Appendix J

Hazard and Incident Management Plan

Hazard Incident Management Plan

Mount Hopeful Battery

Umwelt (Australia) Pty Ltd
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Hazard Incident Management Plan

Mount Hopeful Battery

Umwelt (Australia) Pty Ltd

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Rev	Date	Remarks	Prepared By	Reviewed By
A	24th July 2025	Draft issued for comment	Chris Butson	Renton Parker
0	18th September 2025	Updated to final		
1	25th September 2025	Updated based on comments from Neoen		

Executive Summary

Background

Umwelt (Australia) Pty Ltd are engaged by Neoen Australia Pty Ltd (Neoen) to prepare the planning studies for the Mount Hopeful Battery Project in Rockhampton QLD. The Project is an advanced Battery Energy Storage System (BESS) project with a capacity to deliver up to 600 megawatts of power for a duration of up to 4 hours supporting the grid in terms of ongoing reliability and security.

To support the required approval, it has been proposed to develop a Hazard Incident Management Plan (HIMP) which will assess the potential risks at the site and ensure that the design sufficiently addresses the unique hazards and risks. This document has been produced as a prelude to a Fire Safety Study (FSS) with the intention of providing a basis for review by approval authorities, including the Queensland Fire Department (QFD), and to improve the project outcomes during detailed design.

Umwelt have engaged Riskcon Engineering Pty Ltd (Riskcon) to prepare the HIMP for the site and the assessment is provided in the following document.

Conclusions

A Hazard Incident Management Plan per the HIPAP No. 2 guidelines was prepared for the Mt Hopeful BESS Project located in Rockhampton. The analysis performed in the HIMP 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, if BESS units include the required certifications, fire detection measures, fire protection measures and appropriate separation to adjacent infrastructure that the site will be sufficiently safe.

Additionally, the quantity of fire water for services to utilise shall be in accordance with AS 2419.1:2021 and provided sufficient capacity to respond to any fire scenario on site. Several recommendations have been made below.

Recommendations

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

- Final separation distances between BESS units shall be defined with regard for the level of testing and outcomes of UL9540A reports provided by the selected supplier.
- Adopt an approach to minimise potential for incident propagation due to a MV transformer fire:
    - Consider orienting the BESS containers such that auxiliary equipment is located proximal to the MV transformer aisles of the installation, moving the battery storage compartments of the BESS outside of the 23 kW/m^2 contour.
    - Increase spacing between MV transformers and BESS containers.
    - Provide heat shielding via increased bund height or firewalls (as with HV transformers).
    - Reassess impact during detailed design with specific MV transformer data.
- An emergency response plan shall be prepared in accordance with HIPAP No. 1 – Industry Emergency Planning Guidelines (Ref. [1]).

- The retention pond shall be sized such that it can capture 100% of the fire water storage capacity.

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Abbreviations

Abbreviation	Description
ADG	Australian Dangerous Goods Code
APZ	Asset Protection Zone
AS	Australian Standard
BESS	Battery Energy Storage System
BMS	Battery Management System
DA	Development Application
DGS	Dangerous Goods
EMS	Emergency Management System
FBIM	Fire Brigade Intervention Model
FMDS	Fm Global Datasheet
FRNSW	Fire And Rescue New South Wales
HIMP	Hazard Incident Management Plan
HIPAP	Hazardous Industry Planning Advisory Paper
HV	High Voltage
LEL	Lower Explosive Limit
LFP	Lithium Iron Phosphate
LGA	Local Government Area
LI-ION	Lithium Ion
MV	Medium Voltage
NFPA	National Fire Protection Association
NZS	New Zealand Standard
O&M	Operations And Maintenance
PPM	Parts Per Million
QFD	Queensland Fire Department
QFES	Queensland Fire And Emergency Services
SEP	Surface Emissive Power
STEL	Short Term Exposure Limit
UL	Underwriters Laboratories
VBB	Victoria Big Battery Fire

1.0 Introduction

1.1 Background

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To support the required approval, it has been proposed to develop a Hazard Incident Management Plan (HIMP) which will assess the potential risks at the site and ensure that the design sufficiently addresses the unique hazards and risks. This document has been produced as a prelude to a Fire Safety Study (FSS) with the intention of providing a basis for review by approval authorities, including the Queensland Fire Department (QFD), and to improve the project outcomes during detailed design.

Umwelt have engaged Riskcon Engineering Pty Ltd (Riskcon) to prepare the HIMP for the site and the assessment is provided in the following document.

1.2 Objectives

The objectives of the HIMP are to:

- Review the site operations and dangerous goods (DG) storages at the site for the potential to initiate or propagate an incident at the site.
- Identify heat radiation impacts from potential fire sources at the site and determine the potential impacts on the surrounding areas.
- Review the proposed fire safety features and determine the adequacy of the fire safety systems based on the postulated fires.
- Review the site's proposed layout, water supply and water containment to determine risk of incident propagation and ability for fire services intervention.

1.3 Scope of Services

The scope of work is for the preparation of a HIMP for the facility to assess the potential hazards at the site to ensure the fire protection systems are commensurate with the identified hazards. Queensland Fire and Emergency Services (QFES) refer to the Australasian Fire and Emergency Services Authorities Council (AFAC) Large Scale BESS Guideline (Ref [2]) for identifying and addressing risk associated with BESS projects. This includes guidance on methodologies for development of Fire Safety Studies (FSS), which are analogous to HIMPs. The AFAC Guidelines refer to the following methodologies:

- The Fire and Rescue Victoria (FRV) fire safety guideline GL54 – Fire Safety Study;
- The NSW Department of Planning Hazardous Industry Planning Advisory Paper (HIPAP) No. 2 Fire Safety Study (2011);
- Country Fire Authority (CFA) Design Guidelines and Model Requirements for Renewable Energy Facilities (2023).

The development of this HIMP has been based on the methodology of HIPAP No.2 (Ref. [3]) and 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. A review of the following components of the HIMP are within the scope of work:

- Determination of risk and consequences from fire or explosion scenarios throughout the facility.
- 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.
- Recommendations based upon the study for implementation in the final design.

2.0 Methodology

2.1 Hazard Incident Management Plan Approach

The following methodology was used in the preparation of the HIMP for the facility. The methodology is to follow items required by HIPAP No. 2 (Ref. [3]).

- The fire hazards associated with the facility were identified to determine whether there were any fire or explosion hazards that may impact offsite or result in a 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 facility, 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 facility were then assessed against the maximum permissible levels in HIPAP No. 4 (Ref. [4]).
- The firefighting strategies were then assessed to determine whether these strategies require update in light of the location of the proposed equipment and storage areas.
- The response times for Queensland Fire & Emergency Service (QFES) and Queensland Fire Department (QFD) in the immediate vicinity were assessed.
- A report was then developed for submission to the client and the regulatory authority.

2.2 Limitations and Assumptions

In this instance, the HIMP 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 3.2** and the methodology and approach outlined in **Section 2.1**.
- The report is based on the information provided.
- 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 HIMP as provided in the guidelines issued as HIPAP No. 2 (Ref. [3]) 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 site is located within the Rockhampton Regional Council local government area (LGA), approximately 50 km south of Rockhampton and 70 km west of Gladstone. **Figure 3-1** shows the regional location of the site.

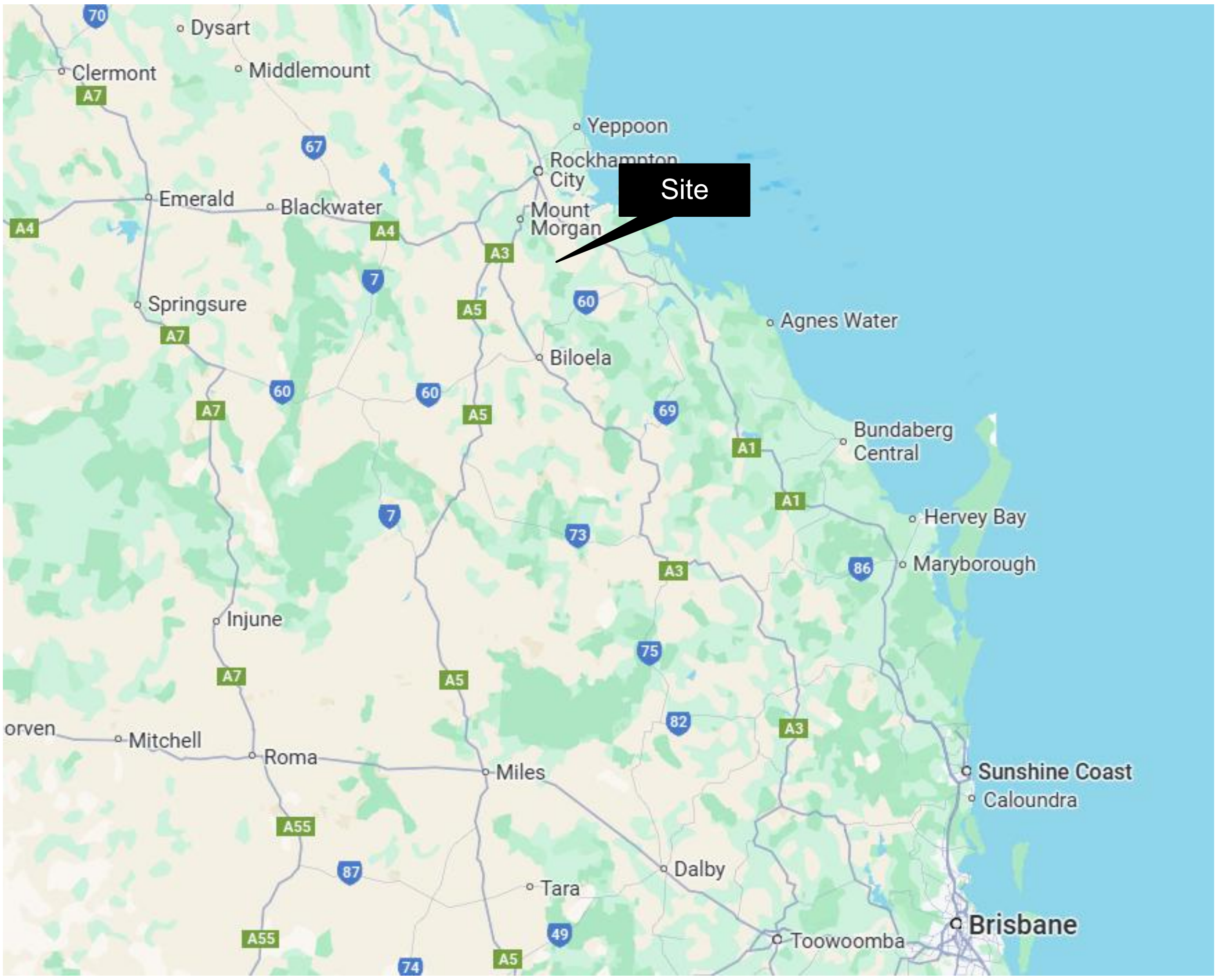

Figure 3-1: Site Location (Source – Google Maps)

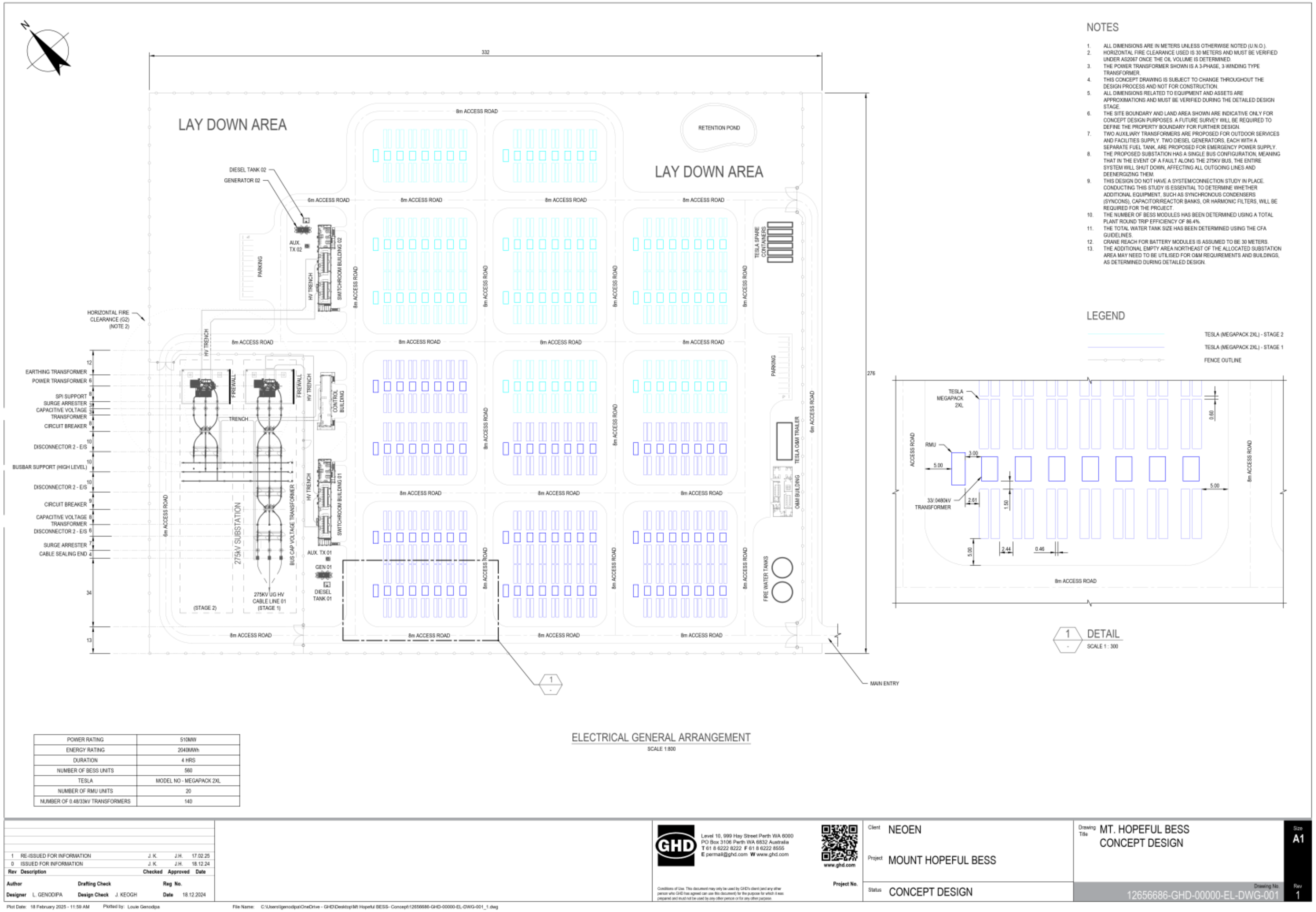

Figure 3-2: Proposed Site Layout

3.2 General Description

The Mount Hopeful Battery is a proposed grid-scale battery energy storage system (BESS) in Central Queensland (the Project). With a planned capacity of up to 600 megawatts (MW) of power for a duration of up to four hours, the Project will enhance the delivery of clean, reliable electricity to the National Electricity Market (NEM), while supporting grid stability and flexibility.

The Project is located near the rural town of Bajool, approximately 50 kilometres (km) south of Rockhampton and 70 km west of Gladstone, Queensland, within the Rockhampton Region Local Government Area (LGA). The Project is mapped within the Rural Zone of the Rockhampton Region Planning Scheme 2015 (planning scheme) and predominately used for low intensity agricultural activities, including cattle grazing. The Project is proposed to occur within the bounds of the 'Study Area' which covers an area of 49 hectares (ha) and occurs across three freehold land parcels and two local roads, being South Ulam Road and an unnamed road reserve. The Study Area also accommodates a Powerlink transmission easement that comprises an existing 275 kilovolt (kV) transmission line, of which the Project will connect into. The Study Area is sparsely vegetated with predominately non-remnant vegetation and is intersected by an unnamed tributary of Eight Mile Creek. The Project gains access via South Ulam Road to the east of the Study Area.

The Project is proposed to be delivered over two stages as follows:

- Stage 1: indicative capacity of 430 MW, with construction expected to commence mid-2025 and to complete by end of 2028.
- Stage 2: indicative additional capacity of 170 MW, with construction expected to commence in 2028 and to complete by end of 2029.

Key components of the Project include:

- Up to 650x Battery Modules
- Up to 170x Medium Voltage (MV) Transformers
- 2x High Voltage (HV) Transformers
- A HV Switching Station.

The Project will also encompass associated ancillary infrastructure necessary to the operation of the BESS, including:

- Site access track
- Overhead and underground electrical cables
- Inverters
- High voltage substation
- Earthing and lightning protection
- Security fencing, closed-circuit television (CCTV) and lighting
- O&M building
- Water retention pond
- Lay down areas

- Fire water tanks with total capacity in accordance with AS 2419.1 (Ref. [5])
- Two Control Buildings
- Harmonic filters

3.3 Quantities of Dangerous Goods

The classes and quantities of DGs provided in **Table 3-1**.

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

Class	Packing Group	Description	Quantity
2.1	n/a	Spray paint	0.01 T
2.2	n/a	Refrigerant R134A in battery packs (1.5 kg per pack)	0.96 T
3	II	Paints and solvents	0.2 T
8	II	Cleaning products	1 T
9	n/a	Lithium Batteries	722 T*
C1	n/a	Diesel fuel	17 T
C2	n/a	Transformer oils in HV transformers	172 kL
C2	n/a	Transformer oils in MV transformers	541 kL

*Note that this is based on the weight of LFP cells contained within the battery packs.

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 **Section 3**. **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
2.2 – Non-flammable, non-toxic gases	Class 2.2 gases are gases which are asphyxiant – gases which dilute or replace the oxygen normally in the atmosphere; or are oxidising – gases which may, generally by providing oxygen , cause or contribute to the combustion of other material more than air does; or gases which do not come under other divisions (flammable and / or toxic).
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.

* The Australian Code for the Transport of Dangerous Goods by Road and Rail (Ref. [6])

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
- Refrigerant gas release
- Release of diesel, ignition and pool fire

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**.

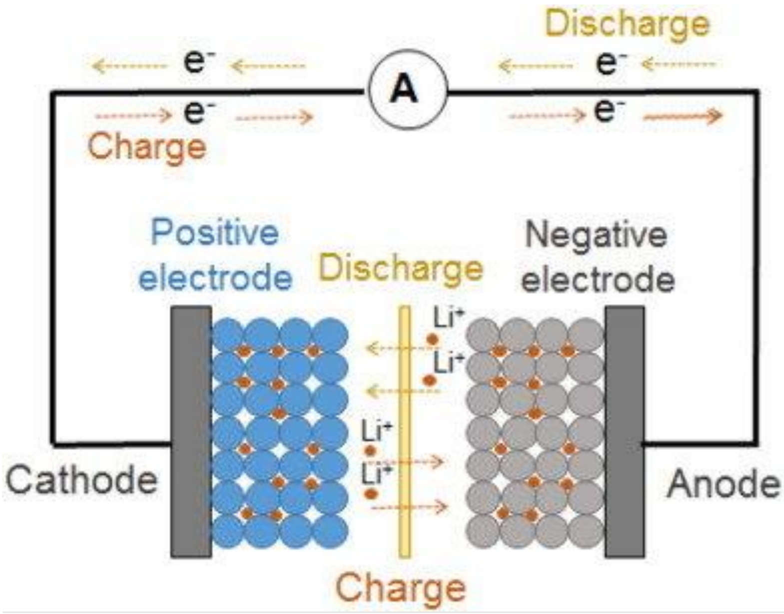

Figure 4-1: Cathode and Anode of a Battery (Source Research Gate)

The key hazard associated with Lithium-ion-BESS (Li-BESS) systems is thermal runaway which can be initiated in a cell by several initiating events including (Ref. [7]):

- Manufacturing defects
- Overcharging
- Overheating
- Mechanical abuse

During thermal runaway, cells can release a large quantity of both toxic and flammable gases creating a risk for explosion and toxicity to bystanders. Thermal runaway in a single cell within a BESS unit has potential to induce thermal runaway propagation which may eventually lead to larger-scale fire and/or explosion incidents (Ref. [8]).

The likelihood and consequence of thermal runaway in a BESS is dependent on several factors including the design, battery chemistry and installed systems. Although the battery supplier has not been selected yet, it is understood that the battery chemistry will be lithium-ion phosphate ($LiFePO_4$, or simply LFP). LFP cells are the current standard for large-scale BESS systems accounting for approximately 80% of the total battery storage market as of 2023, this is largely due to lower cost, higher cycle lives and safety considerations when compared to other chemistries such as nickel manganese cobalt (NMC)(Ref. [9]). Although NMC has a higher energy density, LFP batteries have begun to dominate the grid-scale energy market due to the following advantages when compared to NMC (Ref. [10]):

- Longer cycle life and less capacity reduction over time
- Higher thermal stability and less prone to overheating
- Better mechanical stability
- More stable electrochemically with fewer side reactions which accelerate degradation
- More resilient to state of charge (SOC) and depth of discharge (DOD) with less degradation from deep cycling

As the supplier of the battery units has not yet been selected, a UL9540A cannot be provided. However, in accordance with the relevant national and state-based guidelines, the selected supplier will hold a UL9540A certification for the selected product at cell, module and unit level (as required based on sequential testing). UL9540A tests typically show no cell-to-cell propagation, no flaming outside of the unit and no explosion hazards. When unit level testing is conducted, fire suppression systems are not included demonstrating a high unlikelihood that a fire would propagate to a full BESS fire. UL9540A tests may be provided at request when a supplier is selected.

The final selection for the BESS supplier will provide a product that is compliant with NFPA 68, 69 and 855. The selected system will include appropriate fire protection which generally includes but is not limited to:

- Shut-down separator (for overheating)
- Tear-away tab (for internal pressure relief)
- Vent (pressure relief in case of severe outgassing)
- Thermal interrupt (overcurrent/overcharging/environmental exposure)
- Battery Management Systems (BMS) – constant monitoring of the voltage, temperature and state of charge of individual cells to aid in early detection of a fault condition. Upon detection of cell fault, the BMS disconnects and isolates the cell to prevent propagation of the incident, and alarms the site Emergency Management System (EMS).
- Manual emergency stop button
- Fire suppression system
- Deflagration panels
- Sparker systems

UL9540 A testing of LFP modules and units typically shows no propagation beyond the module however, should a larger issue such as electrical faults or arcing in a number of cells occur, thermal runaway in multiple cells may occur causing the entire unit to catch fire. The spacing between units and fire suppression installed would then be relied upon to prevent fire spread and risk of incident propagation between BESS units. Therefore, this incident has been carried forward for further analysis.

4.5 Li-ion Battery Fire and Toxic Gas Dispersion

As noted in **Section 4.4**, there is the potential for a BESS failure to occur resulting in a fire which may result in toxic by-products of combustion to form. As part of the BESS testing, off gases generated from the thermally running away battery cells are captured and tested to determine the off-gas composition in terms of flammability and toxicity. As noted previously, the supplier has not been selected therefore off-gas sampling results are not available. However, data from numerous testing reports of cell testing shows that only carbon dioxide and carbon monoxide are produced in large quantities. These have been reviewed 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 with Short Term Exposure Limit (STEL) occurring at 30,000 ppm (3%), above 50,000 ppm (5%) a strong respiration effect is observed along with dizziness, confusion, headaches, and shortness of breath. Concentrations in excess of 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 A-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.

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

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 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 4-1**.

$$\boldsymbol{2C_3H_8(g) + 7O_2(g) \rightarrow 6CO(g) + 8H_2O(g)} \qquad \textbf{Equation 4-1}$$

As noted, in **Section 4.5.1** there is the potential for a fire to occur with the BESS units which could form carbon monoxide if there is insufficient oxygen to sustain complete combustion. 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. Therefore, this incident has not been carried forward for further analysis.

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 and provided fire protection used within switch rooms is ubiquitous throughout the world and across industry segments and is therefore not a unique fire scenario. Therefore, this incident has not been carried forward for further analysis.

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

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.

Transformers are insulated using oil which can be mineral, synthetic, natural ester oil or other types which may have flashpoints from 140ºC to 300ºC. Due to the flash point, transformer oil are classified as non-dangerous goods under the Australian Dangerous Goods Code (Ref. [6]) as the oil would need to be heated significantly before any flammable vapour is given off. As ignition of the fluid is extremely difficult, and a fire occurring from an oil-insulated transformer is not considered a credible scenario.

Notwithstanding this, due to the number of transformers on site, this incident has been carried forward for further analysis for conservatism.

4.8 Transformer Electrical Surge Protection Failure and Explosion

Transformers generate large amounts of heat as a result of the high electrical currents. As detailed in **Section 4.7**, 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 oil may start to decompose and vapourise, resulting in gas bubbles of hydrogen and methane (Ref. [11]) 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 programs them to shut down upon detection of an energy spike. However, the surge protection can have a slight delay. 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. [12]).

Although there is the potential for an explosion to occur which may result in impacts to fire protection equipment; however, as noted, these units are ubiquitous and have a low potential for failure. The transformers will be protected against lightning as per the requirements of AS 2067:2016 (Ref. [13]) and the transformer oils typically have a high-flash point reducing the risk of flammable vapour generation. Therefore, this incident has not been carried forward for further analysis.

4.9 Refrigerant Gas Release and Asphyxiation Hazard

The refrigeration system will be used to providing air conditioning and temperature control in the control room and other areas requiring temperature control. A simplified explanation of how a refrigeration system operates to cool an area is provided below.

A refrigeration system contains four essential components:

1. Compressor
2. Expansion valve
3. Refrigerant
4. Heat exchanging pipework

Figure 4-2 has been provided to aid in the description of how the refrigeration system operates to cool a specific area. The refrigeration system cycles the refrigerant gas through the system.

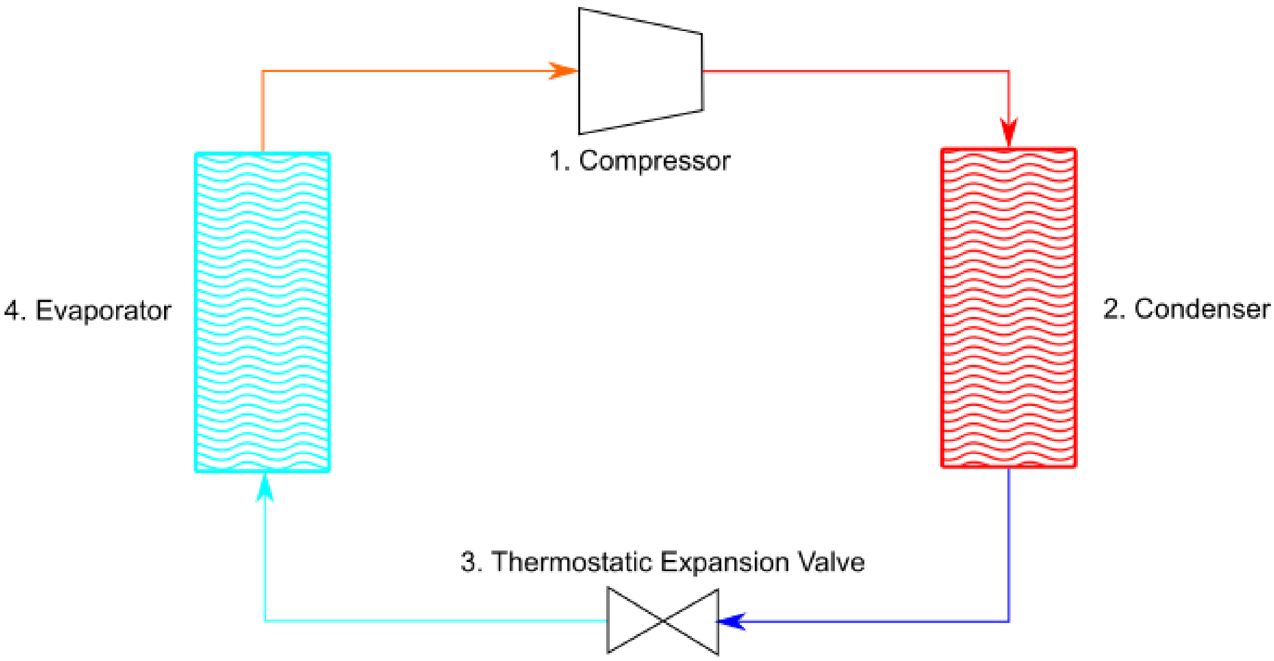

Figure 4-2: Refrigeration Flow Diagram

1. Refrigerant gas from the evaporator enters the compressor where it is pressurised (red) which increases the temperature of the gas. The gas travels along the pipework to the condenser.
2. The condenser is coiled to provide a large surface area to allow the hot gas to dissipate heat. As the gas releases heat through the coils, the gas condenses into a pressurised liquid (dark blue).
3. The pressurised liquid enters the thermostatic expansion valve where it expands across the valve seat, resulting in a sudden drop of pressure of the liquid refrigerant and rapid expansion which cools the liquid (light blue).
4. The cooled refrigerant enters the evaporator which is coiled to provide a large surface area to facilitate exchange of heat from the area to be cooled into the refrigerant. As the refrigerant absorbs heat it boils into a gaseous state.
5. On completion of the cycle, the refrigerant is drawn into the compressor and the cycle repeats.

Refrigeration systems are commonly used in all air conditioning systems which are not subject to frequent releases and if they do occur the leaks are minor resulting in minimal amounts of escaped gas. Therefore, a rupture release would not be a credible scenario given the ubiquitous nature of these systems. In the event a small release occurs it will be dissipated quickly via wind movement around the refrigeration unit prevent accumulation. Additionally, the refrigerant to be used (R-134A) in the BESS units is considered non-toxic and only poses asphyxiation risks in the event of a release. As the units are located outdoors, and each unit only carries a small quantity of the refrigerant there is no risk of toxic impact or asphyxiation; hence, this incident has not been carried forward for further analysis.

4.10 Release of Diesel, Ignition and Pool Fire

Diesel will be used on site equipment primarily during construction but may be present during operations where equipment needs to be moved / relocated / site vehicles. The diesel will likely be stored in a portable refuelling tank which typically are double skinned (i.e. integrally bunded) tanks complying with AS 1940-2017 (Ref. [14]). The presence of two tanks (i.e. inner and outer tank) results in the potential for external leakage to be incredibly low as this requires the failure of both tanks simultaneously. Therefore, a full release of diesel fuel from the tanks would not be expected to occur.

Nonetheless, if a substantial release did occur, combustible liquids do not emit flammable vapours which results in the ignition probability being incredibly. To ignite the spill, a sustained ignition source with sufficient energy would be required to be exposed to create sufficient heat to vapourise the liquid to initiate combustion. Should this occur, the fire would grow to the dimensions of the spill which would be unlikely to be sufficient to result in an offsite impact.

Due to the low likelihood of release, ignition and consequences impacts from a diesel pool fire an offsite impact is not considered to be a credible scenario; hence, this incident has not been carried forward for further analysis.

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.
- HV Transformer internal arcing, oil spill, ignition and bund fire.
- MV Transformer internal arcing, oil spill, ignition and 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 assessment was conducted in **Appendix B** using the view factor method. A maximum cell temperature (488 K) was adopted for the assessment. This is typical of data from cells driven to thermal runaway during UL9540A testing. This temperature was used to determine the Surface Emissive Power (SEP) of the batteries undergoing thermal runaway. The calculation resulted in a SEP of 2.5 kW/m^2 which would be insufficient to result in incident propagation between BESS units.

Based on the test data and the calculated SEP, it is considered that the potential for BESS propagation to occur is unlikely. A review of the proposed layout indicated that the minimum distance between adjacent BESS containers is proposed as 0.46 m. Note that this distance is indicative only and will have to be confirmed through detailed authoritative assessment, including UL9540 certification and UL9540A testing. While the assessment indicated that there should be no propagation risk, depending on the selected supplier, this distance may align with current guidance.

FM Global Data Sheet (FMDS) 5-33 (Ref. [15]) specifies the following separation distances for BESS units:

- Sides that contain access panels, doors or deflagration vents - 1.5 m.
- Sides that have solid walls having no openings – based on installation-level testing.

As the supplier has not yet been identified, the separation distance on sides that have solid walls is currently unknown. Additionally, many suppliers have not yet conducted installation level fire testing, in this case, FMDS 5-33 refers back to the 1.5 m separation distance minimum on all sides.

NFPA 855 (Ref. [16]) specifies that the minimum distance between groups shall be a minimum of 0.9 m, however this is based on a maximum capacity of 50 kWh which is exceeded by all commercial grid-level BESS containers. NFPA 855 (Ref. [16]) then directs energy capacities and spacings to be based on performance criteria from UL9540A test reports which have shown no flaming outside of the unit.

Therefore, depending on the selected supplier, the minimum separation distance as required by industry standards may vary. Therefore, the following recommendation has been made:

- Final separation distances between BESS units shall be defined with regard for the level of testing and outcomes of UL9540A reports provided by the selected supplier.

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

There is potential that arcing may occur within the transformers which may lead to generation of gases and pressure above the structural integrity of the oil reservoir which 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	0
23	17
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. As shown in **Figure 5-1**, the 23 kW/m^2 contour does not impact any other critical infrastructure and so incident propagation is not expected. Regardless, the following two options are being considered to ensure no fire impact on between the transformers:

- Allow for sufficient spacing between transformers which will be verified under AS 2067:2016 (Ref. [13]) taking into account final oil volume; or
- Install a firewall between transformers.

There are no fixed fire protection systems in proximity to the transformer; hence, these are unimpacted by the 3 kW/m^2 contour. As the options will ensure no impact from a transformer fire on the adjacent transformer, no further recommendations are made.

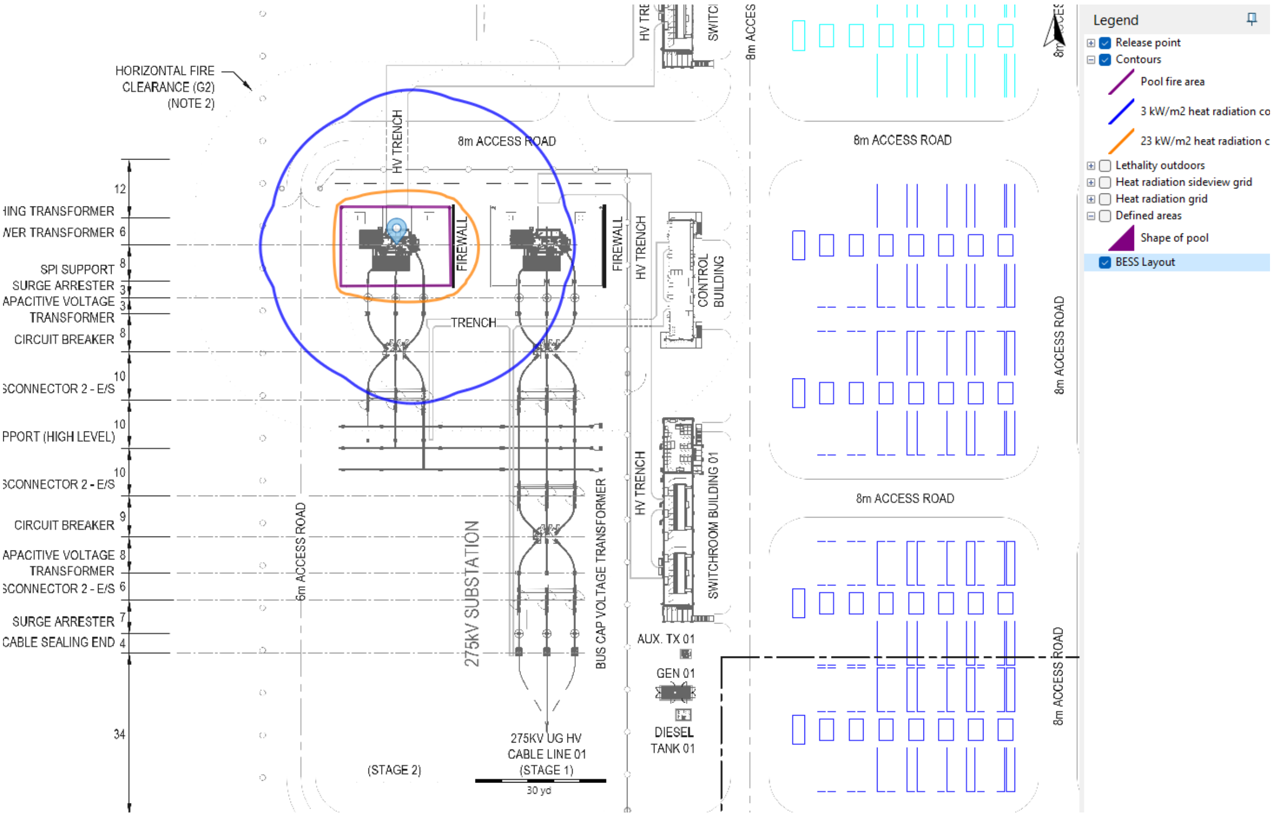

Figure 5-1: HV Transformer Fire Radiant Heat Contours

5.4 MV Transformers Internal Arcing, Oil Spill, Ignition and Fire

There is potential that arcing may occur within the MV transformers which may lead to generation of gases and pressure above the structural integrity of the oil reservoir which 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 5-2**. The radiant heat contours associated with a fire occurring within the MV transformers are shown in **Figure 5-2**.

Table 5-2: Radiant Heat from a PCU and Auxiliary Transformer Fire

Heat Radiation (KW/m^2)	Distance (m)
35	4
23	5
12.6	6
4.7	8
3.0	9

The 23 kW/m^2 contour has been used to assess the potential for propagation of the incident. As shown in **Figure 5-2**, the 23 kW/m^2 contour shows a slight impact under a wind speed of 2 m/s on the BESS units located in parallel with the transformers. Additional sensitivity analysis was conducted to determine the impact of the following parameters on the resultant heat radiation contours:

- Wind speed (up to 5 m/s) - to align with prevailing wind direction and speed at 3pm as measured by the Bureau of meteorology (BoM).
- Non-burning area (up to 20% of pool fire area) – due to equipment penetrations into the bund, a certain % of the pool fire surface does not contain oil and therefore does not burn reducing the area of the radiating surface.
- Shielding (up to 0.5 m) – where there the bund is above the level of the pool fire, it provides a shielding effect to heat radiation reducing the distance of the contours.

Under all sensitivity scenarios, the 23 kW/m^2 contour still had some impact on the adjacent BESS units, this may risk incident propagation due to increased heating of the battery cells, inducing thermal runaway. The bunding of the transformer oil and protection systems of the BESS will mitigate the risk of incident propagation through cooling systems and the BMS, however options should be considered to reduce the reduce the risk of incident propagation due to an MV transformer bund fire:

- Consider orienting the BESS containers such that auxiliary equipment is located proximal to the MV transformer aisles of the installation, moving the battery storage compartments of the BESS outside of the 23 kW/m^2 contour.
- Increase spacing between MV transformers and BESS containers.
- Provide heat shielding via increased bund height or firewalls (as with HV transformers).

At the time of assessment, the transformer oil type, exact dimensions and design of the transformers and bunding is not finalised, further assessment once these parameters are known will allow for a more detailed assessment. It is recommended to build on this modelling and reassess as the design progresses.

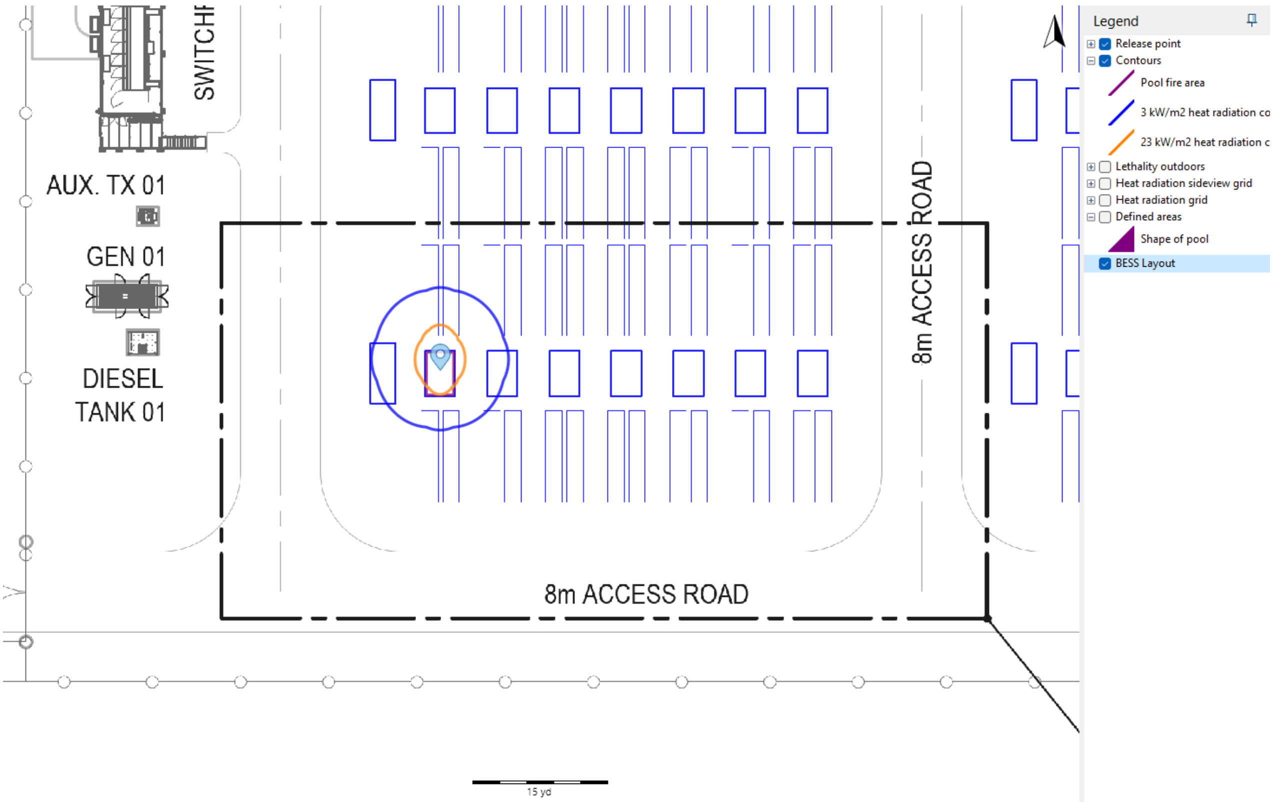

Figure 5-2: MV Transformer Fire Radiant Heat Contours

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 (e.g. fire walls)
- **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 shall include 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 facility 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. [17]).
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 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 areas. In addition, the site will have vegetation management procedures to prevent accumulation of combustible vegetation in proximity to the site equipment and to minimise the potential for bushfire escalation as well as asset protection zones (APZs) determined by a bushfire management plan.

6.1.3 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 where required
- Forms of chemical and DG information
- Availability of Safety Data Sheets
- Compliance with the Work Health and Safety Regulation 2011 (Ref. [18])
- Safe work practices
- Personal Protective Equipment
- Emergency response plan and procedures
- Bushfire Management Plan
- Training of personnel

6.1.4 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. [1]).

6.1.5 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 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. As the provider of the BESS containers is currently unknown, this section is based on minimum requirements that any provider will need to incorporate in the supplied units.

6.2.1 Detection and Alarming

BESS units are to be equipped with sensors to detect the early signs of a fire and provide both auditory and visual alarms at the local and remote levels. Additionally, BESS systems include BMS monitoring for abnormal operation which will selectively shut down systems if incipient stages of thermal runaway or a fire are detected. Fire detection and alarms are also to be provided in switchrooms and control rooms.

6.3 Fire Protection

BESS units can include several fire protection systems including:

- Overpressure vents (deflagration panels)
- Ventilation and smoke exhaust
- Separation between BESS units (discussed in **Section 5.0**).

6.4 Fire Mitigation

6.4.1 Fire Water Supply

The site shall be provided with fire water via tank storage. The water storage capacity will be determined in accordance with AS 2419.1:2021 (Ref. [5]) to ensure that adequate water storage is available to respond to emergencies.

6.4.2 Fire Suppression

BESS systems may include fire suppression devices such as aerosol-based suppression systems or internal sprinklers.

6.4.3 Battery Management Systems

The BMS for all commercial batteries are designed to detect fire and thermal runaway in its incipient stages and safely shut down and isolate the systems at risk. As the supplier has not yet been determined, the action taken by the system is unknown however any selected unit will include a BMS.

6.4.4 Non-Combustible Construction

All BESS containers shall be constructed of non-combustible materials to prevent incident propagation via propagation of combustible materials.

6.4.5 Vegetation Management and Fuel Load Control

The fuel load on the site will be managed through housekeeping, management of vegetations and APZ maintenance.

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. [19]). **Figure 7-1** illustrates the site layout with entry points to the site and fire services infrastructure.

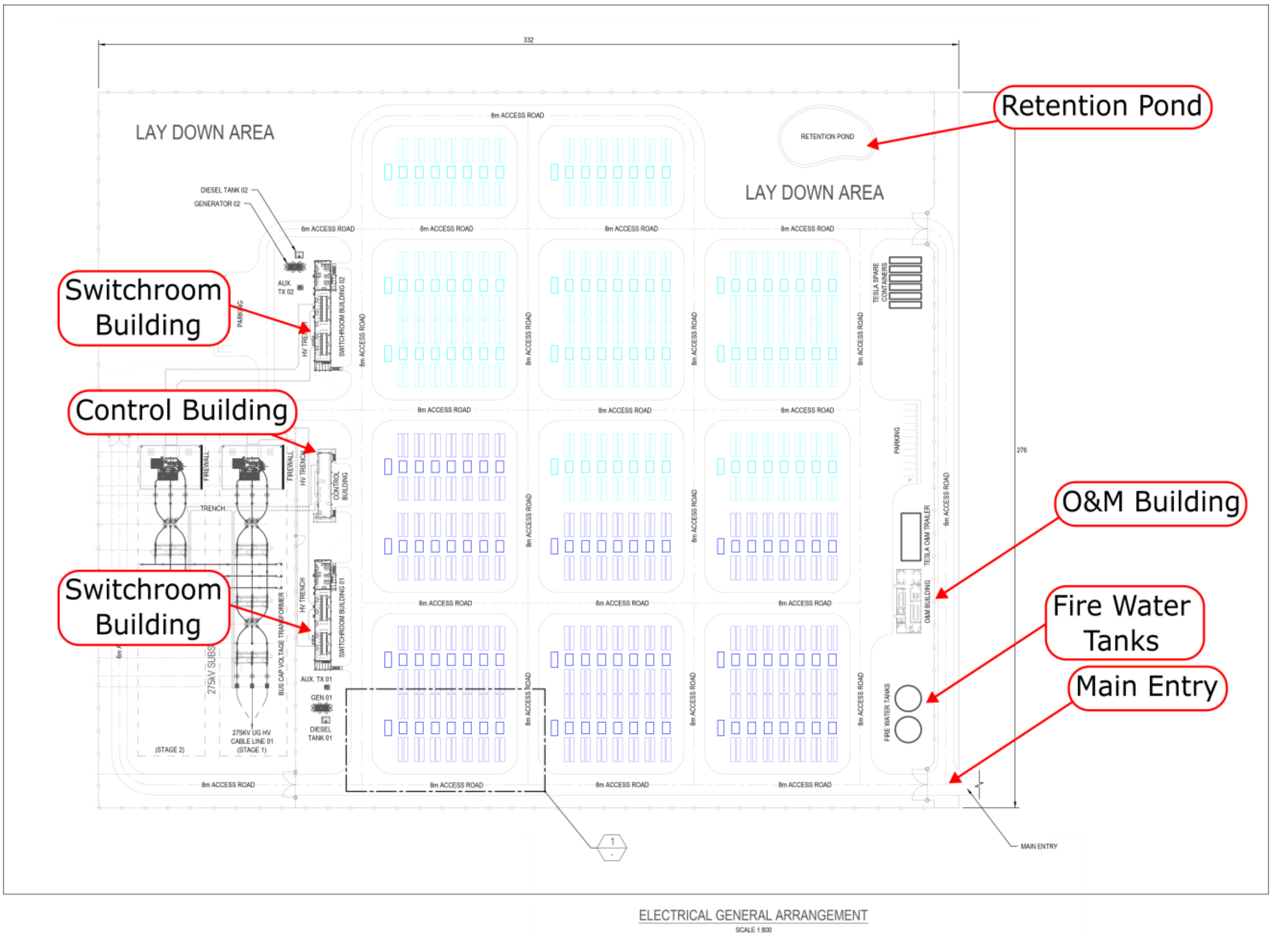

Figure 7-1: Fire Service Entry Point and Site Infrastructure

The closest fire stations to the site are described in **Table 7-1**. The location of the stations relative to the site are shown in **Figure 7-2.**

Table 7-1: Station Locations

Station Name	Station Address	Distance (km)	Time (min)
Rockhampton	113 Kent St, Rockhampton	52.5	42
Mt Morgan	32 Morgan St, Mount Morgan	75	58

Figure 7-2: Location of Site with Respect to Closest Fire Stations

7.2 Response Time – Fire Brigade Intervention Model (FBIM)

Due to the nature of the Fire Brigade Intervention Model (FBIM, Ref. [19]), 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 sections are details the assumptions utilised in this FBIM assessment.

7.2.1 Location of Fire

This FBIM will only be an indicative model of one fire scenario within the facility. 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 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

- Based on available station data, the Rockhampton station is operational 24 hours, 7 days a week and therefore no allowance is made for call out. The Mt Morgan station, whilst being closer to the site by distance is not occupied and is further based on travel time, therefore it has been assumed that resources would be dispatched from Rockhampton.
- Therefore, with a brigade call out time of 1,800 seconds and travel time to the site of 2,520 s fire brigade can be expected to arrive on site 4,320 seconds after fire ignition (72 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.

Table 7-2: FBIM data for Horizontal Travel Speeds

Graph	Travel Conditions	Speed	
		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 the entrance to the main water tank is approximately 20 m. Travel time to the water tanks is considered negligible.
- From the water tank, the furthest point on the site is the northern corner which is approximately 472 m via internal access roads. Assuming vehicles are limited to 10 km/h on site to maintain safety, this will take approximately 170 s to travel.
- It was assumed that QFES would only be required to travel approximately 100 m on foot. Coupled with an egress speed of 0.63 m/s results in a horizontal travel time of up to 63 seconds.
- Thus, the total horizontal travel time to respond to an incident in the farthest location would be expected to be up to 233 seconds.

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 QFES tanker units to the water tanks 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. [19]), 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 1,000 m of travel.

At a speed of 0.63 m/s, this will take firefighting personnel approximately 630 seconds.

7.2.8 Summary

As summarised in **Table 7-3** the FBIM (Ref. [19]) indicates that the arrival times of the brigade from the nearest fire stations is approximately 72 minutes after fire ignition, and it is estimated that it takes another 12.6 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 85 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
Rockhampton	1,800 s	2,520 s	233 s	350 s	5,073 s	630 s

8.0 Fire Water Supply & Contaminated Fire Water Retention

8.1 Detailed Fire Water System Assessment

Fire water will be supplied via storage tanks which are sized in accordance with AS 2419.1:2021 (Ref. [5]) open yard storage. The total quantity of fire water to be supplied to site is not currently known, however based on the size of the site, AS 2419.1:2021 would require 4 fire hydrants flowing simultaneously for 4-hours resulting in a total storage capacity of 576 kL.

The fire hazards assessed in **Section 5.0** 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 unlikely to result in incident propagation. As incident propagation is unlikely, the quantity of firewater provided will be suitable for prevention of spot fires and protection adjacent equipment. As such, the fire risk would be expected to be adequately managed by the provided water supply.

8.2 Contaminated Water/Fire Water Retention

From previous incidents, it has been well established that 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 some cases, application of fire water to a BESS fire can exacerbate the risk due the formation of toxic byproducts. Therefore, the approach for combatting a BESS fire is to prevent propagation to adjacent units and equipment as well as preventing any spot fires which may be initiated during an incident. This is especially true as the risk from applying water to a potentially energised system far exceeds the benefit of the fire water application.

As the site will be provided with fire water supply in accordance with AS 2419.1:2021, there is potential that up to 576 kL of water be discharged on site in the event of a BESS fire to combat fire spread. This has potential to contaminate the surrounding environment if it is not contained. Based on this the following recommendation is made:

- The retention pond shall be sized such that it can capture 100% of the fire water storage capacity.

9.0 Conclusion and Recommendations

9.1 Conclusions

A Hazard Incident Management Plan per the HIPAP No. 2 guidelines was prepared for the Mt Hopeful BESS Project located in Rockhampton. The analysis performed in the HIMP 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, if BESS units include the required certifications, fire detection measures, fire protection measures and appropriate separation to adjacent infrastructure that the site will be sufficiently safe.

Additionally, the quantity of fire water for services to utilise shall be in accordance with AS 2419.1:2021 and provided sufficient capacity to respond to any fire scenario on site. Several recommendations have been made below.

9.2 Recommendations

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

- Final separation distances between BESS units shall be defined with regard for the level of testing and outcomes of UL9540A reports provided by the selected supplier.
- Adopt an approach to minimise potential for incident propagation due to a MV transformer fire:
  - Consider orienting the BESS containers such that auxiliary equipment is located proximal to the MV transformer aisles of the installation, moving the battery storage compartments of the BESS outside of the 23 kW/m^2 contour.
  - Increase spacing between MV transformers and BESS containers.
  - Provide heat shielding via increased bund height or firewalls (as with HV transformers).
  - Reassess impact during detailed design with specific MV transformer data.
- An emergency response plan shall be prepared in accordance with HIPAP No. 1 – Industry Emergency Planning Guidelines (Ref. [1]).
- The retention pond shall be sized such that it can capture 100% of the fire water storage capacity.

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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	• Batteries are tested by manufacturer prior to sale / installation (UL9540A certified) • Overcharging and electrical circuit protection • Battery monitoring systems • 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. [17]) • Ventilation • Explosion venting • Smoke & gas detection • Aerosol suppression system
2	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 separation from other sources of fire
3	Transformers	• Arcing within transformer, vaporisation of fluid and rupture of fluid reservoir	• Transformer fluid release spill, ignition and fire	• Transformer oils tend to have a high flash point • Transformers are bunded • Electrical protection for transformer faults • Control of ignition sources – no smoking / open flames around the transformers
4	Main transformer	• 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 shut down upon detection of extreme energy input • Lightning protection to prevent lightning strikes impacting transformers • 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

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.
- HV Transformer internal arcing, oil spill, ignition and bund fire.
- MV Transformer internal arcing, oil spill, ignition and 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. [4]).

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	• Criteria used by FRNSW to determine accessibility of equipment

Gexcon - Effects

The modelling was prepared using Effects where appropriate, which is proprietary software owned by Gexcon and 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.

B3. 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 B-1**.

$$Q = \tau EF$$ **Equation B-1**

Where;

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

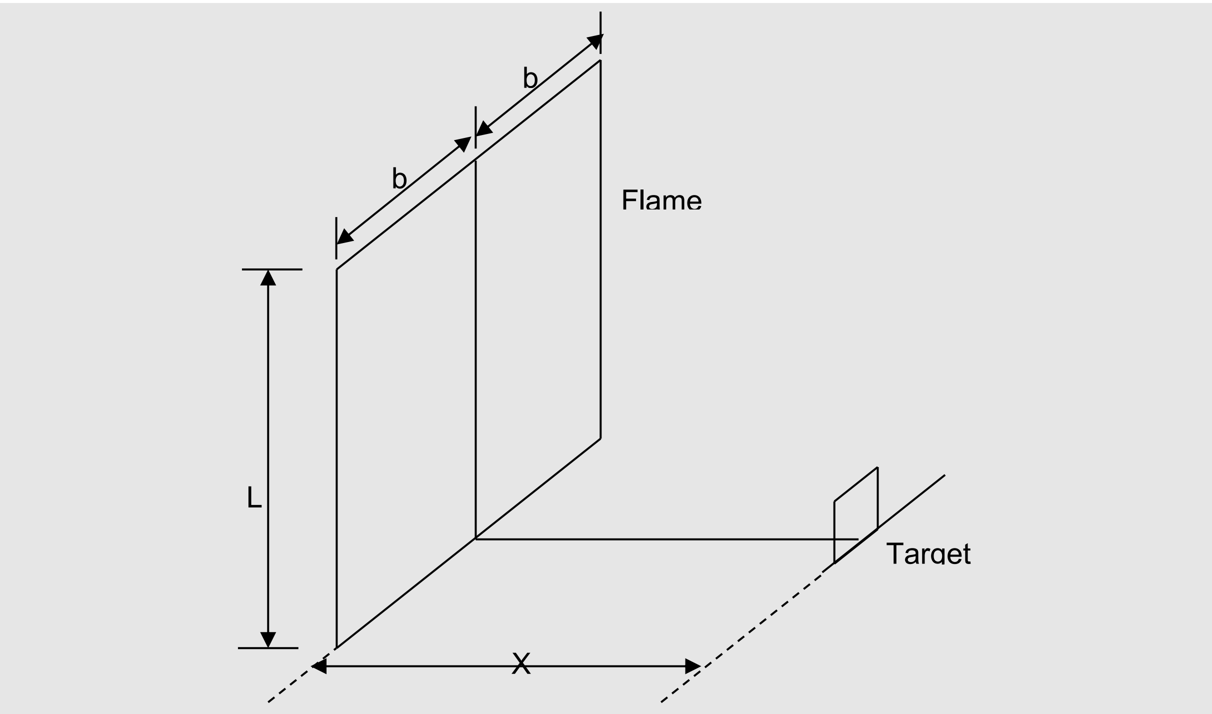
Each of the required inputs is determined in the sections following.

B4.2 View Factor

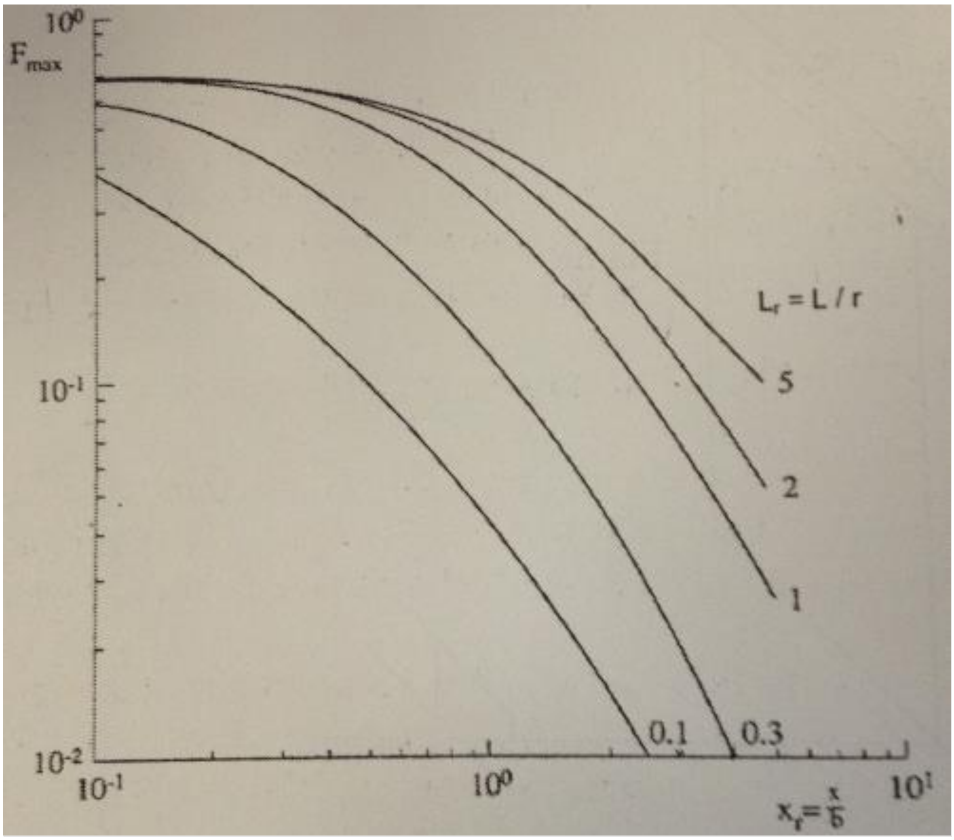
The view factor for a flat surface fire is estimated using the scenario shown in **Appendix Figure B-1** where the flame is the vertical surface of height L and length 2b with receiver located centrally and at a distance of X. Two dimensionless parameters are calculated, and the view factor read from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

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

$$X_r = \frac{X}{b}$$ **Equation B-3**



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



Appendix Figure B-2: Vertical Flame Maximum View Factor (Ref. [20])

B4.3 Transmissivity

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

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

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} = 11,549)
- T = temperature (473 K assumed air is heated to 200°C)

B4. Li-Ion Battery Fault, Thermal Runaway and Fire

The BESS units are not currently selected, however for the purpose of this assessment, the dimensions of a typical 20ft shipping container have been used as this represents an approximation of the measurements of many branded BESS containers. Shipping containers often have dimensions (H x L x W) of approximately 2.6 m x 6.1 m x 2.4 m which typically includes space for the chiller and HVAC system and auxiliary controls. The dimensions of the battery surface area facing outwards from the BESS unit when opened has conservatively estimated to be 2.5 m x 4.8 m.

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 B-2**.

It is necessary to calculate the Surface Emissive Power (SEP) of the radiant surface to calculate the radiant heat at the target. UL 9540 A test data from commonly installed BESS units indicates that the maximum temperature reached by the initiating cell where thermal runaway was induced is approximately 215 ˚C or 488 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:

$$SEP = \varepsilon\sigma T^4 \qquad \textbf{Equation B-5}$$

Where:

- ε = flame emissivity (taken as 0.78 (Ref. [21]))
- σ = 5.67x10^{-11} kW/m^2.k^4
- T = Temperature (488 K)

Substituting into the above equation yields:

$$SEP = 0.78 \times 5.67 \times 10^{-11} \times 488^4 = 2.5\frac{kW}{m^2}$$

B5. HV 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 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: HV Transformer Fire Modelling Inputs

Input	Value	Justification
Chemical name	Linoleic acid	Transformer oil to be used is a natural ester, which is typically a combustible liquid of some formulation which have high flash points. For the purposes of providing a conservative analysis, linoleic acid has been selected. This material has a flash point of approximately 200°C. Natural ester oils typically have flash points exceeding 330°C, thus this material selection is considered to be conservative.

Input	Value	Justification
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 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	86,000 kg	Mass of oil in the transformer
Temperature of pool	20°C	Conditions expected to be observed regularly. Also, negligible impact on results.
Type of pool	Polygon	Modelled based on transformer bund area.
Max pool surface area	24 m x 17 m	Actual transformer bund area has been indicated to be 13.5 m x 10.3 m. The current layout indicates a larger area which has been used to add conservatism to the model.
Height of confined pool above ground level	0 m	Modelled at ground level
Include shielding to bottom side of flame	Yes	
Height of shielding	0.5	Allowance for bunding
Wind speed	2 m/s	Fire seat enclosed in building and unlikely to be impacted by wind at fire seat.
Wind direction	Any direction	Toward infrastructure
Ambient temperature	20°C	Conditions expected to be observed regularly. Also, negligible impact on results.
Ambient pressure	101.33 kPa	Atmospheric pressure
Ambient relative humidity	60%	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 HV Transformer Bund Fire

Heat Radiation (KW/m^2)	Distance (m)
35	0

Heat Radiation (KW/m^2)	Distance (m)
23	17
12.6	23
4.7	32
3.0	37

B6. MV Transformer, Internal Arcing, Oil Spill, Ignition and Fire

The MV transformers include 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.

Provided documentation indicates that the transformers include a bund which is approximately the same dimensions as the transformer footprint (3.6 m x 2.5 m). If a spill from the transformer was to occur, it would fill the base of the bund resulting in a pool fire with the dimensions of the bund. The inputs for the model are provided in **Appendix Table B-4**.

Appendix Table B-4: MV Transformer Fire Modelling Inputs

Input	Value	Justification
Chemical name	Linoleic acid	Transformer oil to be used is a natural ester, which is typically a combustible liquid of some formulation which have high flash points. For the purposes of providing a conservative analysis, linoleic acid has been selected. This material has a flash point of approximately 200^{o}C. Natural ester oils typically have flash points exceeding 330^{o}C, thus this material selection is considered to be conservative.
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 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	3,300 kg	
Temperature of pool	20^{o}C	Conditions expected to be observed regularly. Also, negligible impact on results.
Type of pool	Polygon	Modelled based on transformer bund area.

Input	Value	Justification
Max pool surface area	3.6 m x 2.5 m	Dimension of PCU transformer bund
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	2 m/s	Fire seat enclosed in bund and unlikely to be impacted by wind.
Wind direction	Any direction	Toward BESS units
Ambient temperature	20°C	Conditions expected to be observed regularly. Also, negligible impact on results.
Ambient pressure	101.33 kPa	Atmospheric pressure
Ambient relative humidity	60%	Typical humidity in the area
CO2 concentration	0.0004	CO2 concentration in atmosphere

The results of the analysis are shown in **Appendix Table B-5**.

Appendix Table B-5: Heat Radiation Impacts from a MV Transformer Fire

Heat Radiation (KW/m^2)	Distance (m)
35	4
23	5
12.6	6
4.7	8
3.0	9