Preliminary Hazard Analysis

GinGin BESS

Iberdola Australia Development Pty Limited
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Iberdola Australia Development Pty Limited

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Quality Management

Rev	Date	Remarks	Prepared By	Reviewed By
A	30 January 2024	Draft issued for comment	Zachary Cohn	Renton Parker
0	22 May 2024	Revised site plan and project description, final issued		
1	25 November 2024	Updated BESS layout and transmission line information		

Executive Summary

Background

Iberdola Australia Development Pty Limited (Iberdola) has proposed to develop a Battery Energy Storage System (BESS) in Gin Gin, QLD. As part of the planning approval, it is necessary to prepare a Preliminary Hazard Analysis for each site to assess the potential impacts from incidents at the BESS on the surrounding land uses and potential impacts of bushfire on the BESS. Riskcon Engineering Pty Ltd (Riskcon) has been engaged to assist with preparing the PHAs for the SSDA submission.

Conclusions

A hazard identification table was developed for project site of the GinGin 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 were the ignition of transformer oil resulting in a fire or explosion. An explosion scenario has potential to impact across the site boundary, hence it was carried forward for frequency analysis. The fatality risk estimated for the immediate vicinity was calculated to be 0.89 pmpy which is below the criteria of 50 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. In addition, the 14 kPa contours were not shown to impact any areas which may result in incident propagation; hence, the potential for incident propagation is zero (0) which is less than the acceptable risk criteria for incident propagation.

An assessment of each of the Performance Outcomes (PO) under the State Code 21 was completed to demonstrate that the development complies with the POs and also the policy intent of the document. Based upon the review, it is considered that the facility complies with the policy intent and the PO of State Code 21. Hence, based on the analysis presented in this report, the project would only be classified as potentially hazardous and would be permitted within the current land zoning for the site.

Recommendations

The following recommendations have been made as a result of the analysis:

- 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.
- The vent covers of the BESS shall be constructed of non-combustible material.
- The vents shall not be located above battery packs within the BESS container.

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Abbreviations

Abbreviation	Description
AC	Alternating Current
ADG	Australian Dangerous Goods Code
AS	Australian Standard
BESS	Battery Energy Storage System
DC	Direct Current
DGs	Dangerous Goods
EIS	Environmental Impact Statement
ELF	Extra Low Frequency
EMF	Electric and Magnetic Field
ERPG	Emergency Response Planning Guideline
FCAS	Frequency Control Ancillary Services
FHA	Final Hazard Analysis
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	LiFePO4 (Lithium Iron Phosphate)
MVPS	Medium Voltage Power Station
NMC	Nickel-Manganese-Cobalt
PHA	Preliminary Hazard Analysis
Pmpy	Per million per year
PO	Performance Outcome
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
VBB	Victorian Big Battery

1.0 Introduction

1.1 Background

Iberdola Australia Development Pty Limited (Iberdola) has proposed to develop a Battery Energy Storage System (BESS) in Gin Gin, QLD. As part of the planning approval, it is necessary to prepare a Preliminary Hazard Analysis for each site to assess the potential impacts from incidents at the BESS on the surrounding land uses and potential impacts of bushfire on the BESS. Riskcon Engineering Pty Ltd (Riskcon) has been engaged to assist with preparing the PHAs for the SSDA submission.

1.2 Objectives

The key objectives of this PHA are to:

- Complete the PHA according to the State Code 21 (Ref. [1]) which has been supported by the NSW documents Hazardous Industry Planning Advisory Paper (HIPAP) No. 6 – Hazard Analysis (Ref. [1]). HIPAP 6.
- Assess the PHA results using the criteria in State Code 21 (Ref. [1]). Demonstrate compliance of the site with the relevant codes, standards and regulations (i.e. Planning and Environment Regulation, WHS Regulation, 2011 Ref. [4]).

1.3 Scope of Services

The scope of work is to complete a PHA study for the GinGin BESS project site located approximately 15 km northwest of GinGin in the Bundaberg Regional Council of Queensland.

2.0 Methodology

2.1 Multi-Level Risk Assessment

In the absence of a comprehensive risk assessment methodology prescribed by QLD Department of State Development, Infrastructure, Local Government and Planning, the Multi-Level Risk Assessment approach (Ref. [5]) published by the NSW Department of Planning, Housing and Infrastructure, 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 (DGs) 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**.

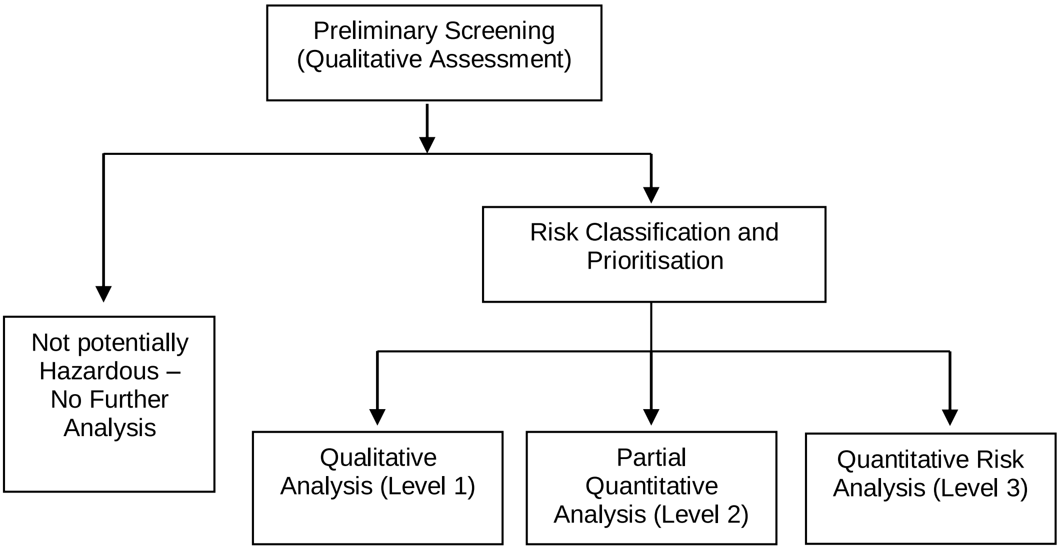

Figure 2-1: The Multi-Level Risk Assessment Approach

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.

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 State Code 21 (Ref. [1]). 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 State Code 21 (Ref. [1]). 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. A final report was then developed, incorporating the comments received for submission to the regulatory authority.

3.0 Site Description

3.1 Site Location

The site is located off Bruce Highway and Monduran Dam Road approximately 15 km north-west of GinGin in the Bundaberg Regional Council in Queensland. The closest sensitive receptor in the surrounding area is approximately 750 m away from the site.

Figure 3-1 shows the regional location of the site. An indicative site plan is presented in **Figure 3-2** and the site map showing transmission lines in **Figure 3-3**.

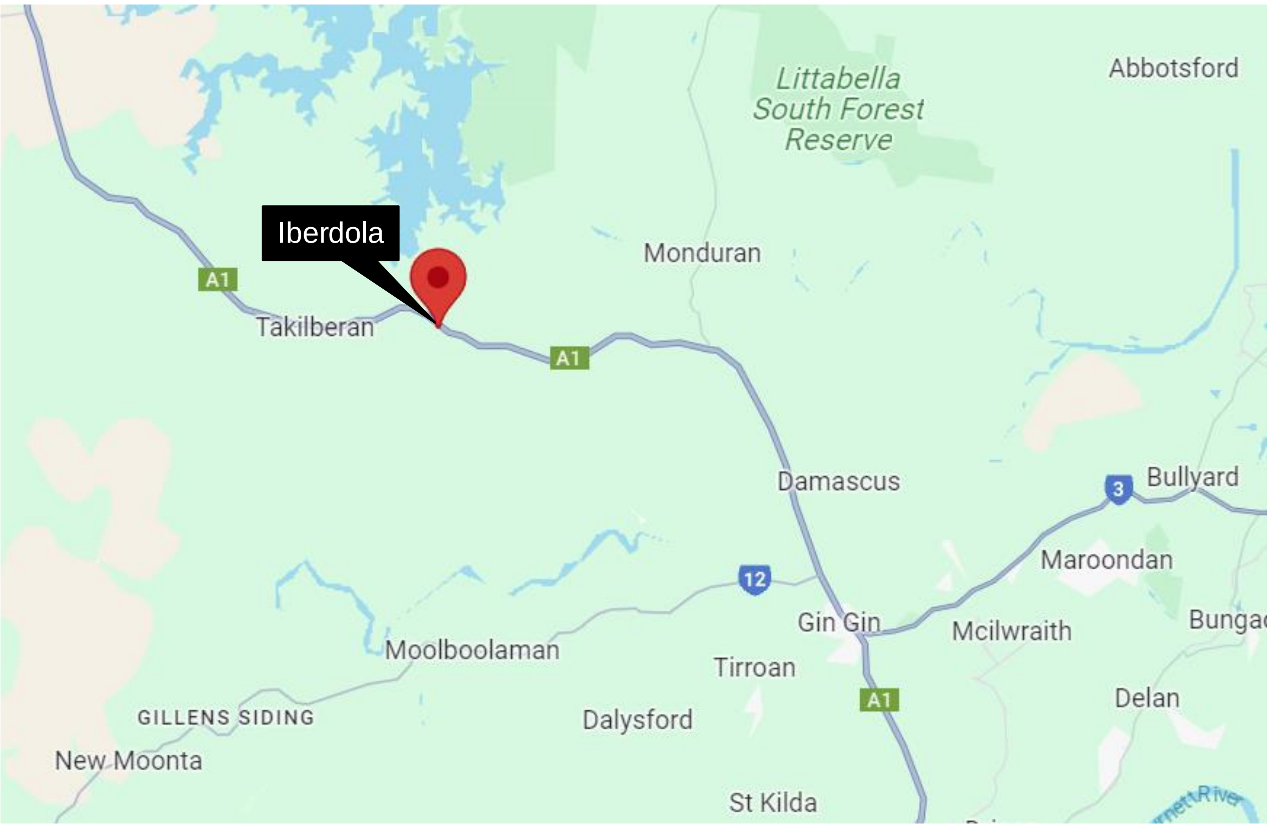

Figure 3-1: Site Location

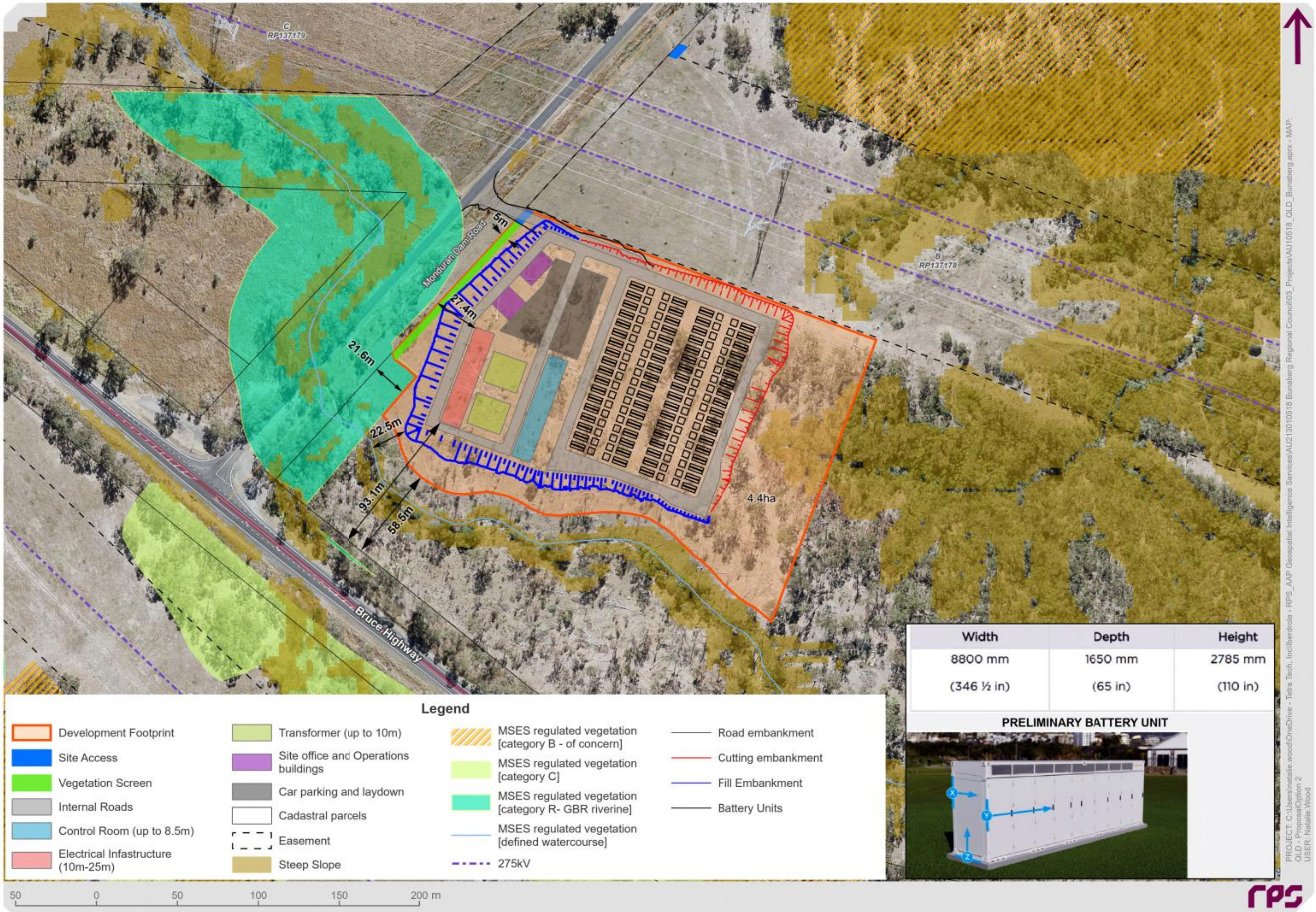

Figure 3-2: Conceptual Project Layout

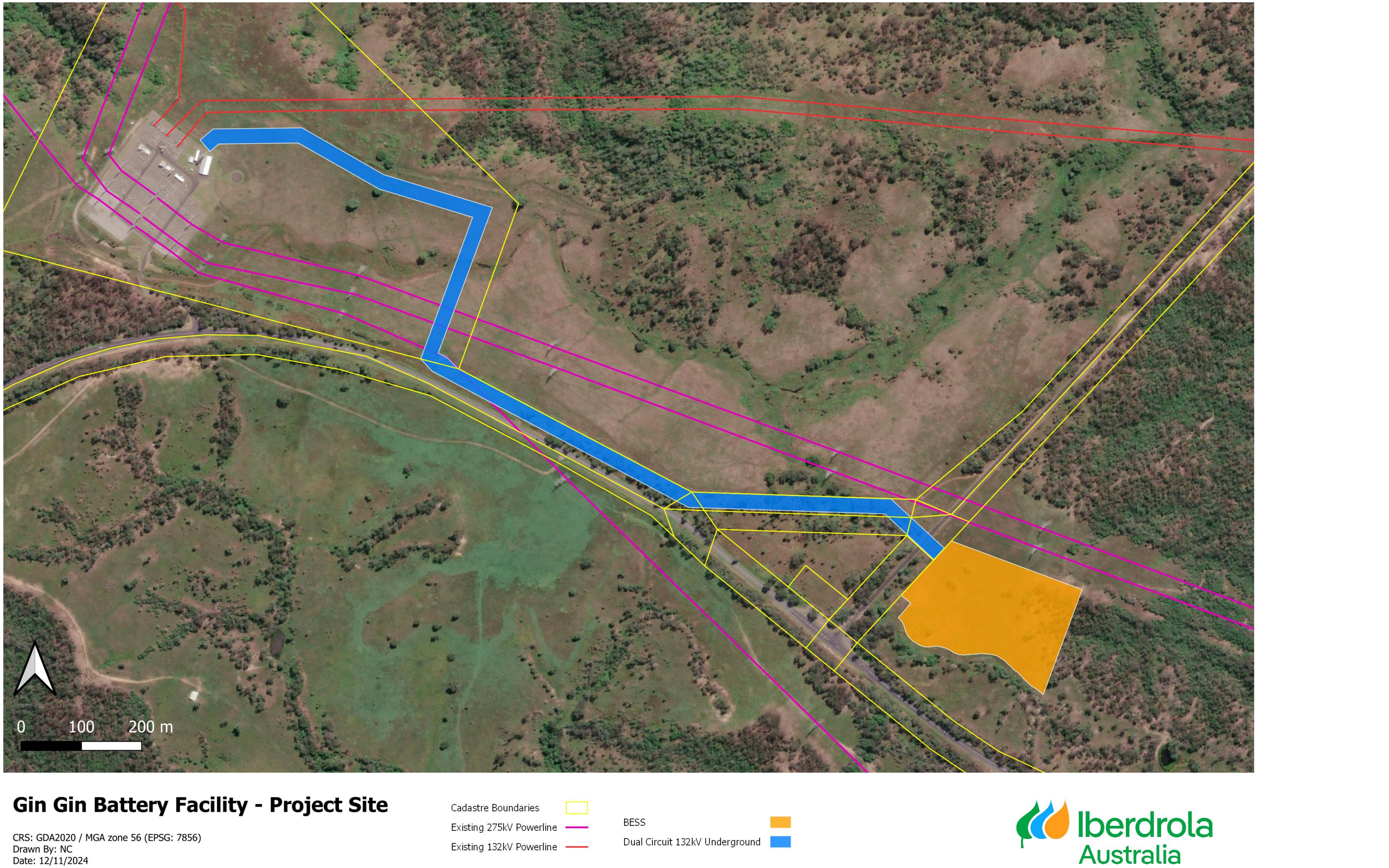

Figure 3-3: Site Map

3.2 General Description

The project will involve the construction of a Battery Energy Storage System (BESS) up to 500 MW and associated infrastructure as part of the BESS. The BESS will consist of battery modules, electrical transformers and inverters, electrical cabling, telecommunications equipment, an electrical control room, a high voltage switch room, an operations and maintenance warehouse, site substation, security lighting, perimeter chainmesh security fencing and site access gates. The generated electricity will be regulated on site by a substation. The BESS will be monitored remotely with no permanent on-site presence. Visitation will be limited to maintenance periods.

Selection of the BESS technology and OEM (Original Equipment Manufacturer) supplier has not yet been finalised. The current proposal is for the BESS to be composed of 192 lithium iron phosphate units (2.8 MW / 5.7 MWh) supplied by Energy Vault each weighing approximately 50 t, alongside 110 MV (medium voltage) transformers (MVPS 4200-S2). The BESSa will be connected to the grid via dual circuit underground 132 kV transmission lines. The cables will be in two side by side trenches in the transmission line corridor as shown in **Figure 3-3**. Hazards associated with these lines are discussed in **Section 4.10** regarding electromagnetic field impacts.

3.3 Quantities of Dangerous Goods & SEPP-RH Screening

The classes and quantities of DGs are provided in **Table 3-1** based on Energy Vault as the OEM for conservatism given the increased total battery module mass relative to the Tesla Megapack arrangement.

Table 3-1: Maximum Quantities of Dangerous Goods Stored

Area	Class	Description	Quantity
BESS	9	Lithium Batteries	9,600 t
Transformer oil	C2	Combustible liquid	440 kL

*Estimated at approximately 4,000 L per transformer from a previous BESS project.

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 State Code 21 (Ref. [1]) 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 State Code 21 (Ref. [1]) 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).

- *Explosion* - It is noted in State Code 21 (Ref. [1]) 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).

- *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 State Code 21 (Ref. [1]) 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 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* – State Code 21 (Ref. [1])discusses the application of societal risk to populations surrounding the Project. It is noted that State Code 21 (Ref. [1])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. [6]

4.3 Hazard Identification

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

- Li-ion battery fault, thermal runaway and fire.
- Victorian 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**.

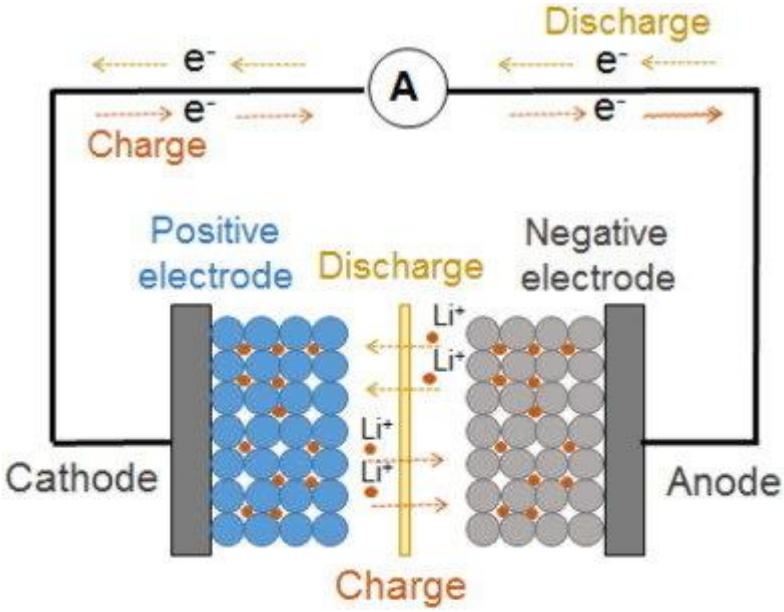

Figure 4-1: Cathode and Anode of a Battery (Source Research Gate)

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 of 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 biproducts 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 very low with the only exceptions being 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 anticipated to be 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 avoiding 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 oxides 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 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. Finally, the containers are fitted with fire suppression systems which will activate to suppress and control a fire preventing escalation to other battery units.

NMC batteries (nickel-manganese-cobalt) are also considered viable due to their high energy density relative to LFP batteries, however operation of NMC does result in oxygen release, potentially increasing fire risks. For this reason, LFP batteries are advised as the industry standard for safety in lithium-ion battery technology.

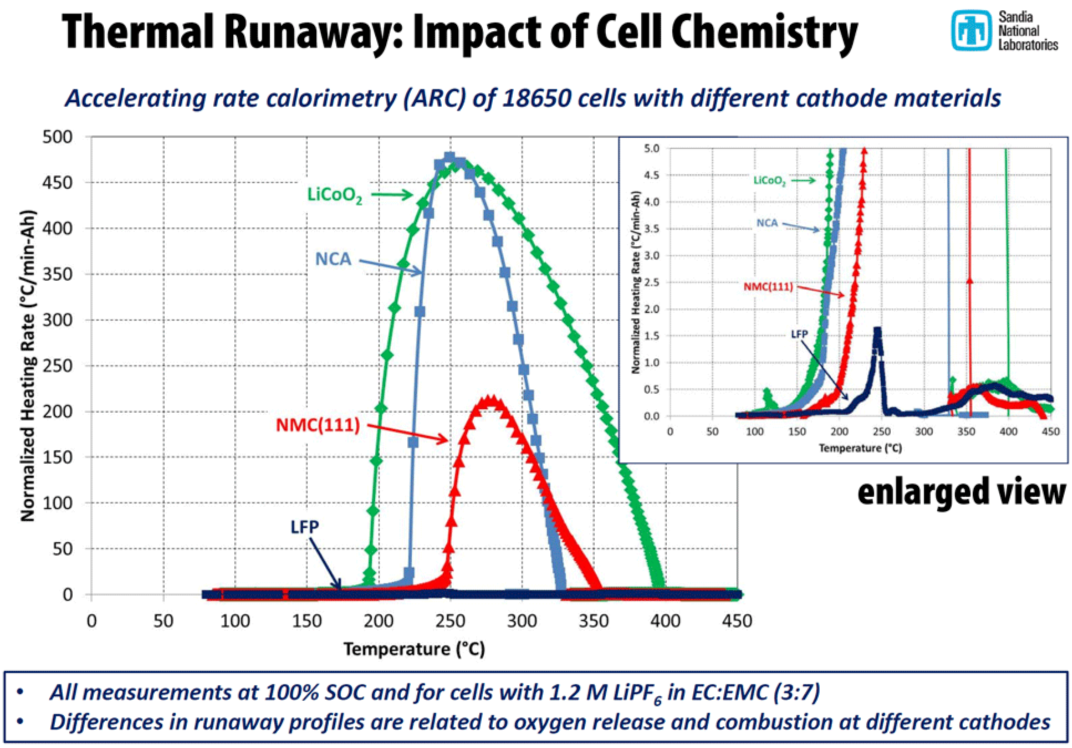

Figure 4-2: Temperature Rise of Lithium-Ion Battery Chemistries (Ref. [7]).

The preliminary battery product considered for the purposes of a preliminary hazard analysis for the project is a BESS with LFP technology. A UL9540A report (test standard report with a systematic evaluation of thermal runaway and propagation in energy storage system at cell, module, unit, and installation levels) may have been completed for this product and is unable to be shared due to privacy reasons. At install, the units will have been tested and have UL9540A test data for fire development and propagation.

Similarly, based on data shown from UL9540A reports for similar systems, the results demonstrate that when thermal runaway is triggered in one cell in a BESS container, the heat generated would neither be transferred to all cells within one battery module, nor from the test module to adjacent ones. 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).

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 stainless-steel enclosure. Similar systems show that generally the container wall remains intact after sustaining heating in a furnace to over 900°C.

Furthermore, each container should also have multiple built-in fire protection devices that work collaboratively, including smoke and thermal sensors, combustible gas detector, pressure relief system, and aerosol E-Stop buttons. For the Energy Vault batteries, safety systems include fire and smoke detectors, explosive gas detectors, active ventilation, dry piping for water suppression and 2-hour firewall. Therefore, a container is expected to automatically detect an internal fire in the first instance.

In conclusion, the LFP technology does not cause fire during thermal runaway. Should fire be developed within one BESS container it would not transfer to nearby containers 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) on other BESS projects, 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 Victorian 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 present project.

The present project has thoroughly 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 Victorian Big Battery (VBB) experienced a fire in July 2021 which also has a back-to-back layout. According to the independent investigation report on its fire incidence, the back-to-back layout was not the cause for propagation. The main reason for fire propagation was strong wind blowing flames from one 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 on the design of the present project. The vent atop the containers shall be made of metal instead of plastic and covered by a metallic mesh shield. Furthermore, the placement of the fans shall be such that batteries or flammable materials shall not be located directly beneath ventilation openings. To ensure the above are captured the following recommendations have been made:

- The vent covers of the BESS shall be constructed of non-combustible material.
- The vents shall not be located above battery packs within the BESS container.

Based upon the designs incorporated with the container based upon 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

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

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

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

4.6.1 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.

$$C_3H_8(g) + 5O_2(g) \rightarrow 3Co_2(g) + 4H_2O(g)$$ **Equation 4-1**

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

4.6.2 Carbon Monoxide

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

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

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

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 and subsequent analysis of, this incident is not required.

4.6.3 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. [8]).

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

$$LiPF_6 \rightarrow LiF + PF_5 \quad \textbf{Equation 4-3}$$

$$PF_5 + H_2O \rightarrow POF_3 + 2HF \quad \textbf{Equation 4-4}$$

$$LiPF_6 + H_2O \rightarrow LiF + POF_3 + 2HF \quad \textbf{Equation 4-5}$$

Of the fluorine gases formed, PF_5 is a short-lived gas while POF_3 is a reactive intermediate. Thermal destruction of a several battery chemistry, configurations and State 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. [8]). 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. Therefore, a toxic gas dispersion impacting sensitive receptors is not deemed a credible scenario and 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 Transformer Internal Arcing, Oil Spill, Ignition and Bund Fire

Transformers contain oil which is used to insulate the transformers during operation. If arcing occurs within the transformer (e.g. due to a low oil level), the high energy passing through the coolant vaporises the oil into light hydrocarbons (methane, ethane, acetylene, etc.) resulting in rapid pressurisation within the reservoir. It is noted that non-mineral oil is proposed to be used with a high flashpoint (KNAN ester-based oil) which provides an increased safety margin, however arcing may still provide sufficient energy to vaporise this oil.

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 anticipated to be 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 every transformer is to be self-bunded on a skid or have a concrete bund, limiting the spread of an oil pool fire. Additionally, the separation distance to the site boundary and other adjacent units would be unlikely to result in incident propagation and offsite impacts. Nevertheless, it has been decided to quantitatively determine the risk of such a fire, hence this incident has been carried forward for further analysis.

4.9 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, as described in **Section 4.8**, 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 ester oil may start to decompose and vapourise, resulting in flammable gas bubbles including hydrogen and methane (Ref. [9]) at 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 generally have surge protection devices which shunt electrical surges safely to ground. However, this surge detection and protection devices are not universally installed nor do they protect against all events 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. [10]). Therefore, while transformers are ubiquitous units with a low potential for failure, there is the potential for an explosion to occur which may result in offsite impacts. Hence, this incident has 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. [11]).

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 over 750 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 Consequence Analysis

5.1 Incidents Carried Forward for Consequence Analysis

The following incidents were identified to have the potential to impact off site:

- Transformer internal arcing, oil spill, ignition and bund fire.
- Transformer electrical surge protection failure and explosion.

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 medium voltage 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**. The contours are located at the worst-case location with respect to proximity to the site boundary.

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

Heat Radiation (KW/m^2)	Distance (m)
35	5
23	5
12.6	7
4.7	9

A review of **Figure 5-1** shows that the radiant heat contours at 4.7 kW/m^2 and 23 kW/m^2 do not impact over the site boundary. It is noted that the site layout used is of a previously proposed layout, however this is akin to the currently proposed layout (**Figure 3-2**) which has yet to be finalised. Additionally, the layout incorporates a 15 meter set back from the site boundary and the largest contour only reaches 9 m, therefore even if the transformers were relocated to the edge of the set back, the contours would not impact over the site boundary. Therefore, the potential for a fatality to occur or for incident propagation to occur would be unlikely; hence, this incident has not been carried forward for further analysis.

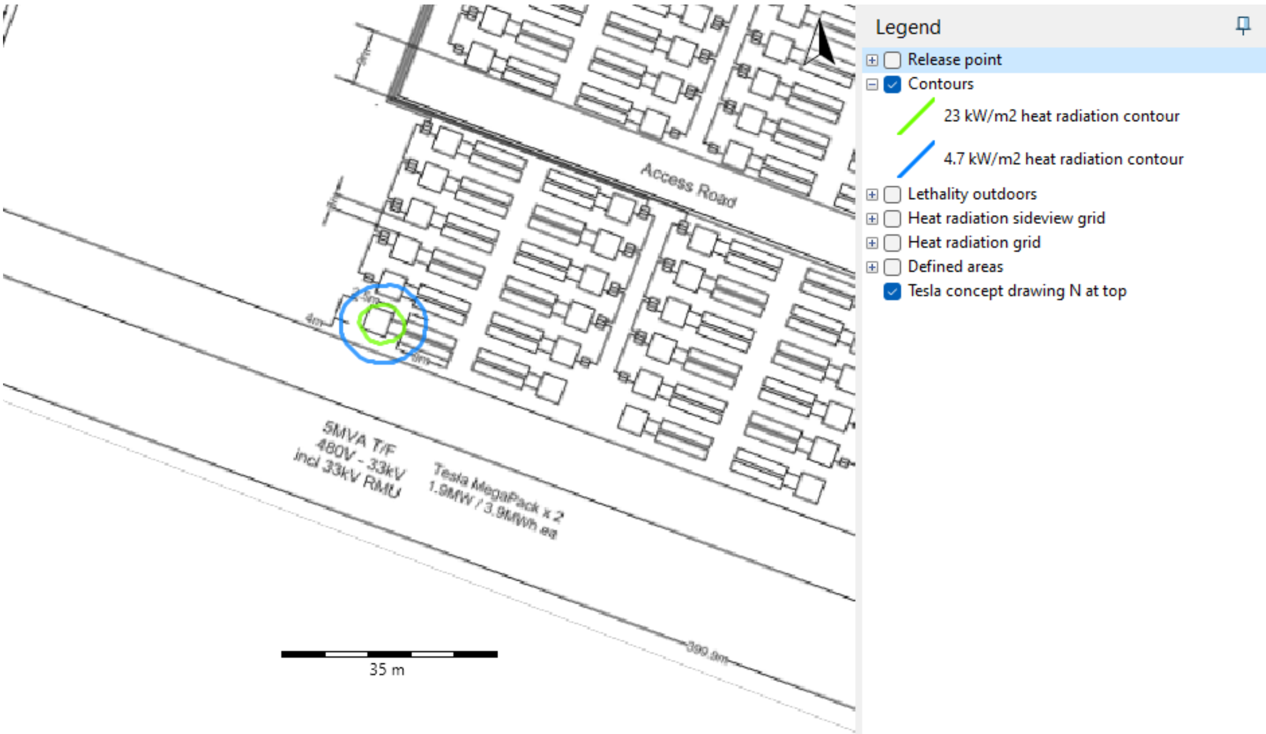

Figure 5-1: Transformer Bund Fire Radiant Heat Contours

5.3 Transformer Electrical Surge Protection Failure and Explosion

In the event that a transformer is impacted by an extreme electricity surge, such as in the event of a lightning strike, the mineral oil within the transformer may ignite and explode resulting in substantial overpressure impacts. A detailed analysis has been conducted in **Appendix B7** with the results summarised in **Table 5-2**.

Table 5-2: Transformer Explosion Overpressures

Overpressure (kPa)	Distance (m)
70	40
35	58
21	80
14	106
7	185

Provided in **Figure 5-2** is a contour showing the explosion impact distances at 7 kPa and 14 kPa to the surrounding areas for the transformers closest to the site boundary, which represent the potential for injury to personnel and incident propagation, respectively. The overpressure contours extend over the site boundary for both the 7 kPa and the 14 kPa contours; hence, there is the potential for incident propagation and injury or fatality to occur. Therefore, this incident has been carried forward for further analysis.

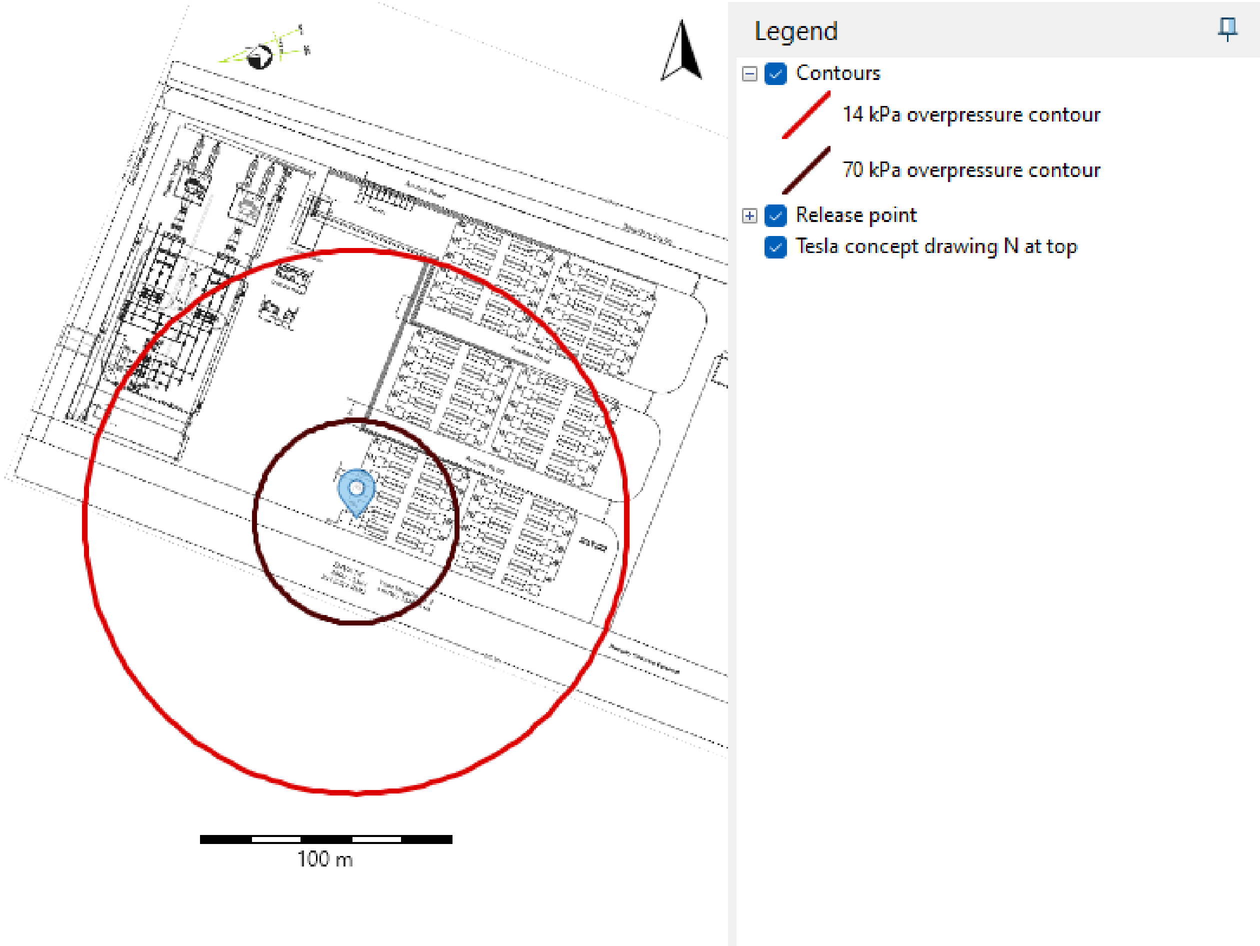

Figure 5-2: Transformer Explosion Overpressure Contours

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 electrical surge protection failure and explosion.

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

6.2 Transformer Electrical Surge Protection Failure and Explosion

The initiating event for a transformer fire is a major oil spill from the transformer casing. This would be classified as a catastrophic failure as all oil contained within the transformer would be released. Failure rate data from the CCPS indicates that the frequency of a catastrophic transformer failure is in the range of 0.125 to 9.26 failures per 10^6 hours (Ref. [12]).

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

Changlong Zhu et al conducted a peer review of a number of academically accepted methods of calculating ignition probability (Ref. [13]). The study concluded that for flammable liquids with flashpoints greater than 100ºC, the probability of direct or delayed ignition was negligible. This data was taken from a number of well-established models including the BEVI Manual (Ref. [14]), the Purple Book (Ref. [15]), and studies conducted on the HMIRS database (Ref. [16]). Furthermore, an assessment of power transformer reliability conducted by Tenbohlen et al which analysed 112 major transformer failures throughout Europe indicates that most major failures do not result in any external effects (Ref. [17]). The Tenbohlen et al study indicates that only 2.7% of major transformer failures result in an explosion (Ref. [17]).

The surrounding land is undeveloped bushland and it is not expected for people to be present adjacent to the BESS the majority of the time. Hence, it has been assumed that personnel may be within the vicinity of the BESS 1 hour per workday or 260 hours/year resulting in an exposure probability of 0.03. Using this exposure potential, the potential for a fatality becomes 1.1×10^{-3} x 0.027 x 0.03 = 8.9×10^{-7} p.a.

6.3 Comparison Against Risk Criteria

6.3.1 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. [3]). 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 6-1**.

Table 6-1: Individual Fatality Risk Criteria

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

The private property surrounding the BESS units is accurately described by the ‘industrial’ criteria shown in **Table 6-1**; hence, the criteria here would be 50 pmpy.

The fatality risk estimated for the immediate vicinity was calculated to be 0.89 pmpy which is below the criteria of 50 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 Incident Propagation

The same guidelines provide acceptable risk criteria for incident propagation at 50 chances pmpy (Ref. [3]). A review of the scenarios that may lead to incident propagation shows that the 23 kW/m^2 contours were not observed to impact offsite and the 14 kPa contours were not shown to impact any areas which may result in incident propagation; hence, the potential for incident propagation is zero (0) which is less than the acceptable risk criteria for incident propagation.

6.5 State Code 21

Provided in **Table 6-2** is an assessment of each of the Performance Outcomes (PO) under the State Code 21 (Ref. [18]) to demonstrate that the development complies with the POs and also the policy intent of the document. Based upon the review, it is considered that the facility complies with the policy intent and the PO of State Code 21.

Table 6-2: State Code 21 Performance Outcome Review

PO	Requirement	Assessment	Compliant (y/n)
1	The hazardous chemical facility does not create a dangerous dose to human health at vulnerable land use or land zoned for a vulnerable land use.	The facility does not result in impacts at land zoned for vulnerable land uses.	Y
2	The hazardous chemical facility does not create a dangerous dose to human health at sensitive land use or land zoned for a sensitive land use.	The facility does not result in impacts at land zone for sensitive land uses.	Y
3	The hazardous chemical facility does not create a dangerous dose to human health at a commercial or community activity land use or land zoned for a commercial or community activity land use.	The facility does not result in impacts at land zoned for commercial or community land uses.	Y
4	The hazardous chemical facility does not create; a) A dangerous dose to human health at open space land use or land zoned for an open space land use, or b) Where (a) cannot be achieved, an individual fatality risk level of $10x10^{-6}$/year and the societal risk criteria in figure 21.1	The facility does not result in impacts at land zoned for open space land use.	Y
5	The hazardous chemical facility does not create either of the following at: a) A dangerous dose to the built environment at industrial land use or land zoned for an industrial land use, and b) An individual fatality risk level of $50x10^{-6}$/year	The facility does not result in a dangerous dose at industrial land uses; and The fatality risk at the site boundary is $8.9x10^{-7}$ which is below the threshold limit.	Y
6	The storage and handling areas for fire risk hazardous chemicals are provided with 24-hour monitored fire detection system that has the ability to detect a fire in its early stages and notify an emergency response at all times.	The facility will be fitted with smoke detection which will alert the operator to commence emergency response.	Y
7	Storage and handling areas for packages of liquid or solid fire risk hazardous chemicals are provided with a spill containment system with a working volume capable of containing a minimum of 100 percent of all packages (prescribed hazardous chemicals and/or non-hazardous chemicals) within the area plus the output of any fixed firefighting system provided for the area over a minimum of 90 minutes.	The formation of significant volumes of contaminated water is unexpected to occur as the use of water to combat a BESS fire is not advised since water is unable to extinguish a BESS fire. As such, the BESS location is such that propagation of the fire is not expected to occur until complete exhaustion of the fuel load, at which point the fire will be extinguished. Notwithstanding this, a contaminated water and stormwater retention basin is present on site.	Y

PO	Requirement	Assessment	Compliant (y/n)
8	Storage and handling areas for liquid or solid fire risk hazardous chemicals in tanks are provided with a spill containment system with a working volume capable of containing a minimum of: a) 110 percent of the largest tank within a spill compound or 25 percent of the aggregate where multiple tanks are located within a spill compound, whichever is the greater; and b) the output of any fixed firefighting system provided for any bulk tank within a spill compound over a minimum of 90 minutes.	No tanks of dangerous goods are stored at the site.	n/a
9	Storage and handling areas for prescribed hazardous chemicals that, if in contact with each other, may react to produce a fire, explosion or other harmful reaction, or a flammable, toxic or corrosive vapour are designed to prevent contact between the prescribed hazardous chemicals.	No incompatible DGs are stored in proximity to each other.	Y
10	Development is designed and sited to mitigate impacts on storage and handling areas from natural hazard including, but not limited to: a) flood; b) bushfire; c) erosion; d) storm tide inundation; e) landslide; f) earthquake; g) wind action.	The site has been designed in accordance with applicable criteria to cover off flood, bushfire, erosion, storm tide inundation, landslide, earthquake and wind action. Bushfire mapping has been undertaken for the site indicating the surrounding area has medium potential bushfire intensity. As such, firefighting water is to be made available in a 100,000 L dedicated tank with associated fire pumps and a hydrant ring main.	Y
11	Development is designed and sited to mitigate the risks from hazard scenarios occurring at existing hazardous chemical facilities.	Currently there are no hazardous chemical facilities adjacent to this facility.	Y

7.0 Conclusion and Recommendations

7.1 Conclusions

A hazard identification table was developed for project site of the GinGin 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 were the ignition of transformer oil resulting in a fire or explosion. An explosion scenario has potential to impact across the site boundary, hence it was carried forward for frequency analysis. The fatality risk estimated for the immediate vicinity was calculated to be 0.89 pmpy which is below the criteria of 50 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. In addition, the 14 kPa contours were not shown to impact any areas which may result in incident propagation; hence, the potential for incident propagation is zero (0) which is less than the acceptable risk criteria for incident propagation.

An assessment of each of the Performance Outcomes (PO) under the State Code 21 was completed to demonstrate that the development complies with the POs and also the policy intent of the document. Based upon the review, it is considered that the facility complies with the policy intent and the PO of State Code 21. Hence, based on the analysis presented in this report, the project would only be classified as potentially hazardous and would be permitted within the current land zoning for the site.

7.2 Recommendations

The following recommendations have been made as a result of the analysis:

- 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.
- The vent covers of the BESS shall be constructed of non-combustible material.
- The vents shall not be located above battery packs within the BESS container.

8.0 References

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Appendix A

Hazard Identification Table

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. [18]) • CATL EnerOne cooling • Aerosol fire suppression • UL9540A testing
Switch rooms, communications, etc.	• Arcing, overheating, sparking, etc. of electrical systems	• Ignition of processors and other combustible material within servers and subsequent fire	• Fires tend to smoulder rather than burn • Isolated location • Switch room separation from other sources of fire
Transformers	• Arcing within transformer, vaporisation of oil and rupture of oil reservoir	• Transformer oil spill into bund and bund fire	• Bunded • Isolated location
	• Power surge to transformers (e.g. from lightning)	• Major failure of surge protection in transformer, vapourisation of oil, ignition and explosion	• Transformers have surge protection system to shut down upon detection of extreme energy input • Lightning protection to prevent lightning strikes impacting transformers • Control of ignition sources – no smoking / open flames around the transformers

Area/Operation	Hazard Cause	Hazard Consequence	Safeguards
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
- Transformer electrical surge protection failure and explosion.

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. [3]).

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 3 m by 6 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.

The transformer oil proposed to be used is a KNAN non-mineral ester oil. For the purposes of this assessment, it has been assumed that a natural ester oil such as FR3 will be used which is composed of soybean oil, itself a mixture of triglycerides. These triglycerides are esters of fatty acids, predominantly linoleic acid. Linoleic acid has a flash point of approximately 200 ^{o}C, while the FR3 oil itself has a higher flash point of 300 ^{O}C. For the purposes of providing a conservative analysis, pure linoleic acid has been selected as the transformer oil. The input file used to model this scenario has been provided in **Appendix Figure B-9.**

Parameters	
Inputs	
Process Conditions	
Chemical name	LINOLEIC ACID (DIPPR)
Calculation Method	
Type of pool fire calculation	Two zone model Rew & Hulbert
Type of pool fire source	Instantaneous
Fraction combustion heat radiated (-)	0.35
Soot definition	Calculate/Default
Source Definition	
Total mass released (kg)	10000
Temperature of the pool (°C)	9
Process Dimensions	
Type of pool shape (pool fire)	Polygon
Non burning area within pool (m2)	0
Height of the confined pool above ground level (m)	0
Meteo Definition	
Wind speed at 10 m height (m/s)	2
Predefined wind direction	W
Environment	
Ambient temperature (°C)	15
Ambient pressure (bar)	1.0151
Ambient relative humidity (%)	83

Appendix Figure B-1: BESS Fire Input File

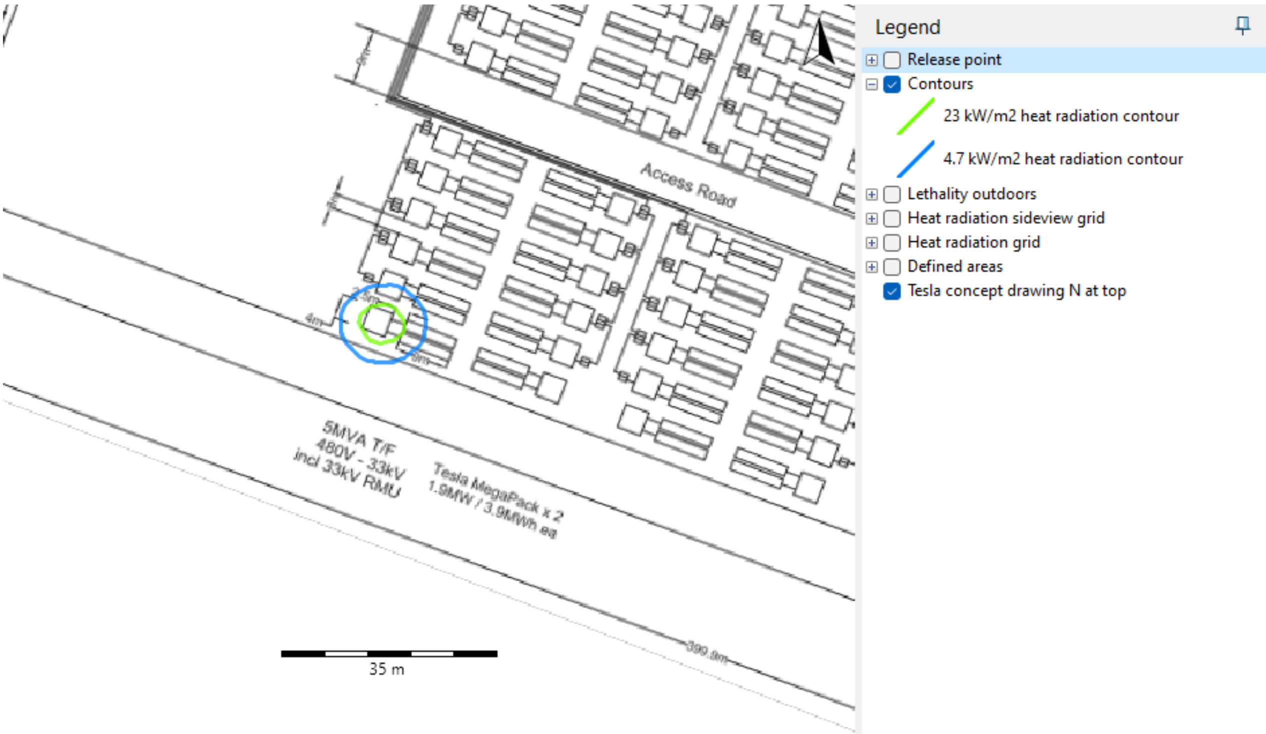
The above information was input into Effects which calculated the following outputs:

- SEP – 51.96 kW/m^2
- Flame height – 5.0 m

The results of the analysis are shown in **Appendix Table B-2**, with the heat radiation contours depicted in **Appendix Figure B-10.**

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

Heat Radiation (KW/m^2)	Distance (m)
35	5
23	5
12.6	7
4.7	9



Appendix Figure B-2: Transformer Bund Fire Impact Contours

B5. Transformer Electrical Surge Protection Failure and Explosion

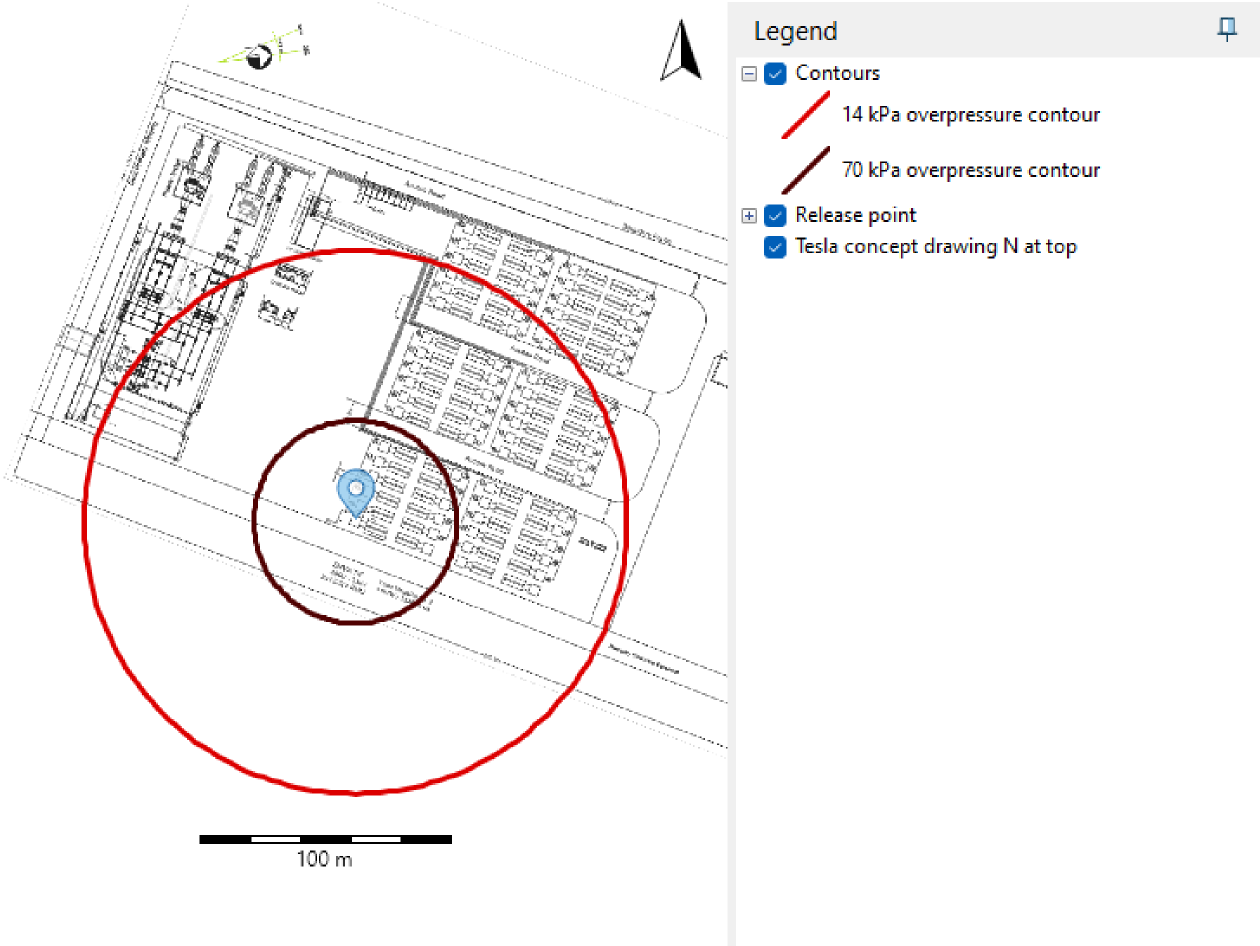
If a transformer is impacted by an extreme electricity surge, such as in the event of a lightning strike, the ester oil within the transformer may ignite and explode resulting in substantial overpressure impacts. The following data has been obtained to model a transformer explosion:

- W 3,560 kg (based on the 4,000 L of oil contained within a single transformer and an oil density of 890 kg/m^3)
- α 0.05 for hydrocarbons (Ref. [19])

The above information into Gexcon Effects with the results of the explosion calculations provided in **Appendix Table B-6**, with the impact contours depicted in **Appendix Figure B-11**.

Appendix Table B-3: Overpressure from a Transformer Explosion

Overpressure (kPa)	Distance (m)
70	40
35	58
21	80
14	106
7	185



Appendix Figure B-3: Transformer Explosion Impact Contours

Appendix C

Estimation of BESS Fire Frequency

C1. Introduction

A literature review to identify the frequency with which BESS fires occur did not yield any definitive results nor are there any databases which were identified containing this information. Subsequently, it is necessary to undertake a review of the BESS industry and fire incidents to estimate the frequency with which BESS units fail resulting in fire.

C2. Methodology

It has been proposed to identify the failure rate of BESS units on an installed capacity basis and identify how many BESS fires have occurred globally. This failure rate could then be applied to the installed capacity at a particular site as the basis for undertaking a quantitative assessment of fatality risk.

C3. BESS Fire Frequency Estimation

The International Energy Agency (IEA) produces a report of the total installed energy storage system around the world. The report from 2021 indicated the total installed capacity was around 17 GW following 5 GW of capacity installed in 2020 which was a 50% increase from the mediocre installation levels in 2019. Assuming a similar installation of 5 GW occurred in 2021, then the total installed capacity would be in the order of 22 GW or 22,000 MW.

Consistent information detailing the size of the battery storages was unable to be identified; hence, it has been assumed that the 22,000 MW of installed capacity represents grid scale deployment requiring 4 hours of storage resulting in total installed capacity of 88,000 MWh.

An extensive search to identify the number of BESS fires which have occurred since large scale BESS commenced being deployed did not provide a definitive number; however, data reported by S&P Global (Ref. [20]) and Marsh Commercial (Ref. [21]) indicated around 20 - 30 fires had occurred since 2017. As it is not clear if there is a centralised database documenting BESS fires, the number of BESS fires has been estimated at 50 since large scale BESS have been deployed which commenced around 2012.

Therefore, there has been approximately 50 BESS fires per 88,000 MWh of installed capacity or an assumed rate of 0.00057 per MWh of total installed capacity. While the rate of installation is proceeding exponentially, for the purposes of identifying a failure rate, it has been assumed that the deployment has been linear and that the failure rate per annum becomes 0.00057 fires per total MWh installed divided by 5 years = 0.00057 / 5 = 1.1×10^{-4} per MWh/y.