



## Preliminary Hazard Analysis

Awaba BESS, Toronto NSW

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Firm Power Pty Ltd

Prepared by

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## Quality Management

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3	14 <sup>th</sup> March 2023	Minor revisions		

## Executive Summary

### Background

Firm Power Pty Ltd (Firm Power) has proposed to develop a Battery Energy Storage System (BESS). The project will comprise of a BESS with a delivery capacity of 50 MW and useable capacity of 100 MWh, along with associated infrastructure (i.e., substation, transformers, etc.).

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).

### Conclusions

A hazard identification table was developed for the Firm Power Awaba 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.

A review of the incidents carried forward for further analysis indicates that there were no observed offsite impacts; therefore, 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 BESS must be tested in accordance with UL9540A.
- Testing to demonstrate clearances required to prevent propagation of fires between separated units.
- BESS to be installed in accordance with manufacturer and UL9540A report recommended clearances based on testing.
- BESS to be installed with fire protection systems specified by the manufacturer and UL9540A report.
- Before construction, detailed design to validate the system can be installed in the project area whilst meeting the recommended clearances.
- UL testing information shall be made available to the certifying authority. It is noted that a confidentiality agreement may be required.

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## 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
LFP	LiFePO <sub>4</sub> (Lithium Iron Phosphate)
MVPS	Medium Voltage Power Station
PHA	Preliminary Hazard Analysis
Pmpy	Per million per year
PV	Photovoltaic
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 Pty Ltd (Firm Power) has proposed to develop a Battery Energy Storage System (BESS). The project will comprise of a BESS with a delivery capacity of 50 MW and useable capacity of 100 MWh, along with associated infrastructure (i.e., substation, transformers, etc.).

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 Awaba BESS project located at 12 Toronto St, Toronto NSW.

## 2.0 Methodology

### 2.1 Multi-Level Risk Assessment

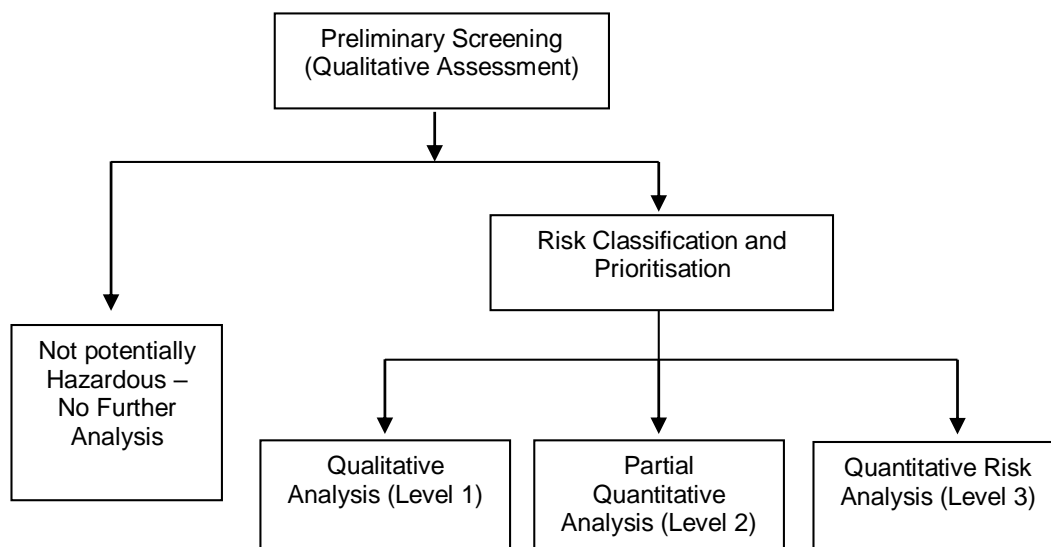
The Multi-Level Risk Assessment approach (Ref. [4]) published by the NSW Department of Planning, Industry and Environment, has been used as the basis for the study to determine the level of risk assessment required. The approach considered the development in context of its location, the quantity and 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.

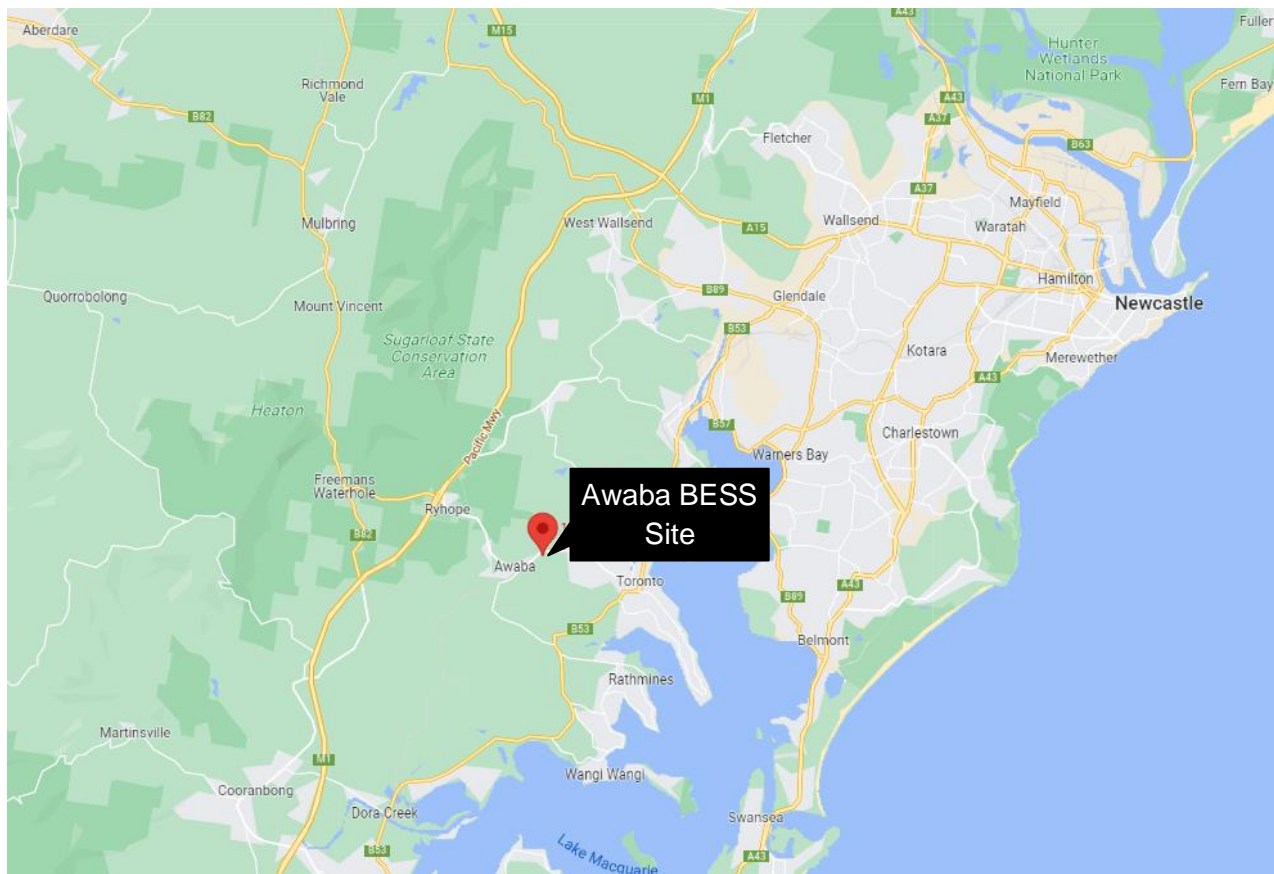
**Risk Assessment and Reduction** – Where incidents were identified to impact offsite and where a consequence and frequency analysis was conducted, the consequence and frequency analysis for each incident were combined to determine the risk and then compared to the risk criteria published in HIPAP No. 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 12 Toronto St, Toronto NSW, which is approximately 20 km southwest of Newcastle. **Figure 3-1** shows the regional location of the site in relation to Newcastle. A site layout has been provided in **Figure 3-3**.



**Figure 3-1: Site Location**

#### 3.2 Adjacent Land Uses

The land surrounding the site is zoned SP2, and includes the Ausgrid Awaba substation and associated 132 kV and 33 kV transmission lines (adjoining the site to the southwest), Awaba Road and the Main Northern Railway Line (15 m and 90 m north, respectively) and the Newstan-Eraring Private Coal Road (150 m south).

There are four residential receivers within 500 m of the site, located about 70 m and 470 m west, 375 m east, and 480 m southeast of the site boundary.

Other existing major nearby uses a crane rental agency approximately 400 m to the east at the western edge of the Toronto industrial area and rural residential lots approximately 300 m to the west at the north- eastern end of Awaba.

All other surrounding land is a mixture of densely vegetated or cleared, undeveloped land, comprising the following land use zones, including:

- RU2 Rural Landscape zone to the northwest and southeast

- IN2 Light Industrial zoning to the east
- C2 Environmental Conservation to the north and south
- RE1 Public Recreation zone to the northeast.

### 3.3 Sensitive Receivers

The nearest sensitive receptors are shown in **Figure 3-4**, including nearby residential locations.

### 3.4 Detailed Description

The purpose of the project is to provide dispatchable energy to the NSW grid and contribute towards the goals of the NSW government's NSW Electricity Infrastructure Roadmap.

The Awaba 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 switchgear, protection and control equipment, metering, reactive power equipment, filtering equipment, auxiliary/earthing transformers and enclosures/buildings for housing equipment;
- Underground or overhead 33kV sub-transmission lines to connect the BESS to the Awaba 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.

#### 3.4.1 Battery Storage

The proposed BESS will be located within containerised units distributed around the site. 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 and grid stability. A typical BESS is shown in **Figure 3-2** and layout for the BESS are contained in the layout shown in **Figure 3-3**.



**Figure 3-2: Typical BESS**

### 3.5 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	Comments
BESS Battery Enclosures	9	Lithium Batteries (LFP Chemistry)	1,050 tonnes	32 x 32 tonnes per battery enclosure
BESS Step Up Transformers	C2	Transformer oils	60,000 L*	15 x 4,000 L per transformer

\*Approximately 4,000 L per transformer.

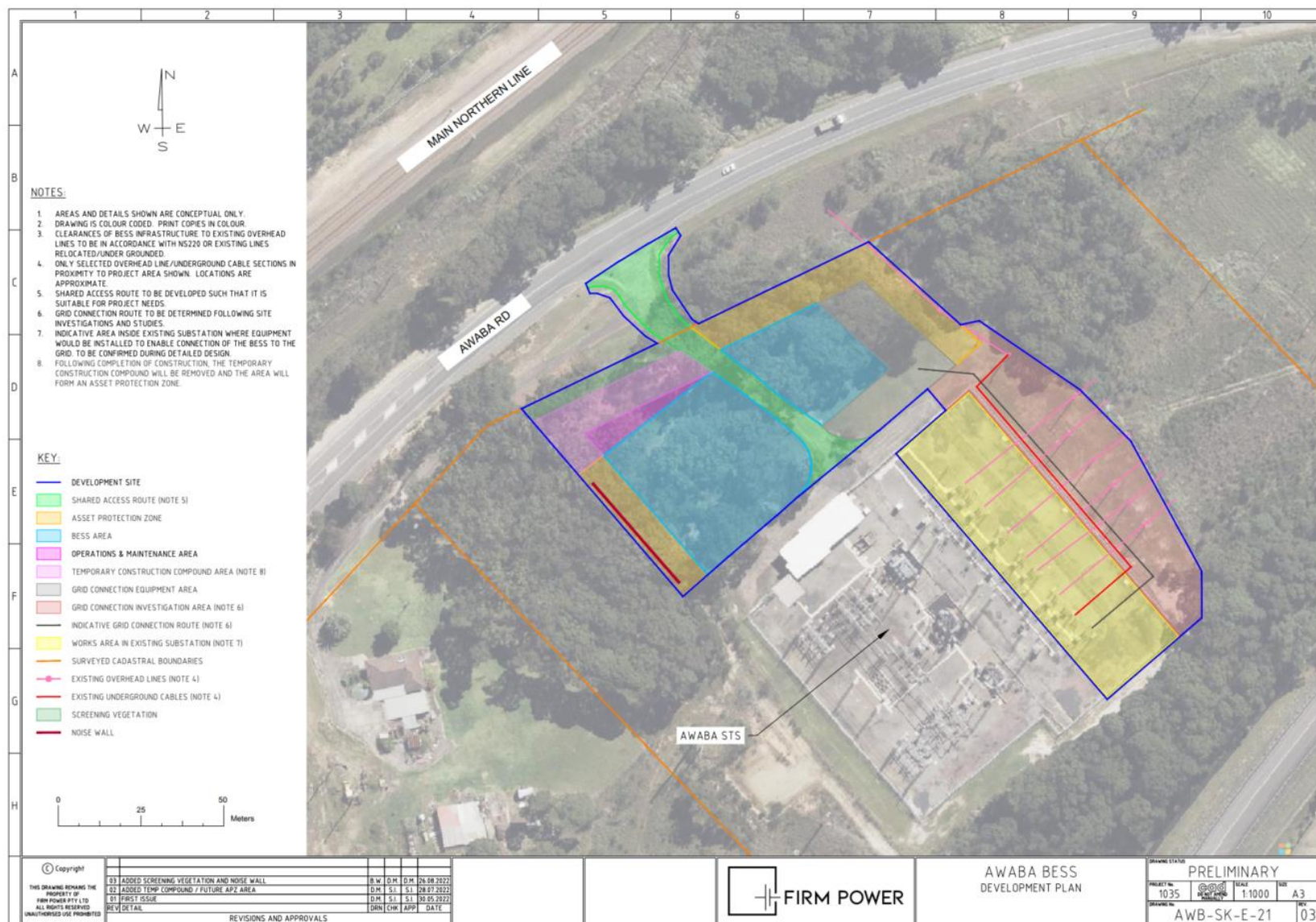
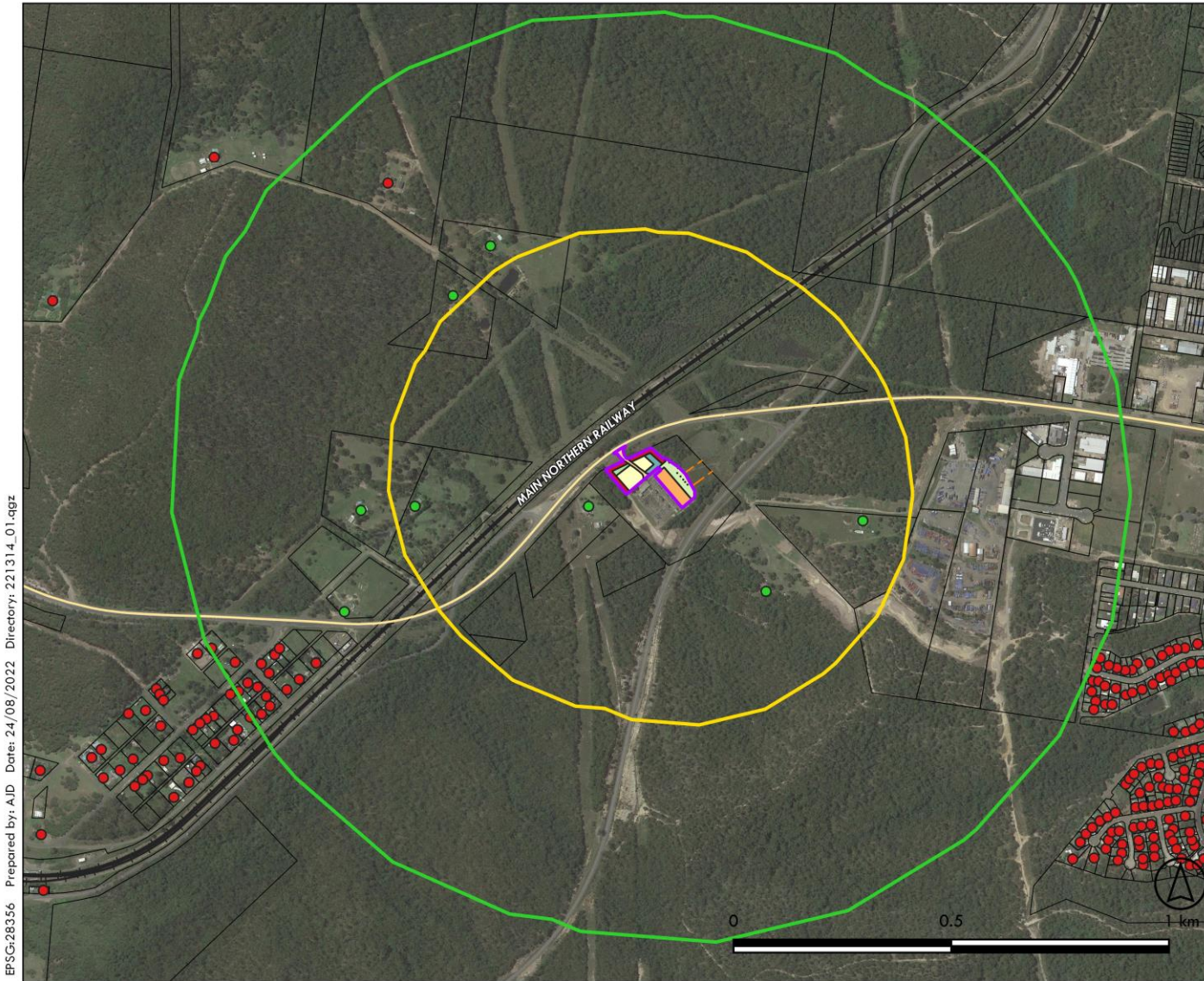


Figure 3-3: Site Layout



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**FIRM POWER**  
**Awaba Battery Energy Storage System**

**LEGEND**

- Cadastral boundaries
  - Project area
  - Railway
  - Road
  - 500m buffer
  - 1000m buffer
- Residential Receivers**
- Receivers Engaged
  - Receivers Not Engaged
- Site layout**
- Exclusion Area
  - Ausgrid 33kV Line
  - Ausgrid Works Area
  - BESS Access Shared
  - BESS Area
  - Grid Connection
  - Investigation Area
  - O&M Area
  - Substation Area

Source: © State Government of NSW, Department of Customer Service, Spatial Services 2021  
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**Figure 3-4: Sensitive Receivers**

## 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 ( $4.7 \text{ kW/m}^2$ ) 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 than  $4.7 \text{ kW/m}^2$ , at the site boundary, are screened from further assessment.

Those incidents exceeding  $4.7 \text{ kW/m}^2$  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  $4.7 \text{ kW/m}^2$  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 70 m from the closest BESS, hence, by selecting  $4.7 \text{ kW/m}^2$  as the consequence impact criteria 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 approximately 70 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 ( $23 \text{ kW/m}^2/14 \text{ kPa}$ ) 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  $23 \text{ kW/m}^2$  and explosion over pressure less than 14 kPa, at the site boundary, are screened from further assessment. Those incidents exceeding  $23 \text{ kW/m}^2$

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

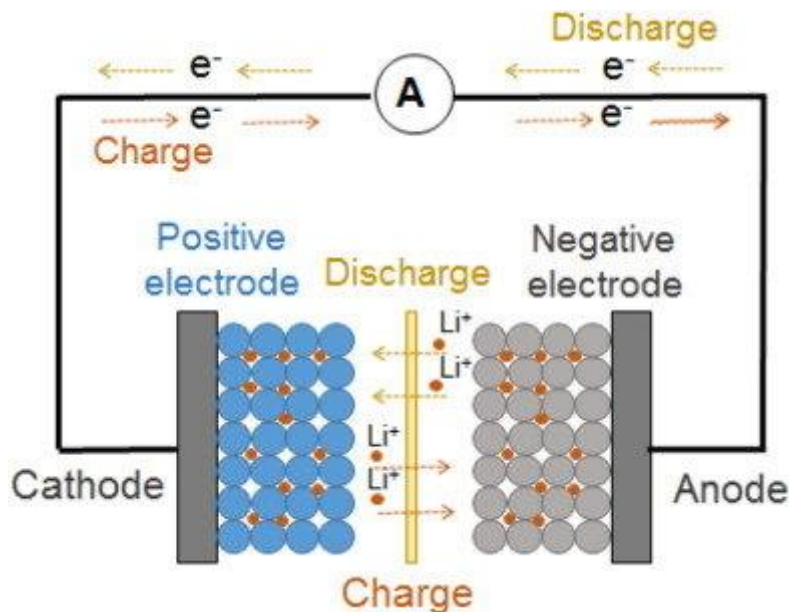
Based on the hazard identification table presented in **Appendix A**, the following hazardous scenarios have been developed:

- Li-ion battery fault, thermal runaway and fire.
- Victoria Big Battery Fire review.
- Li-ion battery fire and toxic gas dispersion.
- Electrical equipment failure and fire.
- Transformer internal arcing, oil spill, ignition and bund fire.
- Transformer electrical surge protection failure and explosion
- 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 by-products being formed within the battery during charge and discharge cycles.

As a result, Li-ion batteries are equipped with several safety features to prevent the batteries from charging or discharging at voltages which result in battery degradation, leading to shorting of the battery and thermal runaway. Safety features 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 in modules which are located within a fenced area; therefore, there is a low potential for damage to occur to the batteries which may initiate an incident.

A review of the batteries proposed to be used as part of this project indicates the battery chemistry is lithium-ion phosphate (LiFePO<sub>4</sub>, 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 °C/min resulting thermal run away and fire which can then propagate to adjacent batteries escalating the incident to a full container fire. For LFP batteries, the thermal rise of the batteries at peak is 1.5°C/min which results in a gradual temperature rise and does not result in fire and thus incident propagation to other batteries. The thermal rise of various battery chemistries is provided in **Figure 4-2** with a zoomed in temperature rise for LFP provided in the top right of **Figure 4-2**. 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.

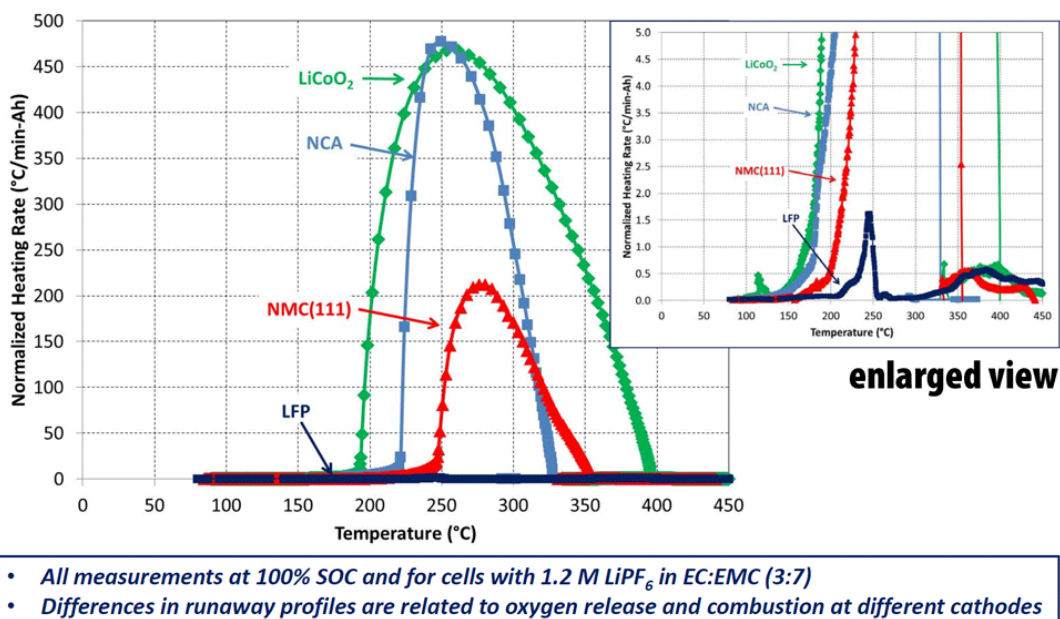
Additional testing for shock and damage to batteries (i.e. nail puncture test) has been shown that LFP batteries when punctured through membranes which typically results in a shorting of the battery and fire does not result in ignition of the battery demonstrating that the battery chemistry is protected against shock damage.

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

In addition to this, manufacturers and integrators can implement different means of preventing battery ignition or controlling if it occurs (such as physical construction arrangements, battery monitoring, heat detection, etc). These are implemented on a system-by-system basis and are specific to the system needs.

## Thermal Runaway: Impact of Cell Chemistry

*Accelerating rate calorimetry (ARC) of 18650 cells with different cathode materials*



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

The battery product that has been assessed for this project is client sensitive and has confidentiality requirements governing the release of information, however a UL9540A report has been completed for this product.

Based on data shown from this UL9540A report and others for similar systems, the results demonstrate that when thermal runaway is triggered in one cell in a BESS container, the heat generated would neither be transferred to all cells within one battery module, nor from the test module to adjacent ones. This is attributed to the nature of LFP technology as well as the sheer mass of the battery module (heavier objects have higher thermal capacity) and the construction arrangements of the enclosures.

Although the LFP technology does not cause fire, there can be circumstances where battery modules catch fire due to leaking coolant or electric faults. In those cases, fire will be constrained by the enclosure. Similar systems show that generally the enclosure wall remains intact after sustaining heating in a furnace to over 900°C.

Furthermore, the proposed battery product has rigorous design and manufacturing processes to maintain quality, battery monitoring systems to assess battery health and disconnect a poor health battery if issues occur and dedicated gas igniters and overpressure vents built into the enclosures if a thermal runaway event was to occur.

Different systems deploy different battery fire mitigation strategies depending on the solution, but any in case the project will implement the manufacturer's recommended fire protection systems.

In addition to a UL9540A Report, the assessed and final selected system will hold relevant UL and IEC certifications (i.e. UL9540, UL1741, UL1973, UN38.3; CE; EMC; NFPA 70; IEEE C37.32; IEC: 62933, 62619, 60204 and ASTM4169).

This documentation collectively demonstrates that thermal runaway on a certified LFP BESS product does not propagate from one module to another when designed and installed in accordance with the manufacturer's requirements and test reports.

In conclusion, the LFP technology does not cause fire during thermal runaway. Should fire be developed within one BESS enclosure it would not transfer to nearby enclosures due to the fire safety design features; hence, this incident has not been carried forward for further analysis.

Notwithstanding, based on conversations with and review by NSW Department of Planning and Environment (DPE), the following recommendations have been made:

- BESS must be tested in accordance with UL9540A.
- Testing to demonstrate clearances required to prevent propagation of fires between separated units.
- BESS to be installed in accordance with manufacturer and UL9540A report recommended clearances based on testing.
- BESS to be installed with fire protection systems specified by the manufacturer and UL9540A report.
- Before construction, detailed design to validate the system can be installed in the project area whilst meeting the recommended clearances.
- UL testing information shall be made available to the certifying authority. It is noted that a confidentiality agreement may be required.

#### 4.5 Victoria Big Battery Fire Review

Notwithstanding the findings of **Section 4.4**, it is necessary to review recent large scale BESS fires to determine whether similar incidents could occur with the Awaba BESS.

The Awaba BESS proposal has considered the separation distance considering fire safety, and operation and maintenance. The fire safety assessment is essentially around heat transfer which has been discussed in detail in **Section 4.4**.

The BESS installation layout has considered fire propagation, the thermal test result of the module thermal runaway and heat flux assessment from the UL9540A report. A conceptual design has been undertaken on a selected system, utilizing specific Design & Installation guidelines and UL9540A reports, and has confirmed that the project can fit within the proposed site boundary.

Additionally, the proposed BESS system will follow a similar arrangement to other comparative including allowing a back-to-back layout, with spacing in accordance with the technical requirements of the system and testing/certificate requirements.

The Victorian Big Battery (VBB) also had a back-to-back layout. According to the independent investigation report on its fire incidence, the back-to-back layout was not the cause. The main reason for fire propagation was strong wind blowing flames from one Megapack into the unprotected vent atop of an adjacent Megapack which resulted in the ignition of the plastic fan which was able to impact the battery modules directly beneath the fan.

Lessons learnt from the VBB incident results in fire safety precautions inform the design of the Awaba BESS system. This involves using appropriate clearances and BESS enclosure designs that prevent a fire propagating like it did in the VBB installation.

Based on improvements in enclosure design based on the learnings of the VBB fire, the available area assessment and the separation distance assessment, it is considered that the propagation between two units is considered unlikely; hence, this incident has not been carried forward for further analysis.

## 4.6 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. 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.

### 4.6.1 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.



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.

### 4.6.2 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**.

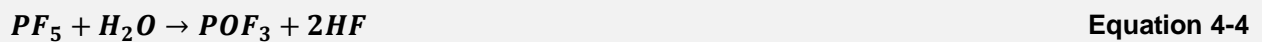


As noted, in **Section 4.6.1** there is the potential for a fire to occur with the BESS units which could form carbon monoxide if there is insufficient oxygen to sustain complete combustion. However, it is noted that the combustible load within the BESS which could result in the formation of carbon monoxide 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.

#### 4.6.3 Fluoride Gases

The electrolyte used in Li-ion batteries typically is lithium hexafluorophosphate (LiPF<sub>6</sub>) 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<sub>5</sub>) and phosphoryl fluoride (POF<sub>3</sub>) (Ref. [7]).

The decomposition of LiPF<sub>6</sub> can be promoted by the presence of water / humidity according to reactions **Equation 4-3** to **Equation 4-5**.



Of the fluorine gases formed, PF<sub>5</sub> is a short-lived gas while POF<sub>3</sub> is a reactive intermediate. Thermal destruction of a several battery chemistry, configurations and State of Charge (SOC) indicated the vast majority of these did not produce observable POF<sub>3</sub> 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 hygroscopic 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.

## 4.7 Electrical Equipment Failure and Fire

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

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

## 4.8 Step Up Transformer Internal Arcing, Oil Spill, Ignition and Bund Fire

Transformers contain oil which is used to cool 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 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. Notwithstanding this, transformers are ubiquitous units with a low potential for failure and the separation distance to the site boundary and other adjacent units would be unlikely to result in incident propagation and offsite impacts. Therefore, this incident has not been carried forward for further analysis.

## 4.9 Step Up Transformer Electrical Surge Protection Failure and Explosion

Transformers generate large amounts of heat as a result of the high electrical currents that pass through them; hence, oil is used as an insulating material within the transformers to protect the mechanical components. However, if the transformer gets an extreme surge of energy, such as that which could occur due to a lightning strike, and the electrical surge protection measures fail, the mineral oil may start to decompose and vapourise, resulting in gas bubbles of hydrogen and methane (Ref. [8]) 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 4.8**.

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, this can have a slight delay which is too slow to stop an electrical overload, such as in the case of a major lightning strike

or significant oil deterioration, leakage of water into the transformer, and physical damage such as a fallen tree (Ref. [9]). Therefore, there is the potential for an explosion to occur which may result in offsite impacts; however, as noted, these units are ubiquitous and have a low potential for failure. Therefore, this incident has not been carried forward for further analysis.

## 4.10 Electromagnetic Field Impacts

### 4.10.1 Introduction

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

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

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

### 4.10.2 Existing Standards

There are currently no existing standards in Australia for governing the exposure limits to ELF EMFs; however, the International Commission on Non-Ionizing Radiation Protection (ICNIRP) has provided some guidelines around exposure limits for prolonged exposure which limits the exposure to 2,000 milligauss (mG) for members of the public in a 24 hour period (Ref. [10]).

**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

#### 4.10.3 Exposure Discussion

A review of the site indicates there are no immediate residences adjacent to the area where the 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 residence is approximately 150 m away from the EMF generating sources at the BESS; 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 Conclusion and Recommendations

### 5.1 Conclusions

A hazard identification table was developed for the Firm Power Awaba 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.

A review of the incidents carried forward for further analysis indicates that there were no observed offsite impacts; therefore, 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.

### 5.2 Recommendations

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

- The BESS must be tested in accordance with UL9540A.
- Testing to demonstrate clearances required to prevent propagation of fires between separated units.
- BESS to be installed in accordance with manufacturer and UL9540A report recommended clearances based on testing.
- BESS to be installed with fire protection systems specified by the manufacturer and UL9540A report.
- Before construction, detailed design to validate the system can be installed in the project area whilst meeting the recommended clearances.
- UL testing information shall be made available to the certifying authority. It is noted that a confidentiality agreement may be required.

## 6.0 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.
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- [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] J. Demos, "What Causes Transformer Explosions and Burns?," Durabarrier USA Fire Barrier Experts, 26 July 2021. [Online]. Available: <https://firebarrierexperts.com/what-causes-transformer-explosions-and-burns/#:~:text=The%20most%20common%20reason%20why,accidents%20caused%20by%20lightning%20strikes.&text=The%20first%20is%20an%20overload,flash%20point%20or%20fire%20point..> [Accessed 2 February 2022].
- [9] P. Hoole, S. Rufus, N. Hashim, M. Saad, S. Abdullah, A. Othman, K. Piralaharan, A. CV and S. Hoole, "Power Transformer Fire and Explosion: Causes and Control," *International Journal of Control Theory and Applications*, vol. 10, no. 16, pp. 211-219, 2017.
- [10] 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.
- [11] 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	<ul style="list-style-type: none"> <li>Failure of Li-ion battery protection systems</li> </ul>	<ul style="list-style-type: none"> <li>Thermal runaway resulting in fire or explosion</li> <li>Incident propagation through battery cells</li> <li>Toxic smoke dispersion</li> </ul>	<ul style="list-style-type: none"> <li>Batteries are tested by manufacturer prior to sale / installation</li> <li>Overcharging and electrical circuit protection</li> <li>Battery monitoring systems</li> <li>Batteries composed of subcomponents (i.e. BBU, cells) reducing risk of substantial component failure</li> <li>Batteries are not located in areas where damage could easily occur (i.e. within the fenced property)</li> <li>Electrical systems designed per AS/NZS 3000:2007 (Ref. [11])</li> </ul>
Switch rooms, communications, etc.	<ul style="list-style-type: none"> <li>Arcing, overheating, sparking, etc. of electrical systems</li> </ul>	<ul style="list-style-type: none"> <li>Ignition of processors and other combustible material within servers and subsequent fire</li> </ul>	<ul style="list-style-type: none"> <li>Fires tend to smoulder rather than burn</li> <li>Isolated location</li> <li>Switch room separation from other sources of fire</li> </ul>
Step Up Transformers	<ul style="list-style-type: none"> <li>Arcing within transformer, vaporisation of oil and rupture of oil reservoir</li> </ul>	<ul style="list-style-type: none"> <li>Transformer oil spill into bund and bund fire</li> </ul>	<ul style="list-style-type: none"> <li>Bunded</li> <li>Isolated location</li> </ul>
	<ul style="list-style-type: none"> <li>Power surge to transformers (e.g. from lightning)</li> </ul>	<ul style="list-style-type: none"> <li>Major failure of surge protection in transformer, vapourisation of mineral oil, ignition and explosion</li> </ul>	<ul style="list-style-type: none"> <li>Transformers have surge protection system to shut down upon detection of extreme energy input</li> <li>Lightning protection to prevent lightning strikes impacting transformers</li> <li>Control of ignition sources – no smoking / open flames around the transformers</li> </ul>
EMF	<ul style="list-style-type: none"> <li>Electric and magnetic equipment</li> </ul>	<ul style="list-style-type: none"> <li>Generation of ELF EMF and injury / nuisance to surrounding area</li> </ul>	<ul style="list-style-type: none"> <li>Large separation distances allow for attenuation of EMFs</li> <li>Cumulative impacts from equipment below acceptable thresholds.</li> <li>Low occupancy density within vicinity of the development</li> </ul>