disposal of damaged equipment. A fire watch should be present until all potentially damaged ESS equipment containing Li-ion batteries is removed from the area following a fire event. The water supply should be replenished as quickly as feasible. Fires involving Li-ion batteries are known to reignite. Li-ion batteries involved in or exposed to fires should be adequately cooled to prevent reignition.

For batteries using Sodium Nickel Chloride technology, no water provision is necessary. Manufacturers recommend the use of class D fire extinguishers, CO_2, or halogenated hydrocarbons in conjunction with proper ventilation for the control of the emission of smoke and small flames coming from the battery. These solutions will be assessed at the detailed design stage by an independent Fire Protection Engineer and suppression system and equipment will be agreed with the FRS.

6.6 Ventilation and cooling / heating

The BESS ventilation system will comply with NFPA 855 (2023) / NFPA 69 guidelines which require the prevention of a dangerous build-up of toxic (50% IDLH) or explosive gases (25% LEL). The gas exhaust / ventilation system must have redundancy and can be separate to any HVAC system providing climate control. Heating and cooling of the battery modules will be provided by an independent liquid cooling system which is separate to any HVAC system providing climate control for the BESS enclosure. When mechanical ventilation is required to maintain concentrations below the required limits, it shall be interlocked, so that the system shuts down upon failure of the ventilation system.

The ventilation and gas extraction system shall also be designed to exhaust flames and gases safely outside the BESS enclosure, without compromising the safety of first responders.

The ventilation system shall be provided with suitable ember protection to prevent embers from penetrating BESS enclosures (HVAC, gas exhaust, deflagration panels).

The HVAC systems should be designed to maintain temperatures within operating limits in the event of a single component failure. A safety shutdown of the system upon failure of the thermal management system shall be implemented unless it can be demonstrated that the thermal management system failure does not result in a hazardous situation. For BESS active liquid cooling / heating systems, a failure of the system due to breach or breakage in the cooling lines should not result in a leakage that will cause short circuiting of the cells inside the battery pack leading to a hazardous condition. Coolant leakage lines should be routed or secured to mitigate the potential for leakage on live parts and, if necessary, fluid monitor and controls of the coolant system may need to be provided. The heating and cooling system will be subject to routing maintenance inspections to ensure the risk of failure is minimised.

6.7 Drainage and separation from the environment

A fire water management plan should include the containment, monitoring and disposal of contaminated fire water. Infrastructure shall be provided for the containment and management of contaminated fire water runoff from BESS. This can include bunding, sumps, and purpose-built impervious retention facilities.

All process water used in the system shall be prevented from contaminating potable water sources in accordance with local regulations through the use of check valves or other means as part of the system design.

The BESS areas require fire water tanks to supress a fire, should one break out in the BESS area.

Fire water runoff may contain particles from a fire. In the unlikely event of fire water being discharged, the runoff must be contained and tested/treated before being allowed to discharge to the local watercourses.

It is proposed to contain the fire water runoff within the swale surrounding the BESS where it can be held and tested before either being released into the surrounding watercourses or taken off site by a tanker for treatment elsewhere. The swale will then be cleaned of all contaminants.

The swale will be lined to prevent any contaminants entering the ground.

The swale will be controlled by a penstock valve that can be closed before a fire is put out.

In order to determine the volume storage of firewater runoff, National Fire Chiefs Council (NFCC) guidance has been used which states firefighting supplies ‘should be capable of delivering no less than 1,900 litres per minute for at least 2 hours’. On top of this supply requirement a 30% additional capacity has been applied for storage in the swale. This equates to approximately 300m3. It should be noted that the 300m3 storage is required for each group of BESS. (i.e. 300m3 will be required if there is 1 BESS on its own or 5 BESS grouped together.) This is based on the likely scenario that only 1 BESS would be on fire at the same time.

By using the swale for firewater storage as well as surface water storage there is the potential that in the event of a fire the swale may already contain surface water and reduce the capacity for firewater storage. Therefore, the swale should be sized to serve both purposes. It has been deemed too conservative to provide the required firewater storage on top of the 1 in 100 year + 40% storage as it is extremely unlikely a fire will occur at the same time as the 1 in 100 year event. Therefore, in order to proceed with a sensible approach an allowance has been made that the 1 in 1 year event could occur at the same time as a fire. Therefore, the swale will need to contain the 1 in 1 year event plus the firewater storage runoff or the 1 in 100 year + 40% event on its own, whichever provides the worst case scenario.

The volume requirements for containment of fire water runoff within the swale and its configuration are subject to agreement with FRS.

Each BESS enclosure will be provided with a sump and drain valve to allow extraction of contaminated fire water and / or electrolyte spill without having to open the door of the enclosure and will prevent contamination of surrounding environment with the extracted liquid being taken off site for treatment. The sump construction will be designed to allow for chemical resistance of electrolyte which may be released from a battery fire and have capacity to hold the total volume of electrolyte plus a 10% safety factor. The sump will encompass the entire floor area of the BESS enclosure with a mentis grating type floor to allow spilled electrolyte to drain without pooling near other racks.

An extra layer of protection will be provided for containment of firewater external of the BESS enclosure in case of rupture or overflow of contaminants. The external floor surface surrounding each BESS container will be lined with an impermeable membrane. The drainage strategy will include for bunded holding lagoons or sunken water capture tanks within the BESS area which will contain the firewater runoff. The firewater will be tested post incident and if contaminated, will be tankered off site to a suitable waste facility for treatment.

The BESS enclosure shall be installed by third party certified and qualified installer. The BESS enclosure will be UL 9540 certificated. Ingress protection testing of BESS enclosures is conducted under UL 9540 and / or IEC62933-5-2 certification of any BESS system. Typical BESS enclosure ingress protection levels are IP 55 / NEMA 3R or IP 66 / NEMA 4. IEC Factory Acceptance Testing or a 3rd party manufacturing audit will be obtained to assure the supplied BESS enclosures comply with the requisite certified ingress protection levels.

IP ratings of BESS containers will be shared with the FRS at the detailed design stage so that risks associated with boundary cooling can be understood and implemented into the Emergency Response Plan (ERP). Potential boundary cooling water ingress points such as HVAC systems and deflagration vents will need to be considered as part of an incident response strategy.

7. Conclusion

This Outline Battery Fire Safety Management Plan has demonstrated in a systematic way the mitigation of the fire safety risks posed by the BESS in the Scheme.

The next step is for further stakeholder consultations to be held to review and agree the plan, or determine actions for further iterations, as required.

Final requirements for battery risk shall be confirmed once the batteries technology is proposed and approved in following stages.

8. References

Ref. 1. Previous similar Battery Energy Storage System risk assessment projects.

Ref. 2. FM Global, “Datasheet 5-33 Electrical Energy Storage Systems,” Factory Mutual Insurance Company, 2020.

Ref. 3. Energy Institute, “Battery Storage Guidance Note 1: Battery Storage Planning,” Energy Institute, London, 2019.

Ref. 4. Liyuan Battery Co., LTD, “Solar Energy Storage with Lithium Battery,” [Online].

Ref. 5. Anesco, “News & Blog,” Anesco, [Online].

Ref. 6. BYD Auto Industry Co., Ltd, “BYD High Energy Density Site Solution,” 2019.

Ref. 7. Fluence Energy, “Ballarat Energy Storage System,” 22 October 2018. [Online].

Ref. 8. Zenobe Energy, “Zenobe Energy,” [Online].

Ref. 9. AECOM, “Preliminary Environmental Information Report (PEI Report) - Chapter 3: Scheme Description,” AECOM, London, 2020.

Ref. 10. Sunnica Ltd, “Downloads,” 21 September 2020. [Online].

Ref. 11. W. S. Council, S. C. Council, E. C. D. Council and C. C. Council, “Sunnica Energy Farm - Response to Statutory Consultation,” Local Authorities Section 42 Statutory Consultation, 2020.

Ref. 12. F. Soarea, L. Carvalho, I. Costa, J. Iria, J.-M. Bodet, G. Jacinto, A. Lecocq, J. Roessner and B. Caillard, “The STABALID Project: Risk Analysis of Stationary Li-ion Batteries for Power System Applications,” 2015.

Ref. 13. AECOM, “EMEA Safety in Design,” 2019.

Ref. 14. Denios Ltd, “Lithium Energy Storage Devices - Safe Storage and Testing,” [Online].

Ref. 15. Kingspan, “Permastore Industrial Tanks,” Kingspan, [Online]

Ref. 16. HM Government, “The Building Regulations 2010 Fire Safety - Approved Document B Volume 1,” 2019.

Ref. 17. Goodenough JB, "Oxide Cathodes," Advances in Lithium-Ion Batteries, WA van Schalkwijk and B Scrosati (eds), Kluwer Academic/Plenum Publishers, NY, 2002.

Ref. 18. For a detailed discussion of the roll of SEI and other surface films, see: Aurbach D, "The Role of Surface Films on Electrodes in Li-Ion Batteries," Advances in Lithium-Ion Batteries, WA van Schalkwijk and BScrosati (eds), Kluwer Academic/Plenum Publishers, NY, 2002.

Ref. 19. Roth EP, Crafts CC, Doughty DH, McBreen J, "Advanced Technology Development Program for Lithium-Ion Batteries: Thermal Abuse Performance of 18650 Li-Ion Cells," Sandia Report: SAND2004-0584, March 2004.

Ref. 20. Battery Separator Products & Literature – Celgard https://www.celgard.com/product-data.

Ref. 21. Roth EP, Crafts CC, Doughty DH, McBreen J, "Thermal Abuse Performance of 18650 Li-Ion Cells," Sandia Report SAND2004-0584, March 2004.

Ref. 22. Webster H, "Fire Protection for the Shipment of Lithium Batteries in Aircraft Cargo Compartments".

Ref. 23. Safety for energy storage Why safe operation of Li-ion energy storage requires a holistic system approach. SAFT White Paper.

Ref. 24. RESEARCH TECHNICAL REPORT Development of Protection Recommendations for Li-ion Battery Bulk Storage: Sprinklered Fire Test. FM Global. October 2016.

Ref. 25. Lithium-Ion Batteries Hazard and Use Assessment. Michael Kahn, PhD, Kevin White, PhD, Richard Thomas Long, PE, Exponent Failure Analysis Associates, Inc. Fire Protection Research Foundation. July 2011.

Ref. 26. FZSoNick Energy Spring Sodium Nickel Technology for Energy Storage Applications

Ref. 27. Yashwant Sawle, M. Thirunavukkarasu, in Design, Analysis, and Applications of Renewable Energy Systems, 2021

Ref. 28. E. Lemaire-Potteau, M. Perrin, S. Genies, BATTERIES | Charging Methods. Encyclopedia of Electrochemical Power Sources, Elsevier, 2009, Pages 413-423, ISBN 9780444527455. https://doi.org/10.1016/B978-044452745-5.00885-6.

Ref. 29. What is a Sodium-nickel chloride Na-NiCl2 battery? - News about Energy Storage, Batteries, Climate Change and the Environment (upsbatterycenter.com)

Ref. 30. Policy Department for Economic, Scientific and Quality of Life Policies Directorate-General for Internal Policies Authors: Michel ARMAND, Nagore ORTIZ-VITORIANO, Javier OLARTE, Aloña SALAZAR, Raquel FERRET PE 740.064 -January 202

Ref. 31. Christensen, R., Na-NiCl2 batteries. In Technology Data for Energy storage, Danish Energy Agency, 2018.

Ref. 32. Dustmann, C-H., Advances in ZEBRA batteries, Journal of Power Sources 127, 85, 2004.

Appendix A Example of Risk Assessment Procedure in BESS

This section details one of the risk assessment methods used to study the potential risk of a fire event leading to the spread of heat and uncontrolled fire with associated emissions through the Scheme lifecycle. Additional risk assessment models may be considered for the development of the Hazard Mitigation and Risk Analysis during the design stage.

The Scheme will minimise fire risk using safety features that are becoming well-established within the industry, and these features will be applied throughout the Scheme lifecycle. Many of the features focus on the cell level fire hazards. Both Li-ion and SNC batteries will be studied in this Risk Assessment.

Regardless of the size, the safety of Li-ion batteries is intrinsically related with the safety at the cell level where several phenomena can occur at cell level, such as chemical imbalance or internal short-circuit, resulting in failures.

In order to mitigate these risks, the following steps have been taken, based upon the Risk Assessment performed in a previous project with similarities to the Scheme (Ref. 1) along with the research of The STABALID Project: Risk Analysis of Stationary Li-ion Batteries for Power System Applications," 2015 (Ref. 12) and others like Advanced technology development program for lithium-ion batteries: thermal abuse performance of 18650 Li-ion cells (Ref. 19) and adapted to suit the Scheme to address life safety and property protection requirements:

- Risk analysis and description.
- Identification risk that may appear in each stage of the battery life cycle.
- Risk Evaluation - Qualitative evaluation of the risks that may appear in each stage of the battery life cycle.
- Mitigation Measures - Safety measures to mitigate the risks identified based on last version of Standards and Lithium- ion test conclusions,
- Risk Re-evaluation - Qualitative evaluation of the risks that may appear in each stage of the battery life cycle because of the mitigation measures being implemented.

Further detail regarding these steps is presented in chapter 6 of this document. sections A.1 and A.2 and Appendix B (Risk Assessments at each Stage) of the document.

The first stage of the risk analysis is the identification of all the fire hazards that may arise during the life cycle of the battery. After analysing all the hazards (blue shapes), they were separated into five main categories (light green shapes), as shown in Figure A-1.

In the next step of the risk control process (risk evaluation), this Outline Battery Fire Safety Management Plan considers the fire events further.

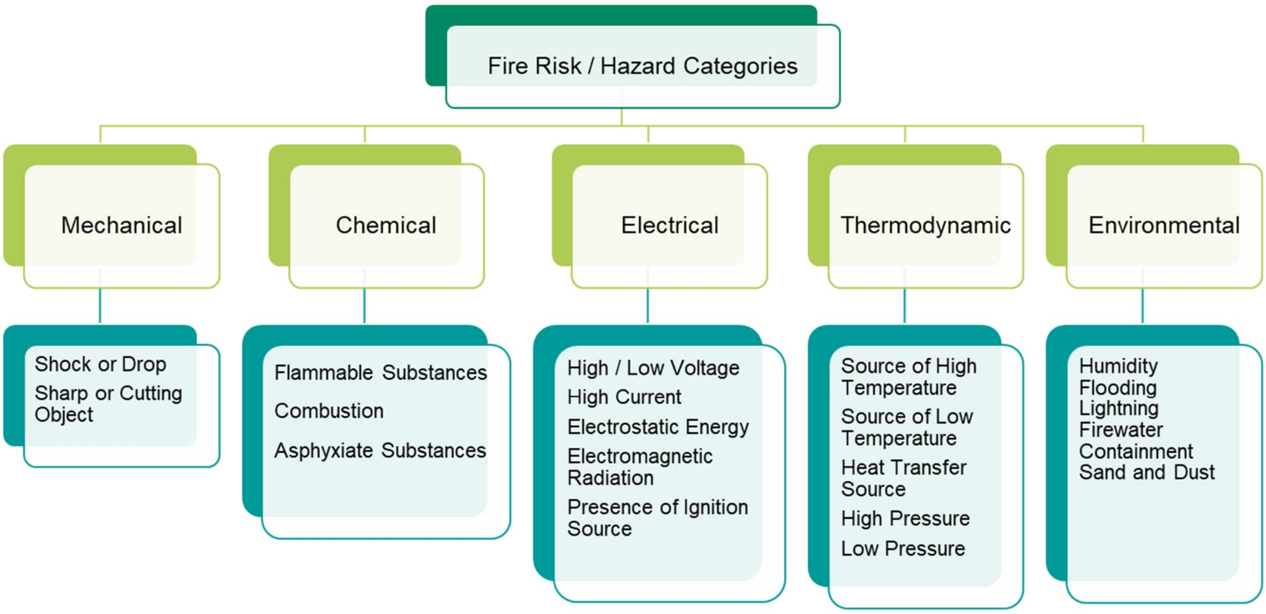


Figure A-1: Risk and Hazards Considered (Ref.13)

A.1 Risk Evaluation

The second stage of the risk control process is to break down the hazards identified into the different phases of the battery life cycle. The stages considered are presented in Figure A-2. For the purpose of this work, the risks of the transportation / removal, periodic inspection / maintenance, and installation / decommissioning are considered similar in nature as the activities in these stages.

The hazards previously identified in Figure A-1 are mapped to the different stages of the battery life cycle of Figure A-2. The same hazard may therefore appear in different stages of the battery life cycle. The results of this mapping process are presented for fire events in tables (one for each life-cycle process stage) in Appendix A (Example of Risk Assessment Procedure in BESS).

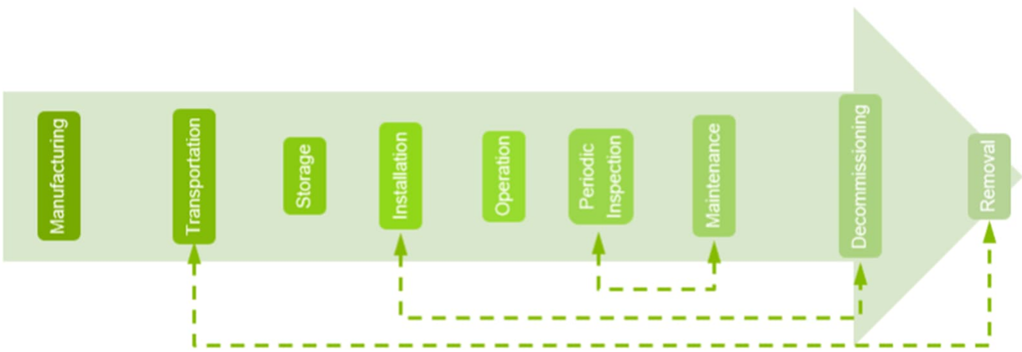


Figure A-2: Stages of Battery Life Considered (Ref.13)

The following step in the risk control process is to evaluate the risks. This is done by describing and characterising the risk, as described by the following bullet points, and illustrated in Figure A-3 and Figure A-4) and presented for fire events in detail for each lifecycle stage in the subsequent sub-sections of this Outline Battery Fire Safety Management Plan.

- Hazard – something that is dangerous and likely to cause any kind of damage.
- Element – specific part or item that may cause or be exposed to damage.
- Cause – Origin of the failure that may cause damage to people / equipment in the nearby surrounding area or to the battery element itself.
- Dangerous Occurrence – An action or circumstance that may lead to an undesirable event.
- Undesirable Event – The result of a dangerous occurrence and a dangerous situation.
- Probability – The probability level of the undesirable event occurring.
- Severity – The severity level of the undesirable event.
- Risk Rating – The residual risk remaining when applying the risk probability and risk severity of an undesirable event.
- Risk Mitigation Methods – Action(s) designed to eliminate, reduce of control the impact of the identified risks. The identifier used is RMM and referenced in Appendix B (Risk Assessments at each Stage).

Level	Probability
1	$P \leq 10^{-9} / h \rightarrow$ Improbable Event
2	$10^{-9} < P \leq 10^{-7} / h \rightarrow$ Remote Event
3	$10^{-7} < P \leq 10^{-5} / h \rightarrow$ Occasional Event
4	$P > 10^{-5} / h \rightarrow$ Probable Event

Table 2 – Probability levels (P)

Figure A-3. Probability levels (Ref. 12)

Level	Severity	Description
1	Minor	• Slight degradation of battery performance → the owner can still use the battery • Maintenance operation is advisable, but not mandatory → limited cost impact • Low risk for user or operator → small reduction in safety conditions
2	Major	• Considerable degradation of battery performance → the owner can still use the battery but a quick maintenance is requested • Low risk for user or operator → important reduction in safety conditions
3	Hazardous	• The battery is out-of-service → possibility of significant damage on the battery • Immediate maintenance is mandatory → significant intervention cost • Low risk for user or operator (possible injury) → large reduction in safety conditions
4	Catastrophic	• The battery is out-of-service → major damage on the battery • Significant risk for user or operator (significant or fatal injury) or important environmental degradation

Table 3 – Severity levels (S)

Figure A-4. Severity levels (Ref. 12)

RA		S			
		1	2	3	4
P	1	Acceptable	Acceptable	Acceptable	Tolerable
	2	Acceptable	Acceptable	Tolerable	Intolerable
	3	Acceptable	Tolerable	Intolerable	Intolerable
	4	Tolerable	Intolerable	Intolerable	Intolerable

Figure A-5. Risk Assessment based on the P and S levels (Ref. 12)

A.2 Risk Analysis

Battery operation description

Li-ion batteries

Lithium-ion (Li-ion) has become the dominant rechargeable battery chemistry for storage systems. This chemistry is different from other rechargeable batteries (e.g., nickel metal hydride, nickel cadmium, and lead acid) due to high energy density.

This consideration together with the use of a flammable organic electrolyte has a great impact on the fire strategy for batteries containing lithium-ion cells, throughout the entire life cycle.

Lithium-ion battery refers to a battery where the anode and cathode materials serve as a host for the lithium ion (Li+). Lithium ions move from the anode to the cathode during discharge and are intercalated. The ions reverse direction during charge.

At this stage, Lithium-ion batteries are one of the technologies considered for the scheme. Therefore, as one of the technologies with highest hazards, this risk analysis will be based on the consideration that lithium-ion batteries are used and there will be no free lithium metal once fire arises.

For Lithium-ion cells, alternating layers of anode and cathode are separated by a porous film (separator) and an electrolyte composed of an organic solvent and dissolved lithium salt provides the media for lithium-ion transport.

Large format battery packs used for BESS are connected together (in series and/or in parallel) into several modules and racks.

Sodium Nickel Chloride (SNC) batteries

Sodium–nickel chloride batteries otherwise called ZEBRA (Zero Emissions Batteries Research Activity) batteries are high-temperature gadget, which works at typical temperature scope of 270°C–350°C. Its cell development contains sodium and nickel chloride electrodes, isolated by a beta-alumina electrolyte, which can conduct sodium particles yet not electrons (Ref.27).

Battery component description

Li-ion batteries

Anode

The lithium-ion cell negative electrode is composed of a lithium intercalation compound coated in a thin layer onto a metal current collector. Several materials must be applied depending on different manufacturers. Principal risks at these areas are the anode coating defects which can lead to cell failure and cell thermal runaway. Self-heating of several lithium-ion graphitic anodes in the presence of electrolyte initiates at temperatures in the 70 to 90° which will be considered for the Fire strategy proposal at this stage. Once batteries are selected, this approach shall be analysed.

Cathode

Multiple positive electrode materials are used in lithium-ion cells. Typical materials used for cathodes are powders that are combined with conductivity enhancers (carbon) and coated in a thin layer onto a current collector. Several studies for typical materials show that cathode materials begin to react exothermically with electrolyte at a range of temperatures from approximately 130 to 250°C.

Electrolyte

The electrolyte in a lithium-ion cell is typically a mixture of organic carbonates such as ethylene carbonate or diethyl carbonate. It will depend for each manufacturer and the battery's properties requirements. These solvents contain solvated lithium-ions, which are provided usually with lithium salts for conduct. Different tests are provided for the typical electrolytes based on bibliography. Several electrolyte features are shown below (refer to Figure A-6):

Electrolyte Component	CAS Registry Number	Molecular Formula	Melting Point[25]	Boiling Point[25]	Vapor pressure (torr)[26]	Flash Point[26]	Auto-Ignition Temperature[26]	Heat of Combustion[27]
Propylene Carbonate (PC)	108-32-7	$C_4H_6O_3$	-49°C -56°F	242°C 468°F	0.13 at 20°C	135°C 275°F	455°C 851°F	-20.1 kJ/ml -4.8 kcal/ml
Ethylene Carbonate (EC)	96-49-1	$C_3H_4O_3$	36°C 98°F	248°C 478°F	0.02 at 36°C	145°C 293°F	465°C 869°F	-17.2 kJ/ml -4.1 kcal/ml
Di-Methyl Carbonate (DMC)	616-38-6	$C_3H_6O_3$	2°C 36°F	91°C 195°F	18 at 21°C	18°C 64°F	458°C 856°F	-15.9 kJ/ml -3.8 kcal/ml
Diethyl Carbonate (DEC)	105-58-8	$C_5H_{10}O_3$	-43°C 45°F	126°C 259°F	10 at 24°C	25°C 77°F	445°C 833°F	-20.9 kJ/ml -5.0 kcal/ml
Ethyl methyl carbonate (EMC)	623-53-0	$C_4H_8O_3$	-14°C 6.8°F	107°C 225°F	27 at 25°C	25°C 77°F	440°C 824°F	None available

Figure A-6. Electrolyte composition (Ref. 25)

Test results shows a lower flash point for several electrolytes which increase the risk of fire. Mitigation measures based on compartmentation and cooling effects will be consider in order to limit ignition.

In addition to the several electrolyte features, a description of typical gases generated from standard ion cell battery based on Sandia TEST is shown in Figure A-7:

Cell Type	Fresh Cell at 100% SOC	Aged Cell[28] at 100% SOC
Max Sample Temperature	25°C	45°C
Gas Species	Volume Percent	
H_2	8.2 %	0.3%
Argon	44.0%	27.8%
N_2	6.2%	9.6%
O_2	0.1%	1.7%
CO	4.2%	11.3%
CO_2	12.6%	26.3%
CH_4	13.5%	11.5%
C_2H_4	3.1%	None detected
C_2H_6	None detected	None detected
Ethyl Fluoride	None detected	None detected
Propylene	None detected	None detected
Propane	None detected	0.06%
Electrolyte Solvent (EC/ EMC mixture)	11.2%	11.5%

Figure A-7. Gas composition of punctured cells (Ref. 21)

Substance	LEL or LFL (Vol %)	UEL or UFL (Vol %)
Hydrogen	4	75
Carbon monoxide	12,5	74
Methane	5	15
Ethane	3	12,4
Propane	2,1	9,5
Butane	1,8	8,4
Methanol	6,7	36
Ethanol	3,3	19
Acetone	2,6	13

Figure A-8. Typical gases LEL/LFL limits

As it is shown above in Figure A-8, Hydrogen gas concentration shall be considered as one of the possible gasses that could be found at the BESS unit. Therefore, in terms of fire safety requirements, H_2 concentration shall be considered, and mitigation measures shall be implemented in order to reduce the H_2 concentration to a maximum of 25 % the lower flammable limit (LFL) according to NFPA 855 [ed.2023].

Separator

Typical analysis for Lithium-ion cell separators most commonly defines them as porous polyethylene, polypropylene, or composite polyethylene / polypropylene films which could be modified for each manufacturer (Ref. 20). The function of the separator is to prevent direct contact between the anode and cathode.

These types of separators are commonly referred to as “shutdown” separators which protect battery from minor shorts and generate a permanent deactivation of the entire cell if temperature rises to approximately 130°C. This element could still lead to thermal runaway if temperature increases over 150 º C due to melting of the separator, letting both anode and cathode to get in contact. In terms of fire safety measures, fast temperature detection and a cooling system in addition to compartmentation will be required.

Current collector

The current collector is used to transfer current throughout the cell. Typically, collectors are based on thin foils of copper and aluminium. At very low cell voltages the potential at the copper current collector increases to the point where copper will begin to oxidise and dissolve as copper ions into the electrolyte.

In the subsequent recharge, the dissolved copper ions plate as copper metal onto negative electrode surfaces, and as result loss of capacity appears. After multiple charge cycles, it could cause lithium plating, losing permeability of the surfaces even going as far as thermal runaway.

In terms of fire safety, measures to limit low voltage status for batteries shall be required. It shall be of particular interest at storage life cycle stage during which the material could be stored for long periods without maintenance. Those effects will require further investigation once battery type and features of each manufacturer are defined.

Cell enclosure

Typically, materials used for cells are based on nickel-coated steel or aluminium. Generally, the enclosure of a hard case cell is one of the cell electrodes covered or shrink-wrap to provide electrical isolation. To limit the effects of pressure, some vents could be included as a part of the design. In terms of fire design, the principal issue will be to determine damages based on impacts or contacts during transport.

Battery pack enclosures

Battery pack enclosures can vary considerably and will depend on the application. Some of the simplest pack enclosures (for hard case cells) are simply a layer of shrink-wrap that holds cells together or hard metal/plastic cases. In terms of fire strategy, plastic case contribution shall be considered due to the potential fire contribution. In terms of design, it will impact directly on the followings:

- Toxic smoke as a consequence of the plastic ignition including corrosive gases.
- Fast visibility reduction which will difficult fire brigade intervention.
- High spread speed of fire due to plastic melting temperature (test show for ABS and Policarbonate (PC) temperature is around 200ºC).

SNC batteries (Ref. 28)

In the charged state, a Zebra cell consists of a negative liquid sodium electrode and a solid positive electrode containing NiCl and nickel. A β-Al2O3 ceramic tube physically separates the electrodes and ensures the transport of sodium ions. To ensure contact between the solid positive electrode and the ceramic electrolyte, the positive electrode is flooded with molten chloroaluminate (NaAlCl4), which is an equimolar eutectic mixture of sodium chloride and aluminium tri chloride. During discharge, sodium is oxidized into Na+ ions, forming sodium chloride, and NiCl is reduced to metallic Ni.

There are no secondary reactions in Zebra batteries. In case of overcharge, when all the sodium chloride has been consumed, excess nickel in the positive electrode reacts with sodium chloroaluminate, which occurs at a higher potential than the cell reaction. In doing so, the current flow through the cell is stopped and this constitutes an intrinsic protection mechanism.

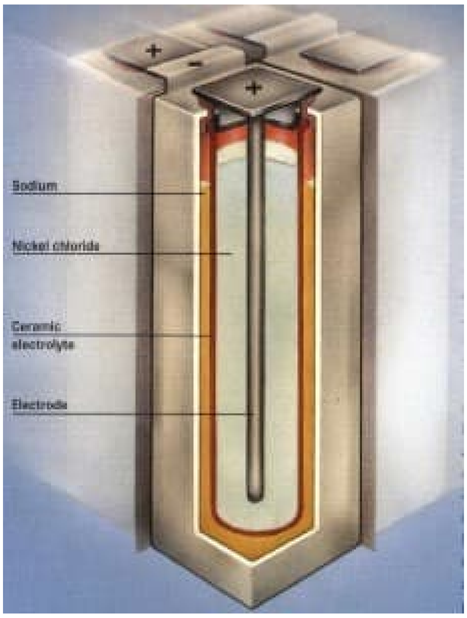


Figure A-9. ZEBRA Battery (Ref. 29)

Typical failure modes

<u>Li-ion batteries</u>

Based on the risks described, failure mode description will be detailed below:

Thermal runaway:

Thermal runaway refers to <u>rapid self-heating</u> of a cell derived from the exothermic chemical reaction of the highly oxidising positive electrode and the highly reducing negative electrode causing that a cell rapidly releases its stored energy.

In terms of fire safety design lithium-ion cell thermal runaway reactions can be very energetic as these cells have very high-energy densities compared to other cell chemistries. For initiation of cell thermal runaway (or ignition of fuel), the rate of heat generation must exceed the rate of heat loss. Test shows that thermal runaway could start after 2 days. It shall be considered in terms of fire design a possible re-ignition of an exposed cell time after the completion of the intervention.

Typical stages analysed as a part of the thermal runaway are detailed below:

1. **Cell internal temperature increases** in excess of 600°C (depending on the battery materials) caused by reactions of the electrodes with electrolyte. This creates changes in the cell, and it will discompose, even generating O_2 in some cases which will act with oxidising parts like the current collector, depending on the material. At this stage, tests show that no significant amount of oxygen is found in cell vent gases (not able to self-sustain the combustion). Based on these effects, fire protection measures will be based on fast heat detection in addition with a fast and effective water-based suppression system.

2. **Cell internal pressure increases:** This occurs because heated electrolyte will both vaporise and decompose, and some cathode materials can also decompose, releasing gas.

3. **Cell undergoes venting**. Due to pressure, the cell will break, releasing gases. Based on tests bright sparks are observed in the vent gases and a dark smoke

appears. According to Fire strategy, there shall be included fire rated protection to limit the spreading to other parts/batteries due to particle and heat emission.

4. **Cell vent gases may ignite:** Vents gases could ignite if there is enough oxygen surrounding. Considering limitations on space due to reference, it is assumed that oxygen will limit the scenario, this will create gases such as CO. For this, a backdraft scenario could result during intervention accompanied with action by fire brigade or maintenance operation.

5. **Cell contents may be ejected.** With hard case cells, release of pressure could result in the ejection of the cell case causing effects on parts around the battery or other equipment. In that case firefighting systems shall be protected for impacts or located at areas where impact is no probable (e.g., racks will limit impact effects on the sprinklers unit, and gas cylinder or combustible can be located at the BESS in a protected envelope).

6. **Cell thermal runaway may propagate to adjacent cells**. If one cell in a pack undergoes a thermal runaway reaction, it is likely to cause thermal runaway in adjacent cells by way of various heat transfer mechanisms as it is detailed in some FAA tests (Ref. 22).

Thermal abuse:

The most direct way to exceed the thermal stability limits of a lithium-ion cell is to subject it to external heating. For long-term storage it could occur at cells in a range of 70 to 90°C (158 to 194°F). From a fire protection standpoint, particularly in bulk storage areas, isolation (thermal separation) of lithium-ion batteries from each other, from hot combustion products, and from oxidizers is important in mitigating and preventing fire spread following an initiating incident such a single cell undergoing thermal runaway. In addition, HVAC systems will be required.

Mechanical Abuse:

Mechanical abuse of cells can cause shorting between cell electrodes leading to localized cell heating that propagates to the entire cell and initiates thermal runaway. This effect could occur even days after the incident, due to internal battery modifications.

For this reason, across their life cycle, batteries shall be tested for vibration, impacts, crushes, puncture, etc. In addition, the location where the batteries are stored shall as well be protected from any impact. Cell susceptibility to severe mechanical damage is a factor in cell shipping and handling. If mechanical damage does not cause cell thermal runaway immediately or within hours of occurrence, it can still cause cell thermal runaway if the cell continues to be cycled and used, so it shall be included a control document which shall identify any kind of effect that affects the batteries.

In addition, electrolyte leakage can occur as the result of mechanical damage to cells, due to internal corrosion of cells or puncture damage causing a spill of hazardous material. Flammable electrolyte increases the risk of fire, so, as a mitigation method, technologies without flammable electrolytes should be selected.

Electrical Abuse:

Overcharge of a lithium-ion cell can cause significant degradation of both anode and cathode. On the anode, overcharge can cause plating rather than intercalation of lithium and then cause internal shorting (dendrites appear which could contact different parts).

In addition, reaction of plated lithium with electrolyte will occur exothermally. On the cathode, overcharge can cause excess removal of lithium from cathode material structures, such that their crystalline structure becomes unstable, resulting in an exothermic reaction. In any case, the reaction pushes a cell out of its thermal stability limits and results in a thermal runaway reaction. It could occur by voltage and due to current, or even due to manufacturer defect (product shall hold a certificate).

External Short Circuit:

High-rate discharging (or charging) can cause resistive heating within cells at points of high impedance causing cells to exceed thermal stability limits.

Over-Discharge:

Simply over-discharging a lithium-ion cell to 0 V will not cause a thermal runaway reaction. However, such over-discharge can cause internal damage to electrodes and current collectors, which can lead to lithium plating if the cell is recharged (particularly, if the cell is repeatedly over-discharged), and can ultimately lead to thermal runaway.

In such cases where the battery is discharged to the low voltage cut off and then stored for an extended period of time, the self-discharge of the cell ultimately results in over-discharge and final thermal runaway.

Forcing a cell into “reversal” (charging to a negative voltage, “forced over-discharge”) may also cause thermal runaway.

Poor Cell Electrochemical Design

Batteries used for BESS shall be tested and shall dispose of certificates of quality. Test shows that anode coating defects could lead into a thermal runaway.

Heat Transfer Environment

Finally, the heat transfer environment of a cell undergoing a thermal runaway reaction can play a large role in the severity of the reaction. High ambient temperatures or adiabatic insulation will increase the likelihood that any given internal fault can drive a cell to thermal runaway and increase the energy available to heat the cell. If cells are assembled in close proximity, and not sufficiently heat sunk, thermal runaway in one of them could initiate the process in another.

In terms of fire safety, it shall be considered to limit propagation from other BESS and from possible natural effects such as natural fire incidents. Mitigation measures shall limit spread based on a free fire strip (users’ roads or free areas of vegetation) or compartmentation measures for BEES.

Transport/Packaging risk

One common issue during transport is improper packaging of the lithium-ion batteries causing impacts and short circuits. Specific packaging according to reference shall be considered.

Storage risk

There is a potential for mechanical damage due to poor handling such as boxes or pallets being dropped or damaged by forklift accidents.

Crush or puncture damage to cells or battery packs can lead to release of electrolyte, short circuiting, and possibly cell thermal runaway that can result in a fire.

There is also potential for external heating of the cells due to a fire initially unrelated to lithium-ion battery packs that ultimately results in venting or thermal runaway. A building defined for storage shall consider batteries as a separate risk and include firefighting methodologies for protection (compartmentation, sprinklers…) according to this risk.

At storage, it shall be considered the possibility of failure at the batteries caused during transport which could start once the elements are located at the storage. In order to avoid these conditions, a quarantine period and checking of battery status shall be integrated as a part of the battery process.

Recycling

As storage risk, a mechanical damage during transport to recycling facilities and handling shall be consider and mitigation requirements shall be included.

<u>SNC batteries (Ref. 30)</u>

When compared to other batteries, Na-NiCl2 batteries have been considered reliable and low maintenance31. However, the use of alkali metals like sodium or lithium at high temperature has raised the question of safety (which is always a concern for electrochemical cells). The problem is quite evident with sodium-sulphur batteries, as the rupture of the ceramic puts Na metal and the molten sulphur/sulfides in contact, releasing a high amount of energy. To limit the consequences of the loss of the electrolyte (beta alumina solid electrolyte – BASE) integrity in both the Na/S and ZEBRA systems, only a thin film of molten sodium is put in contact with the electrolyte by imbibing a steel mesh fed using capillarity. In addition, in case of BASE rupture, the reaction of Na metal with the liquid electrolyte results in the formation of aluminium and sodium chloride, both solids:

$$3Na + NaAlCl4 \Rightarrow 4\ NaCl + Al$$

These reaction products, well below their melting point (Al: 660°C, NaCl: 801°C), caulk the crack preventing further reaction.

Another safety concern is the resistance to overcharge and over-discharge.

The charge capacity of the ZEBRA cell is determined by the quantity of salt (NaCl) available in the cathode. When overcharging the battery (i.e. charging when it is already fully charged) there is an excess of nickel vs. Stoichiometry:

$$Ni^{\circ}_{excess} + 2NaCl \Leftrightarrow NiCl_{2excess} + 2Na^{\circ}$$

The consequence is that this overcharge reaction requires a higher voltage than the normal charge (~3.05 V vs 2.58 for normal operation) (Ref.31).

When over discharging, however, the reaction beyond the full reduction of NiCl2 is the reversible reduction of the NaAlCl4 in the catholyte (i.e. the portion of an electrolyte near a cathode):

$$3Na° + NaAlCl_4 \Leftrightarrow 4\ NaCl + Al°$$

The consequence is that this over discharge reaction requires a lower voltage than the normal charge (~1.58 vs 2.58 for normal operation). (Ref. 32)

Typical operating conditions of Na-NiCl2 batteries comprise charging in 6 and 8 hours (i.e. C/6 – C/8 rate, which means that the battery is charged from 0-100% in 6 and 8 hours, respectively) and discharging in 3 hours. Typical time scales are days to solidify during cooling and tens of hours to liquidize during reheating. During operation, Na-NiCl2 batteries can be repeatedly cooled to ambient temperatures and reheated, i.e., undergo so-called freeze-thaw cycles, without any decrease of battery lifetime.

Appendix B Risk Assessments at each Stage

B.1 Manufacturing Stage

Table A-1: Manufacturing Stage Hazard and Risk Mitigations (Ref. 12)

Hazard and Risk Identification							Pre-mitigation Assessment			Risk Mitigation Methods	Post-mitigation Assessment		
Item	Hazard	Element	Cause	Dangerous Occurrence	Dangerous Situation	Undesirable Event	Probability	Severity	Risk Rating	Risk Mitigation Methods	Probability	Severity	Risk Rating
1	Cell internal short-circuit during control process (charge)	Cell	Cell contamination	Thermal runaway	Incorrect quality evaluation	Toxic gas release /fire	2	3	6	RMM02 RMM03 RMM08 RMM14 RMM26 RMM34	1	3	3
2	Water moisture/filth during manufacturing	Cell	Non controlled ambient	Thermal runaway	Manufacture defect	Thermal runaway	1	4	4	RMM34	1	1	3

B.2 Transportation and Removal Stages

Table A-2: Transportation and Removal Stages Hazard and Risk Mitigations (Ref. 12)

Hazard and Risk Identification							Pre-mitigation Assessment			Risk Mitigation Methods	Post-mitigation Assessment		
Item	Hazard	Element	Cause	Dangerous Occurrence	Dangerous Situation	Undesirable Event	Probability	Severity	Risk Rating	Risk Mitigation Methods	Probability	Severity	Risk Rating
1	Flammable substances	Cell	Electrolyte leakage and inflammation	Battery fire	People in proximity	Burns / loss of life	2	4	8	RMM01 RMM04 RMM05 RMM25 RMM26 RMM27	1	3	3
					Equipment in proximity	Fire propagation	2	4	8		1	2	2
2	High temperature or Heat transfer source	Cell	Thermal Runaway (the cell can reach thermal runaway in case of abnormal conditions such as: cell over charge, charge after an over discharge,	Battery fire	People in proximity	Burns / loss of life	3	4	12	RMM01 RMM02 RMM03 RMM08 RMM09 RMM10 RMM11 RMM12 RMM13 RMM14 RMM25 RMM26	1	3	3
					Equipment in proximity	Fire propagation	3	4	12		1	3	3

Hazard and Risk Identification							Pre-mitigation Assessment			Risk Mitigation Methods	Post-mitigation Assessment		
Item	Hazard	Element	Cause	Dangerous Occurrence	Dangerous Situation	Undesirable Event	Probability	Severity	Risk Rating	Risk Mitigation Methods	Probability	Severity	Risk Rating
			external short circuit on cell/module, internal short circuit on cell/module, etc)										
		Battery System, Module or Cell	High temperature induced by the environment (fire, external heat source) or heat radiation coming from the external environment	Battery fire	People in proximity	Burns/loss of life	2	3	6	RMM01 RMM07 RMM09 RMM10 RMM13 RMM21 RMM25 RMM26 RMM33	1	3	3
					Equipment in proximity	Fire propagation	2	4	8		1	3	3

Hazard and Risk Identification							Pre-mitigation Assessment			Risk Mitigation Methods	Post-mitigation Assessment		
Item	Hazard	Element	Cause	Dangerous Occurrence	Dangerous Situation	Undesirable Event	Probability	Severity	Risk Rating	Risk Mitigation Methods	Probability	Severity	Risk Rating
3	Shock or drop	Module or Cell	Shock against a heavy object or drop	Battery fire	Equipment in proximity	Fire propagation	3	4	12	RMM01 RMM25 RMM26	1	3	3
4	Sharp or cutting objects	Module or Cell	Impact against a heavy object	Battery fire	Equipment in proximity	Fire propagation	3	4	12	RMM01 RMM25 RMM26	1	3	3
5	Improper packaging	Module or Cell	Short circuit /mechanical damage	Battery fire	People in proximity	Burns/loss of life	2	4	8	RMM01 RMM02 RMM25 RMM26	1	4	4
					Equipment in proximity/Accident	Fire propagation	2	4	8		1	4	4
6	Vibration	Module or Cell	Defects on the components	Battery fire	People in proximity	Burns/loss of life	2	4	8	RMM01 RMM25 RMM26	1	3	3
					Equipment in proximity/Accident	Fire propagation	2	4	8		1	3	3

B.3 Storage Stage

Table A-3: Storage Stage Hazard and Risk Mitigation (Ref. 12)

Hazard and Risk Identification							Pre-mitigation Assessment			Risk Mitigation Methods	Post-mitigation Assessment		
Item	Hazard	Element	Cause	Dangerous Occurrence	Dangerous Situation	Undesirable Event	Probability	Severity	Risk Rating	Risk Mitigation Methods	Probability	Severity	Risk Rating
1	Flammable substances	Cell	Electrolyte leakage and inflammation	Battery fire	People in proximity	Burns / loss of life	2	3	6	RMM01 RMM04 RMM05 RMM26 RMM27 RMM35	1	3	3
					Equipment in proximity	Fire propagation	2	4	8		1	2	2
2	High current	Rack	High current delivery by the battery system	High current	People in contact with the battery	Electrical shock	4	2	8	RMM02 RMM06 RMM08 RMM09 RMM14 RMM26 RMM35 RMM36 RMM37	2	2	4
3	High temperature or Heat transfer source	Cell	Thermal Runaway (the cell can reach thermal	Battery fire	People in proximity	Burns / loss of life	3	3	9	RMM01 RMM02 RMM03 RMM08 RMM09	1	3	3
					Equipment in proximity	Fire propagation	3	4	12		2	1	2

Hazard and Risk Identification							Pre-mitigation Assessment			Risk Mitigation Methods	Post-mitigation Assessment		
Item	Hazard	Element	Cause	Dangerous Occurrence	Dangerous Situation	Undesirable Event	Probability	Severity	Risk Rating	Risk Mitigation Methods	Probability	Severity	Risk Rating
			runaway in case of abnormal conditions such as: cell over charge, charge after an over discharge, external short circuit on cell/module, internal short circuit on cell/module, etc)							RMM10 RMM11 RMM12 RMM14 RMM26 RMM35 RMM36 RMM37			
		Battery System, Module or Cell	High temperature induced by the environment (fire, external heat source)	Battery fire	People in proximity	Burns / loss of life	2	4	8	RMM01 RMM07 RMM21 RMM26 RMM33 RMM35 RMM36	1	3	3
					Equipment in proximity	Fire propagation	2	4	8		1	3	3

Hazard and Risk Identification							Pre-mitigation Assessment			Risk Mitigation Methods	Post-mitigation Assessment		
Item	Hazard	Element	Cause	Dangerous Occurrence	Dangerous Situation	Undesirable Event	Probability	Severity	Risk Rating	Risk Mitigation Methods	Probability	Severity	Risk Rating
			or heat radiation coming from the external environment							RMM37			
4	High pressure	Cell	Thermal Runaway (the cell can reach thermal runaway in case of abnormal conditions such as: cell over charge, charge after an over discharge, external short circuit on cell/module, internal short	Battery fire	People in proximity	Burn / loss of life	3	4	12	RMM01 RMM02 RMM03 RMM04 RMM05 RMM07 RMM14 RMM22 RMM26 RMM35 RMM36	1	3	3
					Equipment in proximity	Fire propagation	2	4	8		1	3	3

Item	Hazard	Element	Cause	Dangerous Occurrence	Dangerous Situation	Undesirable Event	Pre-mitigation Assessment: Probability	Pre-mitigation Assessment: Severity	Pre-mitigation Assessment: Risk Rating	Risk Mitigation Methods	Post-mitigation Assessment: Probability	Post-mitigation Assessment: Severity	Post-mitigation Assessment: Risk Rating
			circuit on cell/module, etc)										
5	Shock or drop	Battery system, module or Cell	Shock against a heavy object or drop	Battery fire	People in proximity	Burns / loss of life	3	4	12	RMM01 RMM06 RMM09 RMM26 RMM35 RMM36 RMM37	1	3	3
					Equipment in proximity	Fire propagation	3	4	12		1	3	3
6	Sharp or cutting objects	Battery system, module or Cell	Impact against a heavy object	Battery fire	People in proximity	Burns / loss of life	3	3	9	RMM01 RMM06 RMM09 RMM26 RMM35 RMM36 RMM37	1	3	3
					Equipment in proximity	Fire propagation	3	4	12		2	4	8
7	High voltage	Module or cell	During storage of modules, as spare parts, some charge could be	Module fire	People in proximity	Burns / loss of life	3	3	9	RMM01 RMM02 RMM06 RMM09 RMM10 RMM11	1	3	3
					Equipment in proximity	Fire propagation	3	4	12		2	2	4

Item	Hazard	Element	Cause	Dangerous Occurrence	Dangerous Situation	Undesirable Event	Pre-mitigation Assessment: Probability	Pre-mitigation Assessment: Severity	Pre-mitigation Assessment: Risk Rating	Risk Mitigation Methods	Post-mitigation Assessment: Probability	Post-mitigation Assessment: Severity	Post-mitigation Assessment: Risk Rating
			done. Failure in charger or not appropriate charger.							RMM14 RMM35 RMM36 RMM37			
8	High current	Module or cell	During storage of modules, as spare parts, some charge could be done. Failure in charger or not appropriate charger	Module fire	People in proximity	Burns / loss of life	3	3	9	RMM01 RMM02 RMM06 RMM09 RMM10 RMM11 RMM14 RMM35 RMM36 RMM37	1	3	3
9	Voltage under minimum	Cell and module	Cathode/ Anode loss of properties	Thermal runaway	Battery fire/Deflagration	Loss of life / Fire propagation	2	3	6	RMM01 RMM09 RMM10 RMM14 RMM35 RMM36	1	3	3

Hazard and Risk Identification							Pre-mitigation Assessment			Risk Mitigation Methods	Post-mitigation Assessment		
Item	Hazard	Element	Cause	Dangerous Occurrence	Dangerous Situation	Undesirable Event	Probability	Severity	Risk Rating	Risk Mitigation Methods	Probability	Severity	Risk Rating
10	Internal defects due to transportation	Battery system, module or Cell	Thermal runaway	Battery fire	People in proximity	Potential toxicity	3	4	12	RMM01 RMM02 RMM03 RMM08 RMM09 RMM25 RMM26 RMM35 RMM36	2	2	4
					Equipment in proximity	Fire propagation	3	4	12		2	2	4
11	Cells vent	Battery system, module or Cell	Relief pressure system due to pressure drop out flammable gases	Battery fire	People in proximity	Potential toxicity	2	4	8	RMM05 RMM07 RMM22 RMM35 RMM36	2	1	2
					Equipment in proximity	Flammable gases	2	4	8		2	1	2

B.4 Installation and Decommissioning Stages

Table A-4: Installation and Decommissioning Stages Hazard and Risk Mitigation (Ref. 12)

Hazard and Risk Identification							Pre-mitigation Assessment			Risk Mitigation Methods	Post-mitigation Assessment		
Item	Hazard	Element	Cause	Dangerous Occurrence	Dangerous Situation	Undesirable Event	Probability	Severity	Risk Rating	Risk Mitigation Methods	Probability	Severity	Risk Rating
1	Flammable substances	Cell	Electrolyte leakage and inflammation	Battery fire	People in proximity	Burns / loss of life	2	3	6	RMM01 RMM04 RMM05 RMM15 RMM16 RMM20 RMM27	1	3	3
					Equipment in proximity	Fire propagation	2	4	8		1	4	4
2	High temperature or Heat transfer source	Cell	Thermal Runaway (the cell can reach thermal runaway in case of abnormal conditions such as: cell over charge, charge after an over discharge,	Battery fire	People in proximity	Burns / loss of life	3	3	9	RMM01 RMM02 RMM06 RMM08 RMM09 RMM10 RMM14 RMM16 RMM17 RMM18 RMM19 RMM20 RMM21	1	3	3
					Equipment in proximity	Fire propagation	3	4	12		2	3	6

Hazard and Risk Identification							Pre-mitigation Assessment			Risk Mitigation Methods	Post-mitigation Assessment		
Item	Hazard	Element	Cause	Dangerous Occurrence	Dangerous Situation	Undesirable Event	Probability	Severity	Risk Rating	Risk Mitigation Methods	Probability	Severity	Risk Rating
			external short circuit on cell/module, internal short circuit on cell/module, etc)							RMM23 RMM26			
		Battery System, Module or Cell	High temperature induced by the environment (fire, external heat source) or heat radiation coming from the external environment	Battery fire	People in proximity	Burns / loss of life	2	3	6	RMM01 RMM06 RMM07 RMM09 RMM16 RMM17 RMM18 RMM19 RMM20 RMM21 RMM23 RMM26 RMM29 RMM33 RMM38	1	3	3
					Equipment in proximity	Fire propagation	2	4	8		1	4	4

Hazard and Risk Identification							Pre-mitigation Assessment			Risk Mitigation Methods	Post-mitigation Assessment		
Item	Hazard	Element	Cause	Dangerous Occurrence	Dangerous Situation	Undesirable Event	Probability	Severity	Risk Rating	Risk Mitigation Methods	Probability	Severity	Risk Rating
3	High pressure	Cell	Thermal Runaway (the cell can reach thermal runaway in case of abnormal conditions such as: cell over charge, charge after an over discharge, external short circuit on cell/module, internal short circuit on cell/module, etc)	Battery fire	People in proximity	Burn / loss of life	2	3	6	RMM01 RMM02 RMM03 RMM04 RMM05 RMM06 RMM07 RMM10 RMM11 RMM12 RMM14 RMM16 RMM17 RMM18 RMM19 RMM20 RMM22 RMM23 RMM26 RMM32	1	3	3
					Equipment in proximity	Fire propagation	2	4	8		1	4	4
4	Shock or drop	Battery system,	Shock against a	Battery fire	People in proximity	Burns / loss of life	4	3	12	RMM01 RMM06	2	2	4

Item	Hazard	Element	Cause	Dangerous Occurrence	Dangerous Situation	Undesirable Event	Pre-mitigation Assessment: Probability	Pre-mitigation Assessment: Severity	Pre-mitigation Assessment: Risk Rating	Risk Mitigation Methods	Post-mitigation Assessment: Probability	Post-mitigation Assessment: Severity	Post-mitigation Assessment: Risk Rating
		module or Cell	heavy object or drop		Equipment in proximity	Fire propagation	4	4	16	RMM09 RMM17 RMM18 RMM19 RMM20 RMM22 RMM23 RMM24 RMM26 RMM28	2	4	4
5	Short circuit	Battery system, module or cell	Short circuit during installation	Battery fire	People in proximity	Burns / loss of life	3	4	12	RMM01 RMM02 RMM03 RMM04 RMM05 RMM06 RMM08 RMM09 RMM10 RMM11 RMM12 RMM14 RMM16 RMM17	3	1	3
					Equipment in proximity	Fire propagation	3	4	12		3	1	3

Item	Hazard	Element	Cause	Dangerous Occurrence	Dangerous Situation	Undesirable Event	Pre-mitigation Assessment: Probability	Pre-mitigation Assessment: Severity	Pre-mitigation Assessment: Risk Rating	Risk Mitigation Methods	Post-mitigation Assessment: Probability	Post-mitigation Assessment: Severity	Post-mitigation Assessment: Risk Rating
										RMM18 RMM19 RMM20 RMM22 RMM23 RMM26 RMM37			
6	Sharp or cutting objects	Battery system, module or Cell	Impact against a heavy object	Battery fire	People in proximity	Burns / loss of life	4	3	12	RMM01 RMM06 RMM09 RMM17 RMM18 RMM19 RMM20 RMM22 RMM23 RMM26 RMM28	2	2	4
					Equipment in proximity	Fire propagation	4	4	16		2	2	4

B.5 Operation Stage

Table A-5: Operation Stage Hazard and Risk Mitigations (Ref.12)

Hazard and Risk Identification							Pre-mitigation Assessment			Risk Mitigation Methods	Post-mitigation Assessment		
Item	Hazard	Element	Cause	Dangerous Occurrence	Dangerous Situation	Undesirable Event	Probability	Severity	Risk Rating	Risk Mitigation Methods	Probability	Severity	Risk Rating
1	Flammable substances	Cell	Electrolyte leakage and inflammation	Battery fire	People in proximity	Burns / loss of life	2	3	6	RMM01 RMM04 RMM05 RMM15 RMM16 RMM17 RMM18 RMM19 RMM24 RMM26 RMM27 RMM30 RMM31	1	3	3
					Equipment in proximity	Fire propagation	2	4	8		1	4	4
2	High temperature or Heat transfer source	Module or Cell	Thermal Runaway (the cell can reach thermal runaway in case of abnormal	Battery fire	People in proximity	Burns / loss of life	3	3	9	RMM01 RMM02 RMM03 RMM04 RMM05 RMM06 RMM10	1	3	3
					Equipment in proximity	Fire propagation	3	4	12		2	3	6

Item	Hazard	Element	Cause	Dangerous Occurrence	Dangerous Situation	Undesirable Event	Pre-mitigation Assessment: Probability	Pre-mitigation Assessment: Severity	Pre-mitigation Assessment: Risk Rating	Risk Mitigation Methods	Post-mitigation Assessment: Probability	Post-mitigation Assessment: Severity	Post-mitigation Assessment: Risk Rating
			conditions such as: cell over charge, charge after an over discharge, external short circuit on cell/module, internal short circuit on cell/module, etc)							RMM11 RMM12 RMM14 RMM15 RMM16 RMM17 RMM18 RMM19 RMM24 RMM26 RMM27 RMM30 RMM31			
		Battery System, Module or Cell	High temperature induced by the environment (fire, external heat source) or heat radiation coming from	Battery fire	People in proximity	Burns / loss of life	2	3	6	RMM01 RMM06 RMM07 RMM16 RMM17 RMM18 RMM19 RMM24 RMM26 RMM27 RMM29	2	3	6
					Equipment in proximity	Fire propagation	2	4	8		1	4	4

Hazard and Risk Identification							Pre-mitigation Assessment			Risk Mitigation Methods	Post-mitigation Assessment		
Item	Hazard	Element	Cause	Dangerous Occurrence	Dangerous Situation	Undesirable Event	Probability	Severity	Risk Rating	Risk Mitigation Methods	Probability	Severity	Risk Rating
			the external environment							RMM30 RMM31			
3	High pressure	Cell	Thermal Runaway (the cell can reach thermal runaway in case of abnormal conditions such as: cell over charge, charge after an over discharge, external short circuit on cell/module, internal short circuit on cell/module, etc)	Battery fire	People in proximity	Burn / loss of life	2	3	6	RMM01 RMM02 RMM03 RMM04 RMM05 RMM07 RMM14 RMM16 RMM17 RMM18 RMM19 RMM22 RMM23 RMM24 RMM26 RMM31 RMM32 RMM38	1	3	3
					Equipment in proximity	Fire propagation	2	4	8		1	4	4

Hazard and Risk Identification							Pre-mitigation Assessment			Risk Mitigation Methods	Post-mitigation Assessment		
Item	**Hazard**	**Element**	**Cause**	**Dangerous Occurrence**	**Dangerous Situation**	**Undesirable Event**	**Probability**	**Severity**	**Risk Rating**	**Risk Mitigation Methods**	**Probability**	**Severity**	**Risk Rating**
		BESS enclosure	Thermal runaway propagation inside the BESS enclosure or operation of gaseous fire extinguishing system	Pressure rise in the container due to fire propagation or gaseous fire extinguishant release	-	BESS enclosure over pressure	1	4	4	RMM01 RMM04 RMM05 RMM07 RMM14 RMM16 RMM17 RMM18 RMM19 RMM22 RMM23 RMM24 RMM26 RMM31 RMM32 RMM38	1	4	4
4	Overheat	Cell	Bad Connections, fault in cell	Battery fire	People in proximity	Burns / loss of life	4	3	12	RMM01 RMM02 RMM03 RMM04 RMM05 RMM06 RMM07 RMM08	2	3	6
					Equipment in proximity	Fire propagation	4	4	16		2	3	6

Hazard and Risk Identification							Pre-mitigation Assessment			Risk Mitigation Methods	Post-mitigation Assessment		
Item	Hazard	Element	Cause	Dangerous Occurrence	Dangerous Situation	Undesirable Event	Probability	Severity	Risk Rating	Risk Mitigation Methods	Probability	Severity	Risk Rating
										RMM10 RMM14 RMM16 RMM17 RMM18 RMM19 RMM20 RMM22 RMM23 RMM24 RMM26 RMM31 RMM32 RMM38			
		Battery system	Bad battery cooling, high number of cycling or failure or the heating / cooling system	Battery fire	People in proximity	Burns / loss of life	2	3	6	RMM01 RMM04 RMM05 RMM12 RMM16 RMM17 RMM18 RMM19 RMM20 RMM21	1	3	3
					Equipment in proximity	Fire propagation	2	4	8		1	4	4

Item	Hazard	Element	Cause	Dangerous Occurrence	Dangerous Situation	Undesirable Event	Pre-mitigation Assessment: Probability	Pre-mitigation Assessment: Severity	Pre-mitigation Assessment: Risk Rating	Risk Mitigation Methods	Post-mitigation Assessment: Probability	Post-mitigation Assessment: Severity	Post-mitigation Assessment: Risk Rating
										RMM22 RMM23 RMM31 RMM32 RMM33 RMM38			
5	Over charge	Cell	Failure in Battery Management	Battery fire	People in proximity	Burns / loss of life	3	3	9	RMM01 RMM02 RMM03 RMM10 RMM11 RMM12 RMM14 RMM17 RMM18 RMM19 RMM24 RMM26 RMM27 RMM29 RMM30 RMM31	2	3	6
					Equipment in proximity	Fire propagation	4	4	16		2	3	6

Hazard and Risk Identification							Pre-mitigation Assessment			Risk Mitigation Methods	Post-mitigation Assessment		
Item	Hazard	Element	Cause	Dangerous Occurrence	Dangerous Situation	Undesirable Event	Probability	Severity	Risk Rating	Risk Mitigation Methods	Probability	Severity	Risk Rating
6	Forced discharge or recharge of an over discharged cell	Module or cell	Failure in Battery Management	Battery fire	People in proximity	Burns / loss of life	3	3	9	RMM01 RMM02 RMM03 RMM10 RMM11 RMM12 RMM14 RMM17 RMM18 RMM19 RMM24 RMM26 RMM27 RMM29 RMM30 RMM31	2	3	6
					Equipment in proximity	Fire propagation	3	4	12		1	4	4
7	Internal short circuit	Cell	Production failure that results in internal short circuit with possible thermal runaway	Battery fire	People in proximity	Burns / loss of life	3	3	9	RMM01 RMM02 RMM03 RMM10 RMM14 RMM17 RMM18 RMM19	1	3	3
					Equipment in proximity	Fire propagation	3	4	12		1	4	4

Item	Hazard	Element	Cause	Dangerous Occurrence	Dangerous Situation	Undesirable Event	Pre-mitigation Assessment: Probability	Pre-mitigation Assessment: Severity	Pre-mitigation Assessment: Risk Rating	Risk Mitigation Methods	Post-mitigation Assessment: Probability	Post-mitigation Assessment: Severity	Post-mitigation Assessment: Risk Rating
										RMM24 RMM26 RMM27 RMM29 RMM30 RMM31			
		Module	Module internal short circuit (equivalent to a cell external short)	Battery fire	People in proximity	Burns / loss of life	3	3	9	RMM01 RMM03	1	3	3
					Equipment in proximity	Fire propagation	3	4	12	RMM08 RMM10 RMM14 RMM17 RMM18 RMM19 RMM24 RMM26 RMM27 RMM29 RMM30 RMM31	2	3	6
		Rack	Rack internal short circuit is	Battery fire	People in proximity	Burns / loss of life	2	3	6	RMM01 RMM03	1	3	3

Item	Hazard	Element	Cause	Dangerous Occurrence	Dangerous Situation	Undesirable Event	Pre-mitigation Assessment: Probability	Pre-mitigation Assessment: Severity	Pre-mitigation Assessment: Risk Rating	Risk Mitigation Methods	Post-mitigation Assessment: Probability	Post-mitigation Assessment: Severity	Post-mitigation Assessment: Risk Rating
			equivalent to a module external short		Equipment in proximity	Fire propagation	2	4	8	RMM08 RMM10 RMM14 RMM17 RMM18 RMM19 RMM24 RMM26 RMM27 RMM29 RMM30 RMM31	1	4	4
		Battery system	A battery system internal short is equivalent to a module external or internal short or a rack external or internal short	Battery fire	People in proximity	Burns / loss of life	2	3	6	RMM01 RMM03	1	3	3
					Equipment in proximity	Fire propagation	2	4	8	RMM08 RMM10 RMM14 RMM17 RMM18 RMM19 RMM24 RMM26 RMM27 RMM29	1	4	4

Hazard and Risk Identification							Pre-mitigation Assessment			Risk Mitigation Methods	Post-mitigation Assessment		
Item	Hazard	Element	Cause	Dangerous Occurrence	Dangerous Situation	Undesirable Event	Probability	Severity	Risk Rating	Risk Mitigation Methods	Probability	Severity	Risk Rating
										RMM30 RMM31			
8	External short circuit	Cell	Bus bar or another electronic component in short circuit	Battery fire	People in proximity	Burns / loss of life	3	3	9	RMM01 RMM03	1	3	3
					Equipment in proximity	Fire propagation	3	4	12	RMM08 RMM10 RMM14 RMM17 RMM18 RMM19 RMM24 RMM26 RMM27 RMM29 RMM30 RMM31	2	3	6
		Module	External short circuit between one or several modules caused by bad assembly	Battery fire	People in proximity	Burns / loss of life	2	3	6	RMM01 RMM03	1	3	3
					Equipment in proximity	Fire propagation	2	4	8	RMM08 RMM10 RMM14 RMM17 RMM18	1	4	4

Hazard and Risk Identification							Pre-mitigation Assessment			Risk Mitigation Methods	Post-mitigation Assessment		
Item	Hazard	Element	Cause	Dangerous Occurrence	Dangerous Situation	Undesirable Event	Probability	Severity	Risk Rating	Risk Mitigation Methods	Probability	Severity	Risk Rating
			or short circuit on bus bar							RMM19 RMM24 RMM26 RMM27 RMM29 RMM30 RMM31			
			Bad assembly or a short circuit on the Battery Management Module	Battery fire	People in proximity	Burns / loss of life	2	3	6	RMM01 RMM03	1	3	3
					Equipment in proximity	Fire propagation	2	4	8	RMM08 RMM10 RMM14 RMM17 RMM18 RMM19 RMM24 RMM26 RMM27 RMM29 RMM30 RMM31	1	4	4
9	Fire propagation	Battery system	Thermal Runaway (the	Battery fire or explosion	People in proximity	Burns / loss of life	3	4	12	RMM01 RMM17	2	4	6

Item	Hazard	Element	Cause	Dangerous Occurrence	Dangerous Situation	Undesirable Event	Pre-mitigation Assessment: Probability	Pre-mitigation Assessment: Severity	Pre-mitigation Assessment: Risk Rating	Risk Mitigation Methods	Post-mitigation Assessment: Probability	Post-mitigation Assessment: Severity	Post-mitigation Assessment: Risk Rating
	in the BESS enclosure		cell can reach thermal runaway in case of abnormal conditions such as: cell over charge, charge after an over discharge, external short circuit on cell/module, internal short circuit on cell/module, etc).		Equipment in proximity	Fire propagation	3	4	12	RMM18 RMM19 RMM24 RMM26 RMM27 RMM29 RMM30 RMM31	2	3	6
			Automatic suppression system failure	Battery fire	People in proximity	Burns / loss of life	2	4	8	RMM01 RMM17 RMM18-hydrants RMM19 RMM24	1	3	3
					Equipment in proximity	Fire propagation	2	4	8		1	4	4

Hazard and Risk Identification							Pre-mitigation Assessment			Risk Mitigation Methods	Post-mitigation Assessment		
Item	Hazard	Element	Cause	Dangerous Occurrence	Dangerous Situation	Undesirable Event	Probability	Severity	Risk Rating	Risk Mitigation Methods	Probability	Severity	Risk Rating
										RMM26 RMM27 RMM29 RMM30 RMM31			
10	Shock or drop	Battery system	Shock against a heavy object or drop	Battery fire	People in proximity	Burns / loss of life	3	3	9	RMM01 RMM06 RMM09 RMM17 RMM18 RMM19 RMM20 RMM22 RMM23 RMM24 RMM26 RMM28 RMM29 RMM31	1	3	3
					Equipment in proximity	Fire propagation	3	4	12		2	3	6
11	Sharp or cutting objects	Battery system	Shock against a sharp object	Battery fire	People in proximity	Burns / loss of life	3	3	9	RMM01 RMM06 RMM09 RMM17	1	3	3
					Equipment in proximity	Fire propagation	3	4	12		2	3	6

Hazard and Risk Identification							Pre-mitigation Assessment			Risk Mitigation Methods	Post-mitigation Assessment		
Item	Hazard	Element	Cause	Dangerous Occurrence	Dangerous Situation	Undesirable Event	Probability	Severity	Risk Rating	Risk Mitigation Methods	Probability	Severity	Risk Rating
										RMM18 RMM19 RMM20 RMM22 RMM23 RMM24 RMM26 RMM28 RMM29 RMM31			
12	High voltage	Battery system	High voltage from external or failure in charge.	Battery fire	People in proximity	Burns / loss of life	3	3	9	RMM01 RMM02 RMM03 RMM06 RMM08 RMM09 RMM10 RMM11 RMM14 RMM17 RMM18 RMM19 RMM20 RMM22	2	3	6
					Equipment in proximity	Fire propagation	3	4	12		1	4	4

Item	Hazard	Element	Cause	Dangerous Occurrence	Dangerous Situation	Undesirable Event	Pre-mitigation Assessment: Probability	Pre-mitigation Assessment: Severity	Pre-mitigation Assessment: Risk Rating	Risk Mitigation Methods	Post-mitigation Assessment: Probability	Post-mitigation Assessment: Severity	Post-mitigation Assessment: Risk Rating
										RMM23 RMM24 RMM26 RMM28 RMM29 RMM31 RMM37			
13	High current	Battery system	High current from external or failure in charger or an external short circuit or overload	Battery fire	People in proximity	Burns / loss of life	3	3	9	RMM01 RMM02 RMM03 RMM06 RMM08 RMM09 RMM10 RMM11 RMM14 RMM17 RMM18 RMM19 RMM20 RMM22 RMM23 RMM24 RMM26	2	3	6
					Equipment in proximity	Fire propagation	3	4	12		1	4	4

Hazard and Risk Identification							Pre-mitigation Assessment			Risk Mitigation Methods	Post-mitigation Assessment		
Item	Hazard	Element	Cause	Dangerous Occurrence	Dangerous Situation	Undesirable Event	Probability	Severity	Risk Rating	Risk Mitigation Methods	Probability	Severity	Risk Rating
										RMM28 RMM29 RMM31 RMM37			
14	Electromagnetic radiation	Electronic board	Electromagnetic form surrounding environment or external sources	Battery fire	People in proximity	Burns / loss of life	3	3	9	RMM01 RMM02 RMM03 RMM06 RMM09 RMM10 RMM14 RMM17 RMM18 RMM19 RMM20 RMM22 RMM23 RMM24 RMM26 RMM28 RMM29 RMM31 RMM37	1	3	3
					Equipment in proximity	Fire propagation	3	4	12		1	4	4

Hazard and Risk Identification							Pre-mitigation Assessment			Risk Mitigation Methods	Post-mitigation Assessment		
Item	Hazard	Element	Cause	Dangerous Occurrence	Dangerous Situation	Undesirable Event	Probability	Severity	Risk Rating	Risk Mitigation Methods	Probability	Severity	Risk Rating
15	Sand and dust	BESS enclosure	Dust particles, due to rural location, entering the BESS container and causing short circuit	Battery fire	People in proximity	Burns / loss of life	3	2	6	RMM17 RMM18 RMM19 RMM20 RMM22 RMM23 RMM24 RMM26 RMM29 RMM31 RMM33	2	2	4
					Equipment in proximity	Fire propagation	3	2	6		2	2	4
16	Lightning	Battery system	High current can damage the electronic components	Battery fire	Equipment in proximity	Fire propagation	3	4	12	RMM01 RMM02 RMM03 RMM06 RMM08 RMM09 RMM10 RMM11 RMM14 RMM17 RMM18 RMM19 RMM20	2	3	6

Hazard and Risk Identification							Pre-mitigation Assessment			Risk Mitigation Methods	Post-mitigation Assessment		
Item	Hazard	Element	Cause	Dangerous Occurrence	Dangerous Situation	Undesirable Event	Probability	Severity	Risk Rating	Risk Mitigation Methods	Probability	Severity	Risk Rating
										RMM22 RMM23 RMM24 RMM26 RMM29 RMM31 RMM33			
17	Firewater containment	BESS enclosure	Manual firefighting operations by fire and rescue services	Environment contamination	-	Environment contamination	2	4	8	RMM15	3	2	6
18	Insufficient access	Fire rescue service access	Delayed attendance of fire rescue services	Uncontrolled fire	People in proximity	Burns / loss of life	3	4	12	RMM24	2	2	4
					Equipment in proximity	Fire propagation	3	4	12		2	3	6
19	Water ingress in BESS container from flooding	Battery system, module or cell	Short circuit of battery system	Battery fire	People in proximity	Burns / loss of life	3	2	6	RMM20 RMM21 RMM29	1	1	2
					Equipment in proximity	Fire propagation	3	2	6		1	1	2

Item	Hazard	Element	Cause	Dangerous Occurrence	Dangerous Situation	Undesirable Event	Pre-mitigation Assessment: Probability	Pre-mitigation Assessment: Severity	Pre-mitigation Assessment: Risk Rating	Risk Mitigation Methods	Post-mitigation Assessment: Probability	Post-mitigation Assessment: Severity	Post-mitigation Assessment: Risk Rating
	following heavy rain fall												
20	Explosion originating from inside BESS enclosure	BESS enclosure	Accumulating hazardous gas	Explosion and fire	People in proximity	Burns / loss of life	3	4	12	RMM17 RMM22 RMM23 RMM30 RMM32 RMM38	1	4	4
					Equipment in proximity	Fire propagation	3	4	12		1	4	4
21	Explosion originating from outside BESS enclosure	BESS enclosure	Adjacent BESS explodes due to accumulation of gases	Explosion and fire	People in proximity	Burns / loss of life	3	4	12	RMM17 RMM22 RMM23 RMM29 RMM32 RMM38	2	3	6
					Equipment in proximity	Fire propagation	3	4	12		1	4	4
22	Re-ignition	Module or cell	Adjacent batteries got overheat during fire but not ignite and thermal runaway occurs days after.	Explosion and fire	People in proximity	Burns / loss of life	3	4	12	RMM13 RMM26	3	1	3
					Equipment in proximity	Fire propagation	3	4	12		3	1	3

Hazard and Risk Identification							Pre-mitigation Assessment			Risk Mitigation Methods	Post-mitigation Assessment		
Item	Hazard	Element	Cause	Dangerous Occurrence	Dangerous Situation	Undesirable Event	Probability	Severity	Risk Rating	Risk Mitigation Methods	Probability	Severity	Risk Rating
23	Outside fire	BESS container	BESS affected by non-related incident effects (Natural fire…)	Explosion and fire	People in proximity	Burns / loss of life	2	4	8	RMM01 RMM29 RMM33	2	2	4
					Equipment in proximity	Fire propagation	2	4	8		2	2	4

B.6 Maintenance an Inspection Stages

Mitigation methods described before for the other stages in battery life shall apply to risks arising during the maintenance phase (use of extinguishing equipment, detection, drainage, etc.), in addition to maintenance specific measures.

Table A-6: Maintenance and Inspections Stages Hazard and Risk Mitigations (Ref. 12)

Hazard and Risk Identification							Pre-mitigation Assessment			Risk Mitigation Methods	Post-mitigation Assessment		
Item	Hazard	Element	Cause	Dangerous Occurrence	Dangerous Situation	Undesirable Event	Probability	Severity	Risk Rating	Risk Mitigation Methods	Probability	Severity	Risk Rating
1	Flammable substances	Cell	Electrolyte leakage and inflammation	Battery fire	People in proximity	Burns / loss of life	2	3	6	RMM01 RMM04 RMM05 RMM06 RMM09	1	3	3
					Equipment in proximity	Fire propagation	2	4	8		1	4	4
2	High temperature or Heat transfer source	Cell	Thermal Runaway (the cell can reach thermal runaway in case of abnormal conditions such as: cell over charge, charge after an over discharge, external short circuit on cell/module, internal short	Battery fire	People in proximity	Burns / loss of life	3	3	9	RMM01 RMM02 RMM06 RMM09	1	3	3
					Equipment in proximity	Fire propagation	3	4	12		2	2	6

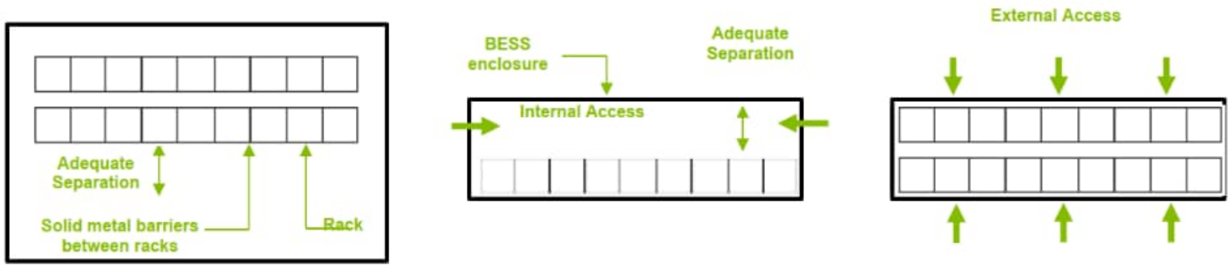
							Pre-mitigation Assessment			Risk Mitigation Methods	Post-mitigation Assessment		
Item	**Hazard**	**Element**	**Cause**	**Dangerous Occurrence**	**Dangerous Situation**	**Undesirable Event**	**Probability**	**Severity**	**Risk Rating**	**Risk Mitigation Methods**	**Probability**	**Severity**	**Risk Rating**
			circuit on cell/module, etc)										
		Battery System, Module or Cell	High temperature induced by the environment (fire, external heat source) or heat radiation coming from the external environment	Battery fire	People in proximity	Burns / loss of life	2	3	6	RMM01 RMM06 RMM07 RMM09	1	3	3
					Equipment in proximity	Fire propagation	2	4	8		1	4	4
3	High pressure	Cell	Thermal Runaway (the cell can reach thermal runaway in case of abnormal conditions	Battery fire	People in proximity	Burn / loss of life	2	3	6	RMM01 RMM06 RMM09	1	3	3
					Equipment in proximity	Fire propagation	2	4	8		1	4	4

Hazard and Risk Identification							Pre-mitigation Assessment			Risk Mitigation Methods	Post-mitigation Assessment		
Item	Hazard	Element	Cause	Dangerous Occurrence	Dangerous Situation	Undesirable Event	Probability	Severity	Risk Rating	Risk Mitigation Methods	Probability	Severity	Risk Rating
			such as: cell over charge, charge after an over discharge, external short circuit on cell/module, internal short circuit on cell/module, etc)										
4	Shock or drop	Battery system, Module or Cell	Shock against a heavy object or drop	Battery fire	People in proximity	Burns / loss of life	4	3	12	RMM01 RMM06 RMM09	2	3	6
					Equipment in proximity	Fire propagation	4	4	16		2	3	6
5	Sharp or cutting objects	Battery system, Module or Cell	Impact against a heavy object	Battery fire	People in proximity	Burns / loss of life	4	3	12	RMM01 RMM06 RMM09	2	3	6
					Equipment in proximity	Fire propagation	4	4	16		2	3	6

Appendix C Mitigation Measures

Table A-7: Proposed List of Risk Mitigation Methods (Ref.12)

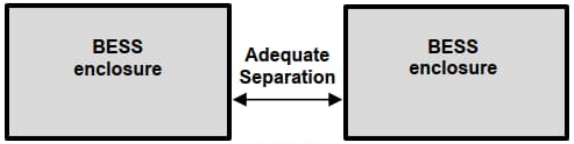
Risk Mitigation Method	Description	Action
RMM01	Implement thermal barriers between cells or provide adequate separation to limit propagation within battery module during thermal runaway. Implement thermal barriers (EI) between battery modules or provide adequate separation to limit fire contamination outside the battery modules. The module construction and assembly shall be solid to minimise internal damage arising from drop or shock. Provide thermal barriers to separate switchgear and battery module areas within BESS enclosure in accordance with FM Global Datasheet 5-33. Racks within the BESS enclosure shall be installed either in single row or double row arrangements with racks back-to-back. Each rack will be separated by non-combustible thermal barriers (EI) to prevent heat transfer. Racks will also have adequate separation from the perimeter walls and between the aisle faces of adjacent racks.	Manufacturer



	Each BESS container will have non-combustible walls, floor and ceiling, and will have a minimum internal fire resistance rating of 1-2 hours. 6 metre separation will be observed unless UL 9540A unit or installation level testing and / or 3rd Party Fire & Explosion testing has demonstrated through heat flux data that distances can	

be reduced. An independent Fire Protection Engineer specialising in BESS will review all UL 9540A test results and any additional fire and explosion test data which has been provided. 6 metre BESS container spacing provision will be observed for site indicative planning purposes.

Cable and pipe penetrations into each BESS enclosure will be sealed and provided with rating equal to that required for the BESS enclosure.



Option 1

RMM02	Protective devices and electric circuits shall be rated in accordance with the safety requirements of BS EN IEC 62933-5 to protect electric circuits against short-circuits.	Manufacturer
RMM03	Use an electronic board design which avoids fire contamination on cell in case of short circuit on the board.	Manufacturer
RMM04	Find out, according to the empty space existing in the battery container, the air leak and nature of gas generated, the acceptability of the substances released in case or thermal runaway, venting or leaking cell. Calculate the maximum number of cells below which the concentration of flammable substances is not hazardous.	Manufacturer
RMM05	The cell size must be enough to create enough air renewal and stay below the hazardous concentration of flammable substances threshold.	Manufacturer
RMM06	The maintenance and installation operators must be qualified, strictly follow the maintenance and installation protocols and wear individual protective equipment.	Developer Installer Operator
RMM07	The maximum allowable operating temperature set by the manufacturer must be higher than the highest anticipated temperature of the environment internal external to the battery system and modules. In addition, Li-ion batteries shall incorporate a pressure relief system.	Manufacturer
RMM08	During assembling phases (cells and modules) verify if each connection is correct.	Manufacturer

RMM09	A maintenance plan shall be planned and kept across all stages of the battery lifecycle. Operators shall strictly follow the maintenance and user manuals.	Operator
RMM10	Implement an electronic protection against cell overheat. A Battery Management System (BMS) will provide the following Safety Functions: - High cell temperature trip will isolate the module or rack when detecting cell temperatures that exceed limits. - Thermal runaway trip will isolate the battery system when a cell is detected to have entered a thermal runaway condition. - Rack switch fail-to-trip will disconnect the rack if any failure is detected. Inverter / charger fail-to-trip will isolate the BESS enclosure at the breaker if the inverter / charger fails to respond to a trip command. - Inverter/charger fall-to-trip (supervisor level): This function initiates a trip command to an upstream breaker to isolate the ESS if the inverter/charger fails to respond to a trip command. The "supervisor" control system controls the entire system, including the combination of racks, the environmental support systems, and the charging/discharging status. The supervisor level should isolate the ESS if the inverter/charger fails to trip on an appropriate signal, or if communication is disrupted between the inverter/charger and the supervisor control.	Manufacturer
RMM11	Implement an electronic protection against overcharge on cell (to stop charge/discharge if a cell reaches the maximum voltage value).	Manufacturer
RMM12	Implement an electronic protection against cell charge after an over discharge	Manufacturer
RMM13	Implement on the battery an electronic protection against overheating on battery which may lead to a battery fire or thermal runaway. The electronic protection will consist of high cell temperature trip which will isolate the module or rack when detecting cell temperatures that exceed limits. A thermal runaway trip will isolate the battery system when a cell is detected to have entered a thermal runaway condition. Rack switch fail-to-trip will disconnect the rack if any failure is detected. Inverter / charger fail-to-trip will isolate the BESS container at the breaker if the inverter / charger fails to respond to a trip command. This will provide additional layers of protection and protection features will be fully compliant with NFPA 855 (2023) stipulations. A post-incident recovery plan shall be developed that addresses the potential for reignition of battery systems as well as removal and disposal of damaged equipment. A fire watch should be present until all potentially damaged ESS equipment containing Li-ion batteries is removed from the area following a fire event.	Developer

RMM14	Implement on the battery an electronic and electrical protection against short circuit and overload to avoid fires in accordance with BS EN IEC 62933-5.	Manufacturer
RMM15	Each BESS enclosure will be provided with a sump and drain valve to allow extraction of contaminated fire water and / or electrolyte spill without having to open the door of the enclosure and will prevent contamination of surrounding environment with the extracted liquid being taken off site for treatment (Ref. 15). The sump construction will be designed to allow for chemical resistance of electrolyte which may be released from a battery fire and have capacity to hold the total volume of electrolyte plus a 10% safety factor. The sump will encompass the entire floor area of the BESS enclosure with a mentis grating type floor to allow spilled electrolyte to drain without pooling near other racks. An extra layer of protection will be provided for containment of firewater external of the BESS enclosure in case of rupture or overflow of contaminants. The external floor surface surrounding each BESS container will be lined with an impermeable membrane. The drainage strategy will include for bunded holding lagoons or sunken water capture tanks within the BESS area which will contain the firewater runoff. The firewater will be tested post incident and if contaminated, will be tinkered off site to a suitable waste facility for treatment. The approach shall be accepted by the Environmental Agency.	Developer Installer
RMM16	The BESS must be fully UL 9540 compliant (Energy Storage System Listing), which includes UL 1741 standard for inverters + UL 1973 standard for stationary batteries, as per NFPA 855. In addition, the battery system and the fire protection system must be tested according to UL 9540A 4th edition (2020).	Manufacturer Developer Installer
RMM17	Install a fire detection and alarm system using coincidence detection in accordance with BS 7273-1 and NFPA 855 (2023) guidelines. The BESS detection system will comply with NFPA 855 (2023) and NFPA 69, this means that smoke, fire and gas detection equipment will be installed. New BESS multi-sensor equipment in development which measures combinations of air temperature, hydrogen, VOCs, overpressure, shock & vibration, and moisture ingress will also be considered if fully tested with the BESS design. The gas detection system will operate in accordance with NFPA 69 explosion prevention standards and additional carbon monoxide detection will be installed, an external BESS beacon and audible alert facility will be linked to the gas detection equipment to provide a warning to site operatives and first responders. The BESS detection system will be reviewed and signed off by an independent Fire Protection Engineer at the detailed design stage, alert communications and protocols will be agreed with FRS and implemented into the Emergency Response Plan (ERP).	Developer Installer

RMM18	The Fire and Rescue Service (FRS) preferred system for the protection of the BESS containers is a water drenching system. An automatic sprinkler system designed to BS EN 12845 and FM Global Datasheet 5-33 is proposed and will be put forward as design options and discussed with the FRS at detailed design stage. The selected fire suppression system will ideally be tested with the BESS system at UL 9540A unit and / or installation level and be fully compliant with UL 9540A fire and explosion prevention objectives. An independent Fire Protection Engineer specialising in BESS will review all UL 9540A test results and any additional fire and explosion test data which has been provided	Developer Installer
RMM19	Due to the remote location of the BESS compounds and limited availability and supply of water, the following NFCC guidelines will be incorporated into the indicative site design. As a minimum, it is recommended by the NFCC that hydrant supplies for boundary cooling purposes should be located close to BESS containers (but considering safe access in the event of a fire) and should be capable of delivering no less than 1,900 litres per minute for at least 2 hours. The FRS may wish to increase this requirement dependant on location and their ability to bring supplementary supplies to site in a timely fashion. Any static water storage tanks (above or below ground) designed to be used for firefighting must be located at least 10 metres away from any BESS container/cabinet. They must be clearly marked with appropriate signage. They must be easily accessible to FRS vehicles and their siting should be considered as part of a risk assessed approach that considers potential fire development/impacts. Outlets and connections should be agreed with the local FRS. Any outlets and hard suction points should be protected from mechanical damage (e.g. through use of bollards). If there are battery storage areas with fire protection, as indicated in RMM36, it shall be checked that the calculated volume for the fire tanks of the BESS and hydrants is sufficient to cover the supply requirements for these storage areas.	Developer Installer
RMM20	The BESS container shall be installed by third party certified and qualified installer. The BESS enclosure will be UL 9540 certificated. Ingress protection testing of BESS enclosures is conducted under UL 9540 and / or IEC62933-5-2 certification of any BESS system. Typical BESS enclosure ingress protection levels are IP 55	Manufacturer Developer Installer

	/ NEMA 3R or IP 66 / NEMA 4. IEC Factory Acceptance Testing or a 3rd party manufacturing audit will be obtained to assure the supplied BESS enclosures comply with the requisite certified ingress protection levels. IP ratings of BESS containers will be shared with the FRS at the detailed design stage so that risks associated with boundary cooling can be understood and implemented into the Emergency Response Plan (ERP). Potential boundary cooling water ingress points such as HVAC systems and deflagration vents will need to be considered as part of an incident response strategy	
RMM21	A heating and cooling system will be provided on each BESS enclosure to prevent the battery system experiencing overheating or freezing environments. Additional electric heater may be provided for humidity control. Monitoring will be provided by the EMS/BMS. In the event of a heating / cooling failure being detected, the enclosure will be automatically switched into standby mode, preventing the battery modules from charging or discharging, and sending a notification to the maintenance team for action. This reduces the risk of temperature rise within the modules and allows time for a repair to take place on site before the system is restarted. The heating and cooling system will be subject to routing maintenance inspections to ensure the risk of failure is minimised.	Installer Operator
RMM22	The BESS container will be designed to withstand overpressures generated by the battery system during thermal runaway. An explosion prevention system to NFPA 69 standards and / or explosion protection system to NFPA 68 and EN 14797 standards will be integrated. If BESS design only integrates explosion protection systems i.e. deflagration panels, then performance must be validated through BESS free burn testing and requisite pressure testing required by NFPA and EN standards. Further, the BESS container will have completed UL 9540A unit and / or installation testing or large-scale 3rd Party Fire & Explosion testing without pressure waves occurring or shrapnel being ejected. An independent Fire Protection Engineer specialising in BESS will review all UL 9540A test results and any additional fire and explosion test data which has been provided.	Manufacturer Developer Installer
RMM23	Permanent operating mechanical ventilation with a rate of at least 0.3 $m^3/min/m^2$ will be provided with air flow monitoring system and alarm to prevent concentration of hazardous gas. . Gas exhaust / ventilation system performance requirement will be defined through 3rd Party testing, UL 9540A unit / installation testing and NFPA 69 (Explosion prevention) standard. An independent Fire Protection Engineer specialising in BESS will review all UL 9540A test results and any additional fire and explosion test data which has been provided.	Developer Installer
RMM24	Access will be provided for pump appliances to manoeuvre within the Scheme with full access to all BESS enclosures. The structures and enclosures within the Scheme are expected to be lower than 6 m height and	Developer

	high reach appliances will therefore not be required. The access routes will be structurally designed to allow a minimum carrying capacity of 15 tonnes (Ref. 166) for hardstanding of pumping appliances. An alternative site access point shall be provided and maintained to enable pump appliances to approach from an up-wind direction.	
RMM25	During transport, preventive actions shall be taken into account to avoid the risks of shock, vibration... etc, as stated in UN Transport Standards and IEC 62281. The design of the packages in which the BESS components are transported shall follow the UN transport regulations.	Manufacturer Installer
RMM26	If damage to a battery is suspected at any point in its cycle, the damaged material will be quarantined to limit the effects of thermal runaway over the next few days. The area shall be protected by fire control and suppression. For those devices for which there is no evidence of damage, they will also be kept isolated, and the charging stage will be monitored to know the internal status (charging failures, time delays, etc…) and to rule out possible failure.	Manufacturer Installer Operators
RMM27	A non-flammable electrolyte shall be selected.	Manufacturer
RMM28	The enclosures shall be designed to reduce tripping, falling and other hazards that may affect the employees when performing installation, maintenance or decommission activities, and may also result in damage to BESS (such as risks of shock, drop, cutting...etc.).	Manufacturer Developer Installer
RMM29	Mitigation measures for risks from hazards outside the BESS shall be implemented. In order to protect the BESS enclosures from exterior risks, they shall be provided with impact protection to prevent damage to battery enclosures by vehicles or construction equipment, as well as including Damage Limiting Constructions (DLC). The Scheme shall be provided with enclosed wiring and buried cabling, except where required to be above-ground for grid connection, to protect from damage and prevent a fire or cable failure from spreading to any of the battery systems. The BESS areas shall be located so that the site entrance and any fire water tanks are not aligned to the prevailing wind direction so that they are less likely to be impacted by smoke in the event of fire. A vegetation-free perimeter shall be included around BEES areas acting as a firebreak (facilitating access to fire roads). .	Manufacturer Developer Installer
RMM30	To provide early identification of the conditions inside the BESS to the fire service, access to information (e.g., temperature and gases) shall be provided from outside the containers, mitigating the risk of deflagration from opening the enclosures.	Manufacturer Developer Installer

RMM31	A supplementary CO_2 suppression system can be incorporated, in addition to the water-based system, to deploy before the water sprinklers and decrease the level of oxygen inside the container (<15%), in order to stop electrical fires and reduce the risk of gas explosion and backdraft.	Manufacturer Developer
RMM32	At or near ceiling, exhaust air should be removed through a system of blowers, fans, and ductwork terminating outdoors away from air inlets, doorways, and other openings. Ductwork should be constructed of non-combustible materials. The exhaust system shall ensure that the combustible concentration (H_2, HCs...) is maintained at or below 25 percent of the LFL for all foreseeable variations in operating conditions and material loading.	Manufacturer Developer
RMM33	The ventilation system shall be provided with suitable ember protection to prevent embers from penetrating BESS enclosures (HVAC, gas exhaust, deflagration panels).	Manufacturer Developer
RMM34	The manufacturer of the batteries and BESS shall have an appropriate certificate to ensure the quality of the products as well as compliance with an approved quality control procedure. In other to minimize battery defects, among other measures, batteries shall be manufactured in controlled dry rooms.	Manufacturer Developer
RMM35	The storage sites shall be safe places with restricted access to reduce the probability of shock or other external aggression occurrence. During the storage phase, the temperature of the environment external to the battery system and modules shall be lower than the maximum recommended by the manufacturer. Storage spaces shall not exceed the maximum dimensions established by the standards (NFPA 855).	Manufacturer Developer Installer
RMM36	Storage of Li-ion sites shall be protected by an Automatic sprinkler system with ESFR sprinklers, working at K320 L/min/bar$^{1/2}$ sprinklers @ 2.4 bar (K22.4 @ 35 psi) or K360 L/min/bar$^{1/2}$ sprinklers @ 2.4 bar (K25.2 @ 35 psi). The water flow demand should allow for 12 sprinkler operations. Installed in accordance with FM Global Property Loss Prevention Data Sheet 2-0. It is recommended that the storage racks have a separate shelf arrangement with no ventilated space between shelves (see ST2 configuration in standard EN 12845) to limit propagation between the batteries.	Manufacturer Developer Installer
RMM37	DC ground fault protection shall be provided for grounded battery systems. For ungrounded battery systems, DC ground fault monitoring with alarming function shall be provided. Have the alarm routed to a constantly attended location or specific operations personnel	Manufacturer Installer
RMM38	The ventilation and gas extraction system shall also be designed to exhaust smoke in case of fire inside the BESS.	Manufacturer Developer

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