Riskcon engineering

Fire Safety Study

Dugald River Wind Farm and BESS Project, QLD

Environmental Resources Management Australia Pty Ltd
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Environmental Resources Management Australia Pty Ltd

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Executive Summary

Background

Environmental Resources Management Australia Pty Ltd (ERM) is assisting MMG Dugald River Pty Ltd (MMG) in developing a Wind Farm comprised of a maximum 24 wind turbine generators and is well underway in the application process. MMG are also adding a Battery Energy Storage System (BESS) Project to store excess energy. The Wind Farm and associated BESS Project are located adjacent to the Dugald River Mine, although it is not directly attributed to the Mine. The Mine will benefit from the renewable energy Project.

The proposed BESS component will proceed in two stages: Stage 1 will consist of 18 BESS units and 9 Medium Voltage Power Stations (MVPSs) connections via a 220/33 kV switchyard to an existing substation. Stage 2 proposes to expand the BESS component to a total of 48 BESS units and 24 MVPSs, with an additional 220/33 kV switchyard connecting to the existing substation. The BESS component will be comprised of BESS units, electrical transformers and inverters, electrical cabling, telecommunications equipment, an electrical control room, connection to sub-station and perimeter fencing.

ERM is gathering the required documentation for BESS facilities according to the recently published State Code 27 by the State Assessment and Referral Agency (SARA) on MMG's behalf, which includes a Risk Management Assessment Report (RMAR), a Fire Safety Study (FSS) and an Emergency Management Plan (EMP). This document represents the FSS required as per PO2-4 of State Code 27. The FSS uses the methodology proposed by the Hazardous Industry Planning Advisory Paper (HIPAP) No. 2 (Ref. [1]). While it is acknowledged that this paper is from the New South Wales (NSW) Department of Planning, Housing and Infrastructure (DPHI), it is nevertheless consulted in the absence of QLD guidelines. Due to BESS being an emerging power systems facility, there is little regulation that directly aligns with the development of these facilities within Queensland. FRNSW have developed a comprehensive Fire Safety Guideline *Technical Information – Large-scale external lithium-ion battery energy storage systems – Fire safety study considerations* (Ref. [2]). This document will be consulted to further the safety provisions of the facility. In addition, the Electrical Safety Office Code of Practice (Ref. [3]) and The Best Practice Guide: Battery Storage Equipment 2018 (Ref. [4]) will also be considered in the assessment.

ERM, on behalf of MMG, has commissioned Riskcon Engineering Pty Ltd (Riskcon) to prepare the required documentation for the BESS component. This document represents the FSS for the Dugald River Mine BESS component.

Conclusions

An FSS was prepared for the proposed BESS component of the Dugald River Wind Farm and BESS Project located near the Dugald River Mine. The analysis performed in the FSS was based on credible fire scenarios to assess whether the protection measures at the site were adequate to combat the hazards associated with the quantities and types of commodities being stored. Based on the assessment, it was concluded that the designs and existing fire protection adequately managed the credible fire risks at the site.

Recommendations

Based on the analysis, the following recommendations have been made:

- All site personnel shall be inducted in site procedures and emergency response protocols relevant to their roles.
- All site personnel who require training must undergo formal training in the required procedures and emergency response protocols relevant to their role.
- Necessary personnel to provide first aid are to be trained in accordance with the QLD Code of Practice for first aid in workplaces 2021– high-risk workplaces (Ref. [5]).
- A team of site personnel are to be trained in the use of the water cart and first-attack firefighting methods.
- Site management to prepare and maintain operational procedures to minimise the number of hazardous incidents and accidents on site and to mitigate the consequences of incidents regarding the handling of dangerous goods and chemicals.
- A site Emergency Response Plan per the requirements of HIPAP No. 1 shall be prepared and shall include measures to advise neighbouring premises in the event of an emergency with potential offsite impacts.
- Dangerous Goods (DG) documentation shall be prepared as required by the Work Health and Safety Regulation 2011 to demonstrate the risks associated with the storage and handling of DGs has been assessed and minimised.
- Any DGs stored at the site shall be stored and handled in accordance with the Work Health and Safety Regulation 2011 and any applicable storage and handling standards.

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Abbreviations

Abbreviation	Description
ADG	Australian Dangerous Goods Code
AFAC	Australasian Fire and Emergency Service Authorities Council Limited
AS	Australian Standard
BESS	Battery Energy Storage System
BMM	Battery Management Module
CBD	Central Business District
CFD	Computational Fluid Dynamics
DA	Development Application
DGs	Dangerous Goods
DPHI	Department of Planning, Housing and Infrastructure
EMP	Emergency Management Plan
ERM	Environmental Resources Management Australia
FRNSW	Fire and Rescue New South Wales
FSS	Fire Safety Study
HIPAP	Hazardous Industry Planning Advisory Paper
ISO	International Organization for Standardization
LEL	Lower Explosive Limit
NSW	New South Wales
MVPS	Medium Voltage Power Station
PCU	Power Conversion Unit
QLD	Queensland
QFD	Queensland Fire Department
RFS	Rural Fire Service
RMAR	Risk Management Assessment Report
SARA	State Assessment and Referral Agency
SEP	Surface Emissive Power

1.0 Introduction

1.1 Background

Environmental Resources Management Australia Pty Ltd (ERM) is assisting MMG Dugald River Pty Ltd (MMG) in developing a Wind Farm comprised of a maximum 24 wind turbine generators and is well underway in the application process. MMG are also adding a Battery Energy Storage System (BESS) Project to store excess energy. The Wind Farm and associated BESS Project are located adjacent to the Dugald River Mine, although it is not directly attributed to the Mine. The Mine will benefit from the renewable energy Project.

The proposed BESS component will proceed in two stages: Stage 1 will consist of 18 BESS units and 9 Medium Voltage Power Stations (MVPSs) connections via a 220/33 kV switchyard to an existing substation. Stage 2 proposes to expand the BESS component to a total of 48 BESS units and 24 MVPSs, with an additional 220/33 kV switchyard connecting to the existing substation. The BESS component will be comprised of BESS units, electrical transformers and inverters, electrical cabling, telecommunications equipment, an electrical control room, connection to sub-station and perimeter fencing.

ERM is gathering the required documentation for BESS facilities according to the recently published State Code 27 by the State Assessment and Referral Agency (SARA) on MMG's behalf, which includes a Risk Management Assessment Report (RMAR), a Fire Safety Study (FSS) and an Emergency Management Plan (EMP). This document represents the FSS required as per PO2-4 of State Code 27. The FSS uses the methodology proposed by the Hazardous Industry Planning Advisory Paper (HIPAP) No. 2 (Ref. [1]). While it is acknowledged that this paper is from the New South Wales (NSW) Department of Planning, Housing and Infrastructure (DPHI), it is nevertheless consulted in the absence of QLD guidelines. Due to BESS being an emerging power systems facility, there is little regulation that directly aligns with the development of these facilities within Queensland. FRNSW have developed a comprehensive Fire Safety Guideline *Technical Information – Large-scale external lithium-ion battery energy storage systems – Fire safety study considerations* (Ref. [2]). This document will be consulted to further the safety provisions of the facility. In addition, the Electrical Safety Office Code of Practice (Ref. [3]) and The Best Practice Guide: Battery Storage Equipment 2018 (Ref. [4]) will also be considered in the assessment.

ERM, on behalf of MMG, has commissioned Riskcon Engineering Pty Ltd (Riskcon) to prepare the required documentation for the BESS component. This document represents the FSS for the Dugald River Mine BESS component.

1.2 Objectives

The objectives of the FSS are to:

- Review the site operations and Dangerous Goods (DG) storage for the potential to initiate or become involved in a fire, including flammable materials which may be present at the site.
- Identify heat radiation impacts from potential fire sources at the site and determine the potential impacts on the surrounding areas and the fire protection system, and
- Review the proposed fire safety features and determine the adequacy of the fire safety systems based on the postulated fires.

1.3 Scope of Services

The scope of work is for the preparation of an FSS for the Project to assess the potential hazards at the site to ensure the fire protection systems are commensurate with the identified hazards. This document follows the methodology recommended in HIPAP No.2 (Ref. [1]).

The FSS focuses on the storage of commodities associated with the new development at the site, in addition to the existing operations at the site, as required by HIPAP No. 2. A review of the following components of the FSS is within the scope of work:

- Determination of risk and consequences from fire or explosion scenarios throughout the Project.
- The preparation of a report on fire prevention, fire detection, fire alarm and fire suppression systems for the site.
- Firewater storage capacity for compliance with Australian Standards and Regulations.
- External fire hydrant configuration and locations.
- Recommendations based upon the study for implementation in the final design.

2.0 Methodology

2.1 Fire Safety Study Approach

The following methodology was used in the preparation of the FSS for the Project. The methodology is to follow items required by HIPAP No. 2 (Ref. [1]).

- The fire hazards associated with the Project were identified to determine whether any fire or explosion hazards may impact offsite or have the potential to escalate. Where fire hazards with the potential to impact offsite or escalate were identified, these were carried forward for consequence assessment.
- The heat radiation impacts or overpressure impacts (consequences) from each of the postulated incidents from the proposed equipment were then estimated, and potential impacts on surrounding areas assessed.
- Impacts of the fires from the proposed equipment were plotted on a layout plan of the proposed Project, to determine whether heat radiation impacts any critical areas (i.e. adjacent storage areas, fire services, safety systems, etc.) and whether such impact affected the ability of firefighters to respond to the postulated fire. The heat radiation impact from incidents at adjacent sites on the buildings and structures at the Project was then assessed against the maximum permissible levels in HIPAP No. 4 (Ref. [6]).
- The firefighting strategies were then assessed to determine whether these strategies require updating in light of the location of the proposed equipment and storage areas.
- The response times for Queensland Fire Department (QFD) in the immediate vicinity were assessed. In addition, further outlying QFD stations were included to provide a 'back-up plan' in the event that the closest fire brigades were unable to attend.
- A report was then developed for submission to the client and the regulatory authority.

In addition, the FRNSW Fire Safety Guideline *Technical Information – Large scale external lithium-ion battery energy storage systems – Fire safety study considerations*, (Ref. [2]) herein referred to as the 'FRNSW BESS Guideline', was reviewed as part of the preparation of the FSS coupled with the Electrical Safety Office Code of Practice Managing electrical risks in the workplace 2021 (Ref. [3]).

2.2 Limitations and Assumptions

In this instance, the FSS is developed based on applicable limitations and assumptions for the development which are listed as follows:

- The report is specifically limited to the project described in **Section 3.0** and the methodology and approach outlined in **Section 2.1**.
- The report is based on the information provided in the following documents, as well as external resources referenced (see **Section 10.0**):
  - BYD – MC Cube-T ESS Datasheet (Date: 04/04/2024)
  - SMA MV Power Station Datasheet (MVPS-S2-SC4xxxUP-DS-en-22 SMA) (Date: Undated)
  - MMG Dugald River Power Project Concept Design (BESS Option) – Drawing no. 3052-FPS-00-DEA-002 Rev(B) (Date: 10/09/2025)

- Cloncurry Shire Planning Scheme Version 2 (Date: 04/07/2017)

- The report does not provide guidance in respect of incidents that relate to sabotage or vandalism of fire safety systems.
- The assessment is limited to the objectives of the FSS as provided in the guidelines issued as HIPAP No. 2 (Ref. [1]) and does not consider property damage such as building and contents damage caused by fire, potential increased insurance liability and loss of business continuity.
- Malicious acts or arson with respect to fire ignition and safety systems are limited in nature and are outside the scope of this report. Such acts can potentially overwhelm fire safety systems and therefore further strategies such as security, housekeeping and management procedures may better mitigate such risks.
- This report is prepared in good faith and with due care for information purposes only and should not be relied upon as providing any warranty or guarantee that ignition or a fire will not occur.

3.0 Site Description

3.1 Site Location

The proposed site for the BESS component of the Dugald River Wind Farm and BESS Project is approximately 2 km East of the Dugald River Mine on Knapdale Range. **Figure 3-1** shows the regional location of the proposed site in far north Queensland, while **Figure 3-2** shows the proposed location relative to the Dugald River Mine site. **Figure 3-3** shows the conceptual BESS Layout with the existing substation. It is acknowledged that the designs are preliminary at this stage; however, any changes to the design are unlikely to be significant to the hazards present.

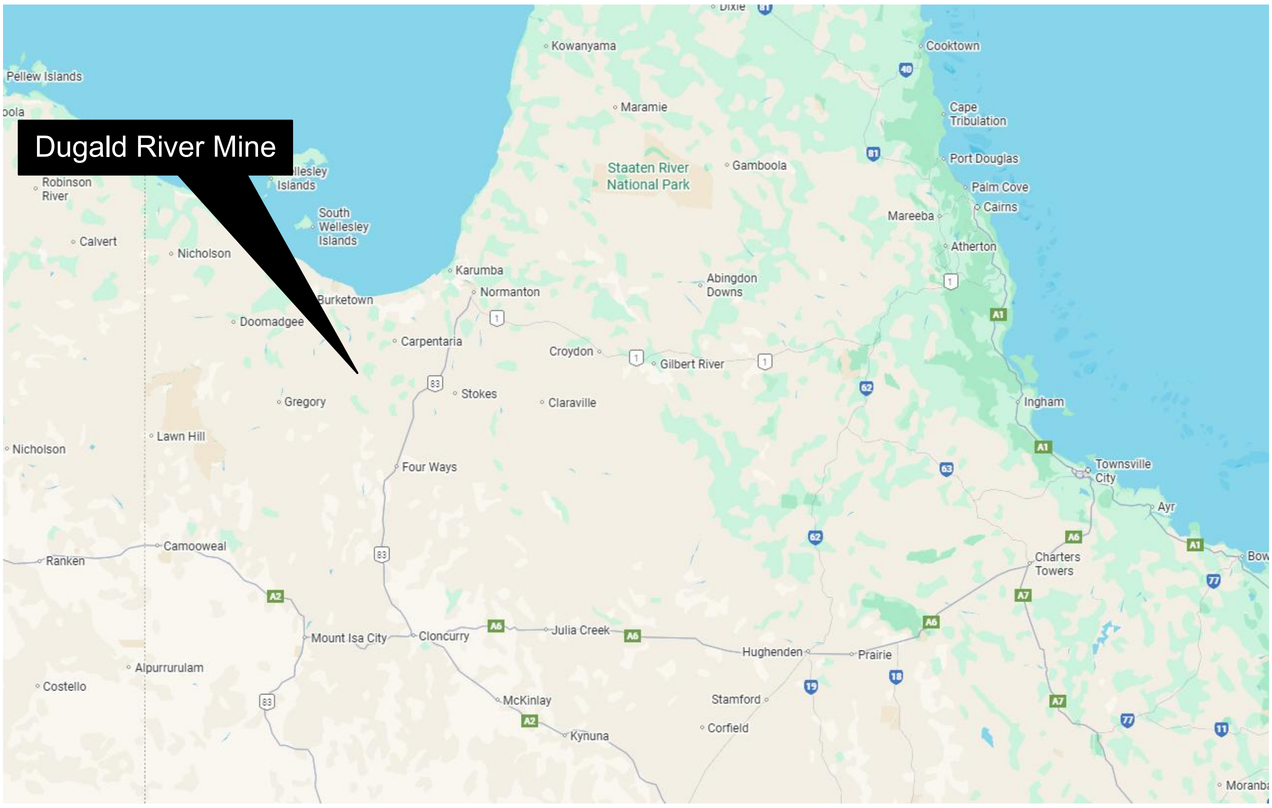


Figure 3-1: Site Location (Source – Google Maps)

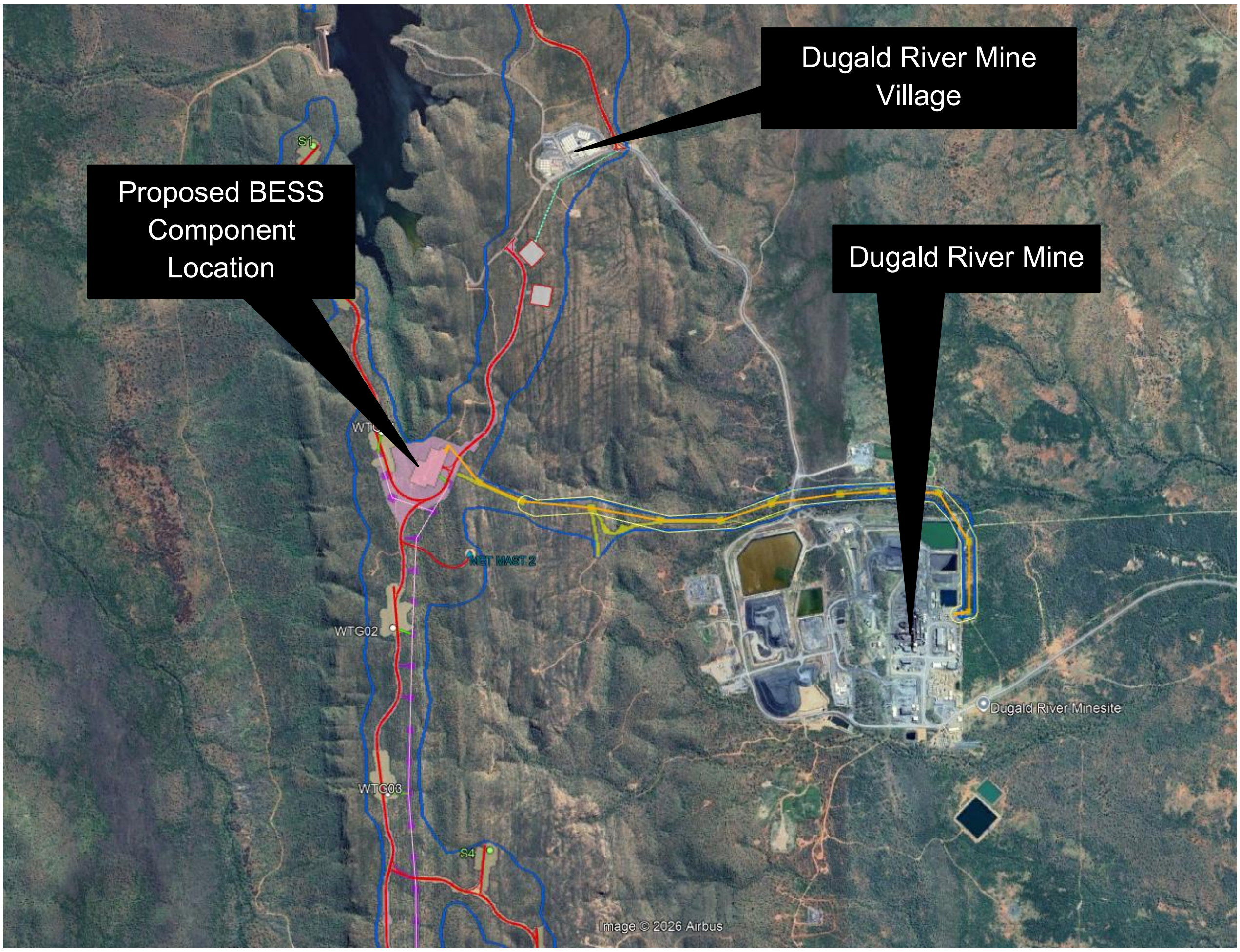


Figure 3-2: Proposed BESS Component Location Relative to Dugald River Mine

3.2 Adjacent Land Uses

The land for both proposed sites is located in a regional / rural area surrounded by the following land used which are adjacent to the sites:

- North – Rural vacant land
- South – Rural vacant land
- East – Rural vacant land
- West – Rural vacant land

3.3 Sensitive Receptors

There are no sensitive receptors within 1 km of the assumed site boundaries of the BESS component footprint.

3.4 General Description

The BESS component of the Wind Farm Project will store dispatchable energy generated from the Wind Farm, the development application for which is already well underway. The BESS component is an addendum to the Wind Farm and forms part of MMG's commitment to decarbonisation. The Project will operate to provide electricity during peak energy consumption. The BESS will be managed by personnel during standard working hours.

The BESS component will proceed in two stages: Stage 1 will consist of approximately 18 BESS systems and 9 Medium Voltage Power Station (MVPSs), which contain Power Conversion Units (PCUs). Stage 1 provides power to the Mine.

Stage 2 will expand to a total of 48 BESS units and 24 MVPSs. The BESS will occupy land adjacent to the existing 220/33V substation with 1 High Voltage (HV) transformer. In Stage 2, a second HV transformer will be added. The infrastructure is anticipated to contribute to a power output of approximately 45 MW at the point of connection and an energy storage ability of 90 MWh over 2 hours during Stage 1. This capacity will increase to 120 MW and 240 MWh respectively. Stage 2 is intended to provide power to the local grid, being the North West Power System. The BESS component will be comprised of BESS units, electrical transformers and inverters, electrical cabling, telecommunications equipment, an electrical control room, connection to the substation and perimeter fencing.

The stored electricity will be exported through an underground or overground transmission line to existing substation, which will be adjacent to the BESS site.

The BESS component of the Project comprises the construction, operation and decommissioning of a BESS facility and associated infrastructure. The BESS site is projected to include the following items (approximate quantities):

- BESS Infrastructure
  - 18 (Stage 1) or a total of 48 (Stage 2) x BESS containers with a total capacity of up to approximately 35 MW/ 70 MWh (Stage 1) or a total of 120 MW/ 240 MWh (Stage 2).
  - 1 x Medium Voltage Power Stations (MVPSs) with Power Conversion Units (PCUs) and per every 2 BESS units transformers up to 4,200 kVA.
- Electricity infrastructure:
  - 1 x Transformer (220/33 kV) (with a second to be added during Stage 2)
  - Electrical cabling between BESS units and transformers.
  - Underground transmission line connection to substation.
  - Switching station.
- Onsite permanent supporting infrastructure:
  - Site access road and entry.
  - Internal access roads.
  - Operations and Maintenance (O&M) Facility including workshops, amenities, equipment sheds, storage and parking areas, fire water tank and fire hydrants.
  - HV/LV switch room building with VESDA model smoke detectors
- Off-site supporting infrastructure:
- Existing public road and communications network; and
- Temporary supporting infrastructure:
  - Fencing works.
  - Delivery of project components, such as battery modules.

- Installation of underground and overhead cabling.
- Installing maintenance and environmental management processes and equipment.

- An Asset Protection Zone surrounding the BESS facility as measured from the inside of the security fence line, with a distance as determined by qualified bushfire consultants. This space should allow unobstructed vehicle access to aid emergency services in the event of a nearby fire.

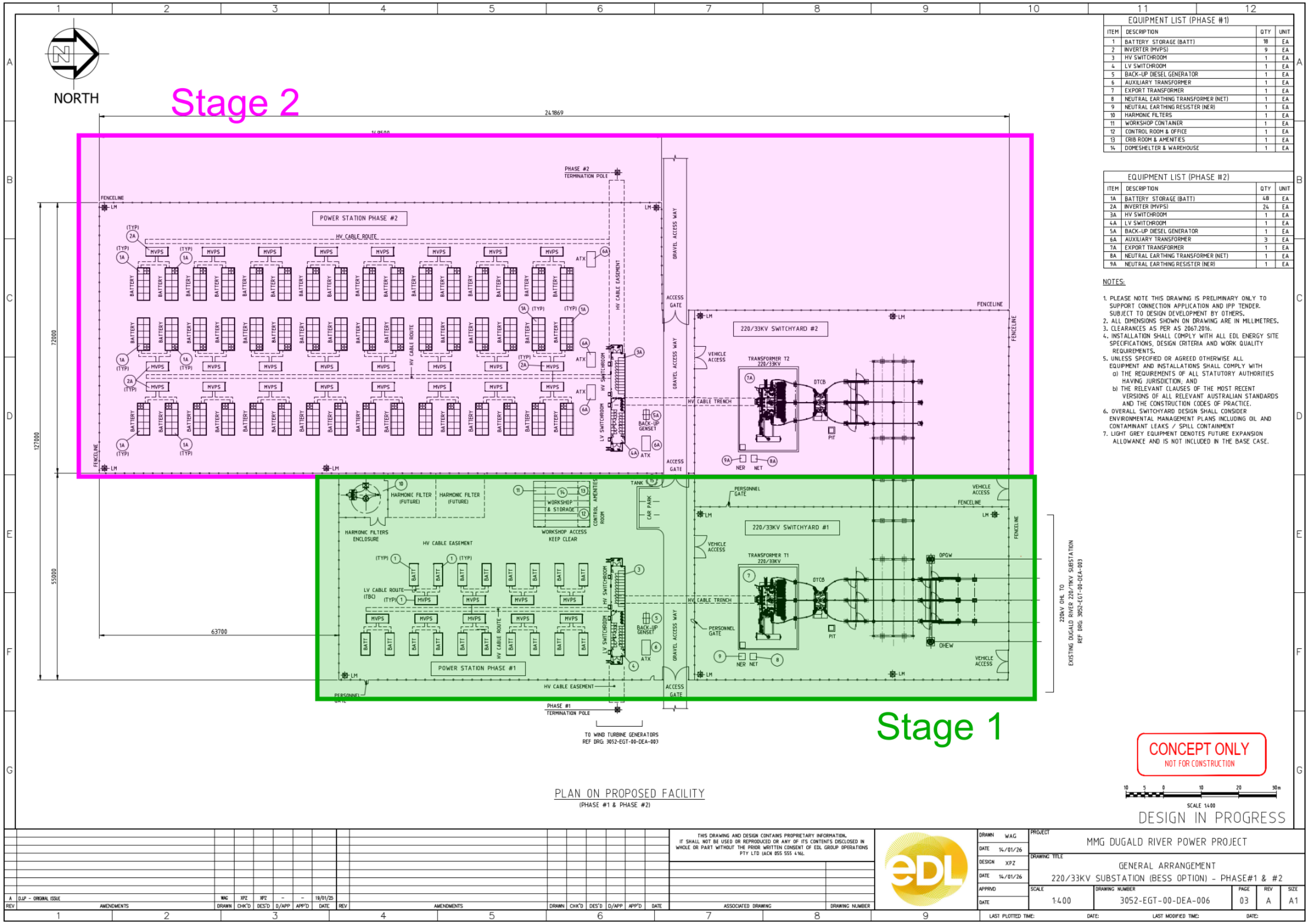


Figure 3-3: Indicative Conceptual BESS Layout. Stage 1 is in Green and Stage 2 is in Pink

3.5 Detailed Description

The purpose of the BESS component of the Project is to store excess dispatchable energy generated by the Wind Farm to the operations of Dugald River Mine, as part of MMG's commitment to decarbonisation.

The BESS will be able to store electricity with a capacity of approximately 45 MW / 90 MWh for Stage 1 and 120 MW / 240 MWh for Stage 2 in total. Stage 1 is intended to provide energy to the Mine, while Stage 2 will supplement the local grid with additional energy, being the North West Power System. The BESS units will store the electricity to be dispatched based on electricity demand fluctuations, providing the opportunity for greater supply dispatch flexibility when electricity demand is highest. This is enabled by the fast response times achievable through lithium-ion battery storage.

3.5.1 Battery Storage

The BESS will be located within the site compound, laydown and substation footprint area. The BESS converts electrical energy into chemical energy and stores the energy internally. The exact BESS model to be used in Stage 1 will be the BYD - MC Cube-T Energy Storage System (ESS – another term for BESS), which is shown in **Figure 3-4**.

Stage 2 proposes to use the recently announced BYD XN Batteries, which can store more energy (up to 14 MWh). Limited details are currently available due to the model being so new; however, as they are also produced by BYD, which have manufactured BESS units that are compliant with UL 9540A test criteria in the past, it is reasonable to assume these new models will be compliant.

Figure 3-4: BYD - MC Cube-T ESS (BESS to be Used in Stage 1)

The BYD - MC Cube-T ESS is housed in a container with the dimensions 6,058 (W) x 2,438 (D) x 2,896 (H) mm and has a rating of IP55. The BYD - MC Cube-T ESS contains local control loops, battery management, liquid cooling, and an alarmed fire detection system. Different BESS models shall have similar properties, including the new BYD XN model.

The unit houses Li-Ion (Lithium Iron Phosphate – LFP) battery modules totalling two (2) modules per rack with up to 4 racks in the unit. For BESS units other than BYD - MC Cube, the internal configuration may differ slightly, although this ultimately has little effect on the impact of the unit on energy storage or safety. Each module shall be monitored by a Battery Management Module (BMM). The BMM tracks cell voltages and temperatures through a Battery Management System

Unit (MSU) and ensures the stability of the batteries, preventing thermal runaway by isolating any cell that falls outside operating parameters.

Temperature and humidity within the container are regulated by an internal cooling system that uses liquid to cool.

The BYD BESS contains heat and smoke detectors and an optional fire suppression system, as per UL 9540 and National Fire Protection Association (NFPA) Standard 855 requirements. In the event of thermal runaway, flammable gases are generated which can be detected to initiate a safety response. The units are fitted with flammable gas detection which identifies flammable gases at 25% of the Lower Explosive Limit (LEL) which will activate an audible alarm.

The BYD BESS have undergone third party certification to attain UL 9540 A, which concluded that the inherent fire mitigation in the design of the BESS is sufficient to operate without additional suppression methods in the event of a fire. The BYD BESS also have been subject to Large Scale Fire Testing (LSFT) according to CSA800, which demonstrated no fire spread between an affected BESS and adjacent containers. Notwithstanding the certification, it is proposed to install the BESS with STAT-X, aerosol-based fire suppression. Similar tests shall be conducted on the new BYD XN models prior to installation in Stage 2, although it is assumed these BESS will also be installed with an aerosol fire suppression system. Evidence of these tests shall be provided to the Council and SARA upon submission of this FSS.

3.5.2 Protection Measures

The following protection measures are listed in the NFPA 855 and UL 9540, which are critical standards with which BESS units shall be compliant to ensure safety and risk mitigation:

- Heat and smoke detection
- Audible alarms
- Fire system emergency start
- Emergency stop
- Pressure relief valve
- Thermally insulated top and sides
- Passive and active ventilation
- Aerosol-based STAT-X fire suppression system.
- Extensive third party certification (UL9540A) and LSFT according to CSA800

NFPA 855 allows for the BESS units to be installed without fire suppression systems where fire, explosion and fault condition testing documents indicate the inherent BESS design is sufficient to limit thermal runaway events. The BYD BESS has achieved this third-party certification UL9540A and has also been subject to LSFT. With evidence of UL9540A data and LSFT, the exclusion of a fire suppression system is justified. Notwithstanding relevant certification, the BYD models will be fitted with an aerosol-based STAT-X fire suppression system.

While the BESS layout in **Figure 3-3** is preliminary, its design contains safety features that are assumed to be incorporated into the final layout design. These include:

- A 3 m clearance of infrastructure (BESS and MVPSs) from access roads and other infrastructure, including between BESS units (which makes the site NFPA 855 compliant).

- Access roads 6 m in width.

3.6 Quantities of Dangerous Goods

Lithium-ion batteries are considered Class 9: Miscellaneous Dangerous Goods. These will be the majority of DGs stored on site. Other DGs that are expected to be stored onsite include oil in the MVPS and transformers. The majority of MVPS' and transformers are proposed to use natural esters as the internal cooling medium, which have a very high flash point and are not DGs. However, the main Power Transformer associated with the substation is proposed to use 34,310 L of uninhibited mineral oil complying with AS 1767. The precise quantities of DGs are to be confirmed, however **Table 3-1** contains the expected quantities of DGs onsite for a project of this scale.

It should be noted that the location chosen for the Project is on land that is not subject to coastal mapping. Furthermore, **Section 4.11** explores the likelihood of natural disaster events occurring at the site of the Project and indicate strongly that natural disasters will not significantly impact the presence of DGs onsite. Thus, the location is not subject to the local bushfire and flood requirements with respect to hazardous materials.

The threshold column in **Table 3-1** indicates placard threshold, at which there are certain legal requirements to comply with Work Health and Safety Regulation 2011 (Ref. [7]). The detailed description of these requirements is beyond the scope of this report.

Table 3-1: Maximum Quantities of Dangerous Goods Stored & Preliminary Risk Screening

Area	Class	Description	Quantity	WHS 2011 Placard Threshold
BESS Units	9	Li-Batteries (Stage 1)	800 T*	N/A
		Li-Batteries (Stage 2)	2,110 T*	
Substation transformer oil	C2	Combustible Liquids (Stage 1)	34,310 L	N/A
		Combustible Liquids (Stage 2)	68,620 L	
MVPS and transformer natural ester medium	N/A	Cooling medium (Stage 1)	26,000 L*	N/A
		Cooling medium (Stage 2)	70,000 L*	

*TBC. Estimated quantity based on similar projects

4.0 Hazard Identification

4.1 Introduction

A hazard identification table has been developed and is presented at **Appendix A**. Those hazards identified to have a potential fire or explosion impact are assessed in the following sections of this document.

4.2 Properties of Dangerous Goods

The type of DGs and quantities stored and used at the site has been described in **Table 3-1**. **Table 4-1** provides a description of the DGs to be stored and handled at the site, including the Class and the hazardous material properties of the DG Class.

Table 4-1: Properties* of the Dangerous Goods and Materials Stored at the Site

Class	Hazardous Properties
9 – Miscellaneous DGs	Class 9 substances and articles (miscellaneous dangerous substances and articles) are substances and articles which, during transport present a danger not covered by other classes. Releases to the environment may cause damage to sensitive receptors within the environment. It is noted that the Class 9s stored within this project are lithium-ion batteries which may undergo thermal runaway (i.e. escalating reaction resulting in heat which ultimately leads to failure of the battery and a fire).
Combustible Liquids	Combustible liquids are typically long chain hydrocarbons with flash points exceeding 60.5°C. Combustible liquids are difficult to ignite as the temperature of the liquid must be heated to above the flash point such that vapours are generated which can then ignite. This process requires either sustained heating or a high-energy ignition source.

* According to the Australian Code for the Transport of Dangerous Goods by Road and Rail (Ref. [8])

4.3 Hazard Identification

Based on the hazard identification table presented in **Appendix A**, the following hazardous scenarios have been developed:

- Li-ion battery fault, thermal runaway and fire.
- Li-ion battery fire, toxic smoke plume
- Electrical equipment failure and fire.
- Transformer internal arcing, oil spill, ignition and bund fire.
- Transformer electrical surge protection failure and explosion
- External fire impact.

Each identified scenario is discussed in further detail in the following sections.

4.4 Li-Ion Battery Fault, Thermal Runaway and Fire

Lithium ion (Li-ion) batteries are composed of a metallic anode and cathode which allows for electrons released from the anode to travel to the cathode where positively charged ions in the solute migrate to the cathode and are reduced. The flow of electrons provides the source of energy which is discharged from a battery and used for work. In a Li-ion battery, the lithium metal composites (a composite of lithium with other metals such as cobalt, manganese, nickel, or any combination of these metals) oxidises (loses an electron) becoming a positively charged ion in solution which migrates through the battery separator to the cathode. At the same time, the lost electron travels through the circuit to the cathode. The lithium ions in solution then recombine with the electron at the cathode forming lithium metal within the cathodic metal composite. This process is shown in **Figure 4-1**.

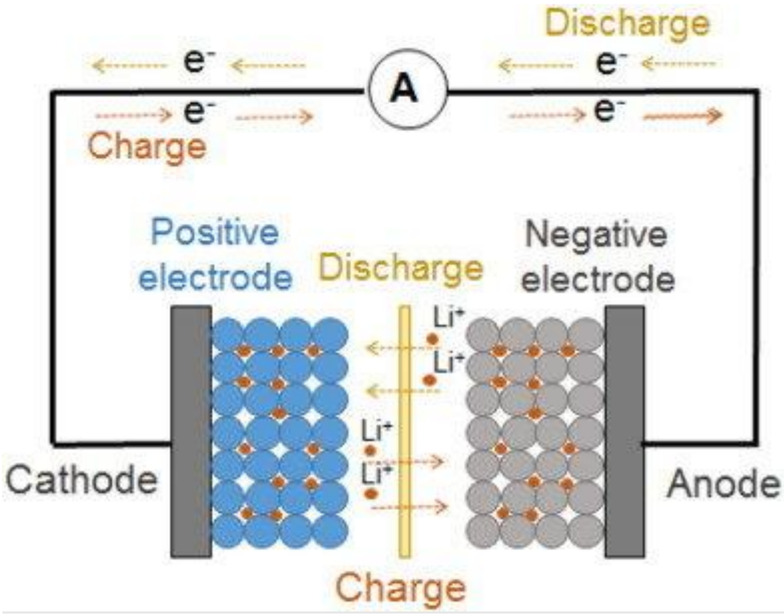


Figure 4-1: Cathode and Anode of a Battery (Source Research Gate)

Initial lithium batteries were designed around lithium metal (i.e. no composite structure) due to the high energy density yielded by the metal. However, when overcharging a battery, lithium ions can begin to plate on the anode in the form of lithium dendrites. Eventually, the dendrites pierce the separator within the battery resulting in a short of the battery which could result in heat, fire, or explosion of the battery. The technology evolved to move away from lithium metal to lithium ions (held within composite materials) which reduced the incidence of lithium dendrites forming resulting in an overall safer battery.

Despite the improvement in battery technology, there are several degradation mechanisms that are still present within the battery which can result in thermal runaway. These include:

- Chemical reduction of the electrolyte at the anode
- Thermal decomposition of the electrolyte
- Chemical reduction of the electrolyte at the cathode
- Thermal decomposition by the cathode and the anode
- Internal short circuit by charge effects

These effects arise primarily as a result of high discharge, overcharging, or water ingress into the battery which results in a host of by-products being formed within the battery during charge and discharge cycles.

As a result, Li-ion batteries are equipped with several safety features to prevent the batteries from charging or discharging at voltages which result in battery degradation, leading to shorting of the battery and thermal runaway. Safety features are described in **Section 3.5.2.**

These features are designed to prevent overcharging or excessive discharge, pressurisation arising from heat generated at the anode or from battery contamination. Protection techniques for Li-ion batteries are standard; hence, the potential for thermal runaway to occur in normal operation is incredibly low with the only exceptions being where batteries are manufactured poorly or due to manufacturing faults, or battery damage (i.e. battery cell is ruptured as this can short circuit the battery resulting in thermal runaway) or in the event of an ancillary system failure during commissioning (i.e. while protection systems are being tested).

The battery product that has been proposed for this project is BYD MC Cube BESS units, with the potential for updating to the BYD XN model. The battery chemistry of the BYD units is lithium-Ion phosphate ($LiFePO_4$, or simply LFP), which are considered to be one of the safest battery chemistries within the industry. The stability of the batteries is due to the cathode which does not release oxygen therefore preventing violent redox reactions resulting in rapid temperature rise as the oxygen oxidizes the electrolyte. Even if the exact model of BESS is changed, it is assumed that a BESS with LFP will be used.

The BYD MC Cube BESS is reportedly compliant with the UL9540 standard, which includes a standardised test called UL9540A. A UL9540A report is a test standard report with a systematic evaluation of thermal runaway and propagation in energy storage system at cell, module, unit, and installation levels. The components are each subjected to induced thermal runaway with the battery management system turned off during these tests. Further detail on the UL9540A criteria for each level of testing is available in **Appendix C.** The BESS units to be installed, whether BYD MC Cube, XN, or otherwise, shall be subject to this test prior to selection for installation at the facility, with the UL9540A test results for fire development and propagation available upon request.

Based on data shown from UL9540A reports for similar systems, the results demonstrate that when thermal runaway is triggered in one cell in a BESS container, the heat generated would neither be transferred to all cells within one battery module, nor from the test module to adjacent ones, indicating compliance at the cell and/or module level. This is attributed to the nature of LFP technology as well as the sheer mass of the battery module (heavier objects have higher thermal capacity). Notwithstanding this evidence that propagation will not occur, it is proposed that the BESS will have STAT-X, aerosol-based fire suppression systems installed.

Although the LFP technology does not typically cause fire, there can be circumstances where battery modules catch fire due to leaking coolant or electric faults. In those cases, fire will be constrained by the stainless-steel enclosure. Similar systems show that generally the container wall remains intact after sustaining heating in a furnace to over 900°C. Furthermore, each container should also have multiple built-in fire protection devices that work collaboratively, including smoke and thermal sensors, combustible gas detector, pressure relief system, and aerosol and E-stop buttons. Therefore, a container is expected to automatically detect and control an internal fire in the first instance, preventing escalation to other battery units as per UL 9540A.

Additional testing for shock and damage to batteries (i.e. nail puncture test) has shown that LFP batteries when punctured through membranes typically results in a shorting of the battery, and fire does not result in ignition of the battery demonstrating that the battery chemistry is protected against shock damage. When exposed to external heat the thermal rise of typical lithium-ion battery chemistries is 200-400°C/min resulting thermal run away and fire which can then propagate to adjacent batteries escalating the incident to a full container fire. For LFP batteries, the thermal rise of the batteries at peak is 1.5°C/min which results in a gradual temperature rise and does not result in fire and thus incident propagation to other batteries. The thermal rise of various battery chemistries is provided in **Figure 4-2** with a zoomed in temperature rise for LFP provided in the top right of **Figure 4-2**.

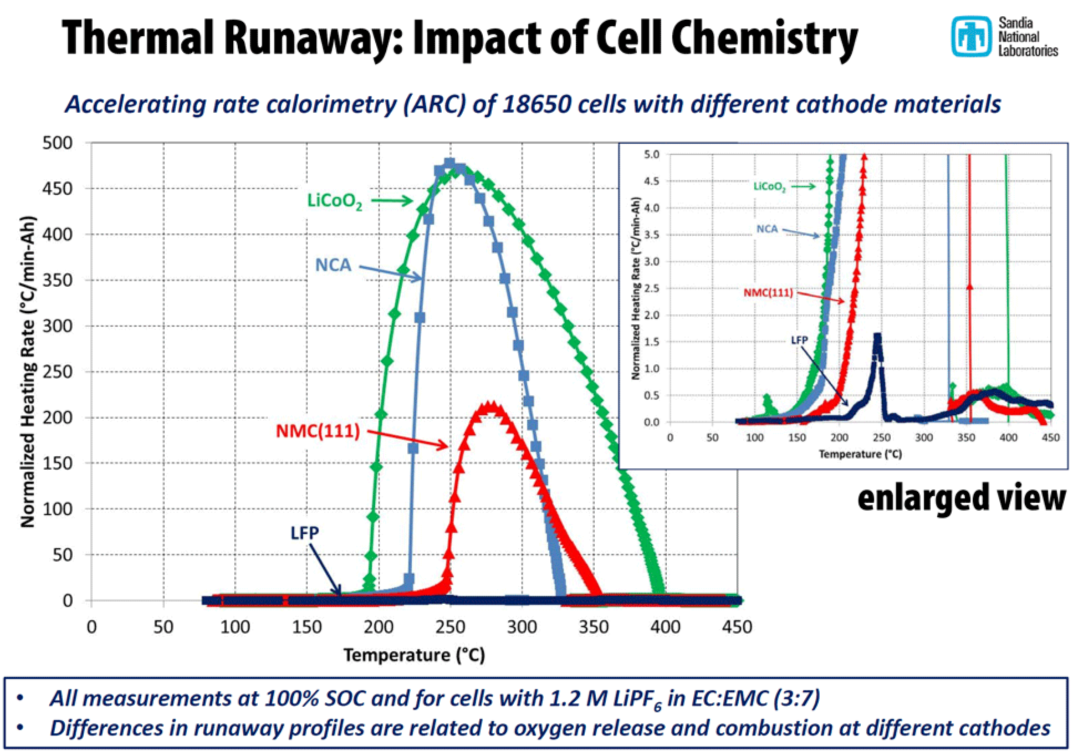


Figure 4-2: Temperature Rise of Lithium-Ion Battery Chemistries (Ref. [9]).

In the event that LFP chemistries do ignite, the combustion by-products release carbon dioxide which reduces the oxygen concentration within a confined space reducing the combustion rate.

In conclusion, the LFP technology does not cause flaming fire during thermal runaway. Should fire be developed within one BESS enclosure it would not transfer to nearby enclosures due to the fire safety design features and the aerosol-based fire suppression system. In terms of physical damage, the batteries are contained within in modules which are located within a fenced area; therefore, there is a low potential for damage to occur to the batteries which may initiate an incident.

Considering BESS fires cannot be put out by applying fire-fighting water, common practice is to let the BESS burn out and control grass fires that may occur around it. Assuming the incident responders apply this practice, there is negligible risk of environmental damage from contaminated firewater.

With respect to the likelihood of BESS fires, analysis of previous BESS fires can help quantify the expected frequency of such an event. There have been two major instances of BESS fires in Australia: The Victorian Big Battery fire in 2021 and the Bouldercombe Battery Project fire in 2023.

The Victorian Big Battery (VBB) experienced a fire in July 2021 which also has a back-to-back layout. According to the independent investigation report on its fire incidence, the back-to-back layout was not the cause for propagation. The main reason for fire propagation was strong wind blowing flames from one BESS into the unprotected vent atop of an adjacent BESS which resulted in the ignition of the plastic fan which was able to impact the battery modules directly beneath the fan. This fire can also be partially attributed to the battery chemistry being Li-NMC, which is more likely to experience thermal runaway.

The Bouldercombe Battery Project fire (BBP) fire in 2023 occurred due to an issue on the AC side and occurred during construction of the facility. The batteries at this facility were LFP. Upon ignition, the BESS unit withstood the fire and demonstrated the inherent safety features that made it compliant with UL 9540A testing; the fire was contained to the single BESS unit, and no external water was required to contain the fire. The BESS unit was subsequently removed and tested, and the BBP is in operation as of April 2024.

While these fires were significant, these are the only two major fires from non-residential BESS units recorded in Australia since BESS have been implemented in major projects since 2018. Given there are over 1,500 BESS units operating in the country, thus, the likelihood of an individual BESS unit catching fire is near negligible.

Notwithstanding this, for conservatism it has been assumed that a flaming fire could occur from a BESS unit which may impact firefighting equipment or result in propagation of the incident to adjacent units. Therefore, this incident has been carried forward for further analysis for conservatism.

4.5 Li-ion Battery Fire and Toxic Gas Dispersion

If a BESS failure occurs resulting in a fire, toxic biproducts of combustion may form. A literature review was conducted on lithium-ion battery fires to identify the toxic gases which may be generated in the event of a fire. The review identified the following gases or classes of gases can form:

- Carbon dioxide;
- Carbon monoxide; and
- Fluorine gases.

Each of these have been discussed in further detail in the following subsections.

4.5.1 Carbon Dioxide

Carbon dioxide is a colourless, odourless, dense gas which is naturally forming and is present in the atmosphere at concentrations around 415 ppm (0.0415%). At low concentrations carbon dioxide is physiologically impotent and at low concentrations does not appear to have any toxicological effects. However, as the concentration grows it increases the respiration rate of exposed persons. The Short Term Exposure Limit (STEL) is 30,000 ppm (3%) as established by SafeWork Australia; thus, levels above 50,000 ppm (5%) will induce a strong respiration effect, along with dizziness, confusion, headaches, and shortness of breath. Concentrations more than 100,000 ppm (10%) may result in coma or death.

Carbon dioxide is a by-product of combustion where hydrocarbon or carbon-based materials are involved. A typical combustion reaction producing carbon from a hydrocarbon has been provided in **Equation 4-1**. This reaction proceeds when there is an excess of oxygen to the fuel being consumed and is known as complete combustion as it is the most efficient reaction pathway.

$$C_3H_8(g) + 5O_2(g) \rightarrow 3CO_2(g) + 4H_2O(g) \quad \textbf{Equation 4-1}$$

The lithium-ion batteries are predominantly composed of metal structures. However, during a fire event ancillary equipment and materials within the batteries will be involved in the fire including wiring, plastics, anodes, etc. which will liberate carbon dioxide. However, a review of the toxicological impacts indicates high concentrations would be required to result in injury or fatality.

Based upon a review of the sensitive areas, and the similar BESS fires (i.e. Victoria BESS fire), it is not considered that the formation of carbon dioxide in a fire would be sufficient to result in downwind impacts sufficient to cause injury or fatality. In other words, there would be insufficient production of carbon dioxide to generate a plume of sufficient concentration to displace the required oxygen for a significant downwind consequence to occur. Therefore, this incident has not been carried forward for further analysis.

4.5.2 Carbon Monoxide

Carbon monoxide is an odourless, colourless gas which is slightly denser than air and occurs naturally in the atmosphere at concentrations around 80 ppb. Carbon monoxide is a toxic gas as it irreversibly binds with haemoglobin which prevents these molecules from carrying out the function of oxygen / carbon dioxide exchange. The loss of 50% of the haemoglobin may result in seizures, coma or death which can occur at concentration exposures of approximately 600 ppm (0.06%).

Carbon monoxide is by-product of combustion if there is insufficient oxygen to enable complete combustion. The reaction pathway for the formation of carbon monoxide is provided in **Equation 4-2.**

$$2C_3H_8(g) + 7O_2(g) \rightarrow 6CO(g) + 8H_2O(g)$$ **Equation 4-2**

Carbon monoxide may be generated if there is insufficient oxygen to sustain complete combustion during a BESS fire. However, it is noted that the combustible load within the BESS which could result in the formation of carbon monoxide is relatively low compared to the available oxygen in the surrounding atmosphere. Therefore, it is considered that the formation of carbon monoxide at levels which would result in a substantial downwind impact are not considered credible and subsequent analysis of, this incident is not required.

4.5.3 Fluoride Gases

The electrolyte used in Li-ion batteries typically is lithium hexafluorophosphate ($LiPF_6$) or other li-salts containing fluorine. In the event of a thermal runaway, the electrolyte will expand and be vented from the battery. In the event of a fire, the vented gas and other components such as the polyvinylidene fluoride binders may form gases such as hydrogen fluoride (HF), phosphorous pentafluoride (PF_5) and phosphoryl fluoride (POF_3) (Ref. [10]).

The decomposition of $LiPF_6$ can be promoted by the presence of water / humidity according to reactions **Equation 4-3** to **Equation 4-5**.

$$LiPF_6 \rightarrow LiF + PF_5$$ **Equation 4-3**

$$PF_5 + H_2O \rightarrow POF_3 + 2HF$$ **Equation 4-4**

$$LiPF_6 + H_2O \rightarrow LiF + POF_3 + 2HF$$ **Equation 4-5**

Of the fluorine gases formed, PF_5 is a short-lived gas while POF_3 is a reactive intermediate. Thermal destruction of a several battery chemistries, configurations and State of Charge (SOC) indicated the vast majority of the batteries did not produce observable POF_3 with the condition that a specific battery chemistry was at 0% SOC (Ref. [10]). Therefore, the main fluorine gas of concern in a Li-ion battery fire is HF.

HF gas is hydroscopic that readily dissolves into water vapour / humidity or moisture in airways, forming hydrofluoric acid. Although hydrofluoric acid is a weak acid, it is highly corrosive and may result in chemical burns. In addition, it has calcium scavenging properties. Hence, it will readily bind with calcium in cells and tissues disrupting the nerve signalling. The immediately dangerous to life or Health (IDLH) for HF is 30 ppm and the 10-minute lethal concentration is 170 ppm.

For a toxic gas dispersion, a battery container fire is necessary as the initiating event. As discussed in **Section 4.4** the potential for a fire to occur is considered negligible due to the highly stable and safe battery chemistries used. By ensuring the BESS units implemented at the Project are compliant with the UL 9540A test criteria, the presence of toxic gases released in the unlikely event of thermal runaway will be negligible.

Furthermore, Franqueville *et al.* (Ref. [11]) completed a Computational Fluid Dynamics (CFD) study to determine the dispersion of toxic gases from Li-Ion batteries in various scenarios. In a worst case scenario, in which the wind reaches 32 km/h and the failed BESS is actively burning, the study showed that a safe distance from the burning Li-Ion battery would be maximum of 54 m. Therefore, a toxic gas dispersion impacting any sensitive receptors beyond a 1 km radius from the BESS facility is not deemed a credible scenario.

4.6 Electrical Equipment Failure and Fire

Electrical equipment is located within the switch room which may fail resulting in overheating, arcing, etc. which could initiate a fire. In the event of a fire, it may begin to propagate to adjacent combustible materials (i.e. wiring). It is noted that electrical equipment fires typically start by smouldering before flame ignition occurs resulting in a slow fire development.

The type of equipment used within the project is ubiquitous throughout the world and across industry segments and is therefore not a unique fire scenario. Based upon fire development within switch rooms the fire would be considered to be relatively slow in growth and would be unlikely to result in substantial impacts in terms of impacts to firefighting equipment and incident propagation. Therefore, this incident has not been carried forward for further analysis.

4.7 MVPS Internal Arcing, Oil Spill, Ignition and Bund Fire/Explosion

MVPS and smaller transformers contain oil, which is used to insulate the transformers during operation. If arcing occurs within the transformer (e.g. due to a low oil level), the high energy passing through the coolant vaporises the oil into light hydrocarbons (methane, ethane, acetylene, etc.) resulting in rapid pressurisation within the reservoir. To minimise the likelihood of such occurrence, transformers are fitted with a low oil pressure switch, oil temperature monitoring and switches, gas formation detectors and a pressure surge protection. These devices identify potential oil and pressure events within the transformer, isolating power and alarming operators.

Notwithstanding the protection systems, if the pressure rise exceeds the structural integrity of the reservoir, and the installed pressure relief devices, the reservoir can rupture allowing the release of oil into the bund. The rupture also allows oxygen to enter the reservoir. The temperature of the gases is above the auto ignition point, but this does not occur until oxygen is present. When oxygen enters the reservoir, the gases auto ignite which generates sufficient heat to ignite the oil in the bund.

The transformer oil to be used on site for the MVPS and smaller transformers will be natural ester based insulating oil. Natural esters have a flash point exceeds 300°C (Ref. [12]) and are classified as non-dangerous goods under the Australian Dangerous Goods Code (Ref. [8]). Therefore, ignition of the fluid is extremely difficult, and a fire occurring from a natural ester insulated transformer is not considered a credible scenario. Furthermore, transformers are ubiquitous units with a low potential for failure.

The significant difficulty associated with the ignition of natural ester combined with the existing safety features means this hazard is sufficiently covered by qualitative risk analysis. The risk of explosion, the initiating event of which is the ignition of the natural ester insulating oil, is also covered by qualitative analysis. Thus, these events are not carried forward for further analysis.

4.8 Substation Transformer Internal Arcing, Oil Spill, Ignition and Bund Fire

Unlike the MVPSs and smaller transformers associated with the individual BESS units, the main substation Power Transformer is proposed to be insulated with uninhibited mineral oil. This oil is a C2 Combustible Liquid, and has a flash point of 130 °C to 150 °C. This means it still takes significant amounts of energy to ignite, but it is easier to ignite compared to the natural esters used for the MVPSs/smaller transformers. The process of a bund fire occurrence would be the exact same as that for the MVPSs; however, the likelihood of ignition is marginally increased due to the use of mineral oil.

The Power Transformer is protected by similar safeguards as those described for the MVPSs and smaller transformers; namely, it includes a low oil pressure switch, oil temperature monitoring and switches, gas formation detectors and a pressure surge protection. Nonetheless, given the fact that slightly more flammable oil is used for insulation in the main Power Transformer, a bund fire of this transformer is carried forward for further analysis.

4.9 Substation Transformer Electrical Surge Protection Failure and Explosion

Transformers generate large amounts of heat as a result of the high electrical currents that pass through them; hence, oil is used as an insulating material within the transformers to protect the mechanical components. However, if the transformer gets an extreme surge of energy, such as that which could occur due to a lightning strike, and the electrical surge protection measures fail, the mineral oil may start to decompose and vapourise, resulting in gas bubbles of hydrogen and methane (Ref. [13]) as temperatures above the autoignition of the gases.

The formation of gases will increase the pressure within the transformer which can result in the transformer structure rupturing which allows the ingress of oxygen. As the oxygen enters, the concentration of flammable gases falls within the explosive limits which are above their autoignition temperatures which ignite resulting in increased formation of hot gaseous products resulting in an explosion. The explosion may generate significant overpressure, sparks and fire and would result in a whole transformer fire, as discussed in **Section 4.7**.

In order to protect against overheating and explosions, transformers have surge protection, which re-directs overvoltage to the ground, protecting the insulation of the transformers. In the event of a major lightning strike, significant oil deterioration or physical damage such as a fallen tree, the surge protection may be too slow to stop an electrical overload (Ref. [14]). However, this is very unlikely as the surge arrestors are very fast-acting and it is proposed that the surge arrestors are correctly graded prior to installation. Furthermore, the transformers will be protected against lightning as per the requirements of AS 2067:2016 (Ref. [15]).

Therefore, there is the potential for an explosion to occur which may result in impacts to fire protection equipment; however, as noted, these units are protected by surge arrestors that are very fast-acting and have a low potential for failure. Qualitative risk analysis is deemed sufficient for this event.

4.10 Electromagnetic Field Impacts

4.10.1 Introduction

Electric and Magnetic Fields (EMFs) are associated with a wide range of sources and occur both naturally as well as man-made. Naturally occurring EMFs, occurring during lightning storms, are generated from Earth's magnetic field. Man-made EMFs are present wherever there is electricity; hence, EMFs are present in almost all built environments where electricity is used.

Extremely low frequency (ELF) electric and magnetic fields (EMF) occupy the lower part of the electromagnetic spectrum in the frequency range 0-3,000 Hz which is the current will change direction 0-3,000 times a second. ELF EMF result from electrically charged particles. Artificial sources are the dominant sources of ELF EMF and are usually associated with the generation, distribution and use of electricity at the frequency of 50 Hz in Australia. The electric field is produced by the voltage whereas the magnetic field is produced by the current.

BESS create EMFs from operational electrical equipment, such as transmission lines, transformers and the electrical components found within BESS units, inverters, etc. This equipment has the potential to produced ELF EMFs in the range of 30 to 300 Hz.

4.10.2 Existing Standards

There are currently no existing standards in Australia for governing the exposure limits to ELF EMFs; however, the International Commission on Non-Ionizing Radiation Protection (ICNIRP) has provided some guidelines around exposure limits for prolonged exposure which limits the exposure to 2,000 milligauss (mG) for members of the public in a 24 hour period (Ref. [16]).

Table 4-2 provides typical magnetic field measurements and ranges associated with EMF sources. It is noted that electric fields around devices are generally close to 0 due to the shielding provided around the equipment. In addition, EMF levels drop away quickly with distance; hence, while a value may be measurable at the source, within a short distance the EMF is undetectable. The Australian Radiation Protection and Nuclear Safety Agency (ARPANSA) advises that the strength of radiation decreases exponentially with distance from the source, and it will become indistinguishable from background radiation within 50 m of a high voltage power line and within 5 to 10 m of a substation. (Ref. [17]).

Table 4-2: EMF Sources and Magnetic Field Strength

Source	Typical Measurement (mG)	Measurement Range (mG)
Television	1	0.2 – 2
Refrigerator	2	2 – 5
Kettle	3	2 – 10
Personal computer	5	2 – 20
Electric blanket	20	5 – 30
Hair dryer	25	10 – 70
Distribution powerline (under the line)	10	2 – 20
Transmission power line (under the line)	20	10 – 200
Edge of easement	10	2 – 50

4.10.3 Exposure Discussion

A review of the site indicates the nearby residences adjacent to the area where the BESS will be developed are separated by over 1000 m providing substantial distance for attenuation of EMFs. Based upon the typical levels which may be generated by transmission equipment the cumulative effect would not exceed the 2,000 mG limit for prolonged exposure.

As the potential for exposure to EMF exceeding the international guidelines is negligible, this incident has not been carried forward for further analysis.

4.11 Natural Disaster Events

4.11.1 Bushfires

There is the potential for an external fire event to impact the BESS Project such as a bushfire incident. The proposed BESS site is within the bushfire prone land with a Medium Potential Bushfire Intensity, as indicated in **Figure 4-3.** As such, the site shall maintain good housekeeping procedures to prevent the accumulation of combustible loads; hence, in such an event any escalation would be expected to be a minor grass fire. Grass fires can move quickly; however, they tend to be short lived as the combustible load is exhausted. Subsequently, sustained radiant heat impacts at the site would not be expected and would be unlikely to result in sufficient heat to impact the BESS or other infrastructure such that incident propagation occurs.

In addition, during operations, the O&M buildings also have portable fire extinguishers that can help in the case of minor fires. In the case of bigger bushfires, emphasise will be placed on evacuating the site to the Dugald River Mine and beyond if required.

The equipment on the site is also protected by the features described in the previous sections and are thus unlikely to be significantly damaged to minor bushfires. The pieces of equipment are also arranged to be sufficiently separated from one another (4 m, as per BYD requirements), meaning there is empty space with no fuel between equipment pieces. This would decelerate the bushfire and reduce the impacts.

The potential for incident escalation as a result of an external fire impact to occur is considered negligible; hence, this incident has not been carried forward for further analysis.

4.11.2 Flooding

There is negligible potential for flooding to occur within this region; the area is subjected to flood mapping, as shown in **Figure 4-4**. However, the proposed BESS location is not subject to Annual Exceedance Probability (AEP) 1% mapping. The local legislation governing development applications, Cloncurry Shire Planning Scheme (Ref. [18]), lists certain requirements for sites subject to AEP 1% mapping with respect to the storage of DGs. As the proposed site is not subject to this mapping, these DG do not need to be met. Furthermore, it indicates the potential for flooding to endanger the BESS operations is negligible. Thus, the likelihood of significant flooding affecting the BESS Project is very small, and the incident has not been carried forward for further analysis.

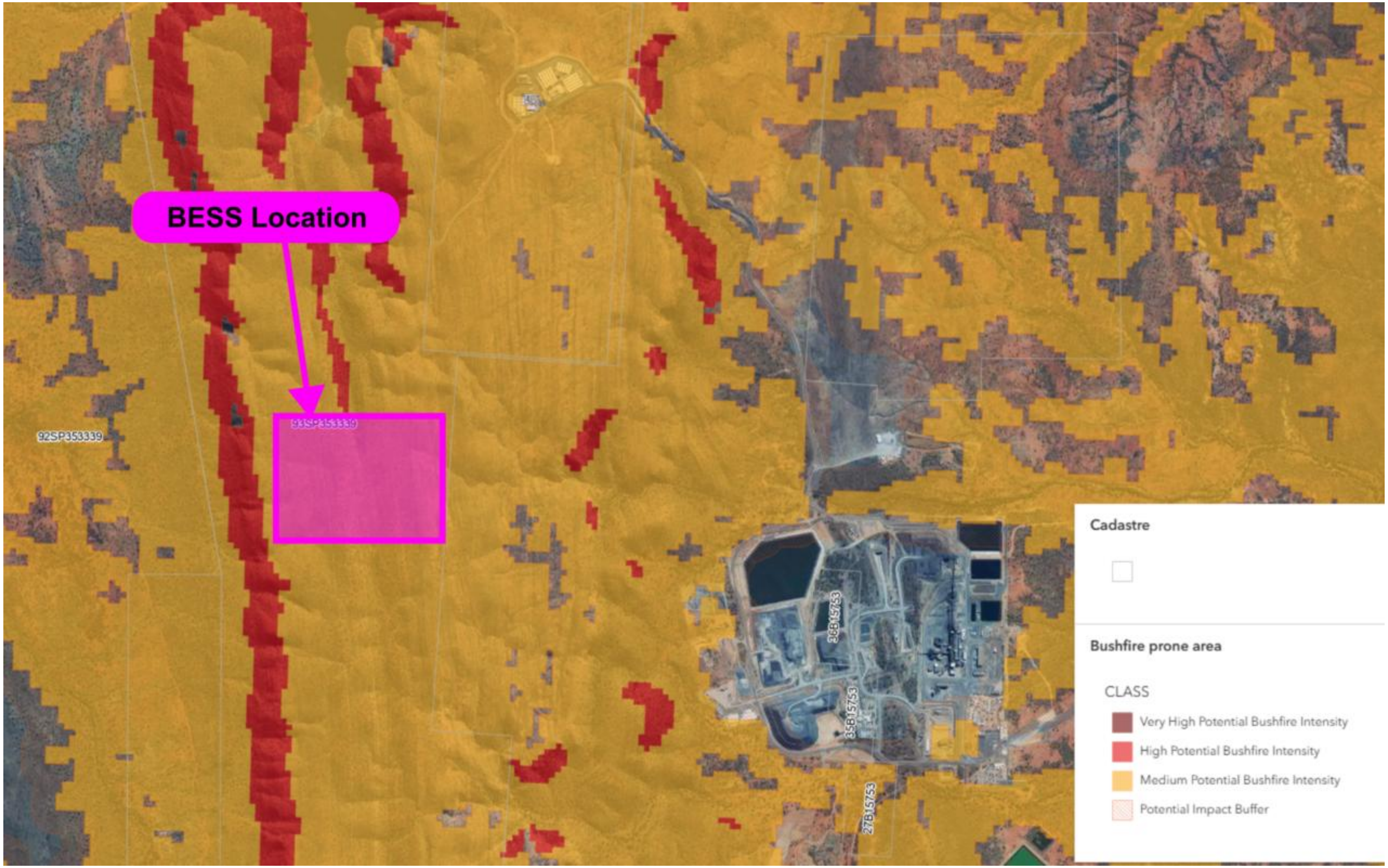


Figure 4-3: Bushfire Prone Land (According to QLD State Planning Policy Mapping)

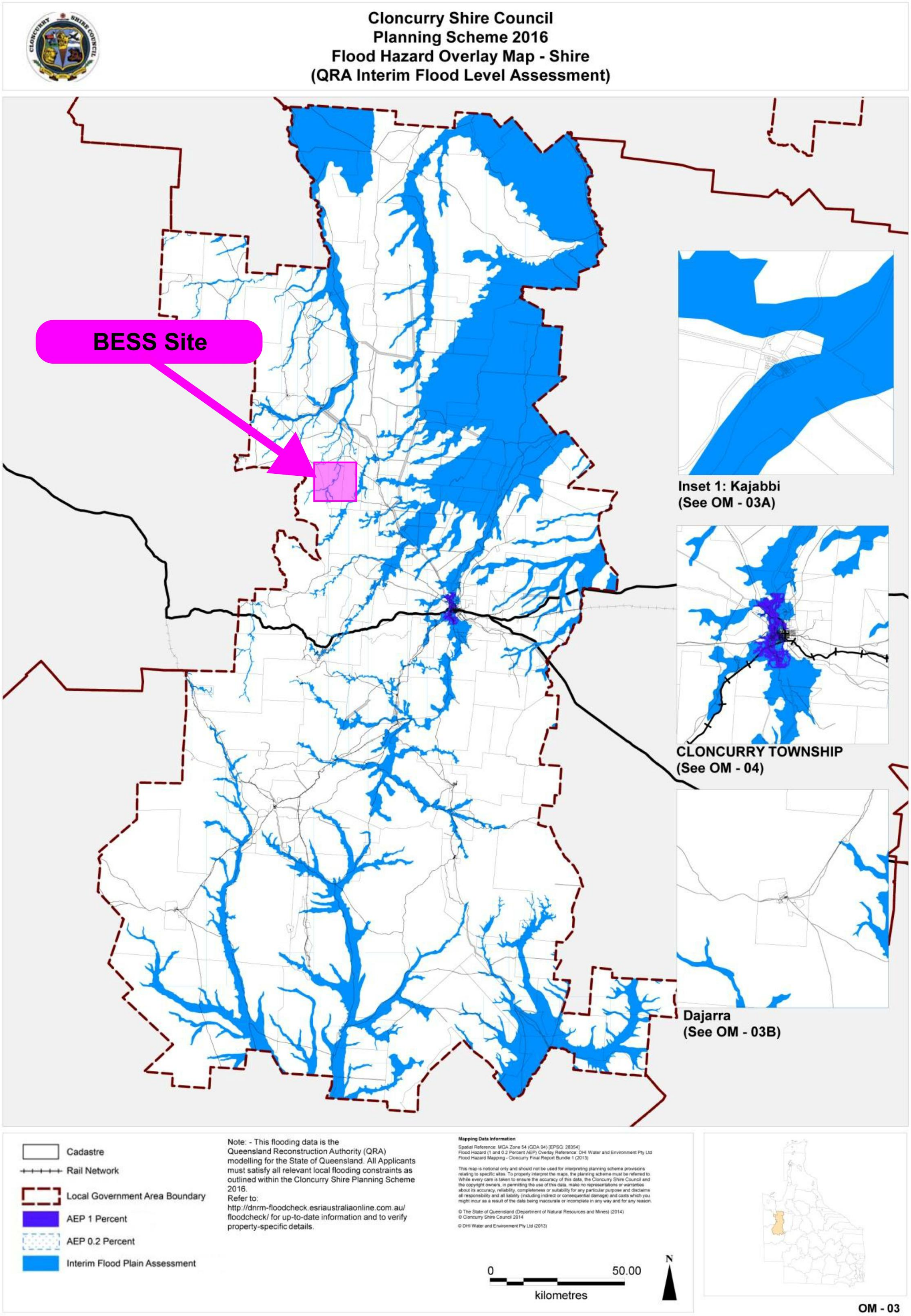


Figure 4-4: Cloncurry Shire Council Flood Mapping. Source: [19]

5.0 Consequence Analysis

5.1 Incidents Carried Forward for Consequence Analysis

The following incidents were identified to have the potential to impact fire protection systems or to complicate firefighting interventions:

- Li-ion battery fault, thermal runaway and fire.
- Main transformer internal arcing, oil spill, ignition and bund fire.

Each incident has been assessed in the following sections. A detailed analysis of each scenario is outlined in **Appendix B**, along with the criteria used to assess each incident.

5.2 Li-Ion Battery Fault, Thermal Runaway and Fire

There is potential that a Li-Ion battery may fault resulting in thermal decomposition and fire which may spread throughout the whole fire unit if not isolated / protected. A detailed review of the test data for a similar BESS unit was conducted in **Appendix B**. The testing conducted for the BESS indicated that the average cell venting temperature was 171°C and the average temperature at the onset of thermal runaway was 239°C with no flaming observed. This temperature value was adopted to determine the Surface Emissive Power (SEP) of the batteries undergoing thermal runaway. The calculation resulted in a SEP of 3.04 kW/m^2 which would be insufficient to result in incident propagation between BESS units.

The test data also identified that the maximum surface temperature of the BESS units under thermal runaway was 14.8°C which is consistent with a radiating surface with a low value. Based on the test data and the calculated SEP, it is considered that the potential for BESS propagation to occur is unlikely. LSFT of the BYD MC-Cube BESS also demonstrated no propagation of a BESS fire to adjacent BESS containers.

5.3 Transformer Internal Arcing, Oil Spill, Ignition and Bund Fire

There is potential that arcing may occur within the 33/220 kV transformers in the substation which may lead to generation of gases and pressure above the structural integrity of the oil reservoir. This may rupture leaking oil into the bund. As a result of the arcing and rupture, the oil may ignite leading to a bund fire within the dimensions of the bund.

A detailed analysis has been conducted in **Appendix B** and the radiant heat impact distances estimated for this scenario are shown in **Table 5-1.** The radiant heat contours associated with a fire occurring within a transformer bund are shown in **Figure 5-1**.

Table 5-1: Radiant Heat from a Transformer Fire

Heat Radiation (kW/m^2)	Distance (m)
35	10
23	18
12.6	23
4.7	32
3.0	37

The 23 kW/m^2 contour has been used to assess the potential for propagation of the incident. **Figure 5-1** shows that the 23 kW/m^2 heat radiation contour from a transformer fire will not impact the site boundary, nor additional infrastructure. Furthermore, the modelling has been completed without consideration for additional fire protection features that may be implemented, such as fire walls. Thus, the impact of a transformer bund fire will be negligible.

The 3.0 kW/m^2 contour is the criterion used by FRNSW for assessing accessibility of hydrants and fire protection systems. This threshold criterion is also assumed to be applicable in QLD. The fire protection measures implemented at the Dugald BESS site are the fire extinguishers in the workshop and switch rooms. As shown in **Figure 5-1**, the 3.0 kW/m^2 contour does not impact these areas. Thus, the available fire-fighting equipment is not impacted by a fire in the main transformer.

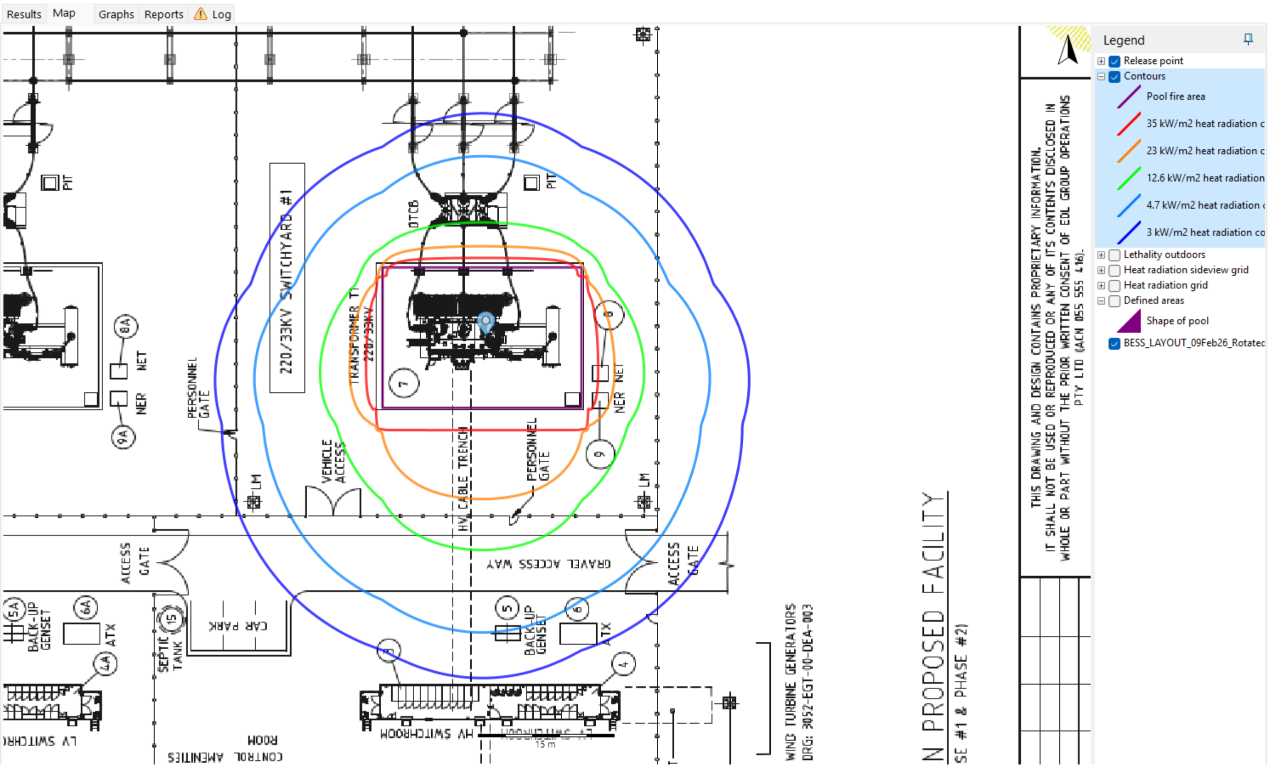


Figure 5-1: Transformer Fire Radiant Heat Contours

6.0 Details of Prevention, Detection, Protection and Mitigation Measures

The fire safety systems at the site can be split into four main categories:

- **Fire Prevention** – systems, installed to prevent the conditions that may result in initiating fire.
- **Fire Detection** – systems installed to detect fire and raise alarm so that emergency response can be affected (both evacuation and firefighting)
- **Fire Protection** – systems installed to protect against the impacts of fire or explosion
- **Fire Mitigation** – systems installed to minimise the impacts of fire and to reduce the potential damage (e.g. fire water application)

Each category has been reviewed in the following sections, with respect to the existing systems incorporated into the design and those to be provided as part of the recommendations herein.

6.1 Fire Prevention

This section describes the fire prevention strategies and measures that will be undertaken at the site.

6.1.1 Control of Ignition Sources

The control of ignition sources reduces the likelihood of igniting a release of material. The site has a number of controls for ignition sources. These include controls for fixed potential ignition sources and controls for introduced ignition sources.

- A permit to work or clearance system will be used - hot work will be controlled as part of the permit to work system.
- Designated smoking areas within the site (i.e. external from building areas).

Table 6-1 presents the potential ignition sources and incidents for the Project which may lead to ignition and fire. The table also summarises the controls that will be used to reduce the likelihood of these potential sources of ignition and incidents resulting in a fire.

Table 6-1: Summary of Control of Ignition Sources

Ignition Source	Control
Smoking	No smoking policy for the site with smoking only permitted in designated areas.
Electrical	Fixed electrical equipment to be designed and installed to AS/NZS 3000:2018 (Ref. [19]).
Arson	The site will have a security fence and monitored security cameras.
Hot Work	A permit to work system and risk assessment prior to starting work will be provided for each job involving the introduction of ignition sources.

6.1.2 Separation of Incidents

The separation of incidents is used to minimise the impacts of a hazardous incident on the surrounding operations or the generation of potential "domino" effects. The storage locations of products have been designed based upon whether a product can be adequately protected by the fire protection system. The BESS UL 9540 A tests (based on the criteria listed in **Appendix C**) indicated that propagation between modules will not occur from thermally running away battery cells. Furthermore, the BESS shall be arranged such that appropriate separation between units is required (BYD specifies that BESS units shall be separated by 4 m). Therefore, propagation within the BESS is unlikely, and therefore, propagation between adjacent BESS units is not considered to be credible.

6.1.3 Housekeeping

The risk of fire can be significantly reduced by maintaining high standards of housekeeping. The site shall maintain a high housekeeping standard, ensuring all debris is cleaned up and removed from the areas. In addition, the site has little vegetation present, which will eliminate the accumulation of combustible vegetation in proximity to the site equipment. This will minimise the potential for bushfire escalation, as indicated by the state mapping in **Figure 4-3.**

6.1.4 Work Practices

The following work practices will be undertaken to reduce the likelihood of an incident. They include:

- DG identification
- Placarding & signage within the site
- Forms of chemical and DG information
- Availability of Safety Data Sheets
- Compliance with the Work Health and Safety Regulation 2011 (Ref. [7]).
- Safe work practices adhered to
- Personal Protective Equipment
- Emergency response plan and procedures
- Bushfire Management Plan
- Training of personnel

6.1.5 Emergency Response Plan

Emergency management is critical in controlling and responding to an emergency. Therefore, to ensure that an appropriate emergency response plan is developed, the following recommendation has been made:

- An emergency response plan shall be prepared in accordance with HIPAP No. 1 – Industry Emergency Planning Guidelines (Ref. [20]).

6.1.6 Site Security

Maintaining a secure site reduces the likelihood either of a fire being started maliciously by intruders or by accident. Access to the site will be restricted at all times and only authorised personnel will be permitted within the site.

6.2 Fire and Gas Detection

This section discusses the detection and protection from fires for the hazardous incidents previously identified. These include detection of fire pre-conditions, detection of a fire suppression activated condition and prevention of propagation. This assessment includes identification of the detection and protection systems required.

6.2.1 Fire Detection and Alarming

The site will utilise BESS units that are UL 9540A compliant. Such BESS units are equipped with smoke detectors and thermal detectors to detect the early signs of a fire. If elevated temperatures or smoke are detected, an audible fire alarm and visual fire strobes fitted on the BESS unit will be activated. In addition, corresponding alarms will be sent to the EMS systems to alert site personnel to begin emergency procedures.

6.2.2 Gas Detection and Alarming

BESS units compliant with UL 9540 are fitted with flammable gas detection, which will alarm and activate the ventilation system. Flammable gases are a by-product of thermal runaway in the battery chemistries; hence, detection of the flammable gases provides another point to isolate BESS failure.

6.3 Fire Protection

The required fire protection systems are summarised below.

To be NFPA 855 compliant, BESS containers must be constructed of non-combustible materials.

BESS units may be fitted with water or gas fire suppression systems. In the event of detection of a fire within the BESS unit, the fire suppression system is triggered, releasing water or inert gas for fire suppression. However, NFPA 855 allows for the BESS units to be installed without fire suppression systems where fire, explosion and fault condition testing documents indicate the inherent BESS design is sufficient to limit thermal runaway events. The UL 9450A data for the BYD BESS indicates an active fire suppression system is not necessary. With evidence of UL 9540A data, the exclusion of a fire suppression system is justified.

6.4 Fire Mitigation

6.4.1 Fire Water Supply

The Australasian Fire and Emergency Service Authorities Council Limited (AFAC) published guidelines for Large-scale battery energy storage systems installations in February 2025 (Ref. [21]). The guidelines recommend the provision of a minimum of a hydrant system complying with the requirements of AS 2419.1:2021 or an assessment of a similar static supply of water. The guidelines also state that, if the nominated BESS site does not have adequate water supply or the designer proposes not to install firefighting infrastructure, evidence must be provided that a fire will be contained within the BESS and substation site boundaries. The analysis provided in **Section 5.0** shows this is the case for the BESS site.

Notwithstanding the evidence that fire would not propagate offsite, it is proposed that fire water can be sourced from the fire water tanks on the Mine and Village sites, each approximately 2 km away from the BESS site. The combined capacity of fire water on the sites is approximately 1,000 m^3 and the Mine operates several water carrying vehicles, including a 2 kL fire truck and a 10 kL water cart. These will assist QFD by supplementing the water supply in the case of a fire.

Based on the low potential for fire and / or propagation of a BESS fire it is considered that the water supply would be adequate to deal with the potential fire hazards at the site (i.e. propagation of a fire from the BESS noting that a BESS fire should not be fought with water). The water may also be used to supply combat measures for transformer fires or other building fires.

However, as explored in **Section 5.0**, fires from the electrical equipment or BESS will be contained within the site boundaries, justifying the exclusion of fire water storage on site.

6.4.2 Ventilation

In the event of thermal runaway, flammable gases are generated which, if ignited, could result in an explosion. The units are fitted with an extraction system that activates when a flammable gas is detected. The purpose of this system is to extract the gases to prevent accumulation to the explosive limits to minimise the potential for an explosion to occur.

7.0 Local Brigade Access and Egress

7.1 Overview

In order to assess the likely fire brigade response times, an indicative assessment of fire brigade intervention has been undertaken based on the methods defined in the Fire Brigade Intervention Model (FBIM, Ref. [22]). **Figure 7-1** is a modified version of **Figure 3-3** and illustrates the site layout with entry points to the site and portable fire extinguishers, which will be the primary fire extinguishing medium.

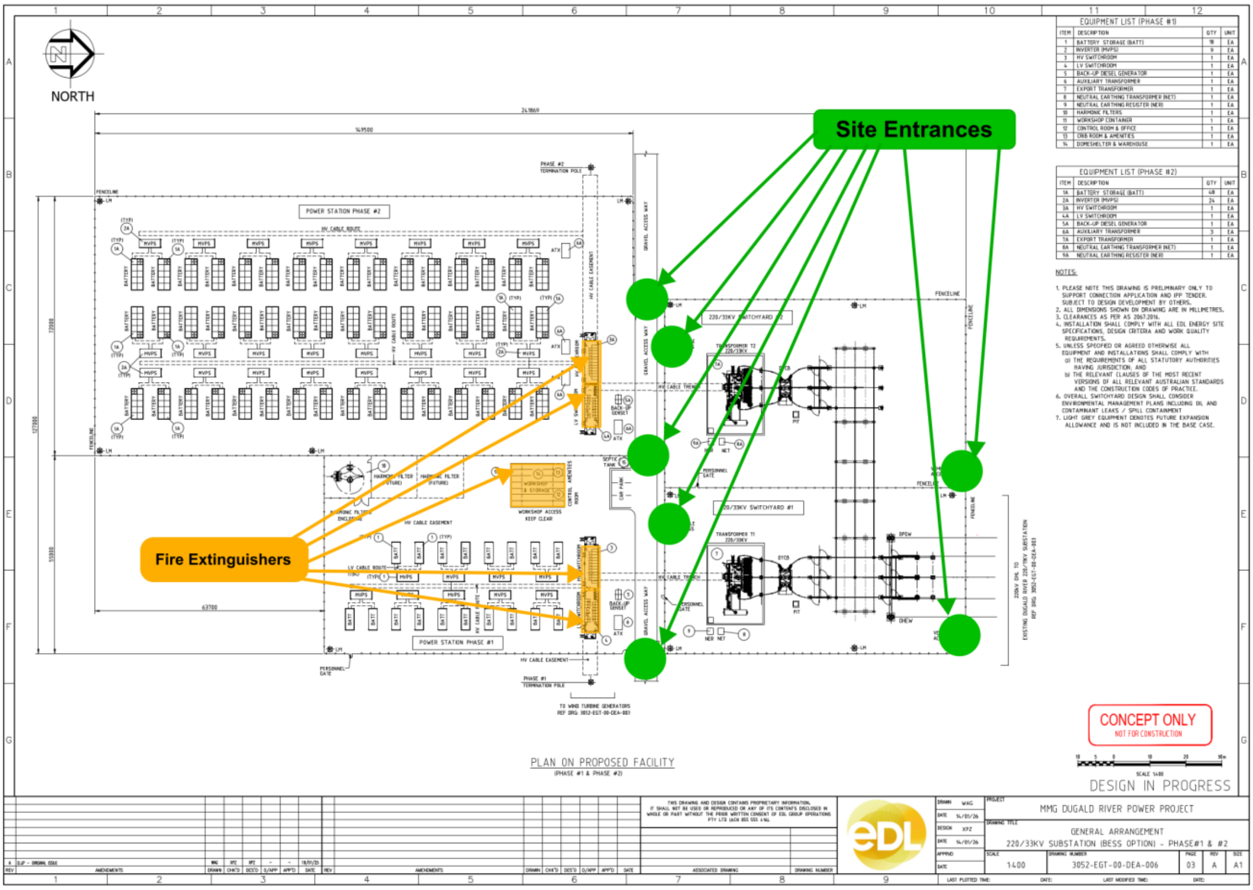


Figure 7-1: Fire Service Entry Point and Site Infrastructure

The closest fire station to the site is Cloncurry Fire Station. However, the Dugald River Mine site, which is 2 km east of the BESS facility, also has firefighting capabilities. These locations are summarised in **Table 7-1**. The expected route from Cloncurry Fire Station to the site is illustrated in **Figure 7-2**, while **Figure 7-3** shows the route from the Dugald River Mine site to the BESS facility. Note that the estimated travel time is increased from that indicated in **Figure 7-3** as the access roads are not currently available to estimate driving time. Thus, a more conservative travel time of 15 minutes is assumed.

Table 7-1: Firefighting Station Locations

Station Name	Station Address	Distance (km)	Time (min)
Cloncurry Fire Station	44 Scarr St, Cloncurry QLD 4824	70	50
Dugald River Mine	Cloncurry QLD 4824	5	15

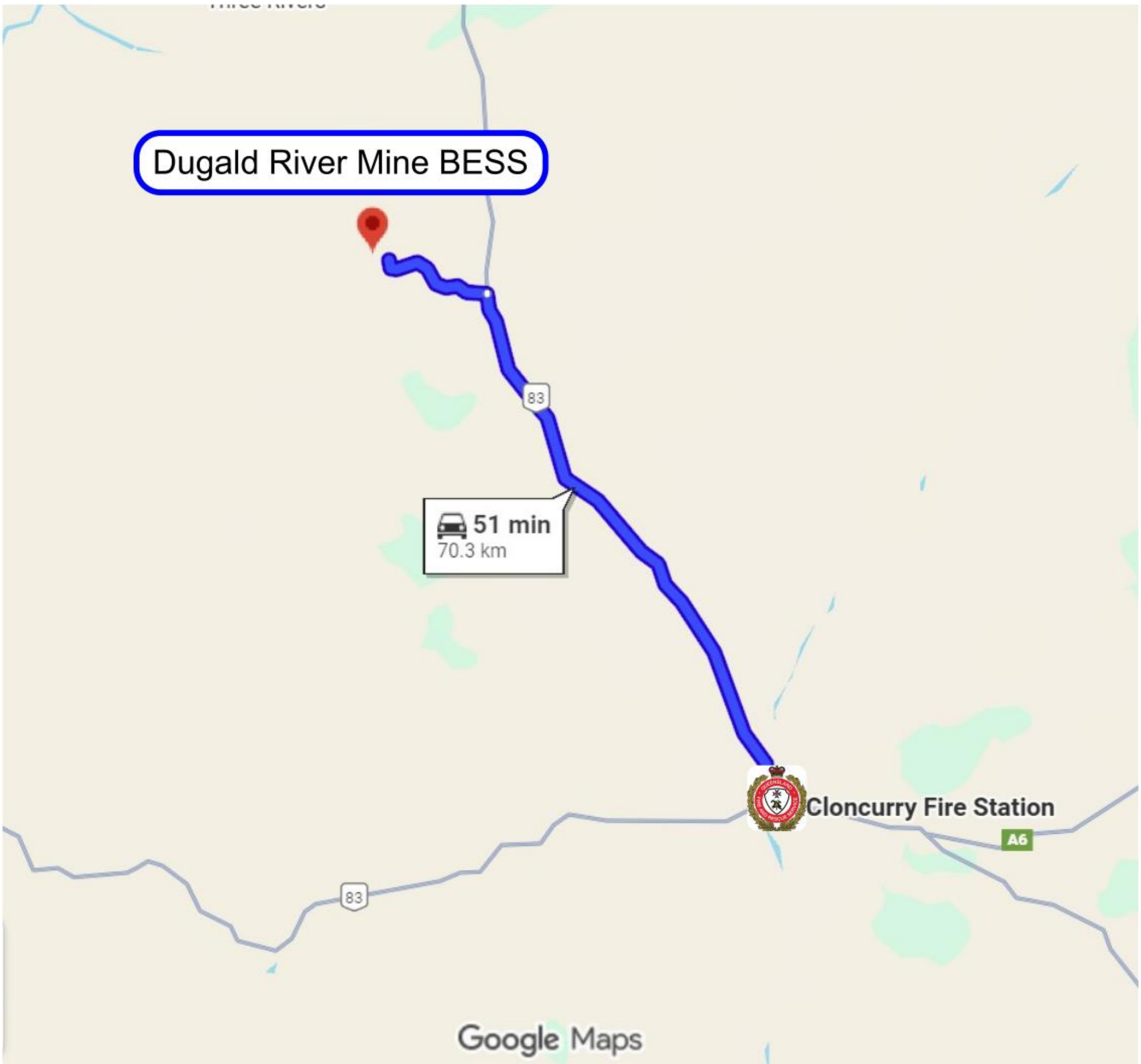


Figure 7-2: Location of BESS Site Relative to Cloncurry Fire Station

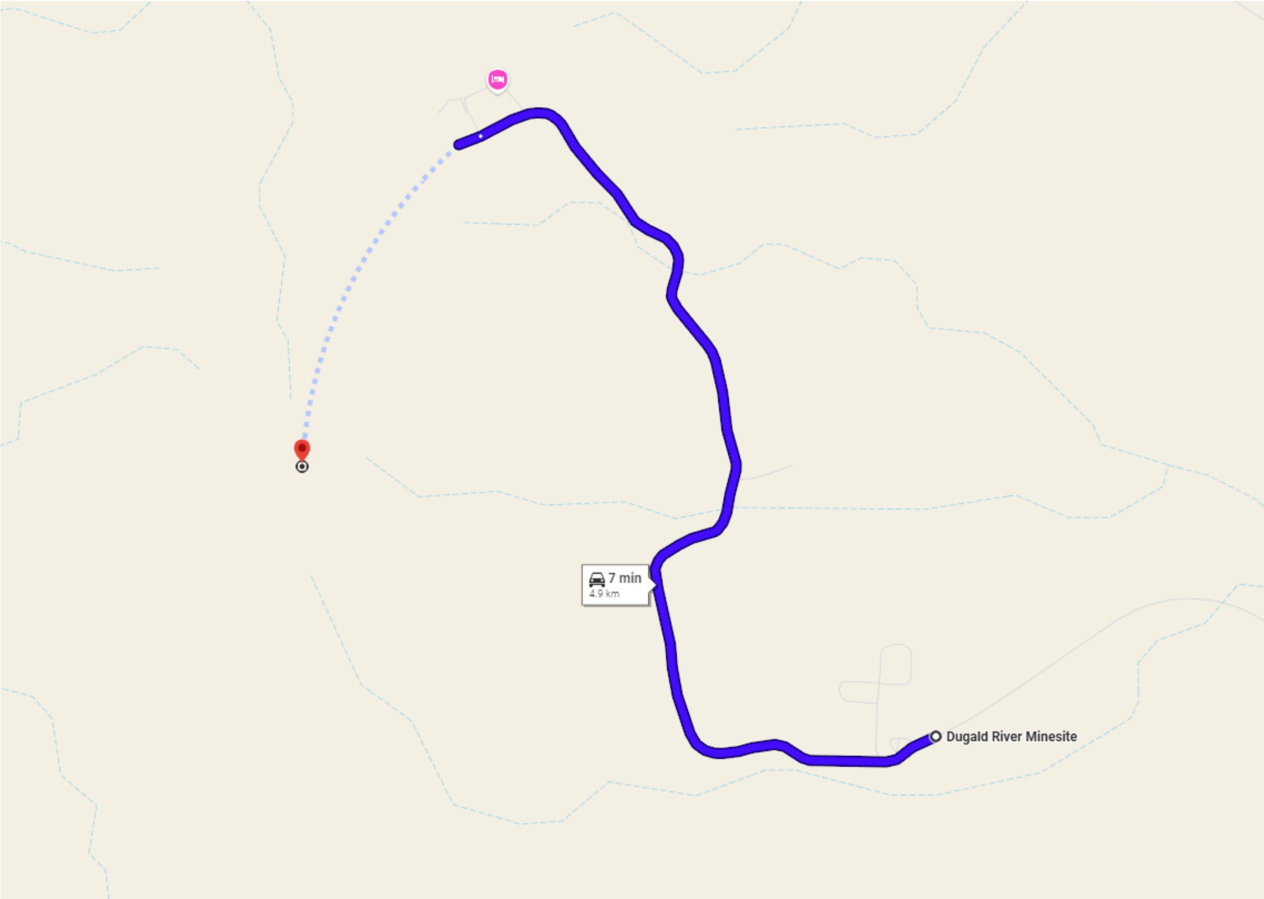


Figure 7-3: Route from Dugal River Mine to BESS Site

7.2 Response Time – Fire Brigade Intervention Model (FBIM)

Due to the nature of the Fire Brigade Intervention Model (FBIM, Ref. [22]), it is necessary to justify the results through the inclusion of assumptions. The accuracy of results weighs heavily upon the measure of which assumptions are made and the sources from which they are derived. The model produced details the time it will take for brigade personnel within the aforementioned location to receive notification of a fire, time to respond and dispatch resources, time for resources to reach the fire scene, time for the initial determination of the fire location, time to assess the fire, time for fire fighter travel to location of fire, and time for water setup such that suppression of the fire can commence. The following are details of the assumptions utilised in this FBIM:

7.2.1 Location of Fire

This FBIM will only be an indicative model of one fire scenario within the Project. For conservative purposes, the FBIM will consider a fire in the furthest incident from the point of entry.

7.2.2 Time between Ignition and Detection

- It is assumed that the initial brigade or Mine site notification is via a direct contact by the site personnel.
- It was conservatively assumed that the time from ignition, detection and notification to fire brigade is 30 minutes, or 1,800 seconds, due to the remote nature of the site.

7.2.3 Time to Dispatch Resources

- The fire station is considered to be manned at the time of the fire.
- As the site is located in a rural area, additional travel time should be considered. The travel time has been assumed to be 50 minutes (3,000 seconds) from the Cloncurry Fire Station or 15 minutes (900 seconds) from Dugald Reiver Mine.
- Therefore, with a call out time of 1,800 seconds, and travel time of 3,000 seconds (50 minutes), the fire brigade can be expected to arrive on site up to 4,800 seconds after fire ignition (80 minutes). Responders from the Mine should arrive to the site 2,700 seconds after ignition (45 minutes).

7.2.4 Time for Initial Determination of Fire Location

- On arrival, the fire location may not be visible to the approaching brigade personnel, thus requiring information to be obtained from the site emergency box.
- Fire brigade personnel assemble at the office area.
- Fire brigade tactical fire plans will be provided.

7.2.5 Time to Assess the Fire

- Horizontal egress speeds have been based on fire brigade personnel dressed in turnout uniform in BA. An average travel speed of 1.4 m/s with a standard deviation of 0.6 m/s as shown in **Table 7-2**. As such, for the purposes of the calculations, a horizontal travel speed of 1.40 – (1.28x0.6) = 0.63 m/s is utilised.
- This same speed is assumed for Cloncurry Fire Station responders and for Dugald River Mine responders.

Table 7-2: FBIM data for Horizontal Travel Speeds

Graph	Travel Conditions	Speed (m/s)	
		Mean	SD*
Q1	Dressed in turnout uniform	2.3	1.4
Q2	Dressed in turnout uniform with equipment	1.9	1.3
Q3	Dressed in turnout uniform in BA with or without equipment	1.4	0.6
Q4	Dressed in full hazardous incident suit in BA	0.8	0.5

*Standard Deviation

Horizontal travel distances will include the following:

- Travel from one of the site entrances to the furthest MVPS is no more than 150 m. Assuming vehicles are travelling at 60 km/h, this results in a travel time of 9 s.
- It was assumed that QFD would only be required to travel approximately 50 m on foot. Coupled with an egress speed of 0.63 m/s results in a horizontal travel time of up to 32 seconds.
- Thus, the total horizontal travel time to respond to an incident in the farthest location would be expected to be in the realm of 41 s.

7.2.6 Time for Water Setup

- The first appliance would be expected to commence the initial attack on the fire.
- Time taken to connect and charge RFS tanker units to any water tanks onsite and collect the water is based on Table X of the Fire Brigade Intervention Model Guidelines, which indicates an average time of 201.6 seconds, and a standard deviation of 115.6 seconds. Using a 90th percentile approach as documented in the FBIM (Ref. [22]), the standard deviation is multiplied by a constant *k*, in this case being equal to 1.28. Therefore, the time utilised in this FBIM is 201.6 + (1.28x115.6) = 350 s.

7.2.7 Search and Rescue

Search and Rescue of the site will consist of a perimeter search of the control building located adjacent to the BESS area. It was assumed this will provide firefighting personnel with an additional 500 m of travel.

At a speed of 0.63 m/s, this will take firefighting personnel approximately 315 seconds.

7.2.8 Summary

As summarised in **Table 7-3** the FBIM (Ref. [22]) indicates that the arrival times of the brigade from the nearest fire stations is approximately 81.5 minutes after fire ignition, and it is estimated that it takes another 11.1 minutes for the fire brigade to carry out activities including the determination of fire location and preparation of firefighting equipment. As such, the initial attack on the fire is expected to commence approximately 92.6 minutes after fire ignition (note rounding affects the basic addition of the reported figures).

Table 7-3: Summary of the Fire Brigade Intervention Model (FBIM)

Fire Station	Alarm Time	Travel Time	Time for Access & Assessment	Set-up Time	Time of Attack	Time for Search & Rescue
Cloncurry Fire Station	1,800 s	3,000 s	91 s	350 s	4,800 s (80 minutes)	315 s
Dugald River Mine	1,800 s	900 s	91 s	350 s	2,700 s (45 minutes)	315 s

8.0 Fire Water Supply & Contaminated Fire Water Retention

8.1 Detailed Fire Water System Assessment

As explained in **Section 6.4.1**, AFAC requires BESS facilities to be provided with a hydrant system in accordance with AS 2419.1:2021 or an equivalently adequate system. The AFAC guidelines allow for no additional fire water to be provided, other than that carried by the fire truck, if evidence that a fire event would be contained to the site boundaries is provided. **Section 5.0** provides this evidence. Notwithstanding this exclusion, firewater may be provided for conservatism.

Hydrants are not available at this site due to its rural location. Instead, water is carted from the Dugald River Mine, which has a total fire water capacity of 1,000 m^3, by a water truck owned by Dugald River Mine. The Mine has a 2 kL fire truck and a 10 kL water carrier, which will supplement the water carried by QFD vehicles.

The site will be equipped with portable fire extinguishers to supply fire protection in place of a fire water supply. The fire hazards have been assessed in **Section 5.0** which identified that there is a low potential for a fire to occur within the BESS units and that in the event of thermal runaway, the radiant heat generated would be unable to result in incident propagation. Furthermore, in the unlikely event of a BESS fire, it is explicitly discouraged to apply water to a BESS fire, negating the need for excess firewater.

Based on this, the water demand required to combat fire incidents at the site is low and would be expected to be adequately managed by the portable fire extinguishers. A fire water tank may be provided for conservatism.

8.2 Contaminated Water/Fire Water Retention

Where most materials are combusted in a fire, they may become toxic (i.e. formation of volatile organic compounds and aromatic hydrocarbons). Hence, when fire water is applied, the materials may mix with the water, resulting in a contaminated runoff. To ensure environmental damage does not occur, the ability of a site to retain contaminated fire-fighting water must be assessed.

A risk assessment methodology is outlined by the NSW Department of Planning document "*Best Practice Guidelines for Contaminated Water Retention and Treatment Systems*" (Ref. [23]). This guide is consulted to provide a conservative assessment of the site in the absence of an alternate guide provided by QLD regulation.

In the case of BESS fires, water should not be applied to a BESS fire; the application of fire water to a BESS fire does not result in extinguishment as the fire will continue until the energy has been discharged from the battery. In addition, application of water can result in additional side reactions as the fire progresses which can form potentially toxic by-products. Therefore, water shall not be applied directly to the BESS itself, but rather to any spot fires in surrounding vegetation to avoid propagation to other equipment/units.

The UL 9540A test data indicates that a flaming fire is not expected to occur; hence, the incident will likely be heated batteries which rupture resulting in the release of flammable gases which are handled by the ventilation system to prevent ignition. Therefore, it is expected an overheating event will mostly be contained within the BESS enclosure itself. The BESS enclosure would thus provide protection in the event that the incident occurs in the rain, avoiding water contamination.

Furthermore, vegetated areas around BESS are typically used for grazing of livestock; hence, the area will not be paved, preventing any reasonable method for providing containment in the event that contamination of fire-fighting water does occur. However, given the protection systems incorporated into the BESS design, the likely outcome of thermal runaway not resulting in a flaming fire, the potential for contaminated water to be generated from this incident is considered low. Accommodating the unlikely formation of contaminated water would be disproportionately expensive compared to the risk of contamination.

Based on the above discussion, no recommendations have been made with respect to contaminated water retention.

9.0 Conclusion and Recommendations

9.1 Conclusions

An FSS was prepared for the proposed BESS component of the Dugald River Wind Farm and BESS Project located near the Dugald River Mine. The analysis performed in the FSS was based on credible fire scenarios to assess whether the protection measures at the site were adequate to combat the hazards associated with the quantities and types of commodities being stored. Based on the assessment, it was concluded that the designs and existing fire protection adequately managed the credible fire risks at the site.

9.2 Recommendations

Based on the analysis, the following recommendations have been made:

- All site personnel shall be inducted in site procedures and emergency response protocols relevant to their roles.
- All site personnel who require training must undergo formal training in the required procedures and emergency response protocols relevant to their role.
- Necessary personnel to provide first aid are to be trained in accordance with the QLD Code of Practice for first aid in workplaces 2021– high-risk workplaces (Ref. [5]).
- A team of site personnel are to be trained in the use of the water cart and first-attack firefighting methods.
- Site management to prepare and maintain operational procedures to minimise the number of hazardous incidents and accidents on site and to mitigate the consequences of incidents regarding the handling of dangerous goods and chemicals.
- A Risk Management Assessment Report shall be completed as per the requirements of State Code 27.
- A site Emergency Management Plan per the requirements of HIPAP No. 1 and State Code 27 shall be prepared and shall include measures to advise neighbouring premises in the event of an emergency with potential offsite impacts.
- Dangerous Goods (DG) documentation shall be prepared as required by the Work Health and Safety Regulation 2011 to demonstrate the risks associated with the storage and handling of DGs has been assessed and minimised.
- Any DGs stored at the site shall be stored and handled in accordance with the Work Health and Safety Regulation 2011 and any applicable storage and handling standards.

10.0 References

[1] Department of Planning, "Hazardous Industry Planning Advisory Paper No. 2 - Fire Safety Study Guidelines," Department of Planning, Sydney, 2011.

[2] Fire and Rescue NSW, "Technical Information – Large scale external lithium-ion battery energy storage systems – Fire Safety Study Considerations," State Goverment NSW, Sydney, 2023.

[3] Electrical Safety Office, "Managing electrical risks in the workforce Code of Practice," Queensland Government, 2021.

[4] E. N. A. C. C. E. C. C. E. S. A. A. A. I. G. Smart energy, "Best Practice Guide For battery Storage Equiptment," un known, 2018.

[5] Work Health and Safety Queensland, "First Aid in the Work Place," Work Health and Safety, 2021.

[6] Department of Planning, "Hazardous Industry Planning Advisory Paper No. 4 - Risk Criteria for Land Use Safety Planning," Department of Planning, Sydney, 2011.

[7] Work Health and Safety QLD, "Work Health and Safety Regulation," Work Health and Safety QLD, 2011.

[8] National Transport Commission (NTC), "Australian Code for the Transport of Dangerous Goods by Road & Rail, 7th Edition," 2011.

[9] Power Tech Systems, "Safety of Lithium-Ion batteries," Power Tech Systems, 2022. [Online]. Available: https://www.powertechsystems.eu/home/tech-corner/safety-of-lithium-ion-batteries/. [Accessed 13 April 2022].

[10] F. Larson, P. Andersson, P. Blomqvist and B.-E. Mellander, "Toxic fluoride gas emissions from lithium ion battery fires," Nature: Scientific Reports, 2017.

[11] J. I. Franqueville, E. J. Archibald and O. A. Ezekoye, "Data-driven modeling of downwind toxic gas dispersion in lithium-ion battery failures using computational fluid dynamics," *Journal of Loss Prevention in the Process Industries,* vol. 86, 2023.

[12] Cargill Incorporated, "FR3 fluid: Acceptable delivery specifications (Electrical Apparatus R2000)," Cargill Incorporated, 2021.

[13] J. Demos, "What Causes Transformer Explosions and Burns?," Durabarrier USA Fire Barrier Experts, 26 July 2021. [Online]. Available: https://firebarrierexperts.com/what-causes-transformer-explosions-and-burns/#:~:text=The%20most%20common%20reason%20why,accidents%20caused%20by%20lightning%20strikes.&text=The%20first%20is%20an%20overload,flash%20point%20or%20fire%20point. . [Accessed 2 February 2022].

[14] P. Hoole, S. Rufus, N. Hashim, M. Saad, S. Abdullah, A. Othman, K. Piralaharan, A. CV and S. Hoole, “Power Transformer Fire and Explosion: Causes and Control,” *International Journal of Control Theory and Applications,* vol. 10, no. 16, pp. 211-219, 2017.

[15] Standards Australia, “AS 2067:2016 - substations and high voltage installations exceeding 1 kV a.c.,” Standards Australia, Sydney, 2016.

[16] International Commission on Non-Ionizing Radiation Protection, “ICNIRP Guideline for Limiting Exposure to Time-Varying Electric and Magnetic Fields (1-100 Hz),” International Commission on Non-Ionizing Radiation Protection, 2010.

[17] EMM Consulting, “Planning Permit Application - Mornington Battery Energy Storage System,” Maoneng Australia Pty Ltd, Sydney, 2021.

[18] Cloncurry Shire Council, “Cloncurry Shire Planning Scheme,” Cloncurry Shire Council, Cloncurry, 2016.

[19] Standards Australia, “AS/NZS 3000:2018 - Wiring Rules,” Standards Australia, Sydney, 2018.

[20] Department of Planning, “Hazardous Industry Planning Advisory Paper No. 1 - Industry Emergency Planning,” Department of Planning, Sydney, 2011.

[21] Australasian Fire and Emergency Service Authorities Council Limited (AFAC) , “Large-scale battery energy storage system installations,” AFAC, Melbourne, 2025.

[22] Australasian Fire Authorities Council, “Fire Brigade Intervention Model V2.2,” Australasian Fire Authorities Council, 2004.

[23] NSW Department of Planning, “Best Practice Guidelines for Contaminated Water Retention and Treatment Systems,” NSW Department of Planning, Sydney, 1994.

[24] The Hague, “Yellow Book: Methods for the calculation of physical effects : due to releases of hazardous materials (liquids and gases),” The Hague, Netherlands, 2005.

[25] e. a. A. Szajewska, “Determining of a Passenger Car Fire Temperature,” Measurement Automation Monitoring, June 2015.

[26] Tesla, “UL 9540A: Test Method for Evaluating Thermal Runaway Fire Propagation in Battery Energy Storage System,” Tesla, 2024. [Online]. Available: UL 9540A: Test Method for Evaluating Thermal Runaway Fire Propagation in Battery Energy Storage System. [Accessed 16 April 2025].

[27] Road Safety Council, The Australian Code for the Transport of Dangerous Goods by Road and Rail Edition 7.7, Canberra: Road Safety Council, 2020.

Appendix A

Hazard Identification Table

Appendix A

A1. Hazard Identification Table

ID	Area/Operation	Hazard Cause	Hazard Consequence	Safeguards
1	Battery Storage	• Battery fault / failure • Failure of Li-ion battery protection systems	• Thermal runaway resulting in fire or explosion • Incident propagation through battery cells • Toxic smoke dispersion • Short-term environmental damage	• Batteries are tested by manufacturer prior to sale / installation • Overcharging and electrical circuit protection • Battery monitoring systems • Batteries composed of subcomponents reducing risk of substantial component failure (such as liquid cooling system) • Batteries are not located in areas where damage could easily occur (i.e. within the fenced property) • Electrical systems designed per AS/NZS 3000:2018 (Ref. [19]) • Ventilation • Explosion venting • Smoke & gas detection • Aerosol-based fire suppression system
2			• Toxic smoke dispersion • Short-term environmental damage	
3	Switch rooms, communications, etc.	• Arcing, overheating, sparking, etc. of electrical systems	• Ignition of processors and other combustible material within servers and subsequent fire	• Fires tend to smoulder rather than burn • Isolated location • Switch room is separated from other sources of fire
4	Transformers	• Arcing within transformer, vaporisation of fluid and rupture of fluid reservoir	• Transformer fluid release spill, ignition and fire	• Natural ester used as dielectric fluid – Natural esters have a high flash point (>300°C) such that ignition is very unlikely to occur. • Transformers are bunded • Electrical protection for transformer faults • Control of ignition sources – no smoking / open flames around the transformers

ID	Area/Operation	Hazard Cause	Hazard Consequence	Safeguards
5	Ancillary transformers	• Power surge to transformers (e.g. fault)	• Major failure of surge protection in transformer, vapourisation of mineral oil, ignition and explosion	• Transformers are in containers which protect from lightning and cables are underground. • Control of ignition sources – no smoking / open flames around the transformers
6	Main transformer	• Arcing and overheating • Failure of pressure relief valves • Spill of oil • Heating > 150 oC • Surge protection failure	• Fire • Damage to property < $1M • Fatality • Incident propagation	• Low oil pressure switch • Gas detectors • Lightning protection • Global use indicates relative safety • Bunding around transformers limits spread • Control of ignition sources – no smoking / open flames around the transformers
7		• Power surge to transformers (e.g. from lightning, fault, etc.)	• Major failure of surge protection in transformer, vapourisation of mineral oil, ignition and explosion	• Transformers have surge protection system to divert overvoltage surges to the ground. Very fast acting • Lightning protection to prevent lightning strikes impacting transformers • Control of ignition sources – no smoking / open flames around the transformers
8	Electrical equipment	• Constant release of electromagnetic field	• Minor health impacts from extended exposure	• Inherently lower levels than background radiation • Drop off within short distances • No sensitive receivers within 1 km of the site
9	Bushfire	• Lightning strike • Maliciously lit fire	• Damage to property < $1M • Fatality/fatalities • Incident propagation	• Separated arrangement of equipment to limit propagation (remove fuel) • Housekeeping procedures to keep grass low. • Inherent fire protection in BESS and high heat resistance of other equipment
10	Flood	• Dugald River overflow	• Damage to property < $1M	• Inherently negligible likelihood of flooding

ID	Area/Operation	Hazard Cause	Hazard Consequence	Safeguards
				• BESS raised slightly off the ground

Appendix B

Consequence Analysis

B1. Incidents Assessed in Detailed Consequence Analysis

The following incidents are assessed for consequence impacts.

- Li-ion battery fault, thermal runaway and fire.
- Main transformer internal arcing, oil spill, ignition and bund fire.

Each incident has been assessed in the sections below.

B2. Radiant Heat Physical Impacts

Appendix Table B-1 provides noteworthy heat radiation values and the corresponding physical effects of an observer exposed to these values (Ref. [6]).

Appendix Table B-1: Heat Radiation and Associated Physical Impacts

Heat Radiation (kW/m^2)	Impact
35	• Cellulosic material will pilot ignite within one minute's exposure • Significant chance of a fatality for people exposed instantaneously
23	• Likely fatality for extended exposure and chance of a fatality for instantaneous exposure • Spontaneous ignition of wood after long exposure • Unprotected steel will reach thermal stress temperatures which can cause failure • Pressure vessel needs to be relieved or failure would occur
12.6	• Significant chance of a fatality for extended exposure. High chance of injury • Causes the temperature of wood to rise to a point where it can be ignited by a naked flame after long exposure • Thin steel with insulation on the side away from the fire may reach a thermal stress level high enough to cause structural failure
4.7	• Will cause pain in 15-20 seconds and injury after 30 seconds exposure (at least second degree burns will occur)
3.0	• FRNSW criterion for accessibility of hydrants and other fire protection systems. Assumed as the criterion for QFD

B3. Gexcon - Effects

The modelling was prepared using Effects where appropriate, which is proprietary software owned by Gexcon which has been developed based upon the TNO Coloured books and updated based upon CFD modelling tests and physical verification experiments. The software can model a range of incidents including pool fires, flash fires, explosions, jet fires, toxic dispersions, warehouse smoke plumes, etc.

B4. View Factor Radiant Heat Model

The modelling for the BESS units was carried out using a manual view factor calculation method outlined below.

B4.1 Radiant Heat Flux

The heat flux (Q) for the view factor model is given by **Equation 10-1**.

$$Q = \tau EF \qquad \textbf{Equation 10-1}$$

Where;

- Q = heat flux (kW/m^2) at the target
- F = geometric view factor
- τ = transmissivity
- E = SEP (kW/m^2)

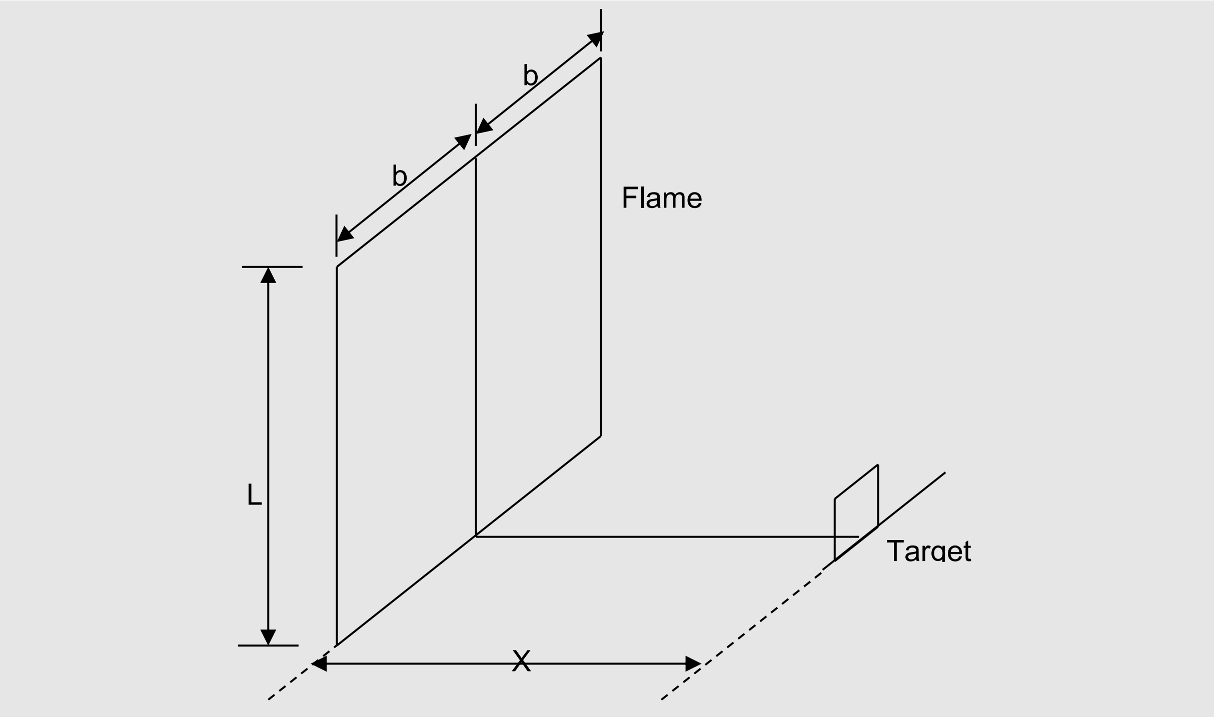
Each of the required inputs is determined in the sections following.

B4.2 View Factor

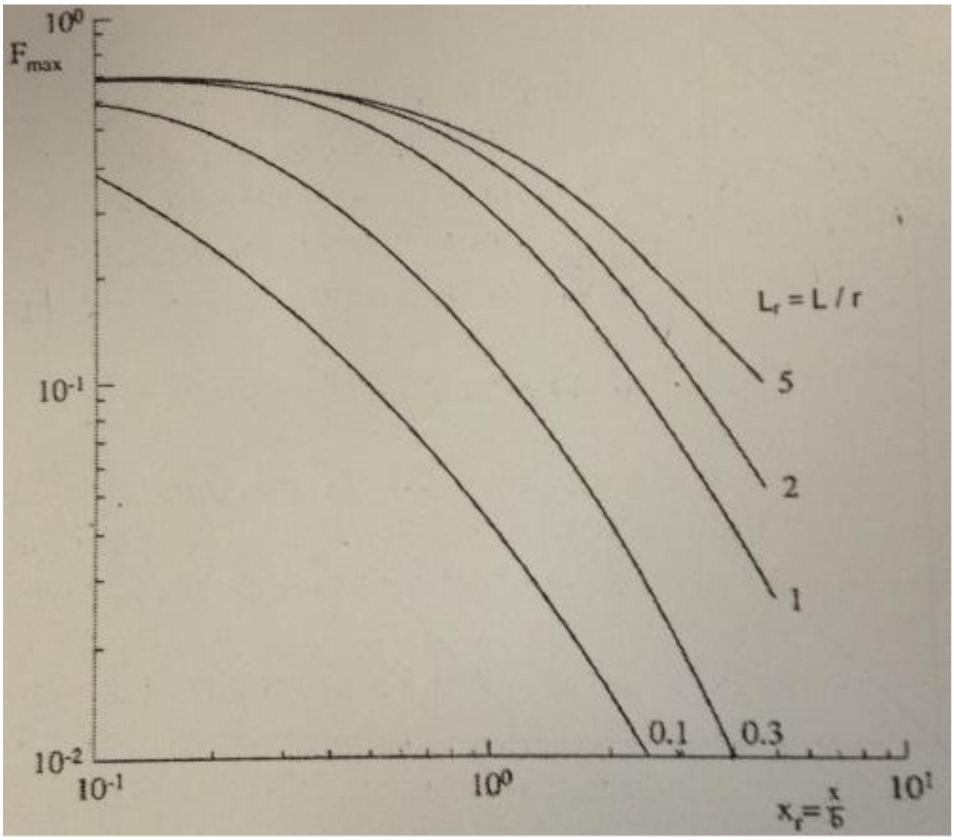
The view factor for a flat surface fire is estimated using the scenario shown in **Appendix Figure B-1** where the flame is the vertical surface of height L and length 2b with receiver located centrally and at a distance of X. Two dimensionless parameters are calculated, and the view factor read from **Appendix Figure B-2**. The dimensionless parameters are shown in **Equation 10-2** and **Equation 10-3**.

$$L_r = \frac{L}{b}$$ **Equation 10-2**

$$X_r = \frac{x}{b}$$ **Equation 10-3**



Appendix Figure B-1: Vertical Flame Geometry View Factor Geometry



Appendix Figure B-2: Vertical Flame Maximum View Factor (Ref. [24])

B4.3 Transmissivity

The transmissivity is estimated using **Equation 10-4**.

$$\tau = 1.006 - 0.01171(\log_{10} X(H_2O) - 0.02368(\log_{10} X(H_2O))^2 - 0.03188(\log_{10} X(CO_2) + 0.001164(\log_{10} X(CO_2))^2 \quad \textbf{Equation 10-4}$$

Where:

- $X(H_2O) = (R_H \times L \times S_{mm} \times 2.88651 \times 10^2)/T$
- $X(CO_2) = L \times 273/T$

And;

- R_H = percentage relative humidity
- L = distance to target (m)
- S_{mm} = saturated water vapour pressure in mm mercury at temperature (at 200°C S_{mm} = 11549)
- T = temperature (473 K assumed air is heated to 200°C)

B5. Li-Ion Battery Fault, Thermal Runaway and Fire

The BESS units selected are the BYD BYD - MC Cube-T ESS, each of which is housed in a container with the dimensions 6,058 (W) x 2,438 (D) x 2,896 (H) mm.

To determine the radiant heat impacts from the BESS in the event of a fire it is necessary to assume the height of the flame. The rule of thumb for most flammable liquid fires is that the height is 2 times the width of the flame; however, a review of the Victorian Big Battery (VBB) fire indicates that it did not align with rule of thumb approach.

Based upon the VBB it has been assumed that the maximum height of the flame is 1 m above the height of the BESS unit. From the VBB it was apparent that only the flame through the roof was exposed as a radiant surface; hence, the assumed flame height of 1 m above the BESS container has been taken as the value of L for input into **Equation 10-2**.

It is necessary to calculate the Surface Emissive Power (SEP) of the radiant surface to calculate the radiant heat at the target. The test data of a similar BESS unit indicated the average temperature of the batteries at thermal runaway was 239°C or 512.15 K. Therefore, for the purposes of modelling this temperature has been used.

The following equation can be used to estimate the SEP of the flame:

$$SEP = \varepsilon \sigma T^4$$ **Equation 10-5**

Where:

- ε = flame emissivity (taken as 0.78 (Ref. [25]))
- σ = 5.67×10^{-11} kW/m^2.k^4
- T = Temperature (512.15 K)

Substituting into the above equation yields:

$$SEP = 0.78 \times 5.67 \times 10^{-11} \times 512.15^4 = 3.04 \frac{kW}{m^2}$$

It is assumed the LSFT data for the BYD MC Cube showed similar results, especially as this test concluded that there was no propagation of the fire from one BESS to another.

B6. Main Substation Transformer Internal Arcing, Oil Spill, Ignition and Bund Fire

Transformers contain oil to provide cooling and insulation. If arcing occurs within the transformer, the oil will rapidly heat generating gases above their auto ignition point. The pressure of the gases may rupture the reservoir allowing oxygen to enter resulting in the gases auto igniting. The oil is released from the reservoir and is ignited by the burning gases.

The transformer is assumed to be bunded and so in the event of a spill and ignition, the pool fire will have dimensions of the bund. The inputs for the model are provided in **Appendix Table B-2**.

Appendix Table B-2: Main Transformer Fire Modelling Inputs

Input	Value	Justification
Chemical name	n-Decanoic acid	Transformer oil to be used is uninhibited mineral oil, which is typically a combustible liquid of some formulation which have high flash points. For the purposes of providing a conservative analysis, n-decanoic acid has been selected. This material has a flash point of approximately 150°C.
Type of pool fire calculation	Rew & Hulbert	The model has been developed for modelling fires based on the radiant heat emitted from the radiant surface. The model uses the clear and sooty portions of the flame to estimate the radiant heat at the target. The terminology (i.e. pool fire) is because these models were originally developed from liquid pool fires. However, the model actually works by looking at the flame surface to estimate the radiant

Input	Value	Justification
		heat that is emitted from that surface. The flame surface is present irrespective of the material burning (i.e. a solid or liquid pool will have a flame that will have a clear and sooty portion). Based on the above discussion, it is considered that the Rew & Hulbert model is appropriate for modelling the fire.
Type of pool fire source	Instantaneous	Conservative as it assumes full fire immediately
Soot definition	Calculated	Calculated
Total mass released	10,000 kg	Mass of oil in the transformers
Temperature of pool	30°C	Conditions expected to be observed regularly. Also, negligible impact on results.
Type of pool	Polygon	Modelled based on transformer bund area.
Height of confined pool above ground level	0 m	Modelled at ground level
Include shielding to bottom side of flame	No	No shielding provided in modelling.
Height of shielding	n/a	n/a
Wind speed	6 m/s	High wind speed modelled for worst-case scenario.
Wind direction	North	Worst-case direction, pushing flames towards BESS units.
Ambient temperature	30°C	Conditions expected to be observed regularly. Also, negligible impact on results.
Ambient pressure	1.0151 bar	Atmospheric pressure
Ambient relative humidity	40%	Typical humidity in the area
CO2 concentration	0.0004	CO2 concentration in atmosphere

The results of the analysis are shown in **Appendix Table B-3.**

Appendix Table B-3: Heat Radiation Impacts from a Transformer Bund Fire

Heat Radiation (kW/m^2)	Distance (m)
35	10
23	18
12.6	23
4.7	32
3.0	37

Appendix C

UL 9540 A Testing Criteria

The UL 9540 A test criteria for BESS cells are the following:

- Thermal runaway cannot be induced in the cell; AND
- The gases vented by the cell are non-flammable in the air.

If the cell does not meet the cell-level test, the test progresses to the BESS modules. The UL 9540 A test criteria for BESS modules are the following:

- Thermal runaway is contained by the module design; AND
- The gases vented by the cell are non-flammable in the air.

If the cell does not meet the module-level test, the test progresses to BESS units. The UL 9540 A test criteria for BESS units are the following:

- No flames are evident outside of the BESS; AND
- The surface temperature of adjacent units does not exceed the cell venting temperature; AND
- The temperature of the wall of the BESS unit does not exceed 97 °C; AND
- No explosion hazards are exhibited.

If the cell does not meet the unit-level test, the test progresses to BESS installation. The UL 9540 A test criteria for the installation of BESS units are the following:

- Any evident flames do not propagate beyond the width of the unit; AND
- The surface temperature of adjacent units does not exceed the cell venting temperature; AND
- The temperature of the wall of the BESS unit does not exceed 97 °C.

Figure 10-1 exhibits a flowchart to help understand the UL 9540A test at different levels.

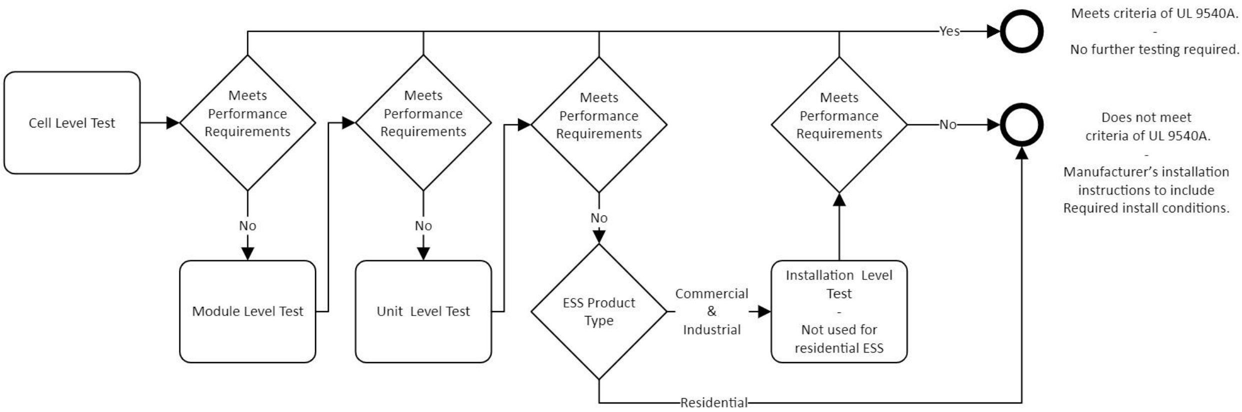


Figure 10-1: Flow Chart for UL 9540A Testing at Different Levels. Source: [26]