Riskcon engineering

Preliminary Hazard Analysis

Muswellbrook BESS

Firm Power Pty Ltd
Document No. RCE-22013_MuswellbrookBESS_PHA_Final_12Jul22_Rev(2)
Date 12/07/2022

Preliminary Hazard Analysis

Muswellbrook BESS

Firm Power Pty Ltd

Prepared by

Riskcon Engineering Pty Ltd
Unit 618 / 159 Ross Street
Forest Lodge, NSW, 2037
www.riskcon-eng.com
ABN 74 626 753 820

Quality Management

Rev	Date	Remarks	Prepared By	Reviewed By
A	7th April 2022	Draft issue for comment	Jason Costa	Renton Parker
0	29th June 2022	Final issued		
1	8th July 2022	Final revised		
2	12th July 2022	Final revised		

Executive Summary

Background

Firm Power has proposed to develop a Battery Energy Storage System (BESS) facility at Lots 11 and 12 (DP839233) off Sandy Creek Road in Muswellbrook NSW. The access driveway lot is Lot 15 DP (905479). The project will comprise of a 150/300 MWh system (delivery capacity/useable storage) along with associated infrastructure (i.e. substations, transformers, etc.).

The Muswellbrook BESS includes the following key infrastructure:

- Enclosed lithium-ion batteries;
- Power conversion systems including associated switchgear, protection and control equipment, transformers and enclosures for housing equipment;
- Underground power and fibre optic cabling interconnecting the equipment;
- Grid connection equipment including main power transformer, switchgear, protection and control equipment, metering, reactive power equipment, filtering equipment, auxiliary/earthing transformers and enclosures/buildings for housing equipment;
- Underground or overhead 132kV sub-transmission lines to connect the BESS to the Muswellbrook substation;
- Earthing and lightning protection systems;
- Site office, storage area/enclosure, internal access tracks, on-site parking, security fencing, CCTV, lighting and temporary construction laydown area;
- Vegetation screening and noise walls; and
- Utilisation of existing site access arrangements.

The primary components associated with the installation of the BESS are as follows:

- Site investigations, vegetation clearing, levelling, bench and access way construction, drainage system installation and installation of foundations/supports to install equipment on;
- Transport to site and installation of equipment;
- Testing and commissioning of the equipment;
- Operation and maintenance.

The Secretary Environmental Assessment Requirements (SEARs) require the preparation of a Preliminary Hazard Analysis (PHA) to assess the risk profile of the development in accordance with the Hazardous Industry Planning Advisory Paper (HIPAP) No. 6 (Ref.) utilising criteria from HIPAP No. 4 (Ref.).

Firm Power has engaged Riskcon Engineering Pty Ltd (Riskcon) to prepare a PHA for the project as part of the State Significant Development Application (SSDA).

Conclusions

A hazard identification table was developed for the Muswellbrook BESS 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 the potential for offsite impacts. Postulated scenarios were discussed qualitatively and any scenarios that would not impact offsite were eliminated from further assessment. Scenarios not eliminated were then carried forward for consequence analysis.

Incidents carried forward for consequence analysis were assessed 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.

Where an offsite impact was identified, a frequency analysis and risk assessment were conducted to identify the potential for fatality, injury and irritation to occur as a result of the development. The results indicated that the fatality risks would not exceed the acceptable criteria. Similarly, the injury and irritation criteria were not exceeded. Finally, the potential for incident propagation as assessed at the 23 kW/m^2 contour which didn't show any potential for off-site impact and similarly the 14 kPa contours didn't impact any areas of interest thus incident propagation would not be considered to occur.

Based on the analysis conducted, it is concluded that the risks at the site boundary are not considered to exceed the acceptable risk criteria; hence, the project would only be classified as potentially hazardous and would be permitted within the current land zoning for the site.

Recommendations

Notwithstanding the conclusions drawn, the following recommendations have been made:

- The transformers spill containment shall be designed according to the requirements of AS 2067:2016 – "Substations and high voltage installations exceeding 1 kV a.c'
- A Final Hazard Analysis (FHA) shall be prepared based upon the finalised layout of the site to demonstrate that the risk criteria remains below the acceptable levels.

Table of Contents

List of Figures

List of Tables

List of Appendix Tables

Abbreviations

Abbreviation	Description
AC	Alternating Current
ADG	Australian Dangerous Goods Code
AS	Australian Standard
BESS	Battery Energy Storage System
CBD	Central Business District
DC	Direct Current
DGs	Dangerous Goods
ELF	Extra Low Frequency
EMF	Electric and Magnetic Field
ERPG	Emergency Response Planning Guideline
FCAS	Frequency Control Ancillary Services
HF	Hydrogen Fluoride
HIPAP	Hazardous Industry Planning Advisory Paper
ICNIRP	International Commission on Non-Ionizing Radiation Protection
IDLH	Immediately Dangerous to Life and Health
PCU	Power Control Unit
PHA	Preliminary Hazard Analysis
Pmpy	Per million per year
SEARs	Secretary’s Environmental Assessment Requirements
SEP	Surface Emissive Power
SEPP	State Environmental Planning Policy
SOC	State of Charge
SSDA	State Significant Development Application
STEL	Short Term Exposure Limit

1.0 Introduction

1.1 Background

Firm Power has proposed to develop a Battery Energy Storage System (BESS) facility at Lots 11 and 12 (DP839233) off Sandy Creek Road in Muswellbrook NSW. The access driveway lot is Lot 15 DP (905479). The project will comprise of a 150/300 MWh system (delivery capacity/useable storage) along with associated infrastructure (i.e. substations, transformers, etc.).

The Muswellbrook BESS includes the following key infrastructure:

- Enclosed lithium-ion batteries;
- Power conversion systems including associated switchgear, protection and control equipment, transformers and enclosures for housing equipment;
- Underground power and fibre optic cabling interconnecting the equipment;
- Grid connection equipment including main power transformer, switchgear, protection and control equipment, metering, reactive power equipment, filtering equipment, auxiliary/earthing transformers and enclosures/buildings for housing equipment;
- Underground or overhead 132kV sub-transmission lines to connect the BESS to the Muswellbrook substation;
- Earthing and lightning protection systems;
- Site office, storage area/enclosure, internal access tracks, on-site parking, security fencing, CCTV, lighting and temporary construction laydown area;
- Vegetation screening and noise walls; and
- Utilisation of existing site access arrangements.

The primary components associated with the installation of the BESS are as follows:

- Site investigations, vegetation clearing, levelling, bench and access way construction, drainage system installation and installation of foundations/supports to install equipment on;
- Transport to site and installation of equipment;
- Testing and commissioning of the equipment;
- Operation and maintenance.

The Secretary Environmental Assessment Requirements (SEARs) require the preparation of a Preliminary Hazard Analysis (PHA) to assess the risk profile of the development in accordance with the Hazardous Industry Planning Advisory Paper (HIPAP) No. 6 (Ref. [1]) utilising criteria from HIPAP No. 4 (Ref. [2]).

Firm Power has engaged Riskcon Engineering Pty Ltd (Riskcon) to prepare a PHA for the project as part of the State Significant Development Application (SSDA).

1.2 Objectives

The key objectives of this PHA are to:

- Complete the PHA according to the Hazardous Industry Planning Advisory Paper (HIPAP) No. 6 – Hazard Analysis (Ref. [1]);
- Assess the PHA results using the criteria in HIPAP No. 4 – Risk Criteria for Land Use Planning (Ref. [2]); and
- Demonstrate compliance of the site with the relevant codes, standards and regulations (i.e. Planning and Environment Regulation, WHS Regulation, 2017 Ref. [3]).

1.3 Scope of Services

The scope of work is to complete a PHA study for the Firm Power BESS project located near Sandy Creek Road in Muswellbrook, NSW. No other projects are included within the scope of work.

.

2.0 Methodology

2.1 Multi-Level Risk Assessment

The Multi-Level Risk Assessment approach (Ref. [4]) published by the NSW Department of Planning, Industry and Environment, has been used as the basis for the study to determine the level of risk assessment required. The approach considered the development in context of its location, the quantity and type (i.e. hazardous nature) of Dangerous Goods stored and used, and the project's technical and safety management control. The Multi-Level Risk Assessment Guidelines are intended to assist industry, consultants and the consent authorities to carry out and evaluate risk assessments at an appropriate level for the project being studied.

There are three levels of risk assessment set out in Multi-Level Risk Assessment which may be appropriate for a PHA, as detailed in **Table 2-1**.

Table 2-1: Level of Assessment PHA

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

The Multi-Level Risk Assessment approach is schematically presented in **Figure 2-1**.

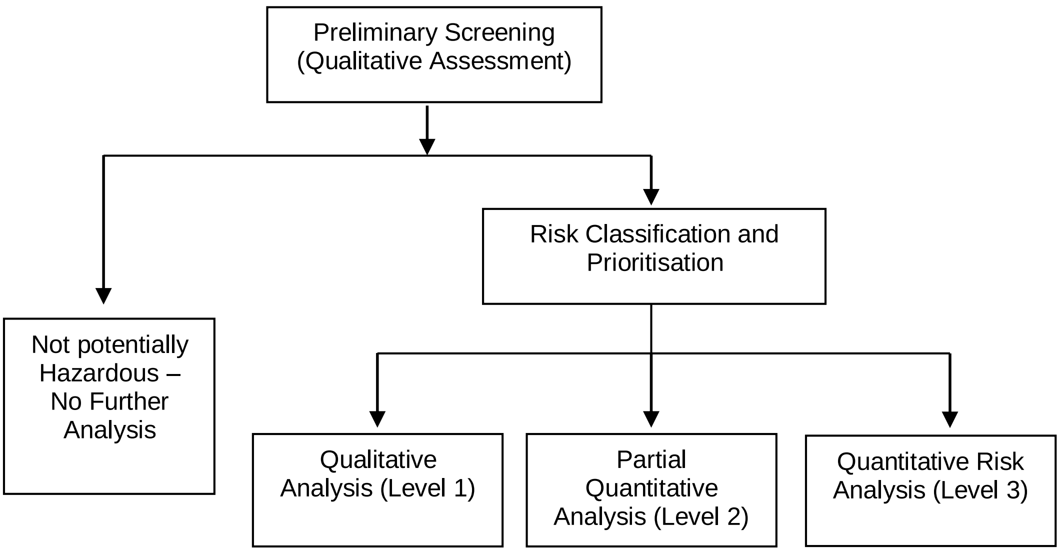

Figure 2-1: The Multi-Level Risk Assessment Approach

Based on the type of DGs to be used and handled at the proposed project, a **Level 2 Assessment** was selected for the Site. 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. This approach is commensurate with the methodologies recommended in "Applying SEPP 33's" Multi Level Risk Assessment approach (DPIE, 2011).

2.2 Risk Assessment Study Approach

The methodology used for the PHA is as follows;

Hazard Analysis – A detailed hazard identification was conducted for the site facilities and operations. Where an incident was identified to have a potential off-site impact, it was included in the recorded hazard identification word diagram (**Appendix A**). The hazard identification word diagram lists incident type, causes, consequences and safeguards. This was performed using the word diagram format recommended in HIPAP No. 6 (Ref. [1]).

Each postulated hazardous incident was assessed qualitatively in light of proposed safeguards (technical and management controls). Where a potential offsite impact was identified, the incident was carried into the main report for further analysis. Where the qualitative review in the main report determined that the safeguards were adequate to control the hazard, or that the consequence would obviously have no offsite impact, no further analysis was performed. **Section 3.1** of this report provides details of values used to assist in selecting incidents required to be carried forward for further analysis.

Consequence Analysis – For those incidents qualitatively identified in the hazard analysis to have a potential offsite impact, a detailed consequence analysis was conducted. The analysis modelled the various postulated hazardous incidents and determined impact distances from the incident source. The results were compared to the consequence criteria listed in HIPAP No. 4 (Ref. [2]). The criteria selected for screening incidents is discussed in **Section 3.1**.

Where an incident was identified to result in an offsite impact, it was carried forward for frequency analysis. Where an incident was identified to not have an offsite impact, and a simple solution was evident (i.e. move the proposed equipment further away from the boundary), the solution was recommended, and no further analysis was performed.

Frequency Analysis – In the event a simple solution for managing consequence impacts was not evident, each incident identified to have potential offsite impact was subjected to a frequency analysis. The analysis considered the initiating event and probability of failure of the safeguards (both hardware and software). The results of the frequency analysis were then carried forward to the risk assessment and reduction stage for combination with the consequence analysis results.

Risk Assessment and Reduction – Where incidents were identified to impact offsite and where a consequence and frequency analysis was conducted, the consequence and frequency analysis for each incident were combined to determine the risk and then compared to the risk criteria published in HIPAP No. 4 (Ref. [2]). Where the criteria were exceeded, a review of the major risk contributors was performed, and the risks reassessed incorporating the recommended risk reduction measures. Recommendations were then made regarding risk reduction measures.

Reporting – On completion of the study, a draft report was developed for review and comment by Firm Power. A final report was then developed, incorporating the comments received by Firm Power for submission to the regulatory authority.

3.0 Site Description

3.1 Site Location

The site is located off Sandy Creek Road, Muswellbrook NSW which is northwest of Sydney and is approximately 3 km northeast of the centre of Muswellbrook. **Figure 3-1** shows the regional location of the site in relation to Muswellbrook. A site layout has been provided in **Figure 3-4**.

Figure 3-1: Site Location

3.2 Adjacent Land Uses

The land is located in a regional / rural area and is currently surrounded by rural farmland on all sides. The closest developed residences are approximately 370 metres to the southwest of site.

A residential estate (Northview) has been approved for development to the west of the site and will be situated approximately 250 m from the site at the closest point. Identified sensitive receptors have been discussed further in **Section 3.5**.

A proposed Muswellbrook bypass highway may encroach within 100 m to the east of the site in the future.

The BESS site is not likely to significantly impact any of these adjacent land uses, and noise walls have been proposed as indicated in **Figure 3-4** to further reduce noise impact to residential areas.

3.3 Detailed Description

The proposed Muswellbrook BESS is a 150 megawatt (MW) stand-alone battery system to be located adjacent to Ausgrid's Muswellbrook Substation in the Upper Hunter region of NSW. The project will have capacity to store up to 150 MW of energy for 2 hours resulting in a storage of 300 MWh through lithium-ion battery storage which can fill peak demands due to the quick dispatchability of battery storage.

Once operational, the Muswellbrook BESS will provide a range of electricity and power market services.

3.3.1 Ring Main Units

Ring main units are switchgear that protect and isolate the electrical connections to the Step Up Transformers and the Step Up Transformers themselves. These will be up to 10 ring main units across the site and each unit is contained in an enclosure to protect them from the external environment.

3.3.2 3.3.2 Step Up Transformer

The Step Up Transformers convert the Inverter voltage (typically between 400V and 690V) to the collector system voltage (typically 11kV to 33kV) for transfer of electric energy to the substation. There will be up to 50 Step Up Transformers across the site. Each unit is typically skid mounted.

3.3.3 3.3.3 Inverters

The inverters convert Direct Current (DC) from the batteries to Alternating Current (AC) for connection to the Step Up Transformer. The inverters can be installed outdoors adjacent to the step up transformer and battery container, or housed inside the battery container depending on the manufacturer and technology.

The areas where the ring main units, step up transformers and inverters will be installed are identified in **Figure 3-4**. **Figure 3-2** provides an example of a typical ring main unit, step up transformer and inverter.

Figure 3-2: Typical Single Inverter

3.3.4 Battery Storage

The proposed BESS will be located within enclosures and will either be co-located with PCUs distributed around the site or aggregated in one BESS storage area depending on detailed project design.

The BESS will enable the facility to be a flexible energy generation source, providing energy when it is required the most. The BESS converts electrical energy into chemical energy and stores the energy internally. It may also contribute towards network security Frequency Control Ancillary Services (FCAS) in the Region. A typical BESS is shown in **Figure 3-3** and areas where BESS are contained in the layout shown in **Figure 3-4**.

Figure 3-3: Typical BESS

3.4 Quantities of Dangerous Goods Stored and Handled

The classes and quantities of DGs to be approved in the project are summarised **Table 3-1**.

Table 3-1: Maximum Classes and Quantities of Dangerous Goods Stored

Area	Class	Description	Quantity
BESS	9	Lithium Batteries	2,600 t
Step-Up Transformer	C1	Transformer oils	200,000 L*
Substation Transformer	C1	Transformer oils	40,000 L

*Approximately 4,000 L per transformer.

3.5 Sensitive Receptors

The nearest sensitive receptors are shown in **Figure 3-5** with the nearby future development indicated by receptors F1, F2 and F3.

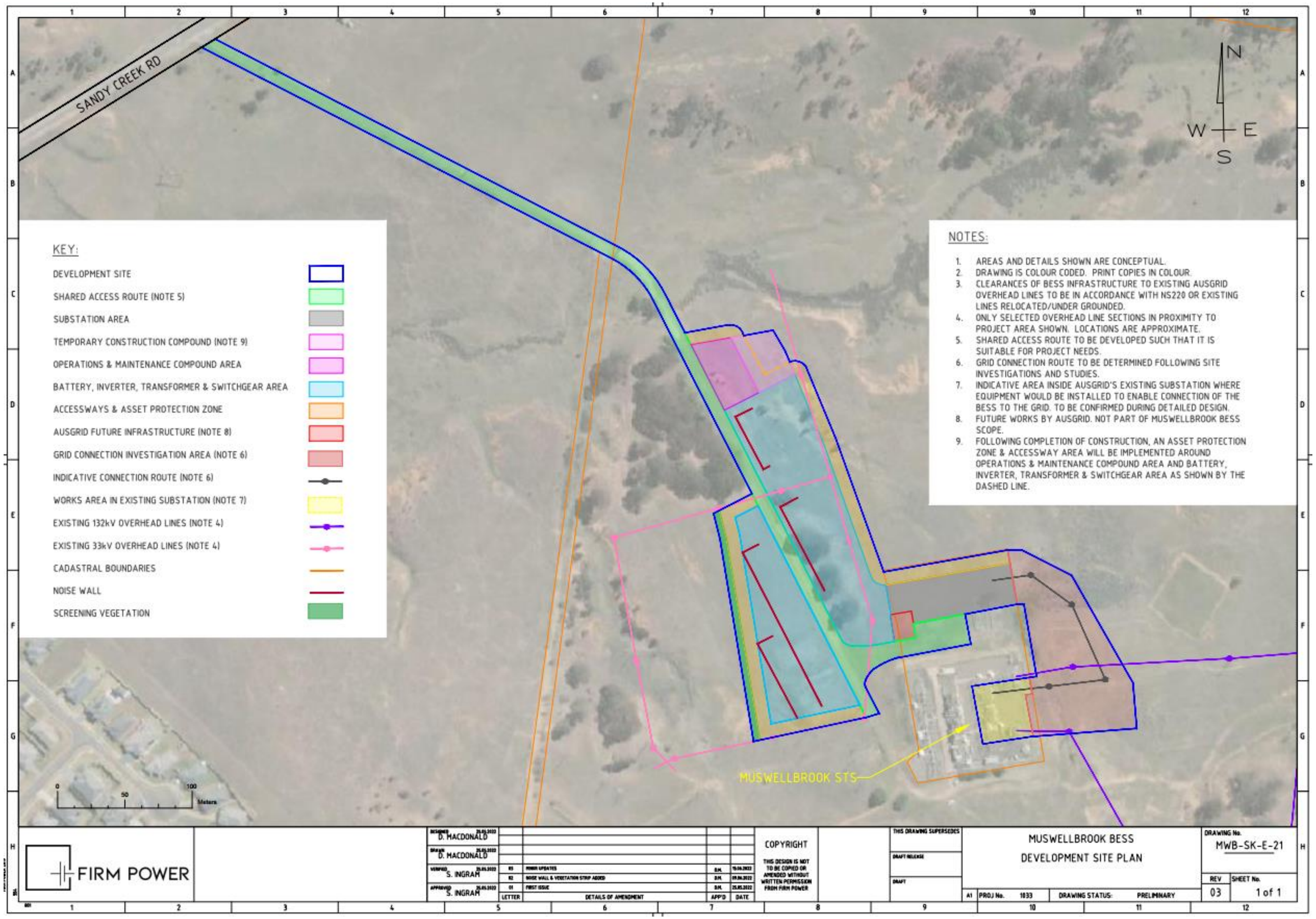

Figure 3-4: Site Layout

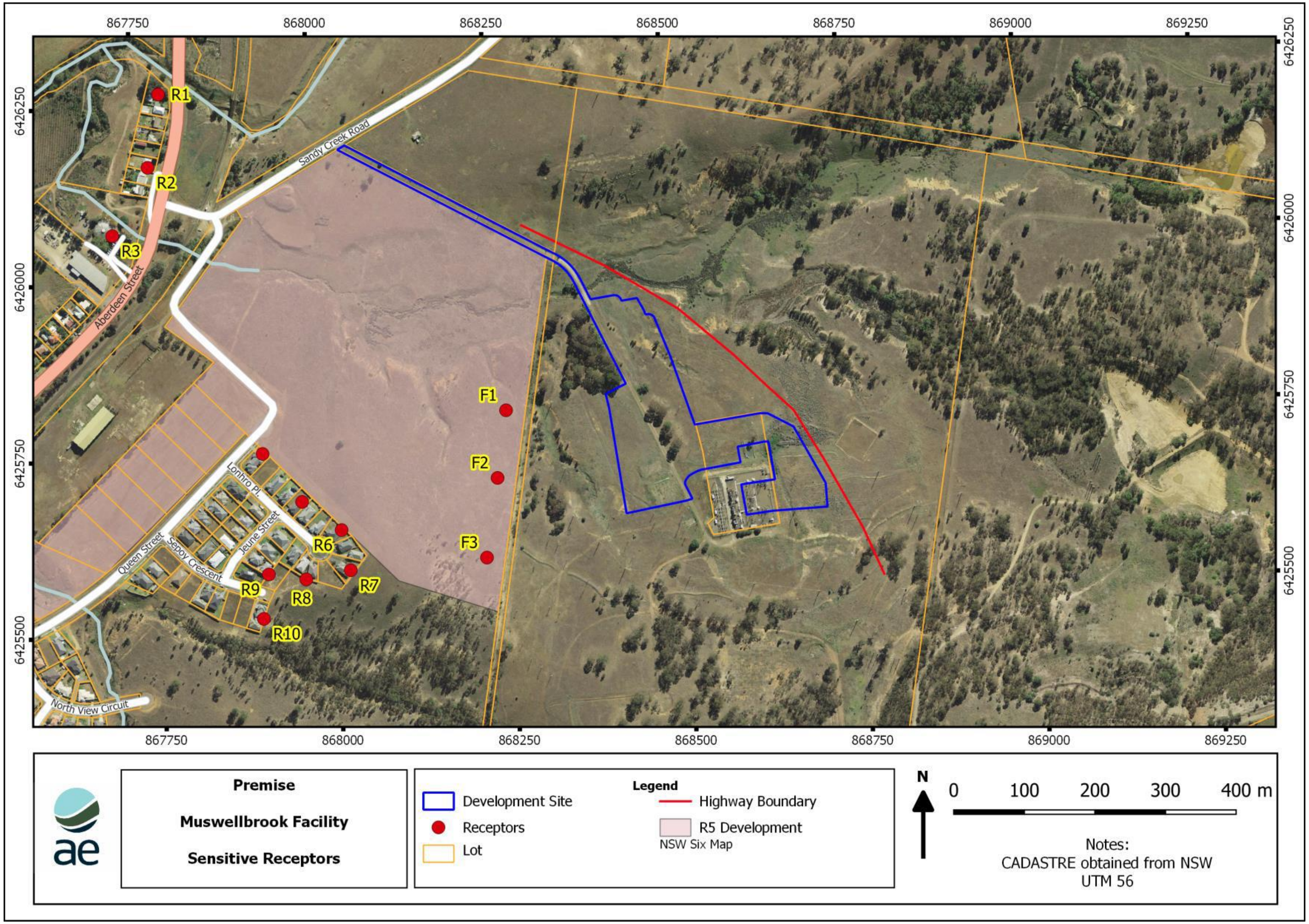

Figure 3-5: Sensitive Receptors (Source – Noise Impact Assessment)

4.0 Hazard Identification

4.1 Introduction

A hazard identification table has been developed and is presented at **Appendix A**. This table has been developed following the recommended approach in Hazardous Industry Planning Advisory Paper No .6, Hazard Analysis Guidelines (Ref. [1]). The Hazard Identification Table provides a summary of the potential hazards, consequences and safeguards at the site. The table has been used to identify the hazards for further assessment in this section of the study. Each hazard is identified in detail and no hazards have been eliminated from assessment by qualitative risk assessment prior to detailed hazard assessment in this section of the study.

In order to determine acceptable impact criteria for incidents that would not be considered for further analysis, due to limited impact offsite, the following approach has been applied:

- *Fire Impacts* - It is noted in Hazardous Industry Planning Advisory Paper (HIPAP) No. 4 (Ref. [2]) that a criterion is provided for the maximum permissible heat radiation at the site boundary (4.7 kW/m^2) above which the risk of injury may occur and therefore the risk must be assessed. Hence, to assist in screening those incidents that do not pose a significant risk, for this study, incidents that result in a heat radiation less that at 4.7 kW/m^2, at the site boundary, are screened from further assessment.

  Those incidents exceeding 4.7 kW/m^2 at the site boundary are carried forward for further assessment (i.e. frequency and risk). This is a conservative approach, as HIPAP No. 4 (Ref. [2]) indicates that values of heat radiation of 4.7 kW/m^2 should not exceed 50 chances per million per year at sensitive land uses (e.g. residential). It is noted that the closest residential area is approximately 200 m from the site, hence, by selecting 4.7 kW/m^2 as the consequence impact criteria (at the site boundary) the assessment is considered conservative.

- *Explosion* - It is noted in HIPAP No. 4 (Ref. [2]) that a criterion is provided for the maximum permissible explosion over pressure at the site boundary (7 kPa) above which the risk of injury may occur and therefore the risk must be assessed. Hence, to assist in screening those incidents that do not pose a significant risk, for this study, incidents that result in an explosion overpressure less than 7 kPa, at the site boundary, are screened from further assessment. Those incidents exceeding 7 kPa, at the site boundary, are carried forward for further assessment (i.e. frequency and risk). Similarly, to the heat radiation impact discussed above, this is conservative as the 7 kPa value listed in HIPAP No. 4 relates to residential areas, which are over approximately 200 m from the site.

- *Toxicity* – Toxic bi-products of combustion may be generated by a BESS fire; hence, toxicity has been assessed with criteria based upon the Emergency Response Planning Guidelines (ERPG).

- *Property Damage and Accident Propagation* - It is noted in HIPAP No. 4 (Ref. [2]) that a criterion is provided for the maximum permissible heat radiation/explosion overpressure at the site boundary (23 kW/m^2/14 kPa) above which the risk of property damage and accident propagation to neighbouring sites must be assessed. Hence, to assist in screening those incidents that do not pose a significant risk to incident propagation, for this study, incidents that result in a heat radiation less than 23 kW/m^2 and explosion over pressure less than 14 kPa, at the site boundary, are screened from further assessment. Those incidents exceeding 23 kW/m^2

at the site boundary are carried forward for further assessment with respect to incident propagation (i.e. frequency and risk).

- *Societal Risk* – HIPAP No. 4 (Ref. [2]) discusses the application of societal risk to populations surrounding the proposed project. It is noted that HIPAP No. 4 indicates that where a development proposal involves a significant intensification of population, in the vicinity of such a project, the change in societal risk needs to be taken into account. In the case of the project, there is currently no significant intensification of population around the proposed site; hence, societal risk has not been considered in this assessment.

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
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. [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/explosion.
- Li-ion battery fire and toxic gas dispersion.
- Electrical equipment failure and fire.
- Transformer internal arcing, oil spill, ignition and bund fire.
- Electromagnetic field Impacts.

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**.

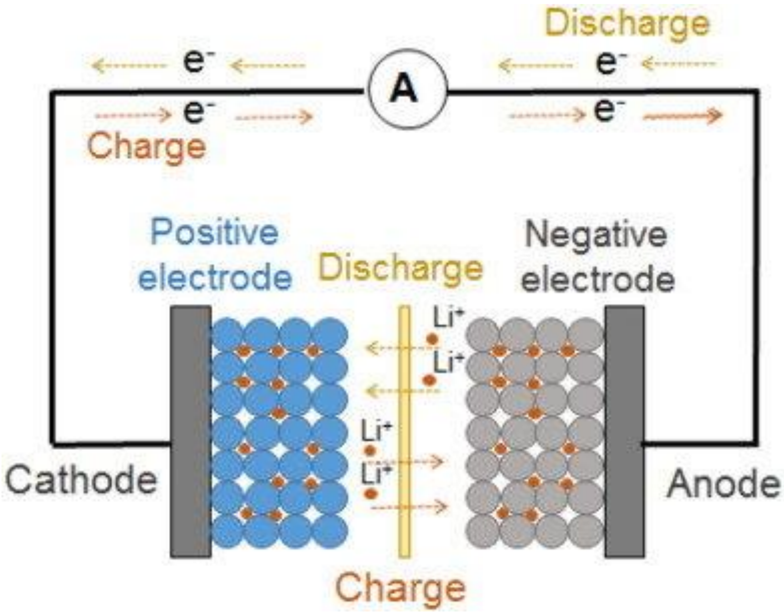

Figure 4-1: Cathode and Anode of a Battery (Source Research Gate)

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 bi-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 generally include:

- 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)

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).

In terms of physical damage, the batteries are contained within modules which are located within enclosures and a fenced area; therefore, there is a low potential for damage to occur to the batteries which may initiate an incident.

A review of the batteries proposed to be used as part of this project indicates the battery chemistry is lithium-Iron phosphate (LiFePO4, or simply LFP) which are considered to be one of the safest battery chemistries within the industry. When exposed to external heat the thermal rise of typical lithium ion battery chemistries is 200-400 ^{o}C/min resulting thermal run away and fire which can then propagate to adjacent batteries escalating the incident to a full container fire. For LFP batteries, the thermal rise of the batteries at peak is 1.5^{o}C/min which results in a gradual temperature rise and does not result in fire and thus incident propagation to other batteries. The thermal rise of various battery chemistries is provided in **Figure 4-2** with a zoomed in temperature rise for LFP provided in the top right of **Figure 4-2**. 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 oxidises the electrolyte.

Additional testing for shock and damage to batteries (i.e. nail puncture test) has been shown that LFP batteries when punctured through membranes, which 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.

In the event that LFP chemistries do ignite by artificial means, the combustion by product released is carbon dioxide which reduces the oxygen concentration within a confined space reducing the combustion rate. Finally, enclosures can be fitted with fire suppression systems which activate to suppress and control a fire to prevent propagation. They may also be designed such that the battery enclosure limits the extent of the fire in a safe and controlled manner, consuming itself slowly and without explosive bursts, projectiles, or unexpected hazards. The enclosure uses vents to direct gases, smoke, and flame out of the top of the unit and thereby minimises risk and exposure to any nearby response personnel.

Based upon the inherent protection afforded by LFP chemistries, it is considered that a thermal runaway event and subsequent battery enclosure fire is not a credible scenario; hence, this incident has not been carried forward for further analysis.

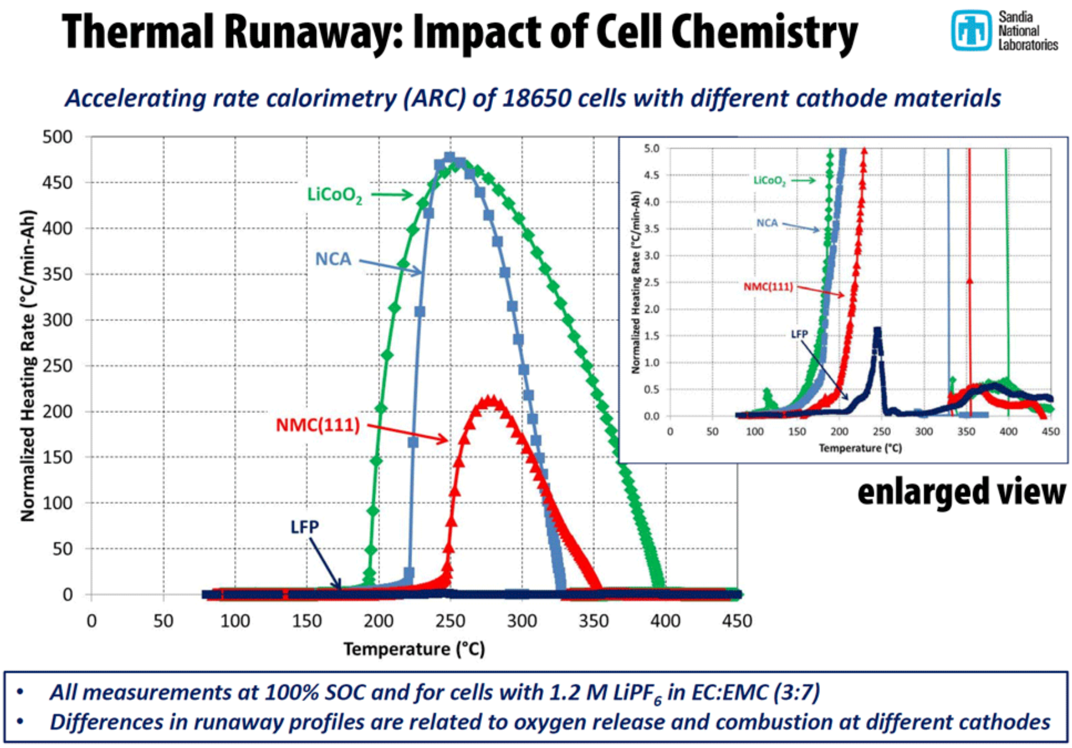

Figure 4-2: Temperature Rise of Lithium-Ion Battery Chemistries (Ref. [6]).

4.5 Li-ion Battery Fire and Toxic Gas Dispersion

If a BESS failure occurs resulting in a fire toxic bi-products of combustion to 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 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 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.

$$C_3H_8(g) + 5O_2(g) \rightarrow 3Co_2(g) + 4H_2O(g) \qquad \textbf{Equation 4-1}$$

The lithium-ion batteries are predominantly composed of metal structures. However, during a fire event ancillary equipment and materials within the batteries will be involved in the fire including wiring, plastics, anodes, etc. which will liberate carbon dioxide. However, a review of the toxicological impacts indicates high concentrations would be required to result in injury or fatality. Based upon a review of the sensitive areas, and the similar BESS fires (i.e. Victoria BESS fire), it is not considered that the formation of carbon dioxide in a fire would be sufficient to result in downwind impacts sufficient to cause injury or fatality. In other words, there would be insufficient production of carbon dioxide to generate a plume of sufficient concentration to displace the required oxygen for a significant downwind consequence to occur. Therefore, this incident has not been carried forward for further analysis.

4.5.2 Carbon Monoxide

Carbon monoxide 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**

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.

4.5.3 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 several battery chemistry configurations and States of Charge (SOC) indicated the vast majority of these did not produce observable POF_3 with the only observance occurring in a specific battery chemistry at 0% SOC (Ref. [7]). Therefore, the main fluorine gas of concern in a Li-ion battery fire is HF.

HF gas is hydroscopic readily dissolving into water vapour / humidity or moisture in airways forming hydrofluoric acid. Hydrofluoric acid is a weak acid although is highly corrosive and may result in chemical burns. In addition, it is calcium scavenging. 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. As the potential for the initiating event is considered unlikely, 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 and in the ring main units 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 or ring main units, the fire would be considered to be relatively slow in growth and would be unlikely to result in substantial impacts in terms of offsite impact or incident propagation. 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 cool the units 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 switches and a pressure surge switch (Buckholtz relay). 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.

As there is the potential for a fire to occur within transformers, this incident has been carried forward for further analysis.

The transformers haven't been subject to detailed design at this stage; hence, the following recommendation has been made:

- The transformers spill containment shall be designed according to the requirements of AS 2067:2016 – "Substations and high voltage installations exceeding 1 kV a.c'

4.8 Electromagnetic Field Impacts

4.8.1 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 where 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.

Electrical facilities create EMFs from operational electrical equipment, such as transmission lines, substations and the electrical components found within BESS units, inverts, etc. This equipment has the potential to produced ELF EMF's in the range of 30 to 300 Hz.

4.8.2 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. [8]).

Table 4-2 provides typical magnetic field measurements and ranges associated with EMF sources. It is noted that electric fields around devices are generally close to 0 due to the shielding provided around the equipment. In addition, EMF levels drop away quickly with distance; hence, while a value may be measurable at the source, within a short distance the EMF is undetectable.

Table 4-2: EMF Sources and Magnetic Field Strength

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

4.8.3 Exposure Discussion

A review of the site indicates there are no immediate residences adjacent to the area where the facility or BESS will be developed 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. In addition, the closest future residence is approximately 100 m away from the EMF generating sources at the facility; hence, the potential for the EMF to exceed the accepted levels is considered negligible.

As the potential for exposure to EMF exceeding the international guidelines is negligible, 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 potential to impact off site:

- Transformer internal arcing, oil spill, ignition and bund fire.

Each incident has been assessed in the following sections.

5.2 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**. It is noted the contours are located at the worst-case location within the substation with respect to the site boundary.

Table 5-1: Radiant Heat from a Transformer Bund Fire

Heat Radiation (KW/m^2)	Distance (m)
35	6
23	8
12.6	11
4.7	18

As can be seen in **Figure 5-1** the radiant heat contours at 4.7 kW/m^2 impact over the security fence and therefore impact over the site boundary. It is noted that under different wind conditions and directions there may not be any impact over the site boundary at 4.7 kW/m^2; however, as only a minor incursion over the site boundary occur in conditions with unfavourable wind, and the site is located within the boundaries of a private property, it is not expected that a fatality would occur. The 23 kW/m^2 contour is associated with incident propagation which also does not impact over the boundary nor the site boundary. Therefore, incident propagation offsite would not be expected to occur from transformer bund fire.

Notwithstanding, this incident has been carried forward for further analysis for conservatism.

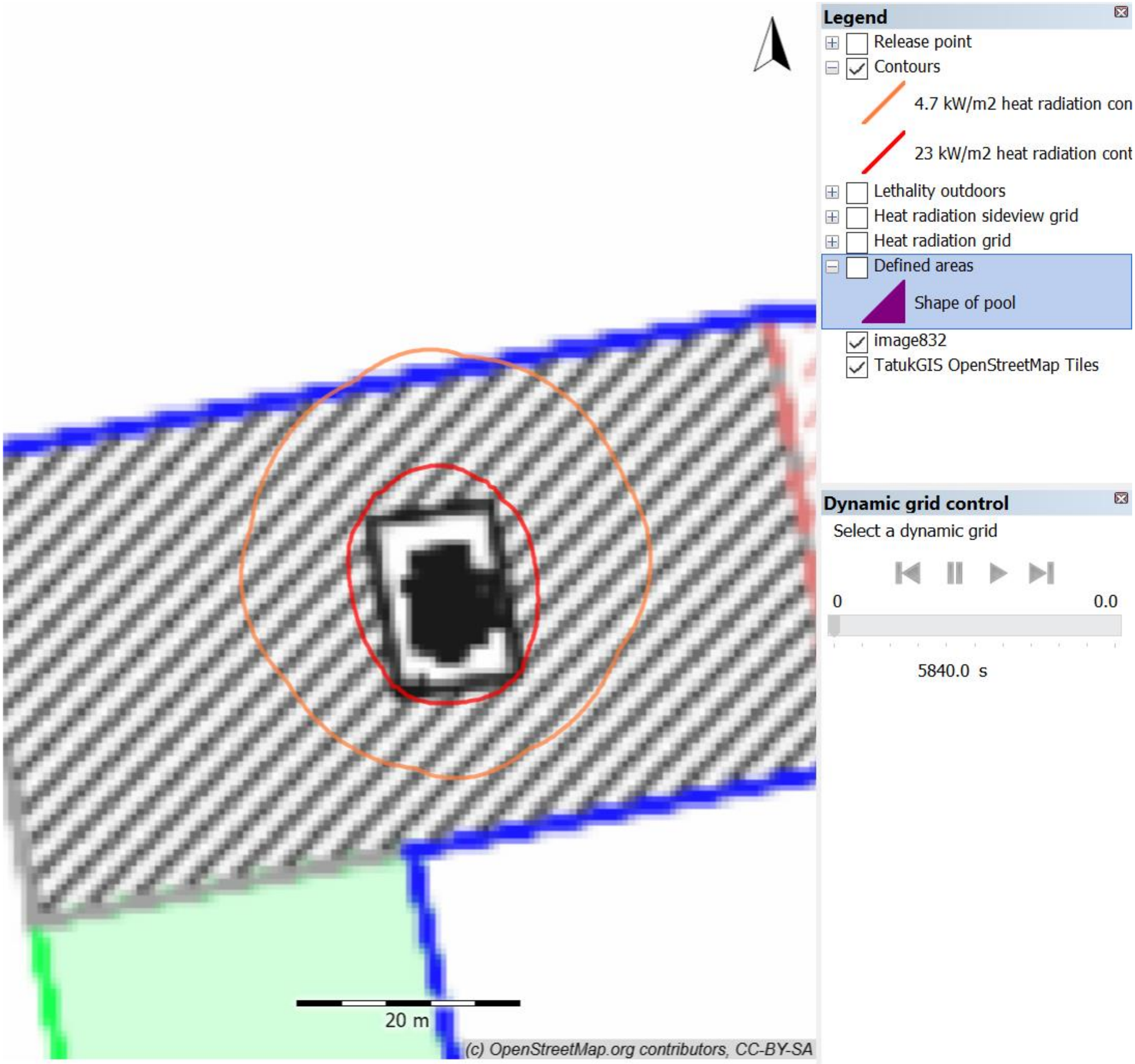

Figure 5-1: Transformer Bund Fire Radiant Heat Contours

6.0 Frequency Analysis and Risk Assessment

6.1 Incidents Carried Forward for Frequency Analysis

The following incidents have been carried forward for frequency analysis and risk assessment:

- Transformer internal arcing, oil spill, ignition and bund fire.

Each of these incidents have been assessed in the following sections.

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

There are two components to determining the fatality risk from a transformer scenario. The first is the probability of failure of the unit, and the second is the probability of such a failure resulting in a fatality. A detailed report titled "Assessment of Power Transformer Reliability" (Ref. [9]) was prepared in 2011 in a collaboration by several German universities and electrical institutions. In this report, failure rate analysis of both power transformers and generator step-up transformers as a function of voltage class is conducted. The results of the generator step-up transformers failure rate analysis are outlined in **Table 6-1** as these values are most applicable to the Muswellbrook site, in addition to being more conservative than the failure rates of power transformers. The most conservative value of 1.61% has been selected for this analysis

Table 6-1: Generator Step-Up Transformer Failure Rate Data

Voltage Level	110 kV	220 kV	380 kV
Number of failures	2	4	12
Transformer years	726	1355	744
Failure Rate	**0.28%**	**0.30%**	**1.61%**

The same report provides information regarding the external effects of the 112 failures analysed within the report as shown in **Figure 6-1**. For the purpose of this analysis, it is assumed that only fire or explosion/burst incidents will contribute to the potential for a fatality. The probability of either of these external effects occurring is the sum of fire probability (6.3%) and explosion or burst probability (2.7%) for a total of 9%.

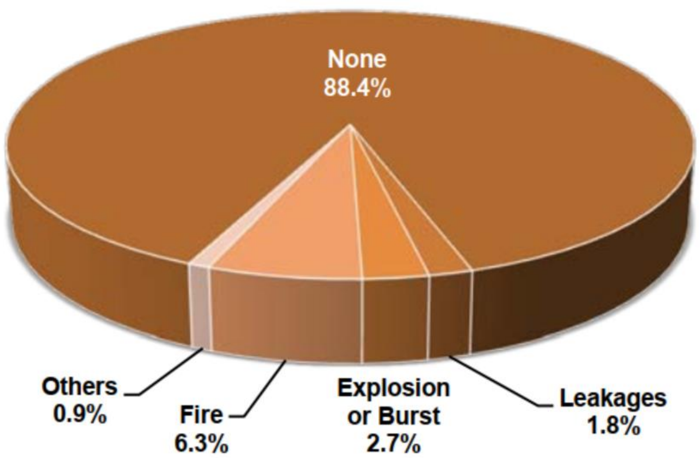

Figure 6-1: External effects of transformer failures

A transformer incident will only impact the closest site boundary if a northerly wind is blowing; hence, this has been used to identify the frequency with which northerly conditions occur based upon the average wind rose at 9 AM and 3 PM with data taken from the Scone Airport as provided in **Appendix D**. Northerly wind conditions occur approximately 8.5% of the time at 9 AM and 5.0% for 3 PM. Taking the average results in a northerly wind probability of 6.75%.

It is also assumed that personnel will be in a position to be affected by such an incident for approximately 1 hour per week, or 0.6% probability.

Multiplying through the modifiers results in an overall fatality potential at the site boundary of 0.0161 x 0.09 x 0.0675 x 0.006 = 5.9×10^{-7} p.a.

6.3 Total Fatality Risk

The fatality risk at the site boundary has been tabulated in **Table 6-2**.

Table 6-2: Total Fatality Risk

Incident	Fatality Risk (p.a.)
Transformer Incident	5.9×10^{-7}
Total	**5.9×10^{-7}**

6.4 Comparison Against Risk Criteria

6.4.1 Fatality Risk

The acceptable criteria have been taken from the NSW Department of Planning, Industry and Environment *Hazardous Industry Planning Advisory Paper No. 4 – Risk Criteria for Land Use Safety Planning* (Ref. [2]). The acceptable risk criteria published in the guideline relates to injury, fatality and property damage. The values in the guideline present the maximum levels of risk that are permissible at the land use under assessment as defined in **Table 6-3**.

Table 6-3: Individual Fatality Risk Criteria

Land Use	Suggested Criteria (risk in 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

The private property surrounding the site and BESS units is not neatly described by the criteria shown in **Table 6-3**; however, the most applicable based upon the description would be active open spaces with a criterion of 10 pmpy.

The fatality risk estimated at the site boundary was calculated to be 0.59 pmpy which is below the criteria of 10 pmpy. Therefore, from a fatality risk perspective the development does not result in an exceedance of the criteria and would be considered acceptable for the proposed location.

6.4.2 Injury / Irritation

HIPAP No. 4 outlines that concentrations that would result in injury or irritation should not exceed 10 pmpy and 50 pmpy respectively. The impacts from a transformer fire do not impact sensitive areas and the fatality risk at the site boundary is below acceptable criteria therefore the risk of injury or irritation would also be below acceptable criteria.

6.5 Incident Propagation

The same guidelines provide acceptable risk criteria (Ref. [2]) for incident propagation as 50 chances pmpy. A review of the scenarios that may lead to incident propagation shows that the 23 kW/m^2 contour was not observed to impact offsite; hence, the potential for incident propagation is zero (0) which is less than the acceptable risk criteria for incident propagation.

7.0 Conclusion and Recommendations

7.1 Conclusions

A hazard identification table was developed for the Muswellbrook BESS 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 the potential for offsite impacts. Postulated scenarios were discussed qualitatively and any scenarios that would not impact offsite were eliminated from further assessment. Scenarios not eliminated were then carried forward for consequence analysis.

Incidents carried forward for consequence analysis were assessed 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.

Where an offsite impact was identified, a frequency analysis and risk assessment were conducted to identify the potential for fatality, injury and irritation to occur as a result of the development. The results indicated that the fatality risks would not exceed the acceptable criteria. Similarly, the injury and irritation criteria were not exceeded. Finally, the potential for incident propagation as assessed at the 23 kW/m^2 contour which didn't show any potential for off-site impact and similarly the 14 kPa contours didn't impact any areas of interest thus incident propagation would not be considered to occur.

Based on the analysis conducted, it is concluded that the risks at the site boundary are not considered to exceed the acceptable risk criteria; hence, the project would only be classified as potentially hazardous and would be permitted within the current land zoning for the site.

7.2 Recommendations

Notwithstanding the conclusions drawn, the following recommendations have been made:

- The transformers spill containment shall be designed according to the requirements of AS 2067:2016 – "Substations and *high voltage installations exceeding 1 kV a.c'*
- A Final Hazard Analysis (FHA) shall be prepared based upon the finalised layout of the site to demonstrate that the risk criteria remains below the acceptable levels.

8.0 References

[1] Department of Planning, Industry and Environment, “Hazardous Industry Planning Advisory Paper No. 6 - Guidelines for Hazard Analysis,” Department of Planning, Industry and Environment, Sydney, 2011.

[2] Department of Planning, Industry and Environment, “Hazardous Industry Planning Advisory Paper No. 4 - Risk Criteria for Land Use Safety Planning,” Department of Planning, Industry and Environment, Sydney, 2011.

[3] SafeWork NSW, “Work Health and Safety Regulation,” SafeWork NSW, Lisarow, 2017.

[4] Department of Planning, Industry and Environment, Multi-Level Risk Assessment, Sydney: Department of Planning, Industry and Environment, 2011.

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

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

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

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

[9] S. Tenbohlen, F. Vahidi, J. Gebauer, M. Krüger and P. Müller, “Assessment of power transformer reliability,” *Power,* vol. 73, no. 581, p. 478, 2011.

[10] Standards Australia, “AS/NZS 3000:2007 - Wiring Rules,” Standards Australia, Sydney, 2007.

Appendix A

Hazard Identification Table

Appendix A

A1. Hazard Identification Table

Area/Operation	Hazard Cause	Hazard Consequence	Safeguards
Battery Storage	• 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 • Overcharging and electrical circuit protection • Battery monitoring systems • Batteries composed of subcomponents (i.e. BBU, cells) reducing risk of substantial component failure • Batteries are not located in areas where damage could easily occur (i.e. within the fenced property) • Electrical systems designed per AS/NZS 3000:2007 (Ref. [10])
Switch rooms, communications, ring main units, 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
Substation	• Arcing within transformer, vaporisation of oil and rupture of oil reservoir	• Transformer oil spill into bund and bund fire	• Bunded • Isolated location
EMF	• Electric and magnetic equipment	• Generation of ELF EMF and injury / nuisance to surrounding area	• Large separation distances allow for attenuation of EMFs • Cumulative impacts from equipment below acceptable thresholds. • Low occupancy density within vicinity of the development

Appendix B

Consequence Analysis

Appendix B

B1. Incidents Assessed in Detailed Consequence Analysis

The following incidents are assessed for consequence impacts.

- Transformer internal arcing, oil spill, ignition and bund fire.

Each incident has been assessed in the sections below.

B2. Gexcon - Effects

The modelling was prepared using Effects 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.

B3. 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. [2]).

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)
2.1	• Minimum to cause pain after 1 minute

B4. 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.

It has been assumed that the transformer has bund dimensions of approximately 10 m x 15 m; hence, 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.

Transformer oil is typically a combustible liquid of some formulation which have high flash points. For the purposes of providing a conservative analysis, fuel/bunker oil sample has been selected.

The above information was input into Effects which calculated the following outputs:

- SEP – 67 kW/m^2
- Flame height – 13.0 m

The results of the analysis are shown in **Appendix Table B-2.**

Appendix Table B-2: Heat Radiation Impacts from a Transformer Bund Fire

Heat Radiation (KW/m^2)	Distance (m)
35	6
23	8
12.6	11
4.7	18