Preliminary Hazard Analysis

Finley BESS

Premise Australia Pty Ltd
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Premise Australia Pty Ltd

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Executive Summary

Background

Premise Australia Pty Ltd (Premise) have been engaged by BESS Pacific Pty Ltd (BESS Pacific) to obtain approval for the Battery Energy Storage System (BESS) facility to be located on Lot 3 DP740920 at Riverina Highway, Finley NSW. The BESS will be a 100 MW / 200 MWh system which exceeds the 30 MW limit and would therefore require a Preliminary Hazard Analysis. The Secretary's Environmental Assessment Requirements (SEARs), as part of the approval process, requires the preparation of a Preliminary Hazard Analysis (PHA) in accordance with the Hazardous Industry Planning Advisory Papers (HIPAP) No. 4 and No. 6 (Ref. [1] and [2]) as part of the State Significant Development Application (SSDA).

Riskcon Engineering Pty Ltd (Riskcon) has been engaged to assist with preparing the PHA for the Finley BESS as part of the SSDA submission for the development.

Conclusions

A hazard identification table was developed for the Finley BESS to identify potential hazards that may be present at the development 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. A review of the incidents carried forward for further analysis indicates that there were no observed offsite impacts.

Hence, based on the analysis presented in this report, the development site would only be classified as potentially hazardous and would be permitted within the current land zoning for the development site.

Recommendations

- 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 development site area whilst meeting the recommended clearances.
- A BESS container shall not be located within 2 m when orientated side to side.
- Two BESS containers (BESS duplex) shall not be stored closer than 0.15 m when oriented side to side.
- A BESS duplex shall not be located within 1 m when oriented end to end.
- The UL9540A test data for the batteries selected for the project shall be made available to the DPE to confirm that incident propagation isn't possible at the distance recommended in this report.
- The fire protection details of the BESS containers and associated test data shall be made available to the DPE.
- Any ventilation fans or ducts in the BESS container shall be constructed of non-combustible materials.

- The ventilation fans shall be located such that they do not reside directly above batteries within the 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
DPHI	Department of Planning, Housing, and Infrastructure
ELF	Extra Low Frequency
EMF	Electric and Magnetic Field
ERPG	Emergency Response Planning Guideline
HF	Hydrogen Fluoride
HIPAP	Hazardous Industry Planning Advisory Paper
HVAC	Heating Ventilation and Air Conditioning
ICNIRP	International Commission on Non-Ionizing Radiation Protection
IDLH	Immediately Dangerous to Life and Health
LFP	LiFePO4 (Lithium Iron Phosphate)
MV	Medium Voltage
NMC	Nickel-Manganese-Cobalt
PHA	Preliminary Hazard Analysis
PO	Performance Outcome
SEP	Surface Emissive Power
SOC	State of Charge
STEL	Short Term Exposure Limit
VBB	Victorian Big Battery

1.0 Introduction

1.1 Background

Premise Australia Pty Ltd (Premise) have been engaged by BESS Pacific Pty Ltd (BESS Pacific) to obtain approval for the Battery Energy Storage System (BESS) facility to be located on Lot 3 DP740920 at Riverina Highway, Finley NSW. The BESS will be a 100 MW / 200 MWh system which exceeds the 30 MW limit and would therefore require a Preliminary Hazard Analysis. The Secretary's Environmental Assessment Requirements (SEARs), as part of the approval process, requires the preparation of a Preliminary Hazard Analysis (PHA) in accordance with the Hazardous Industry Planning Advisory Papers (HIPAP) No. 4 and No. 6 (Ref. [1] and [2]) as part of the State Significant Development Application (SSDA).

Riskcon Engineering Pty Ltd (Riskcon) has been engaged to assist with preparing the PHA for the Finley BESS as part of the SSDA submission for the development.

1.2 Objectives

The key objectives of this PHA are to:

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

1.3 Scope of Services

The scope of work is to prepare a PHA in accordance with HIPAP No. 6 and No. 4 for the Finley BESS as part of the SSDA submission for the development located on Lot 3 at Riverina Highway, Finley 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, 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**.

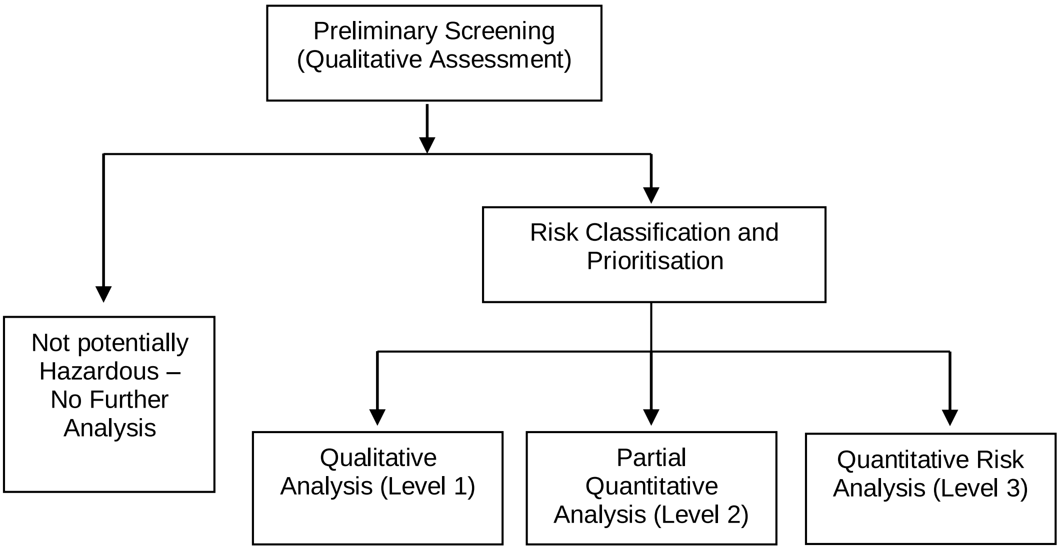

Figure 2-1: The Multi-Level Risk Assessment Approach

Based on the type of DGs to be used and handled at the development site, a **Level 1 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. [2]).

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. [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 HIPAP No. 4 (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 Development Site Location

The site is located on the north-eastern corner of Canalla Rd and Brockmanns Road intersection in Finely New South Wales. The site is legally described as a portion of Lot 3 DP740920 at Riverina Highway, Finley New South Wales. The site is within the Berrigan Shire Council approximately 5 km west of Finley NSW 2713. The surrounding properties are agricultural in nature; however, no farming is currently taking place, and the closest sensitive receptor is separated by over 500 m from the BESS units. The site has a total area of 3.5 hectares (ha).

Figure 3-1 shows the regional location of the development site. **Figure 3-2** shows the preliminary site layout of the full development. **Figure 3-3** shows the proposed BESS layout.

Figure 3-1: Development Site Location

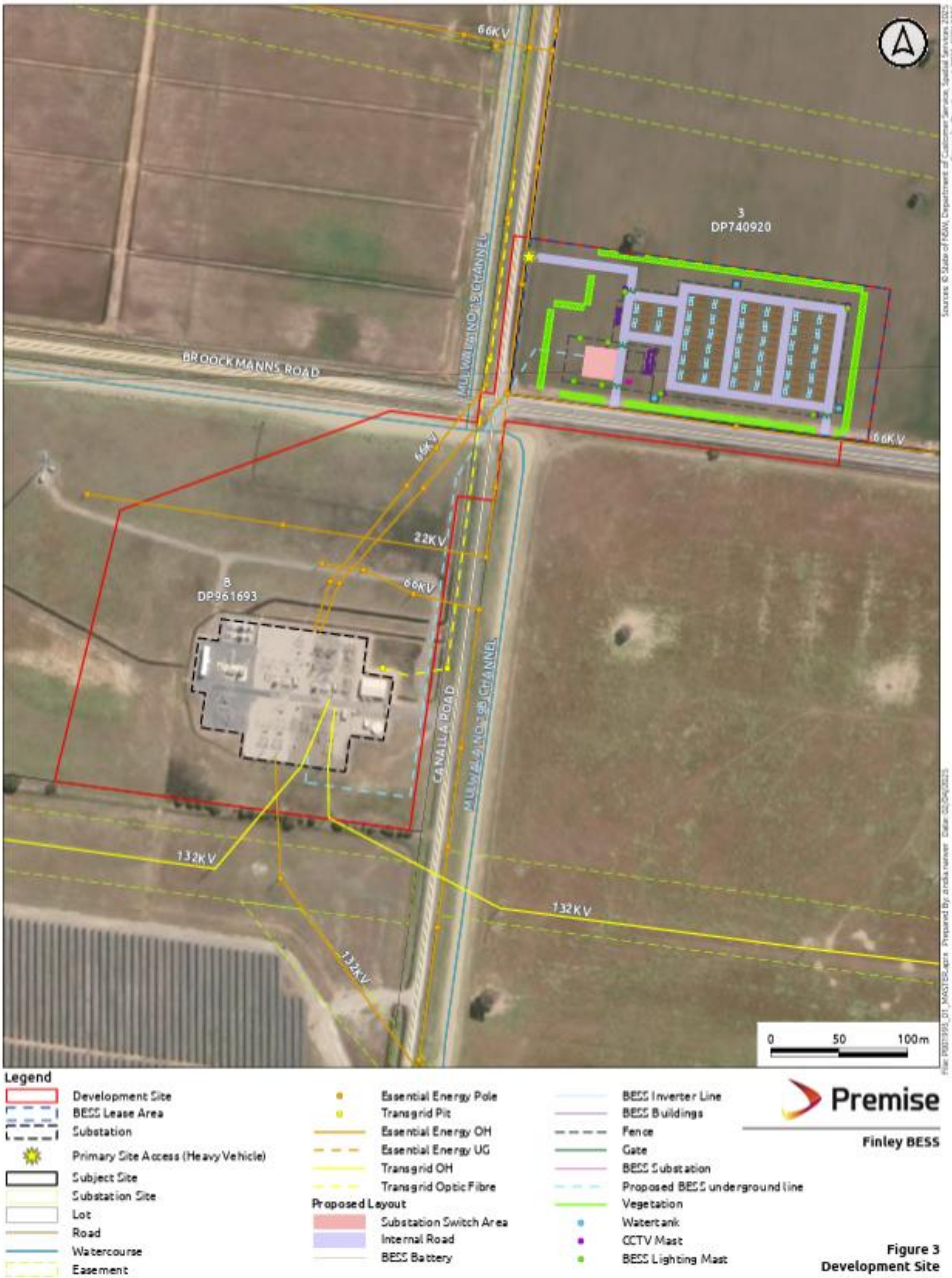

Figure 3-2: Development Site Layout

Figure 3-3: BESS Layout

3.2 General Description

BESS Pacific seeks to establish a 100 MW BESS facility with a connection to the existing electricity grid via a Transmission Line (TL) route comprising of above and below ground cables. The BESS development site will connect to TransGrid's FINLEY 132/66 kilovolt (kV) Transmission Substation (TS).

Up to 80 battery enclosures (units) are proposed to be installed, with batteries stored in racks consisting of 418 battery cells. The maximum estimated energy capacity of each unit is 1.98 MWh. Each unit employs lithium iron phosphate (LFP) battery modules and is equipped with Heating Ventilation and Air Conditioning (HVAC) and a Battery Management System for operational control. Each container measures 6,058 x 2,438 x 2,896 mm, with a total weight of approximately 35 tonnes. **Figure 3-4** provides an example of a typical BESS Module.

The containers will conform to IEC 62619 and the development site to AS/NZS 5139 and the CFA Design Guidelines and Model Requirements for Renewable Energy Facilities v4 where relevant. This includes the installation of an active fire protection system within each container.

The development site will involve the construction, operation and decommissioning of a Battery Energy Storage System (BESS) and associated infrastructure for the existing. The conceptual development site includes:

- BESS with a capacity of up to 100 MW / 200 MWh.
- Electricity Infrastructure:
  - Approximately 40 inverter and transformer stations.
  - Approximately 80 lithium batteries, with modular containers.
  - 132/33 kW main transformer.
  - 132 kV transmission line.
  - Control room and 33 kV switch gear.
  - Auxiliary transformer.
  - High voltage steel poles.
  - High voltage cabling.
  - Internal access roads to connect panels and ancillary infrastructure.
- On-site permanent supporting infrastructure:
  - Development site access road and entry.
  - Hardstand and internal roads.
  - Operations and maintenance facility including site office, amenities, equipment sheds, storage and parking areas.
- Off-site supporting infrastructure:
  - Existing public road and communications network.
- Temporary supporting infrastructure:
  - Construction facilities such as offices, accommodation camp, car park and amenities.
  - Fencing and landscaping works.
  - Concrete batching plants.
  - Installation of underground and overhead cabling.
  - Water sourcing.
  - Installing maintenance and environmental managements processes and equipment.

Figure 3-4: Indicative Image of BESS Modules

3.3 Detailed Description

The purpose of the development site is to provide clean renewable energy to the NSW grid, and contribute further renewable generation towards the goals of the NSW government's NSW Electricity Infrastructure Roadmap.

The energy will be imported from the grid commonly at midday in periods of low energy price and the up to 200 MWh BESS will enable storage of this clean renewable energy to be dispatched to help accommodate electricity demand fluctuations and ensure supply when demand is highest. This is achievable due to the fast response times achieved through lithium-ion battery storage which can fill peak demands due to the quick dispatchability of battery storage. The development site will have capacity to store up to 100 megawatts (MW) of energy for 2 hours resulting in a storage of 200 MWh.

3.3.1 PCUs

Power Conversion Units, or PCUs, house transformers and inverters which will be sited between the BESS units. A Transmission Line will connect the converted grid energy to the BESS development site. There will be approximately 40 PCUs across the BESS development site which is typically comprised of:

- 1 x PCU transformer
- 3 x inverters

The inverters convert the Direct Current (DC) to Alternating Current (AC), while the transformers increase the voltage from Low Voltage to a Medium or High Voltage, as required for the electricity grid connection. PCUs are a compact, containerised product, with each unit measuring approximately 2.5 metres wide by 2.9 metres high, with a depth of 6 metres (equivalent to a 20 foot shipping container for the inverter units). The exact height of these PCUs will be subject to detailed design. **Figure 3-5** provides an example of a typical PCU.

Figure 3-5: Typical Single Inverter

3.3.2 Battery Storage

The proposed BESS will be located within containerised units. The BESS will enable the import of energy from the grid during low energy cost periods to create a flexible energy generation source, providing energy when it is required the most. The BESS converts electrical energy into chemical energy and stores the energy internally. It may also contribute towards network security Frequency Control Ancillary Services (FCAS) in the Region. A typical BESS is shown in **Figure 3-4** and layout for the BESS contained in the layout is shown in **Figure 3-3.**

3.4 Quantities of Dangerous Goods

The classes and quantities of DGs provided in **Table 3-1** are indicative and will need to be updated once confirmed. The type of transformer oil is not yet confirmed; hence it is conservatively assumed as a C1 combustible liquid for the purposes of this PHA. Transformer oil quantities are calculated based on 2,200 L per MV transformer. Additionally, the SEPP threshold of the individual classes have been provided for the purposes of the SEARs.

Table 3-1: Maximum Quantities of Dangerous Goods Stored

Area	Class	Description	Quantity	SEPP Threshold
BESS	9	Lithium Batteries	1,372 T	N/A
Transformer oil	C1	Combustible liquid	88 kL	N/A

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. [2]). 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.

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 the Hazardous Industry Planning Advisory Paper (HIPAP) No. 4 (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 development site boundary, are screened from further assessment.

  Those incidents exceeding 4.7 kW/m^2 at the development site boundary are carried forward for further assessment (i.e. frequency and risk). This is a conservative approach, as HIPAP No. 4 (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). It is noted that the closest residential area is more than 500 m from the closest BESS, hence, by selecting 4.7 kW/m2 as the consequence impact criteria the assessment is considered conservative.

- *Explosion* - It is noted in HIPAP No. 4 (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 development site boundary, are screened from further assessment. Those incidents exceeding 7 kPa, at the development 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 more than 500 m from the closest BESS.

- *Toxicity* – Toxic by-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. [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 development site boundary, are screened from further assessment. Those incidents exceeding 23 kW/m^2 at the site boundary are carried forward for further assessment with respect to incident propagation (i.e. frequency and risk).

- *Societal Risk* – HIPAP No. 4 (Ref. [1]) discusses the application of societal risk to populations surrounding the Project. It is noted that HIPAP No. 4 (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 considered. In the case of the development site, there is currently no significant intensification of population around the development 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 development site has been described in **Section 3**. **Table 4-1** provides a description of the DGs to be stored and handled at the development 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 Development 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 development site 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.
- 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 phosphorus and iron) 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**.

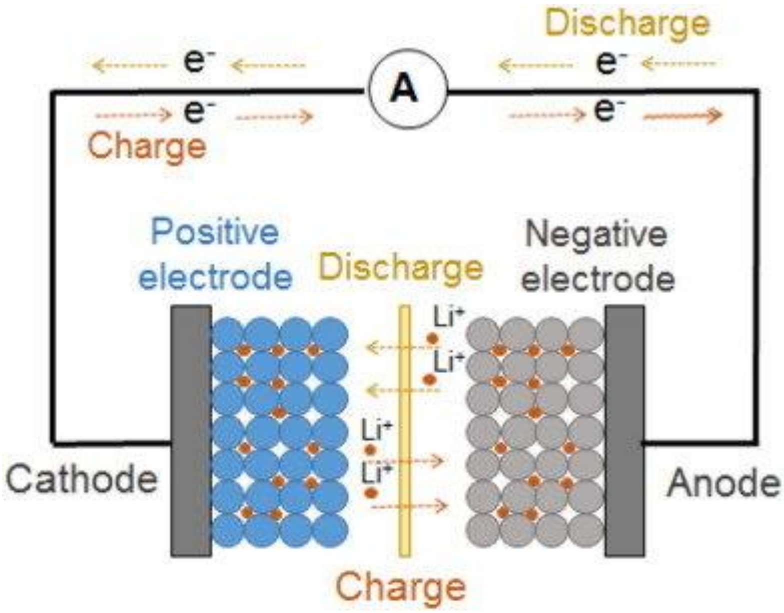

Figure 4-1: Cathode and Anode of a Battery (Source Research Gate)

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 mechanical abuse to 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 development site 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 (**Appendix B**).

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.

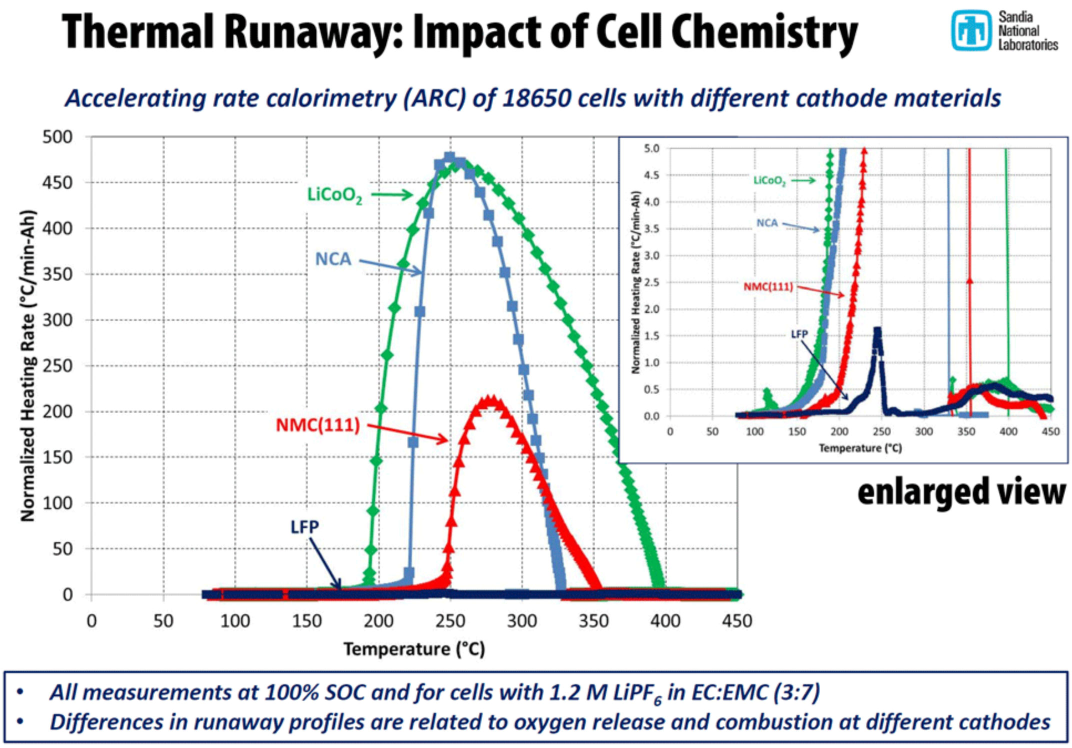

Figure 4-2: Temperature Rise of Lithium-Ion Battery Chemistries (Ref. [6]).

The preliminary battery product considered for the purposes of a preliminary hazard analysis for the development site 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) have been completed for this product and is available if requested. 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 and E-stop buttons. Therefore, a container is expected to automatically detect an internal fire in the first instance.

In conclusion, the LFP technology single cells have a low possibility of catching fire during thermal runaway. If a fire were to develop within one BESS container it would not transfer to nearby containers due to the fire safety design features that would prevent a system-wide fire event; 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 development site 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 development site.

The present development site 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 development site. 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. [7]).

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

$$LiPF_6 \rightarrow LiF + PF_5$$ **Equation 4-3**

$$PF_5 + H_2O \rightarrow POF_3 + 2HF$$ **Equation 4-4**

$$LiPF_6 + H_2O \rightarrow LiF + POF_3 + 2HF$$ **Equation 4-5**

Of the fluorine gases formed, PF_5 is a short-lived gas while POF_3 is a reactive intermediate. Thermal destruction of a several battery chemistries, configurations and State of Charge (SOC) indicated the vast majority of the batteries did not produce observable POF_3 with the condition that a specific battery chemistry was at 0% SOC (Ref. [7]). Therefore, the main fluorine gas of concern in a Li-ion battery fire is HF.

HF gas is hydroscopic 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 distributed throughout the development site 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 development site is ubiquitous throughout the world and across industry segments and is therefore not a unique fire scenario. Based upon a fire development in the switch room or in other areas of the development site 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. Surge protection devices are present in the Ring Main Units (RMUs) and in the switch room and all electrical equipment is earthed to reduce ignition risks. 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.

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 development 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 oil may start to decompose and vaporise, resulting in flammable gas bubbles including hydrogen and methane (Ref. [8]) 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. [9]). 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 EMFs in the range of 30 to 300 Hz.

4.10.2 Existing Standards

There are currently no existing standards in Australia for governing the exposure limits to ELF EMFs; however, the International Commission on Non-Ionizing Radiation Protection (ICNIRP) has provided some guidelines around exposure limits for prolonged exposure which limits the exposure to 2,000 milligauss (mG) for members of the public in a 24 hour period (Ref. [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 development site indicates the nearby residences adjacent to the area where the BESS will be developed are separated by over 500 m providing substantial distance for attenuation of EMFs. Based upon the typical levels which may be generated by transmission equipment the cumulative effect would not exceed the 2,000 mG limit for prolonged exposure. In addition, the closest residence is over 500 m away from the EMF generating sources at the BESS; hence, the potential for the EMF to exceed the accepted levels is considered negligible.

The Australian Radiation Protection and Nuclear Safety Agency (ARPANSA) advises that the strength of radiation decreases exponentially with distance from the source, and it will become indistinguishable from background radiation within 50 m of a high voltage power line and within 5 to 10 m of a substation. (Ref. [11]).

A field study was undertaken to characterise the EMF between the frequencies of 0 – 3 GHz at two large scale solar facilities operated by the Southern California Edison Company in Porterville and San Bernardino, (Ref. [12]).

The field study findings were adopted to estimate the EMF measurements for the development site. The findings are as follows:

- The highest DC magnetic fields were measured adjacent to the inverter (277 μT) and transformer (258 μT). These fields were lower than the ICNIRP's occupational exposure limit.
- The highest AC magnetic fields were measured adjacent to the inverter (110 μT) and transformer (177 μT). These fields were lower than the ICNIRP's occupational exposure limit.
- The strength of the magnetic field attenuated rapidly with distance (i.e. within 2-3 metres away, the fields drop to background levels).
- Electric fields were negligible to non-detectable. This is mostly likely attributed to the enclosures provided for the electricity-generating equipment.

As the strengths of EMF attenuate rapidly with distance, the ICNIRP reference level for exposure to the general public will not be exceeded and the impact to the general public in surrounding land uses is negligible.

As the potential for exposure to EMF exceeding the international guidelines is negligible, this incident has not been carried forward for further analysis.

4.11 Available Space for BESS Allocation Review

4.11.1 BESS Configuration

The DPHI has indicated in the past that assessment should be undertaken to show whether the allocated space for the BESS is sufficient to accommodate all the units that are planned to be installed. As a UL9540A report has been undertaken by Premise prior to this report's writing, the separation distances required for the BESS have been assessed and provided.

A Li-Ion battery may fault resulting in thermal decomposition and fire which may spread throughout the whole fire unit if not isolated / protected. A detailed analysis has been conducted in the UL 4950 A report which is available upon request. Based on the analysis it was concluded that incident propagation of the long side of the BESS would be unlikely to occur at a distance of 2 m and an alternating distance of 0.15 m or 1 m for the short side. The minimum separation requirement arrangement has been shown in **Figure 4-3**. Additionally, the proposed layout of the BESS includes a face-to-face separation distance of 3.048 m and is provided in **Figure 4-4**.

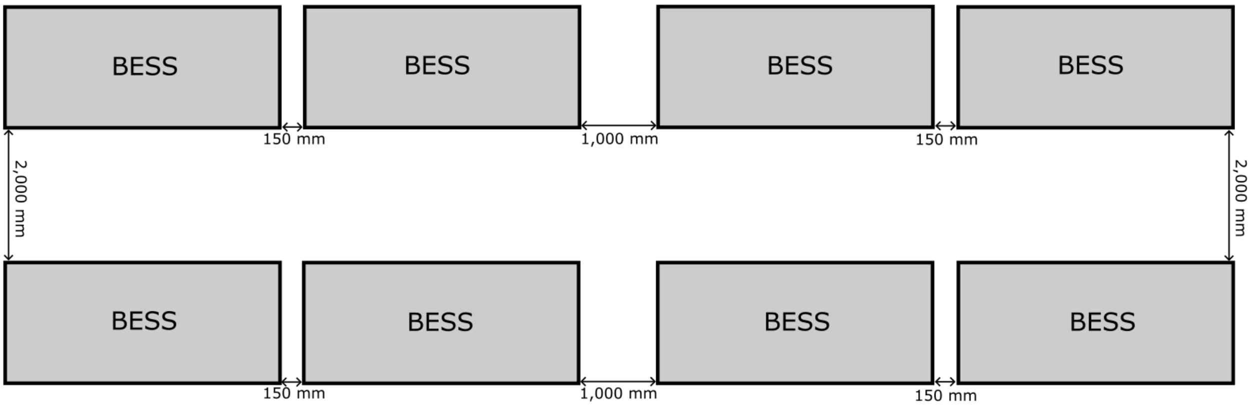

Figure 4-3: BESS Container Required Minimum Separation Distances

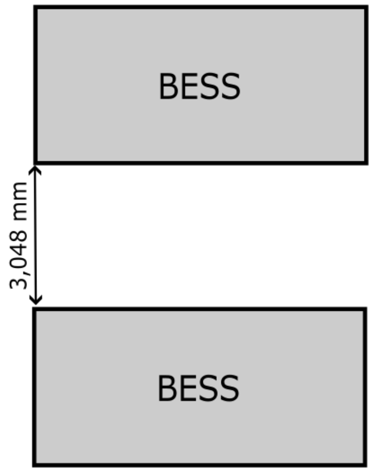

Figure 4-4: Proposed Finley BESS face to face separation Distances

Based on the analysis conducted above the following recommendations have been made:

- A BESS container shall not be located within 2 m when orientated side to side.
- Two BESS containers (BESS duplex) shall not be stored closer than 0.15 m when oriented side to side.
- A BESS duplex shall not be located within 1 m when oriented end to end.
- The UL 9540A test data shall be made available the DPHI as part of the detailed design phase.

The required separation distances will increase the total area a BESS container will occupy; therefore, it is necessary to confirm that there is sufficient land within the development site to accommodate the number of BESS containers proposed for the development. The dimensions of the BESS in addition to the required separation distances have been summarised in **Table 4-3**.

Table 4-3: BESS Area Requirements

Item	Value
Length (m)	6.06
Width (m)	2.44
BESS Area without separation (m^2)	14.79

Length with separation included (m)	7.21
Width with separation included (m)	6.44
Total Area per BESS with separation (m^2)	46.43
Number of BESS	80
Total Area Required (m^2)	3,715 m^2
BESS Compound	11,200 m^2

As can be seen the required area is 3,715 m^2 is less than the 11,200 m^2.

The arrangement of the BESS area in proximity to the other infrastructure and the dimensions of the BESS compound are provided in **Figure 4-5**. Therefore, even with additional conservatism for spacing or any restrictions at the development site not accounted for, there is ample area to locate the BESS to achieve the required separation distances calculated in this report.

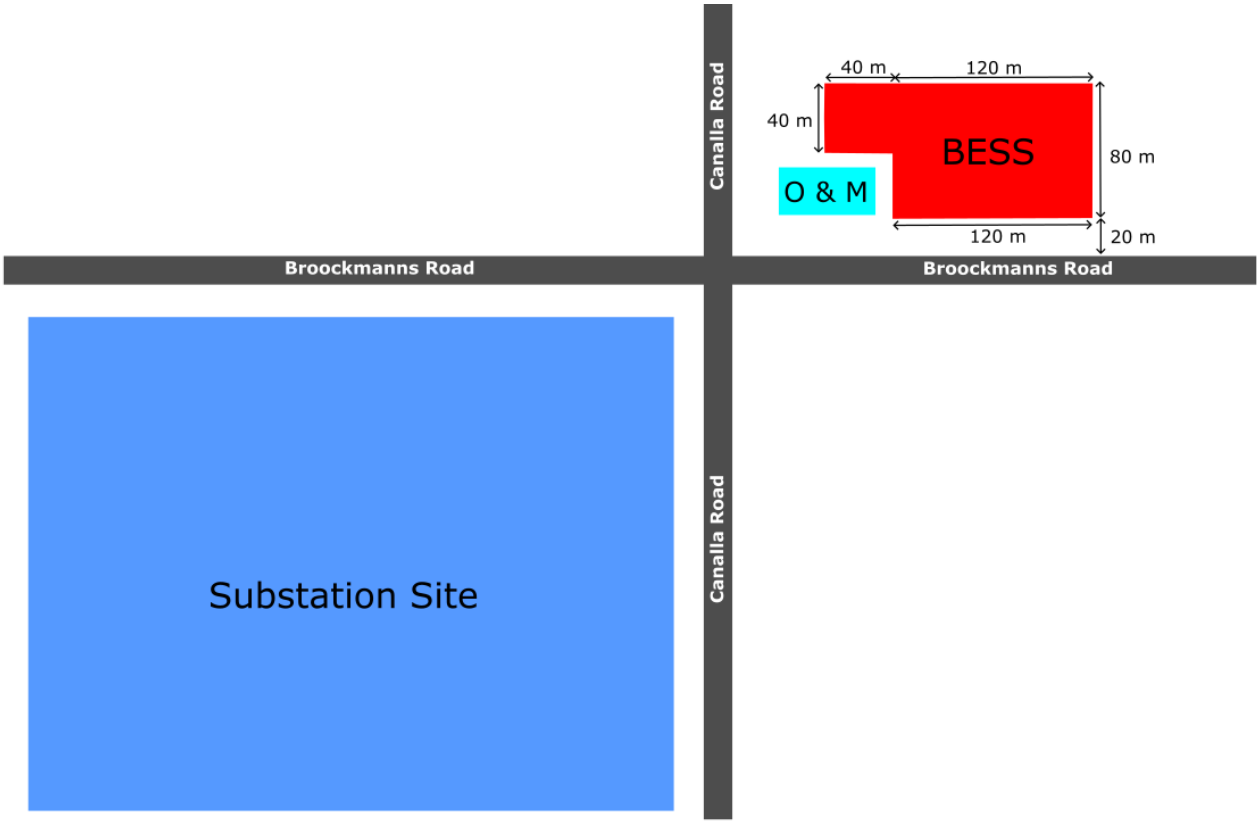

Figure 4-5: BESS Compound Area

4.11.2 Victorian Big Battery Findings

The Victorian Big Battery (VBB) had an issue during commissioning which ultimately resulted in the batteries thermally running away and a fire occurring which propagated from one BESS to the directly adjacent BESS. A fire incident investigation found that the propagation primarily occurred due to radiant heat from the initial fire impacted BESS melting a ventilation fan which then failed, falling onto the batteries below the vent which then heated to thermal runaway. Therefore, to minimise the potential for incident propagation between BESS the following additional recommendations have been made:

- Any ventilation fans or ducts in the BESS container shall be constructed of non-combustible materials.
- The ventilation fans shall be located such that they do not reside directly above batteries within the container.

The preferred BESS supplier has been selected for the development site and a UL 9540A report has been prepared. Hence, the assessment of the required separation distance is provided based upon battery specific test data. To support the separation requirements outlined in this report it is recommended that:

- The UL9540A test data for the batteries selected for the project shall be made available to the DPE to confirm that incident propagation isn’t possible at the distance recommended in this report.
- The fire protection details of the BESS containers and associated test data shall be made available to the DPE.

5.0 Conclusion and Recommendations

5.1 Conclusions

A hazard identification table was developed for the Finley BESS to identify potential hazards that may be present at the development 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. A review of the incidents carried forward for further analysis indicates that there were no observed offsite impacts.

Hence, based on the analysis presented in this report, the development site would only be classified as potentially hazardous and would be permitted within the current land zoning for the development site.

5.2 Recommendations

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

- 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 development site area whilst meeting the recommended clearances.
- A BESS container shall not be located within 2 m when orientated side to side.
- Two BESS containers (BESS duplex) shall not be stored closer than 0.15 m when oriented side to side.
- A BESS duplex shall not be located within 1 m when oriented end to end.
- The UL9540A test data for the batteries selected for the project shall be made available to the DPE to confirm that incident propagation isn't possible at the distance recommended in this report.
- The fire protection details of the BESS containers and associated test data shall be made available to the DPE.
- Any ventilation fans or ducts in the BESS container shall be constructed of non-combustible materials.
- The ventilation fans shall be located such that they do not reside directly above batteries within the container.

6.0 References

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Appendix A

Hazard Identification Table

Appendix A

A1. Hazard Identification Table

Area/Operation	Hazard Cause	Hazard Consequence	Safeguards
Battery Storage	• Failure of Li-ion battery protection systems	• Thermal runaway resulting in fire or explosion • Incident propagation through battery cells • Toxic smoke dispersion	• Batteries are tested by manufacturer prior to sale / installation • Overcharging and electrical circuit protection • Battery monitoring systems • Batteries composed of subcomponents (i.e. modules, 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 3000:2018 (Ref. [13]) • HVAC system • Blast panels and pressure relief vents • Gaseous fire suppression • UL9540A testing (**Appendix B**)
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	• Self-bunded transformer skids • Separated from combustible materials and sensitive receptors
	• Power surge to transformers (e.g. from lightning)	• Major failure of surge protection in transformer, vaporisation 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	• 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

B1. Detailed Consequence Analysis for Unit Separation Calculations

The following incidents are assessed for consequence impacts:

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

Each incident has been assessed in the sections below.

B2. Radiant Heat Flux

The heat flux (Q) for the view factor model is given by **Equation B-1**.

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

Where;

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

F = geometric view factor

τ = transmissivity

E = SEP (kW/m^2)

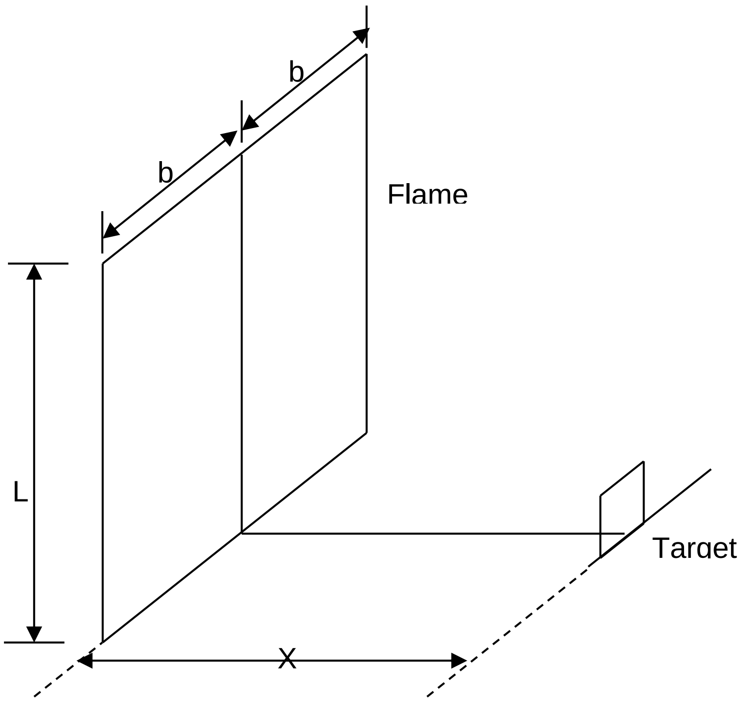
Each of the required inputs is determined in the sections following.

B3. View Factor

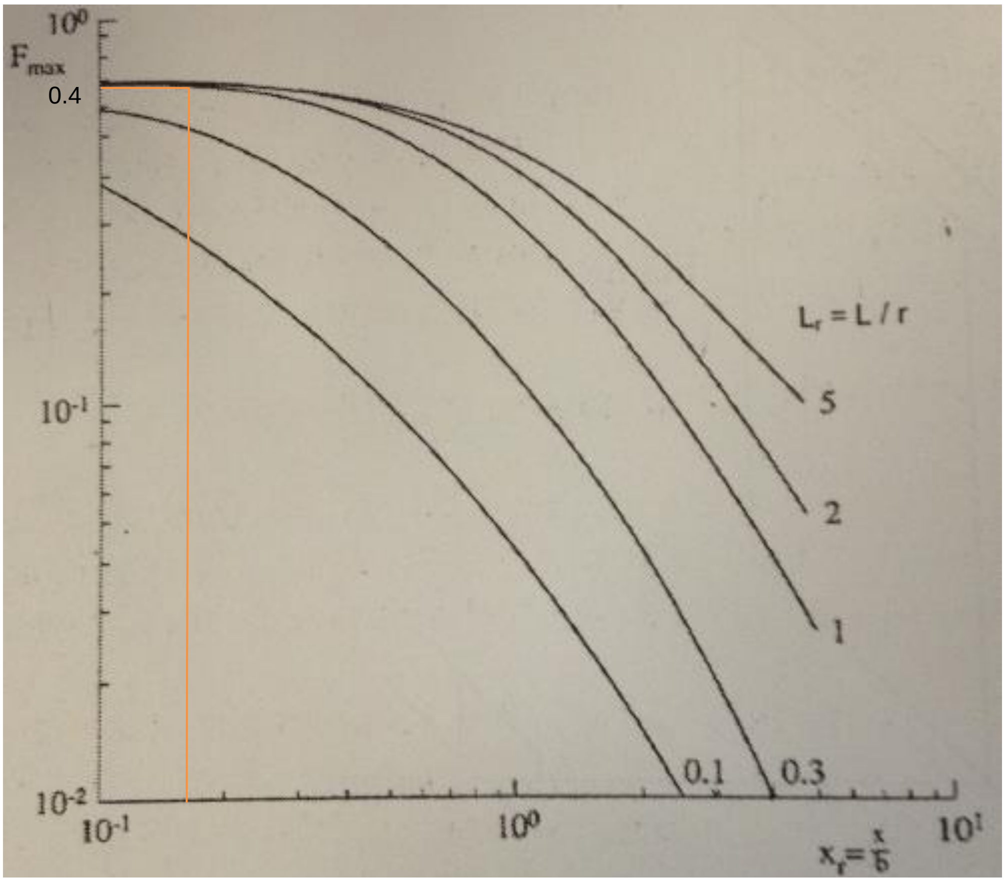
The view factor for a flat surface fire is estimated using the scenario shown in **Appendix Figure B-1** where the flame is the vertical surface of height L and length 2b with receiver located centrally and at a distance of X. Two dimensionless parameters are calculated, and the view factor read from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

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

$$X_r = \frac{x}{b} \quad \textbf{Equation B-3}$$



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



Appendix Figure B-2: Vertical Flame Maximum View Factor

B4. Transmissivity

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

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

Where:

$X(H_2O) = (R_H \times L \times S_{mm} \times 2.88651 \times 10^2)/T$

$X(CO_2) = L \times 273/T$

And;

R_H = percentage relative humidity (assumed 60%)

L = distance to target (m)

S_{mm} = saturated water vapour pressure in mm mercury at temperature (at 200°C S_{mm} = 11549)

T = temperature (473 K assumed air is heated to 200°C)

B5. Li-Ion Battery Fault, Thermal Runaway and Fire

The BESS units are speculative and have the assumed dimensions of 2.44 m wide x 6.06 m long. To determine the radiant heat impacts from the BESS in the event of a fire it is necessary to assume the height of the flame. The rule of thumb for most flammable liquid fires is that the height is 2 times the width of the flame; however, a review of the Victorian Big Battery (VBB) fire indicates that it did not align with short cut approach. Based upon the VBB it has been assumed that the maximum height of the flame is 1 m above the height of the BESS unit. From the VBB it was apparent that only the flame through the roof was exposed as a radiant surface; hence, the assumed flame height of 1 m above the BESS container has been taken as the value of L = 3.9 m for input into **Equation B-2**. The width of the flame is estimated to extend

It is necessary to calculate the Surface Emissive Power (SEP) of the radiant surface to calculate the radiant heat at the target. For the purposes of this assessment, it has been assumed that the temperature of a BESS fire is 1,000°C or 1,273.15 K. The following equation can be used to estimate the SEP of the flame:

$$SEP = \varepsilon \sigma T^4$$ **Equation B-5**

Where:

ε = flame emissivity (taken as 0.78 (Ref. [14]))

$\sigma = 5.67 \times 10^{-11}$ kW/m^2.k^4

T = Temperature (1273.15 K)

Substituting into the above equation yields:

$$SEP = 0.78 \times 5.67 \times 10^{-11} \times 1273.15^4 = 116 \frac{kW}{m^2}$$

The radiant surface will change depending on the side of the BESS selected; hence, it is necessary to assess two flame surfaces to understand the length and width flame surfaces. From **Equation B-2** the value for Lr is constant for each direction with the results for this BESS summarised in **Appendix Table B-1**.

Appendix Table B-1: Values of Lr

BESS Side	Value of Lr
Long side	1.29
Short side	3.20

The model works by calculating the value for Xr which is based on a distance from the fire. Therefore, as the distance increases the value of Xr will change altering the value read from **Appendix Figure B-2** and the impact of transmissivity. The radiant heat value of concern is 23 kW/m^2 which is the defined value for incident propagation. Therefore, a range of distances have been calculated for each BESS side with the aim of calculating the distance required to prevent incident propagation. **Appendix Table B-2** has been used to calculate the view factors for each side of the BESS at a range of distances.

Appendix Table B-2: Values of Xr and View Factor

Distance (m)	Long Side		Short Side	
	Xr	View Factor	Xr	View Factor
0.5	0.17	0.4	0.41	0.1
1	0.33	0.3	0.82	0.08
1.5	0.50	0.22	1.23	0.4
2	0.66	0.2	1.64	0.04
2.5	0.83	0.1	2.05	0.03
3	0.99	0.05	2.46	0.01

The transmissivity is then calculated for each of the distances as shown in **Appendix Table B-3**. It is noted that the only variable that impacts the transmissivity is the distance; hence, these will be the same for the distances under observation.

Appendix Table B-3: Transmissivity Values

Distance (m)	Transmissivity
0.5	0.97
1	0.97
1.5	0.97
2	0.96
2.5	0.96
3	0.96

The SEP, view factor and transmissivity are then combined to determine the overall radiant heat experience at each of the distances as shown in **Appendix Table B-4**.

Appendix Table B-4: Radiant Heat Values

Distance (m)	Radiant Heat (kW/m2)	
	Long Side	Short Side
0.5	45.0	11.3
1	33.8	9.0
1.5	24.8	4.6
2	22.3	4.2
2.5	11.1	3.3
3	5.6	1.1