Risk Management Assessment Report

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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Rev	Date	Remarks	Prepared By	Reviewed By
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B	30th March 2026	Revised draft issued for comment		
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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 facility 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 the substation/s 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) to comply with PO2-4. This document presents the RMAR, which aligns with the risk management guidelines established in AS ISO 31000:2018 (Ref. [1]).

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

Conclusions

A RMAR was prepared for the proposed BESS component of the Dugald River Wind Farm and BESS Project located near the Dugald River Mine. A hazard identification table was developed for the BESS component of the Project to identify potential hazards that may be present at the site as a result of operations or storage of materials. Based on the identified hazards, scenarios were postulated that may result in an incident with a potential for offsite impacts. Postulated scenarios were discussed qualitatively and any scenarios that would not impact offsite were eliminated from further assessment. The likelihood and consequences of these events were qualitatively discussed to determine the risk.

Incidents carried forward for quantitative analysis were modelled in EFFECTS in detail to estimate the impact distances. Impact distances were developed into scenario contours and overlaid onto the site layout diagram to determine if an offsite impact would occur. The impact distances of the incidents analysed using EFFECTS were shown to not affect adjacent equipment and thus, would not cause incident propagation. Furthermore, there are no potential off-site impacts. The likelihood of these events was semi-quantitatively determined to be near negligible, meaning the risks (combining the limit consequence and low likelihood) of these events are acceptably low.

Based on the analysis conducted, it is concluded that there are no unacceptable risks at the site boundary, nor any risk of incident propagation. Thus, the risks are considered sufficiently managed by the inherent safety features of the BESS units and by existing safety precautions.

Recommendations

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

- Evidence of UL 9540A testing and LSFT shall be provided to the regulator and SARA upon acquisition and submission for approval.
- 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. [2]).
- 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 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.

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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
EMS	Environmental Management Strategy
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
MMG	MMG Dugald River Pty Ltd
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.

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1.2 Objectives

According to AS ISO 31000:2018, the key objectives of this RMAR are to:

- Identify potential hazards to the BESS facility that would hinder regular operations or have potential off-site impacts.
- Analyse the consequences and likelihood of a hazardous event, thus assigning hazards a risk level.
- Evaluate the risks against relevant risk criteria to determine where additional action is required, until the risks are mitigated As Low As Reasonably Practicable (ALARP).

1.3 Scope of Services

The scope of work is to prepare a RMAR for the BESS Project to assist in evaluating possible dangerous goods and demonstrating the facility is safe to operate and compliant with the relevant codes, standards, and regulations. Additional facilities, including the Wind Turbines comprising the Dugald River Mine Wind Farm, are considered beyond the scope of this assessment.

2.0 Methodology

2.1 Risk Assessment Methodology

The risk assessment methodology described below is based on the Australian Standard AS31000-2018, “Risk Management-Principles and Guidelines”, as per the requirements of State Code 27. The risk assessment methodology broadly uses the principles of Identification, Analysis and Evaluation, as summarised in **Figure 2-1**.

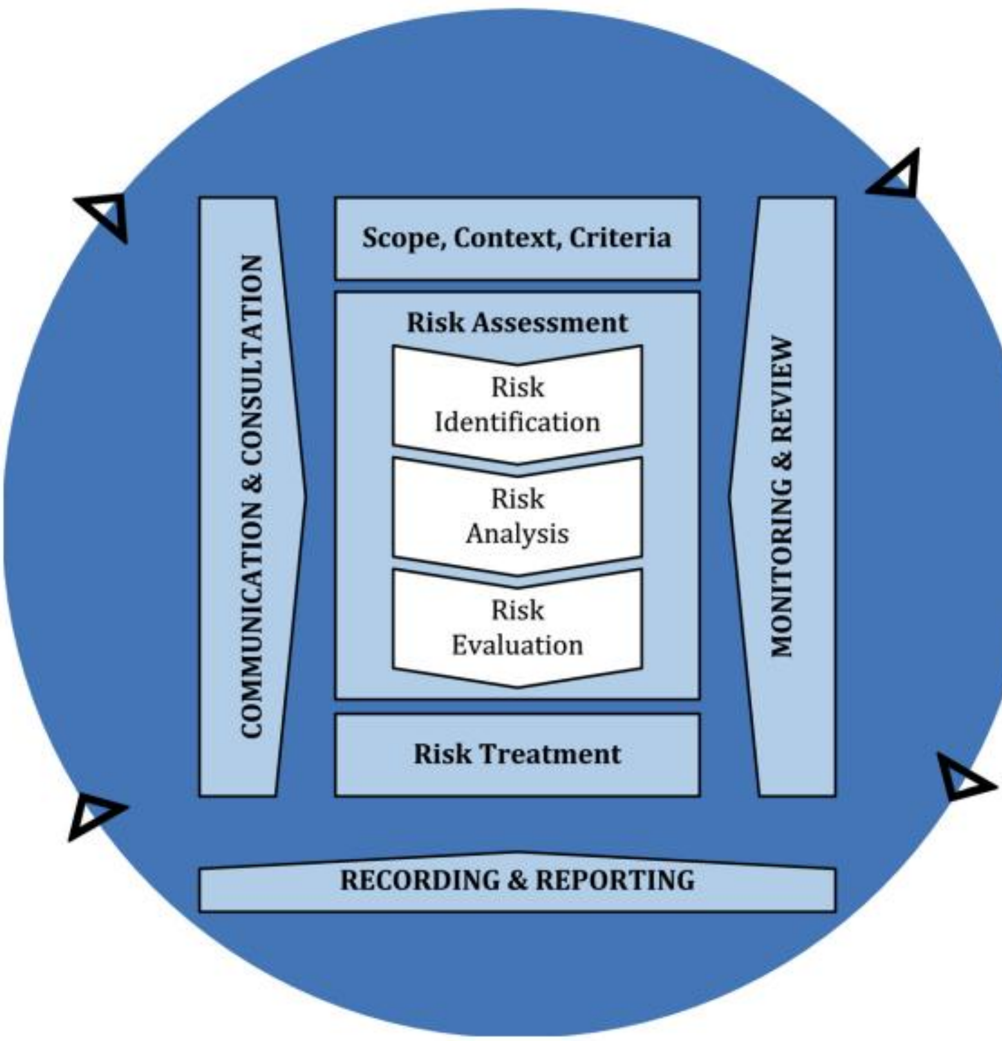

Figure 2-1: Risk Assessment Process (Source: AS ISO 31000:2018)

2.1.1 Hazard Identification Methodology

While AS ISO 31000:2018 refers to ‘Risk Identification’, it is more accurate to discuss hazard identification, with ‘hazard’ being defined as a source of potential harm or damage to health, property or the environment. ‘Risk’ is the description of the combined assessment of consequence and likelihood of a hazardous event and is more useful in the later stages of Analysis and Evaluation.

To properly assess risks, hazard identification is a crucial step. For this Project, hazards are identified based on previous projects, previous hazardous events that have occurred, and potential hazards arising from properties of the specific dangerous goods stored on-site.

2.1.2 Risk Analysis Methodology

Risk analysis is the process of assessing the consequences of hazardous events in conjunction with the likelihood of these events. The methodologies of risk analysis presented in AS31000 range from fully quantitative to fully qualitative. The Multi-Level Risk Assessment approach, published and adopted by NSW Department of Planning, Housing and Infrastructure (DPHI), is a useful screening tool to determine the type of risk assessment to use. The levels of a Multi-Level Risk Assessment (Ref. [3]) are summarised in **Table 2-1**.

Table 2-1: Multi-Level Risk Assessment

Level	Type of Analysis	Appropriate If:
1	Qualitative	No major off-site consequences and societal risk is negligible
2	Partially Quantitative	Off-site consequences but with low frequency of occurrence
3	Quantitative	Where 1 and 2 are exceeded

A partially quantitative (Level 2) methodology is normally used for low- to medium-range risk analysis and early-phase analyses and uses the risk matrix approach. Based on the type of DGs to be used and handled at the proposed site, this level of assessment (Level 2) is considered suitable. This approach provides a qualitative assessment of those DGs of lesser quantities and hazard, and a quantitative approach for the more hazardous materials to be used on-site.

The qualitative approach uses a series of tables to assess the consequence severity and likelihood of an identified hazard (to cause harm to people, property or the environment (see **Table 2-2** and **Table 2-3**) and uses a risk matrix to assess the risk level of the identified hazard (see **Figure 2-2**). The results indicate the level of risk associated with the hazard.

Table 2-2: Consequence Values Used in Risk Assessment

Consequence		Consequence Description			
Score	Descriptor	Operations/ Maintenance	Financial	Safety	Environment
1	Insignificant	Short duration down time – adequate redundancy, process unaffected	Less than $5k damage	First Aid Injury (FAI), no lost time	Localised spill contained in a bund or in the immediate spill area Fugitive emissions
2	Minor	Downtime – managed without affecting process (e.g. recycle within the plant)	$5k to $100k damage	Medical Treatment Injury, no lost time	Spill contained in site Short term emissions
3	Moderate	Major non-critical equipment failure	$100k to $1M damage	Lost Time Injury or illness (LTI)	Spill escapes to stormwater or groundwater system Some complaints received over environmental issue

Consequence		Consequence Description			
Score	Descriptor	Operations/ Maintenance	Financial	Safety	Environment
4	Major	Critical equipment failure Structural failure Failure to meet licence conditions	$1M to $10M damage	Permanent disability Single fatality	Major spill to the stormwater system Prosecution from air emissions Numerous neighbour complaints
5	Catastrophic	Extended downtime causing loss of asset Explosion/Major Fire	More than $10M damage	Multiple fatalities	Large media coverage of environmental incident Fines from DPE

Table 2-3: Likelihood Values Used in Risk Assessment

Likelihood Indicator		Likelihood Description
Score	Indicator	
A	Almost Certain	Has occurred many times, repeated occurrence
B	Likely	Occurs annually, has happened & will re-occur
C	Occasional	Has occurred once in the past, may occur some time
D	Unlikely	Has occurred in organisation at other sites, but not at this site, <10% chance of happening during the plant's life
E	Rare	Has not occurred at in the organisation but has occurred in the industry, has the potential to occur, <1% chance of happening but only in exceptional circumstances

Likelihood	Consequence: Insignificant 1	Minor 2	Moderate 3	Major 4	Catastrophic 5
A (almost certain)	S	S	H	H	H
B (likely)	M	S	S	H	H
C (moderate)	L	M	S	S	H
D (unlikely)	L	L	M	M	S
E (rare)	L	L	L	M	M

H	High Risk – Requires both hardware and procedures to mitigate
S	Significant Risk – Review hardware requirements and develop new procedures
M	Moderate Risk – Review existing procedures for adequacy, additional procedures where required
L	Low Risk – Managed mainly with existing procedures

Figure 2-2: Risk Matrix used in Risk Assessment

Where risks are identified to require quantitative consequence assessment, the hazardous event is modelled in EFFECTS by Gexcon and the consequence contours are assessed compared to the consequence criteria listed in HIPAP No. 4 (see **Appendix B**). The potential for incident propagation is assessed from the consequence contours.

Where the hazardous event has consequence contours that impact the site boundary or have the potential for incident propagation, the frequency of such an event is quantitatively determined. Otherwise, the consequences are considered sufficiently controlled for qualitative frequency analysis.

2.1.3 Risk Evaluation Methodology

Risk evaluation is the process of comparing the risk level assigned to acceptable risk criteria. Where the risk is deemed to be unacceptable, risk mitigation strategies and safeguards are recommended, and the risk is re-analysed. This re-analysis and re-evaluation is repeated until the risk level is deemed acceptable and the risk is reduced ALARP.

For risks analysed **qualitatively**, the risk level assigned to the hazard shall be considered acceptable if it is of moderate (M) or low (L) risk.

For risks analysed **quantitatively**, the risk is compared to the risk criteria published in the Hazardous Industry Planning Advisory Paper (HIPAP) No. 4, published by NSW DPHI. The acceptable risk criteria published in the HIPAP relate to injury, fatality and property damage. The values presented in **Table 2-4** are the maximum acceptable levels of risk for the land-use, as fatality is considered the worst-case scenario.

Table 2-4: Individual Fatality Risk Criteria

Land Use	Suggested Criteria (risk per million per year)
Hospitals, schools, child-care facilities, old age housing	0.5
Residential, hotels motels and tourist resorts	1
Commercial developments including retail centres, offices and entertainment centres	5
Sporting complexes and active open spaces	10
Industrial	50

Where risks exceed the acceptable risk criterion for the land use, additional risk mitigation strategies and safeguards are recommended until the risk is reduced below the acceptable risk criterion.

2.2 Methodology Summary

The methodology used, as established in AS ISO 31000:2018, is summarised below.

- **Hazard Identification** – an integral part of any risk assessment is the identification of hazards. Without the hazard first being identified it will not be possible to assess the risk and, where required, apply risk reduction measures.

  It is necessary to obtain a reasonable understanding of the project under assessment and to use experienced people to assist in identifying the hazards. This can be done by individuals or in a workshop situation.

- **Risk Analysis** –the risk analysis can take the form of a semi-quantitative study, which is performed to address the potential hazards identified with the observed tasks. The study can be a workshop style or individual assessment. Identified hazards are systematically worked through identifying consequences, likelihoods and risks.

  Risks are recorded in tabular format as shown below:

No.	Hazard and Cause	Consequence	Safeguard	S*	L*	R*	Recommended Risk Reduction Measure	Residual Risk		
								S*	L*	R*

* S = Severity, L = Likelihood Value, R = Risk Level

- **Risk Evaluation and Reduction** – as shown in the table above, once the risk have been assessed the risk level is evaluated against acceptable risk criteria, and risk reduction measures are sought where required. These are then recorded and the risk reanalysed to estimate the residual risk. The residual risk indicates the effectiveness of the proposed risk reduction measures and whether further risk reduction is required to reach the ALARP level.

- **Reporting** – on completion of the study a report is developed listing the objectives, scope of work, methodology, results, conclusions and recommendations.

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.

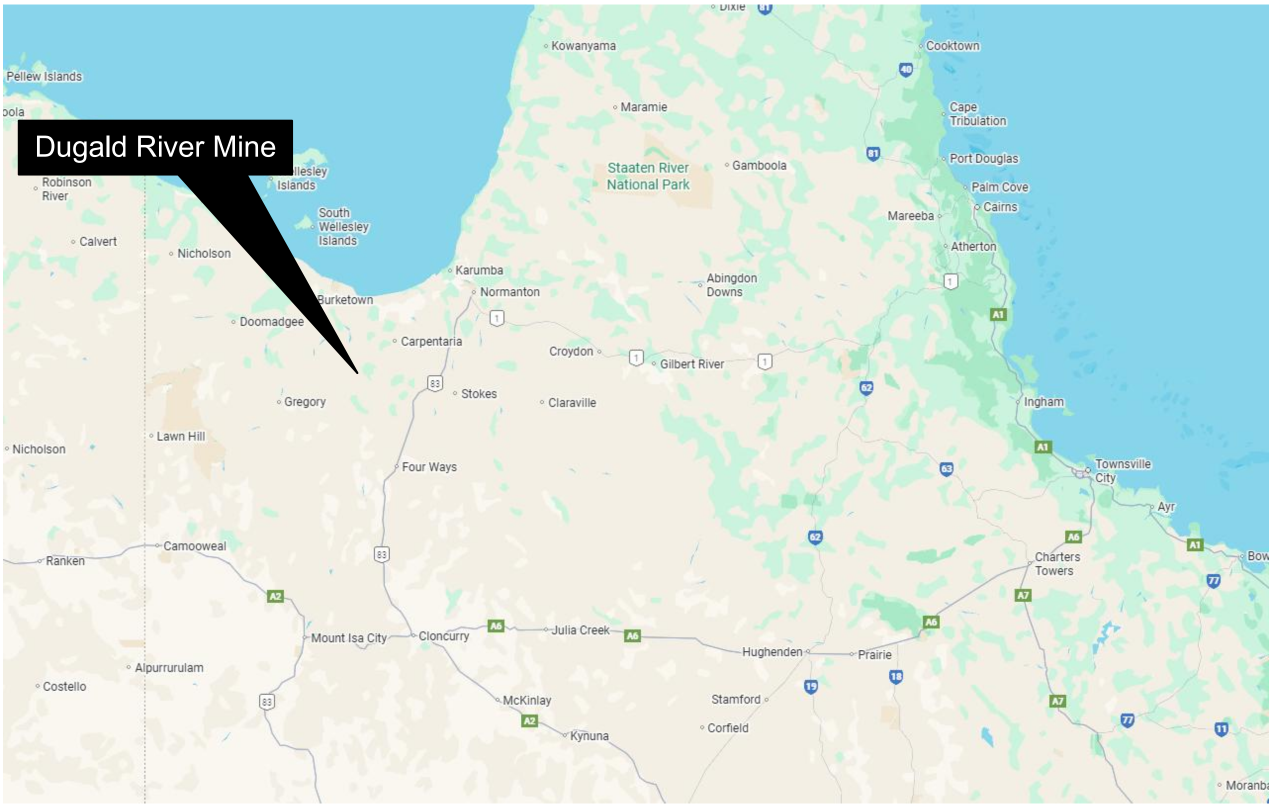

Figure 3-1: Site Location (Source – Google Maps)

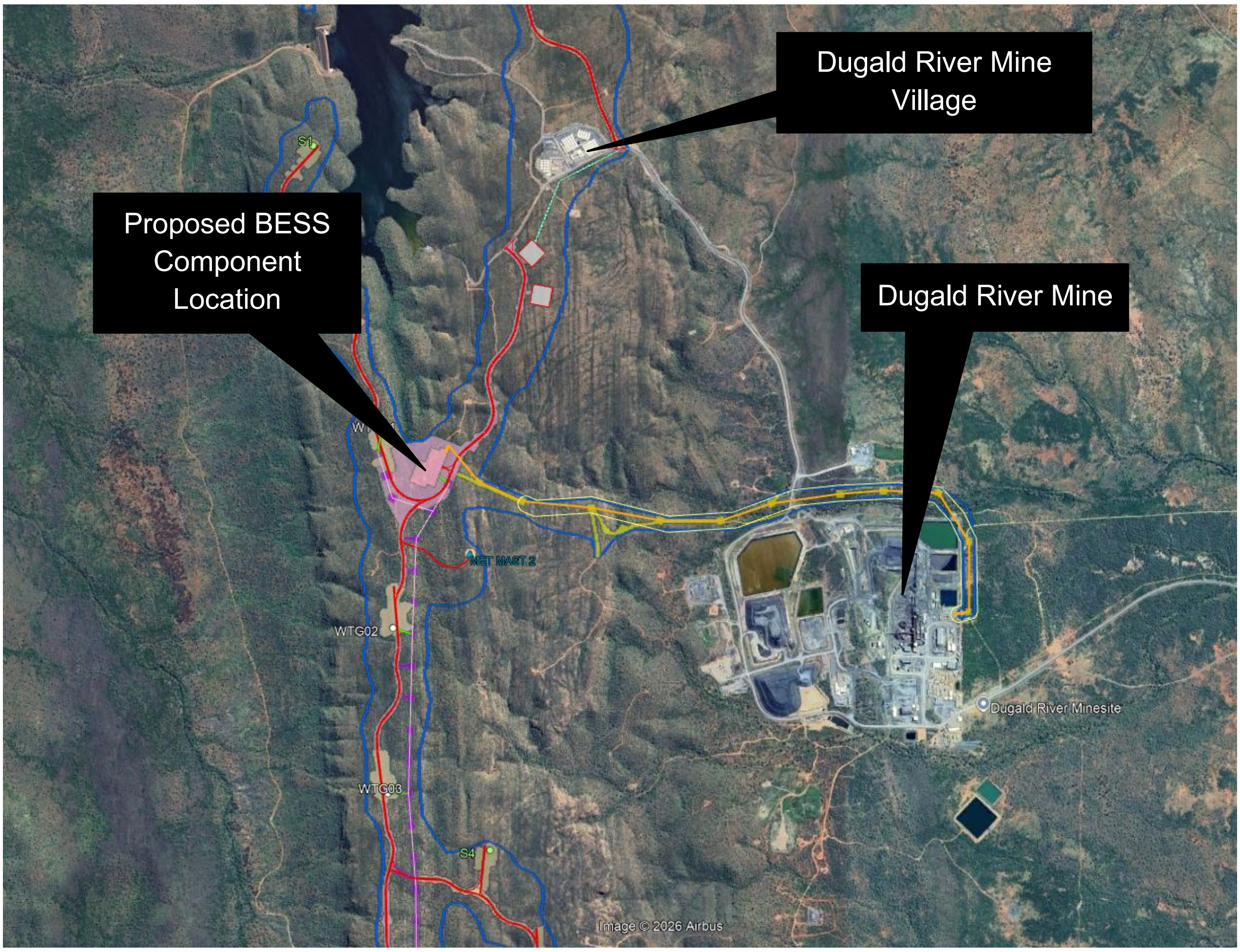

Figure 3-2: Proposed BESS Component Location Relative to Dugald River Mine

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.

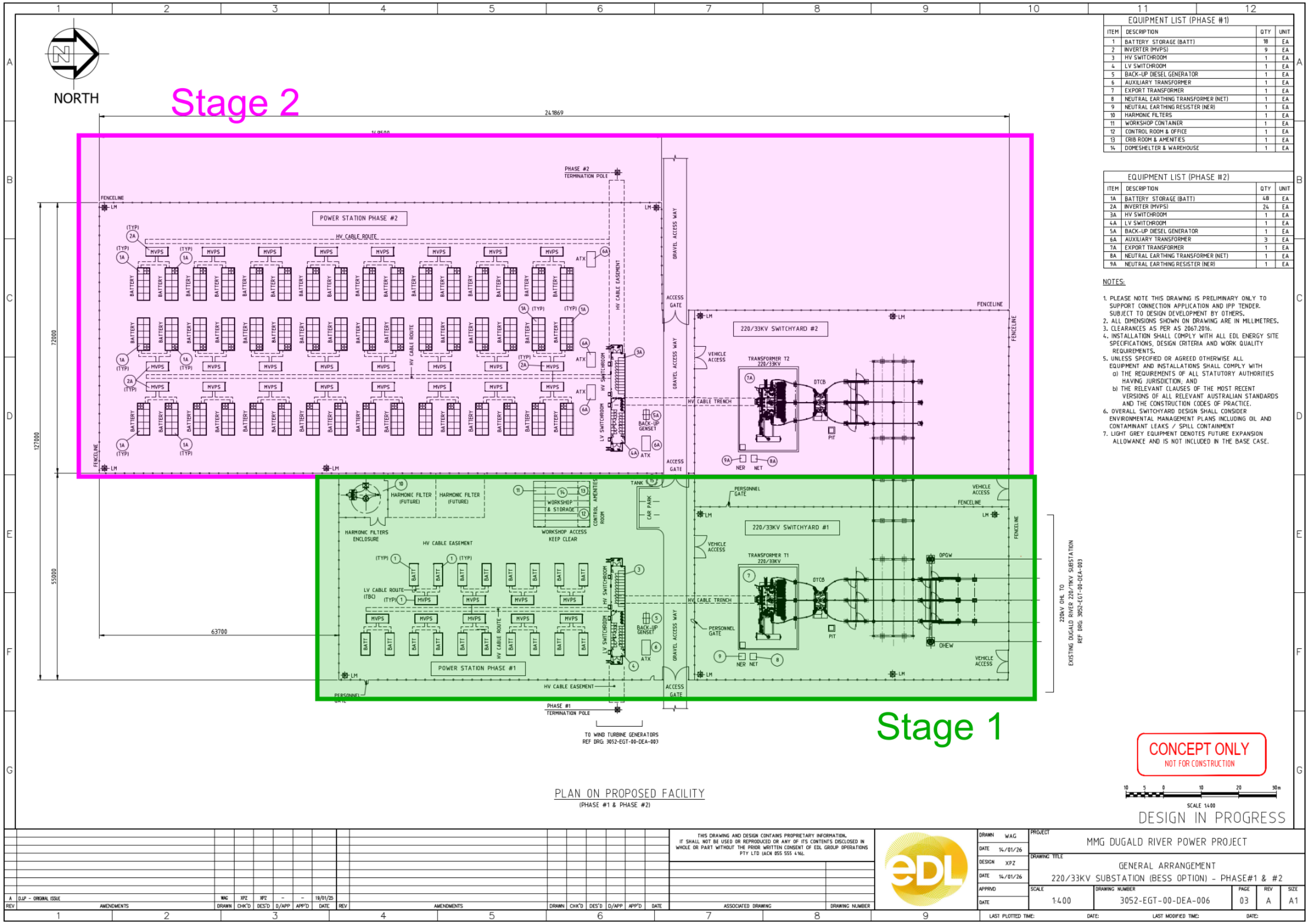

Figure 3-3: Indicative Conceptual BESS Layout. Stage 1 is in Green and Stage 2 is in Pink

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 9540 A 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 RMAR.

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 (UL 9540 A) 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 UL 9540 A and has also been subject to LSFT. With evidence of UL 9540 A 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. [4]). 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 and Qualitative Risk Analysis

4.1 Introduction

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

Where the hazards or hazardous events are qualitatively deemed to be of low enough consequence or likelihood, a qualitative risk analysis is conducted at the end of each subsection, and a risk level is assigned. Where the hazards required further analysis, they are carried forward for quantitative risk analysis (**Section 5.0**).

4.2 Properties of Dangerous Goods

The type of DGs and quantities stored and used at the site have 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 that, 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 (substation transformer oil)	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. [5])

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.
- MVPS/transformer internal arcing, oil spill, ignition and bund fire.
- Substation transformer internal arcing, oil spill, ignition and bund fire.
- Substation 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**.

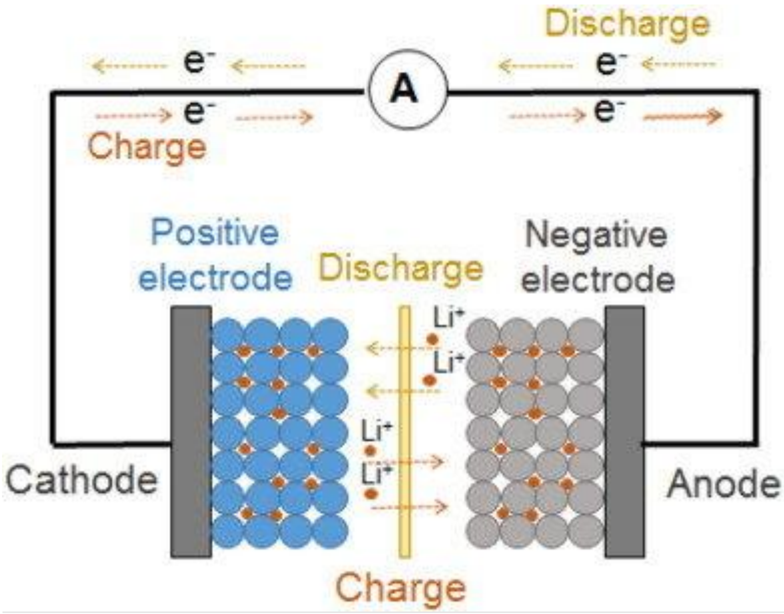

Figure 4-1: Cathode and Anode of a Battery (Source Research Gate)

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 (LiFePO4, 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 UL 9540 A. A UL 9540 A 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 UL 9540 A 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 UL 9540 A test results for fire development and propagation available upon request.

Based on data shown from UL 9540 A 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 200-400ºC/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 1.5ºC/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**.

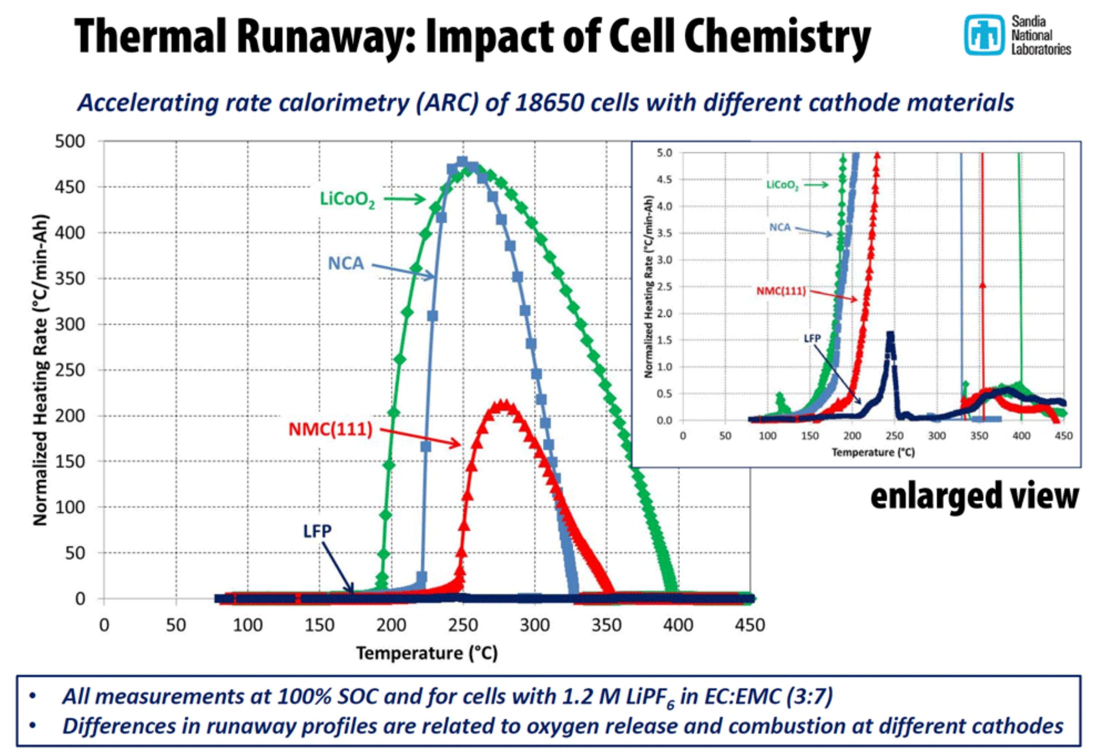

Figure 4-2: Temperature Rise of Lithium-Ion Battery Chemistries (Ref. [6]).

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.

The consequences of a Li-ion battery are reduced by the inherent safety features and proper fire-fighting methods, and the likelihood is deemed low. Thus, the risk of this event can be suitably analysed qualitatively.

4.4.1 Risk Analysis

The consequences and likelihood of a flaming Li-ion battery fire are summarised in **Table 4-2.**

Table 4-2: Qualitative Risk Analysis of Li-Ion Battery Fire

Hazard	Cause	Consequence	Safeguard	Assessed Risk		
				S	L	R
Li-ion Battery Fire	Puncturing or internal damage Internal arcing	Injury/single fatality Damage to property <$1M	• Low likelihood of initiating event (stable battery chemistry) • Unmanned site during regular operations – low likelihood of people being present • No sensitive receivers within 1 km of site • Inherent design limits incident propagation (when UL 9540A compliant) • Sufficient spacing between units to limit spread	4	D	M

4.5 Li-ion Battery Fire and Toxic Gas Dispersion

If a BESS failure occurs resulting in a fire, toxic byproducts 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.

$$C_3H_8(g) + 5O_2(g) \rightarrow 3CO_2(g) + 4H_2O(g)$$ **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. [7]).

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. [7]). 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 9540 A test criteria, the presence of toxic gases released in the unlikely event of thermal runaway will be negligible.

Furthermore, Franqueville *et al.* (Ref. [8]) 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.

Due to the near negligible likelihood of toxic or suffocating gases forming, a qualitative risk analysis is deemed sufficient.

4.5.4 Risk Analysis

The consequences and likelihood of toxic gas formation and dispersion from a Li-Ion battery are summarised in **Table 4-3.**

Table 4-3: Qualitative Risk Analysis of Li-Ion Battery Toxic Gas

Hazard	Cause	Consequence	Safeguard	Assessed Risk		
				S	L	R
Li-ion Battery and Toxic Gas Release	Li-Ion fire	Risk to worker health Air pollution	• Low likelihood of initiating event (stable battery chemistry) • Rapid dispersion of potentially toxic gases to below the threshold IDLH • Unmanned site during regular operations – low likelihood of people being present • No sensitive receivers within 1 km of site	3	E	L

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. Furthermore, it is proposed that the switch room building is supplied with VESDA model smoke detectors, which are able to detect smouldering fires and very low smoke concentration. The building is also proposed to be built with fire-resistant materials, limiting the spread of electrical fires in the rare event of such a fire. Therefore, considering all the safeguards implemented, qualitative risk analysis is considered suitable for this hazardous event.

4.6.1 Risk Analysis

The consequences and likelihood of an electrical fire from electrical equipment failure are summarised in **Table 4-4.**

Table 4-4: Qualitative Risk Analysis of Electrical Fire

Hazard	Cause	Consequence	Safeguard	Assessed Risk		
				S	L	R
Electrical fire	Electrical equipment failure	Fire Damage to equipment <$1M Injury to worker (some lost time)	• Slow fire development • Arcing safeguards in equipment • Lightning protection • Switch-off procedure	3	E	L

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. [9]) and are classified as non-dangerous goods under the Australian Dangerous Goods Code (Ref. [5]). 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.

4.7.1 Risk Analysis

The consequences and likelihood of an MVPS/small transformer fire or explosion from surge protection failure are summarised in **Table 4-5.**

Table 4-5: Qualitative Risk Analysis of MVPS/Transformer Fire and Explosion

Hazard	Cause	Consequence	Safeguard	Assessed Risk		
				S	L	R
MVPS transformer	Arcing Failure of pressure relief valves Spill of oil Heating > 300 °C Surge protection failure	Fire Explosion Damage to property < $1M Injury Incident propagation	• Low oil pressure switch • Gas detectors • Lightning protection • Use of natural esters for insulating oil (non-flammable) • Global use indicates relative safety	3	E	L

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 quantitative 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. [10]) 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. [11]). 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. [12]).

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.

4.9.1 Risk Analysis

The consequences and likelihood of a transformer explosion from surge protection failure are summarised in **Table 4-3.**

Table 4-6: Qualitative Risk Analysis of Transformer Explosion

Hazard	Cause	Consequence	Safeguard	Assessed Risk		
				S	L	R
Transformer	Surge protection failure	Explosion Damage to property < $1M Fatality/fatalities	• Low likelihood of lightning strike • Lightning protection	4	E	M

		Incident propagation	• Use of natural esters for insulating oil (non-flammable) • Global use indicates relative safety			

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. [14]).

Table 4-7 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. [15]).

Table 4-7: 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

Source	Typical Measurement (mG)	Measurement Range (mG)
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 can be qualitatively analysed.

4.10.4 Risk Analysis

The consequences and likelihood of damage from electromagnetic field impacts are summarised in **Table 4-8.**

Table 4-8: Qualitative Risk Analysis of EMF Impacts

Hazard	Cause	Consequence	Safeguard	Assessed Risk		
				S	L	R
EMF impacts	Electrical equipment and BESS	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	1	C	L

4.11 Natural Disaster Events

4.11.1 Bushfires

There is the potential for an external fire event to impact the BESS Component of the 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, emphasis 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, 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 low; hence, this incident is reasonably analysed qualitatively.

4.11.2 Flooding

There is negligible potential for flooding to occur within this region; the area is subject 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. [16]), 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, the requirements for these DGs 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 Component of the Project is very small, and the incident has not been carried forward for further analysis.

4.11.3 Risk Analysis

The consequences and likelihood of site damage from natural disasters are summarised in **Table 4-9.**

Table 4-9: Qualitative Risk Analysis of Transformer Explosion

Hazard	Cause	Consequence	Safeguard	Assessed Risk		
				S	L	R
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	4	D	M
Flood	Dugald River overflow	Damage to property < $1M	• Inherently negligible likelihood of flooding • BESS raised slightly off the ground	3	E	L

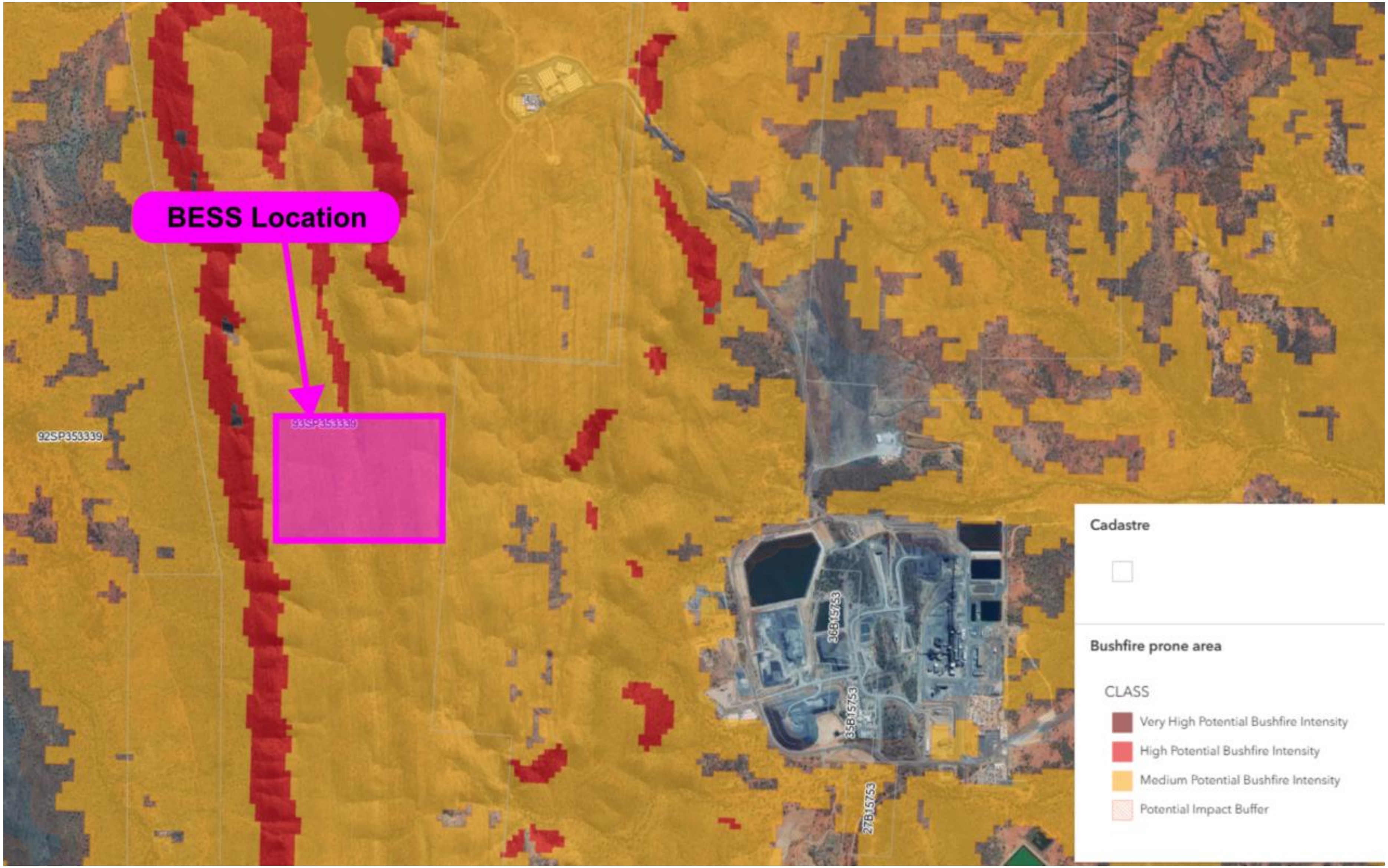

Figure 4-3: Bushfire Prone Land (According to QLD State Planning Policy Mapping)

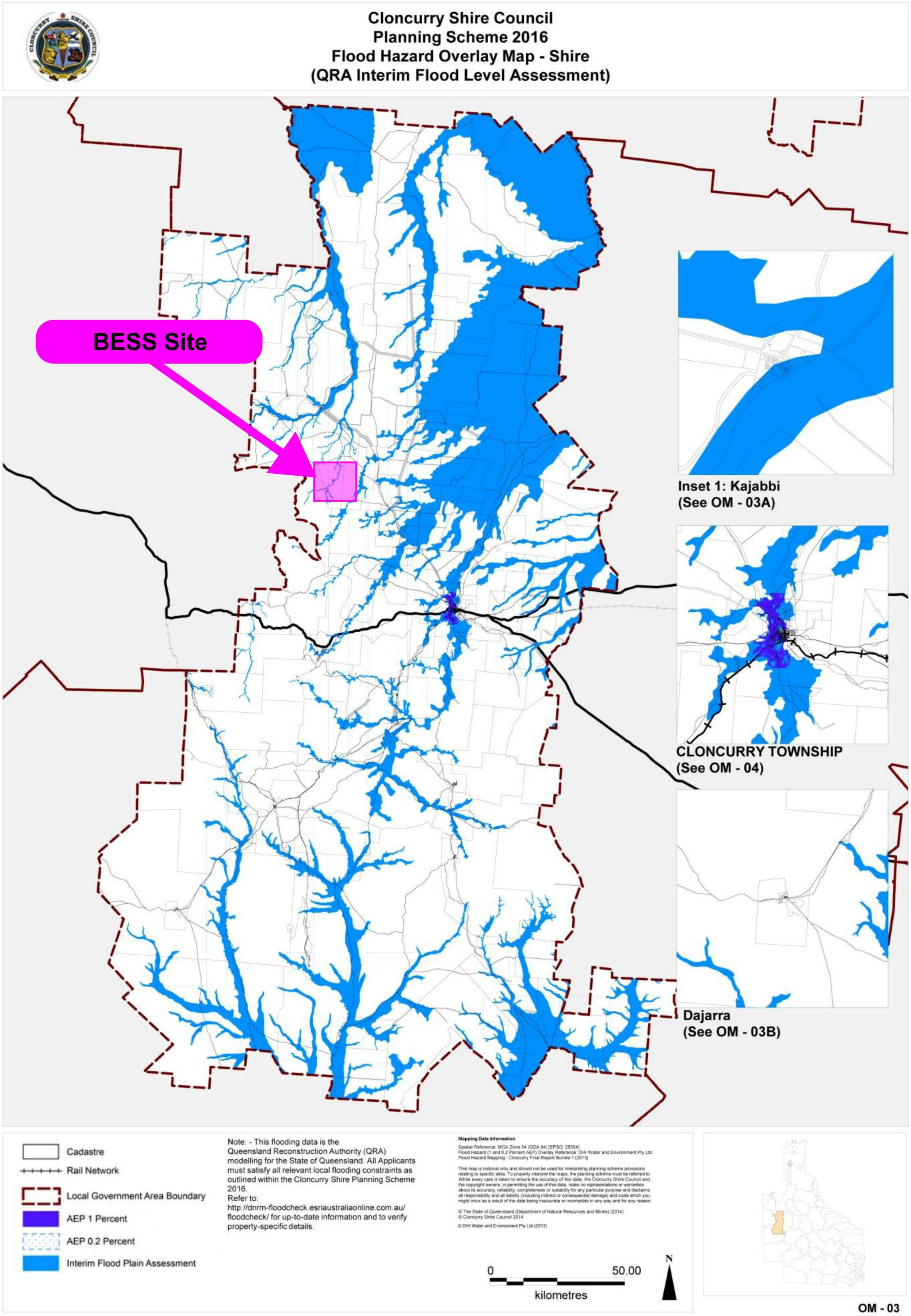

Figure 4-4: Cloncurry Shire Council Flood Mapping. Source: [19]

5.0 Quantitative Risk Analysis

5.1 Incidents Carried Forward for Quantitative Risk Analysis

The following incidents were identified to have the potential to impact fire protection systems or to complicate firefighting interventions, and thus require quantitative risk analysis:

- Main transformer internal arcing, oil spill, ignition and bund fire.

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

5.2 Main 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.

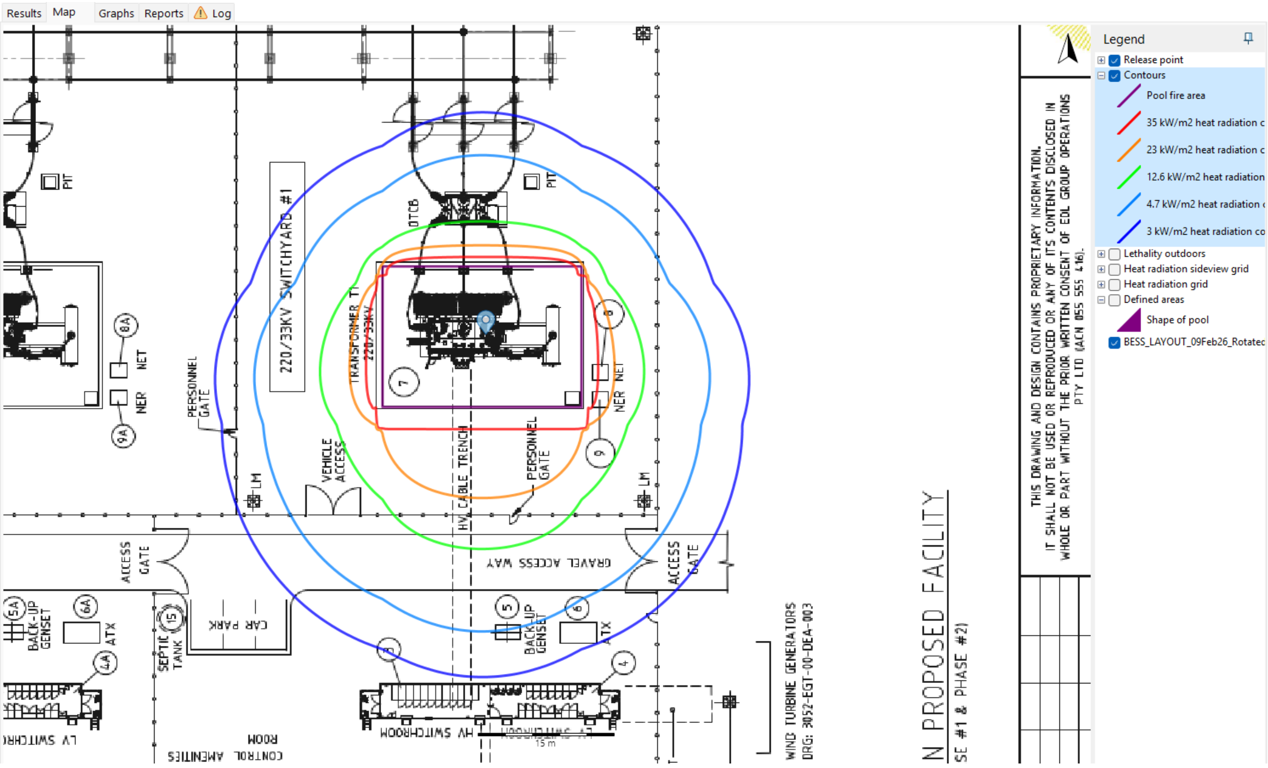

Figure 5-1: Transformer Fire Radiant Heat Contours

5.3 Likelihood Analysis

The initiating event for a transformer fire is a major oil spill from the transformer casing. This would be classified as a catastrophic failure as all oil contained within the transformer would be released. Failure rate data from the CCPS indicates that the frequency of a catastrophic transformer failure is in the range of 0.125 to 9.26 failures per 10^6 hours (Ref. [17]).

It is noted that this data base was compiled in 1989 and as such is somewhat outdated. It would be expected that more modern equipment would be more reliable due to advances in materials, better understanding of oil management in transformers, better monitoring systems and process safety requirements. Therefore, the lower range of expected failures has been selected for this assessment to reflect the increased safety present in the transformer systems at the site. Hence, the failure frequency would be 0.125 per 10^6 hours, or 1.10×10^{-3} p.a.

However, a transformer fire also requires an ignition source. An assessment of power transformer reliability conducted by Tenbohlen et al which analysed 112 major transformer failures throughout Europe indicates that most major failures do not result in any external effects (Ref. [18]). The Tenbohlen et al study indicates that only 6.3% of major transformer failures result in a fire (Ref. [18]). This results in the likelihood of a transformer fire being $1.10 \times 10^{-3} \times 0.063 = 6.9 \times 10^{-5}$ p.a. Assuming the site operates for 20 years and there are 24 transformers, this is a 3% chance of a transformer fire throughout the entire lifespan of the BESS component of the Project. This is considered a very conservative estimation for this analysis as it is assumed non-flammable natural esters will be used as transformer oils, lowering the likelihood of ignition. Nevertheless, this value is assumed for conservatism.

Given that the site is typically unmanned and would only be attended for maintenance and inspections, the risk to humans is further limited. In a worst-case scenario, the site would be attended for maintenance for an hour every week (which may apply in the early stages of the site's occupation). This would result in a human being on-site, and potentially within the consequence contours previously established, for 4% of the year. This means there is a 0.13% chance of fatality if the person is impacted by the 23 kW/m^2. However, it is unlikely that the transformer would suddenly burst into a flaming fire, and is more likely to build into the fire slowly modelled in **Sections 5.2**, giving the person ample time to move away from the impact areas. Thus, the likelihood of fatality can be significantly reduced qualitatively to be considered near negligible.

The consequences of the transformer fire have already been shown not to propagate, meaning the incident would limit property damage. Furthermore, the impacts of a short-lived fire on the environment (such as via smoke) disperse quickly, leaving negligible lasting environmental impacts.

6.0 Risk Evaluation

The results of the risk analyses conducted throughout **Sections 3.6 and 5.0** are compared to the acceptable risk criteria. **Appendix A** contains the results of the qualitative risk analyses, which shows that all hazards have a risk of medium (M) or lower, which is the acceptable qualitative risk threshold.

For the quantitatively analysed risks, the consequence contours determined from EFFECTS are shown not to cause incident propagation, nor to impact the site boundary. The likelihood of such events causing damage to humans, property or the environment is semi-quantitatively shown to be negligible. Thus, the risks associated with the main transformer are considered acceptable.

Thus, the initial risks presented by the BESS and the equipment of the site are considered sufficiently mitigated for normal operations.

7.0 Conclusion and Recommendations

7.1 Conclusions

A RMAR was prepared for the proposed BESS component of the Dugald River Wind Farm and BESS Project located near the Dugald River Mine. A hazard identification table was developed for the BESS component of the Project to identify potential hazards that may be present at the site as a result of operations or storage of materials. Based on the identified hazards, scenarios were postulated that may result in an incident with a potential for offsite impacts. Postulated scenarios were discussed qualitatively and any scenarios that would not impact offsite were eliminated from further assessment. The likelihood and consequences of these events were qualitatively discussed to determine the risk.

Incidents carried forward for quantitative analysis were modelled in EFFECTS in detail to estimate the impact distances. Impact distances were developed into scenario contours and overlaid onto the site layout diagram to determine if an offsite impact would occur. The impact distances of the incidents analysed using EFFECTS were shown to not affect adjacent equipment and thus, would not cause incident propagation. Furthermore, there are no potential off-site impacts. The likelihood of these events was semi-quantitatively determined to be near negligible, meaning the risks (combining the limit consequence and low likelihood) of these events are acceptably low.

Based on the analysis conducted, it is concluded that there are no unacceptable risks at the site boundary, nor any risk of incident propagation. Thus, the risks are considered sufficiently managed by the inherent safety features of the BESS units and by existing safety precautions.

7.2 Recommendations

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

- Evidence of UL 9540A testing and LSFT shall be provided to the regulator and SARA upon acquisition and submission for approval.
- 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. [2]).
- 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 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.

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Appendix A

Risk Assessment Table

Appendix A

A1. Risk Identification and Assessment Table

ID	Area/Operation	Cause	Consequence	Existing Safeguards	Risk		
					S	L	R
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 • Damage to property <$1M	• 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	4	D	M
2			• Toxic smoke dispersion • Injury to worker • Short-term environmental damage		3	E	L
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	3	E	L
4	MVPS transformer	• Arcing and overheating	• Fire • Explosion	• Low oil pressure switch • Gas detectors	3	E	L

ID	Area/Operation	Cause	Consequence	Existing Safeguards	Risk		
					S	L	R
		• Failure of pressure relief valves • Spill of oil • Heating > 300 oC • Surge protection failure	• Damage to property < $1M • Injury • Incident propagation	• Lightning protection • Use of natural esters for insulating oil (non-flammable) • Global use indicates relative safety • Bunding around transformers limits spread • Control of ignition sources – no smoking / open flames around the transformers			
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	3	E	M
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	Carried forward for quantitative analysis		
7		• Power surge to transformers (e.g.	• Major failure of surge protection in	• Transformers have surge protection system to divert	4	E	M

ID	Area/Operation	Cause	Consequence	Existing Safeguards	Risk S	Risk L	Risk R
		from lightning, fault, etc.)	transformer, vapourisation of mineral oil, ignition and explosion	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	1	C	L
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	4	D	M
10	Flood	Dugald River overflow	Damage to property < $1M	• Inherently negligible likelihood of flooding • BESS raised slightly off the ground	3	E	L

Appendix B

Consequence Analysis

B1. Incidents Assessed in Detailed Consequence Analysis

The following incidents are assessed for consequence impacts.

- 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. [20]).

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	• QFD criteria to access equipment

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 8-1**.

$$Q = \tau E F \quad \textbf{Equation 8-1}$$

Where;

- Q = heat flux (kW/m^2) at the target

- F = geometric view factor
- τ = transmissivity
- E = SEP (kW/m^2)

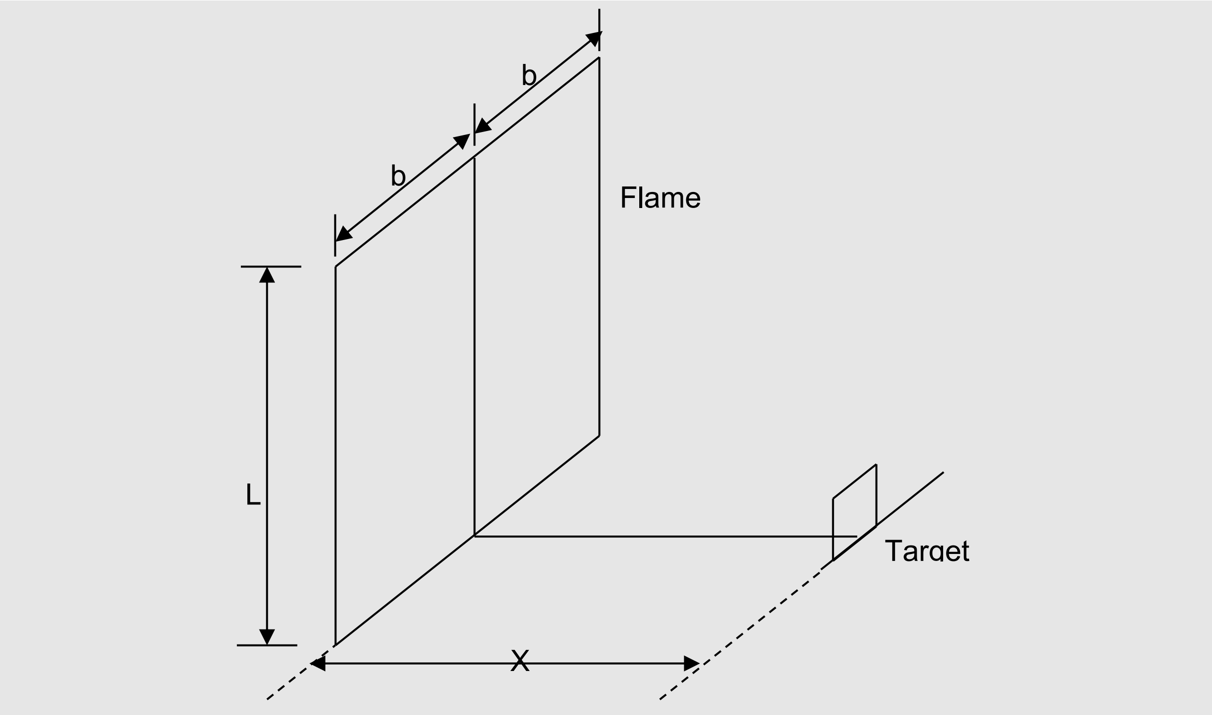
Each of the required inputs is determined in the sections following.

B4.2 View Factor

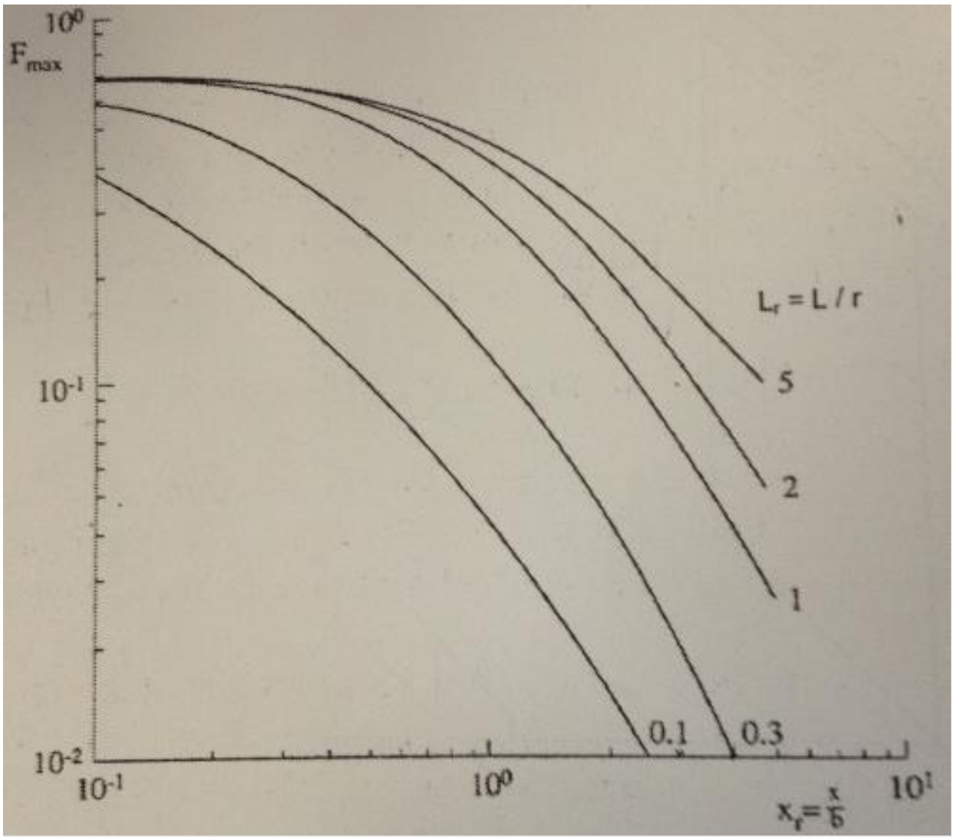
The view factor for a flat surface fire is estimated using the scenario shown in **Appendix Figure B-1** where the flame is the vertical surface of height L and length 2b with receiver located centrally and at a distance of X. Two dimensionless parameters are calculated, and the view factor read from **Appendix Figure B-2**. The dimensionless parameters are shown in **Equation 8-2** and **Equation 8-3**.

$$L_r = \frac{L}{b}$$ **Equation 8-2**

$$X_r = \frac{x}{b}$$ **Equation 8-3**



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



Appendix Figure B-2: Vertical Flame Maximum View Factor (Ref. [21])

B4.3 Transmissivity

The transmissivity is estimated using **Equation 8-4**.

$$\tau = 1.006 - 0.01171(\log_{10} X(H_2O) - 0.02368(\log_{10} X(H_2O))^2 - 0.03188(\log_{10} X(CO_2) + 0.001164(\log_{10} X(CO_2))^2 \quad \textbf{Equation 8-4}$$

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 8-2**.

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 8-5**

Where:

- ε = flame emissivity (taken as 0.78 (Ref. [22]))
- σ = 5.67x10^{-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. Without clear specifications for the transformers in the substation, the bund is assumed to be 60 m^2. 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

Input	Value	Justification
		actually works by looking at the flame surface to estimate the radiant 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	30,000 kg	Mass of oil in the main transformer, given total volume of 34,310 L and a density of 0.9 kg/L.
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

UL9540 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 8-1 exhibits a flowchart to help understand the UL 9540 A test at different levels.

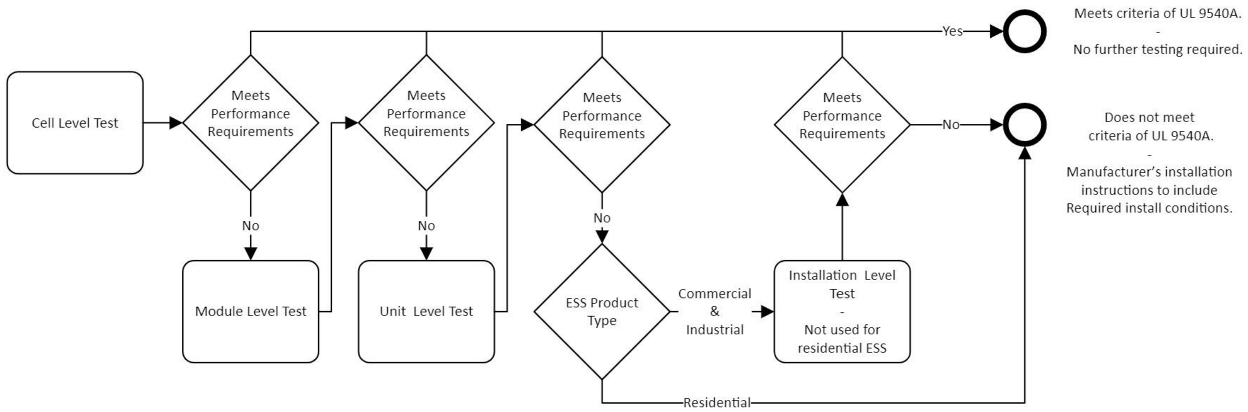


Figure 8-1: Flow Chart for UL 9540 A Testing at Different Levels. Source: [23]