# Preliminary Hazard Analysis

## Brewongle Solar Farm

Edify Energy Pty Ltd
Document No. RCE-24143_EdifyEnergy_PHA_Final_4Mar25_Rev(0)
Date 4/03/2025

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Edify Energy Pty Ltd

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Date 4/03/2025

# Quality Management

| Rev | Date | Remarks | Prepared By | Reviewed By |
|---|---|---|---|---|
| A | 22 July 2024 | Draft issue for comment | Moji Seyedi | Renton Parker |
| 0 | 4 March 2025 | Issue Final | Renton Parker | Jason Costa |

# Executive Summary

## Background

Riskcon Engineering has been engaged by Environmental Resources Management Australia (ERM) Pty Ltd to conduct a Preliminary Hazard Analysis (PHA) for the Brewongle Solar Farm, located at 315, Tarana Road, Brewongle NSW 2795. The Project will consist of 90 MWac of installed Photovoltaic (PV) panels with a peak power of 90.0 MW. The Project is exploring a 90 MW / 180 MWh centralised or decentralised Battery Energy Storage System (BESS) options.

The discharge capacity of the proposed options exceed 30 MW; hence, the Secretary Environmental Assessment Requirements (SEARs) require the preparation of a Preliminary Hazard Analysis (PHA) to assess the risk profile of the development in accordance with the Hazardous Industry Planning Advisory Paper (HIPAP) No. 6 (Ref. [1]) utilising criteria from HIPAP No. 4 (Ref. [2]).

This report supports a State Significant Development (SSD) Development Consent approval under Part 4, Division 4.7 of the *Environmental Planning and Assessment Act 1979* (SSD-64834490), as part of the Environmental Impact.

## Conclusions

A hazard identification table was developed for the Brewongle Solar Farm PV & BESS project to identify potential hazards that may be present at the Project as a result of operations or storage of materials. A review of the facility indicated that the potential for offsite impact is unlikely due to the size and nature of the site; however, it was identified that there is the potential for incident propagation between BESS units; hence, these were carried forward for consequence analysis. The consequence analysis was performed to define minimum separation distances that must be achieved between BESS units to prevent incident propagation between BESS units.

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

## Recommendations

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

- The site induction shall include information regarding the gas pipeline including location and protections to identify the gas pipeline (i.e., marker tape, etc.).
- All personnel working at the site shall be inducted prior to commencing any work.
- Appropriate marking shall be provided along the length of the gas pipeline as required to minimise the potential for unauthorised works occurring within the vicinity of the gas pipeline, in conjunction with the Site Induction and relevant site-specific construction management plans.
- A BESS container shall not be located within 2 m of an adjacent BESS container when orientated side to side. The separation distance may be reduced following selection of a supplier and the results of the UL9540A test data for the selected BESS container.
- A BESS container shall not be located within 1 m of an adjacent BESS container when orientated end to end. The separation distance may be reduced following selection of a supplier and the results of the UL9540A test data for the selected BESS container.

- Any ventilation fans or ducts in the BESS container shall be constructed of non-combustible materials.
- The UL9540A test data for the batteries selected for the project shall be made available 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 during detailed design.
- The maximum storage capacity at a distributed BESS location shall not exceed 20 MWh.
- The separation distance between any two BESS locations shall be 20 m.
- The minimum separation distance between a BESS location and the site boundary shall be 20 m.
- The minimum separation distance between a BESS location and the pipeline shall be 50 m.
- It is noted that the recommendation separation distances a worst case to be conservative based on a flexible design and that the BESS storage area would be reviewed to ensure that all required separation distances can be achieved as detailed design commences (i.e. specific battery supplier details are available).

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# Abbreviations

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

# 1.0 Introduction

## 1.1 Background

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## 1.2 Objectives

The key objectives of this PHA are to:

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

## 1.3 Scope of Services

The scope of work is to complete a PHA study for the Brewongle Solar PV and BESS options located at 315 Tarana Road, Brewongle NSW 2795.

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# 2.0 Methodology

## 2.1 Multi-Level Risk Assessment

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

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

**Table 2-1: Level of Assessment PHA**

| Level | Type of Analysis | Appropriate If: |
|---|---|---|
| 1 | Qualitative | No major off-site consequences and societal risk is negligible |
| 2 | Partially Quantitative | Off-site consequences but with low frequency of occurrence |
| 3 | Quantitative | Where 1 and 2 are exceeded |

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

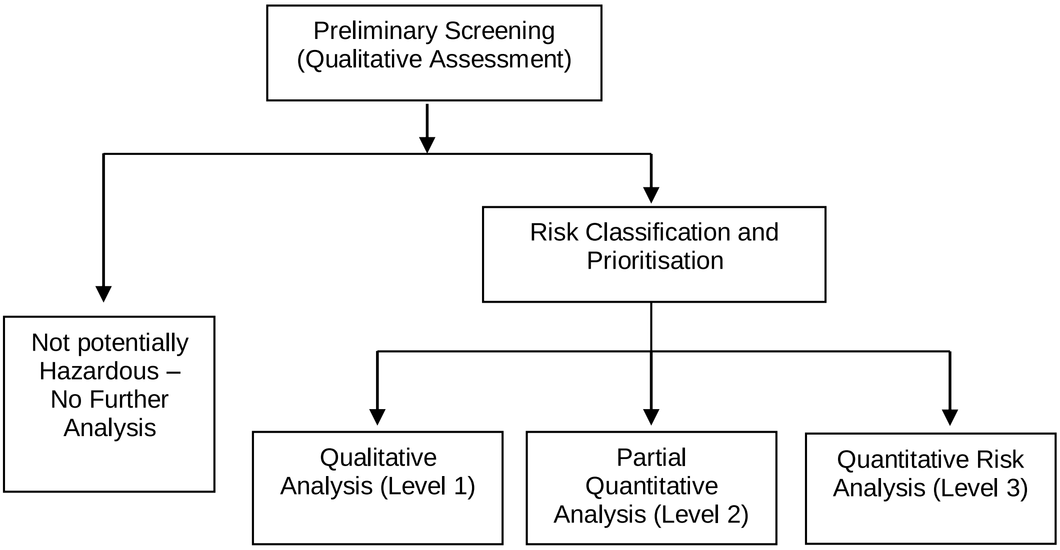


**Figure 2-1: The Multi-Level Risk Assessment Approach**

Based on the type of DGs to be used and handled at the proposed project, a **Level 2 Assessment** was selected for the Site. This approach provides a qualitative assessment of those DGs of lesser quantities and hazard, and a quantitative approach for the more hazardous materials to be used on-site. This approach is commensurate with the methodologies recommended in “Applying SEPP 33’s” Multi Level Risk Assessment approach (DPIE, 2011).

## 2.2 Risk Assessment Study Approach

The methodology used for the PHA is as follows:

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

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

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

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

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

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

# 3.0 Site Description

## 3.1 Site Location

The Project is located at 315 Tarana Road, Brewongle NSW 2795 which is northwest of Sydney and is approximately 12 km southeast of Bathurst. **Figure 3-1** shows the regional location of the Project in relation to Sydney and Bathurst, respectively.

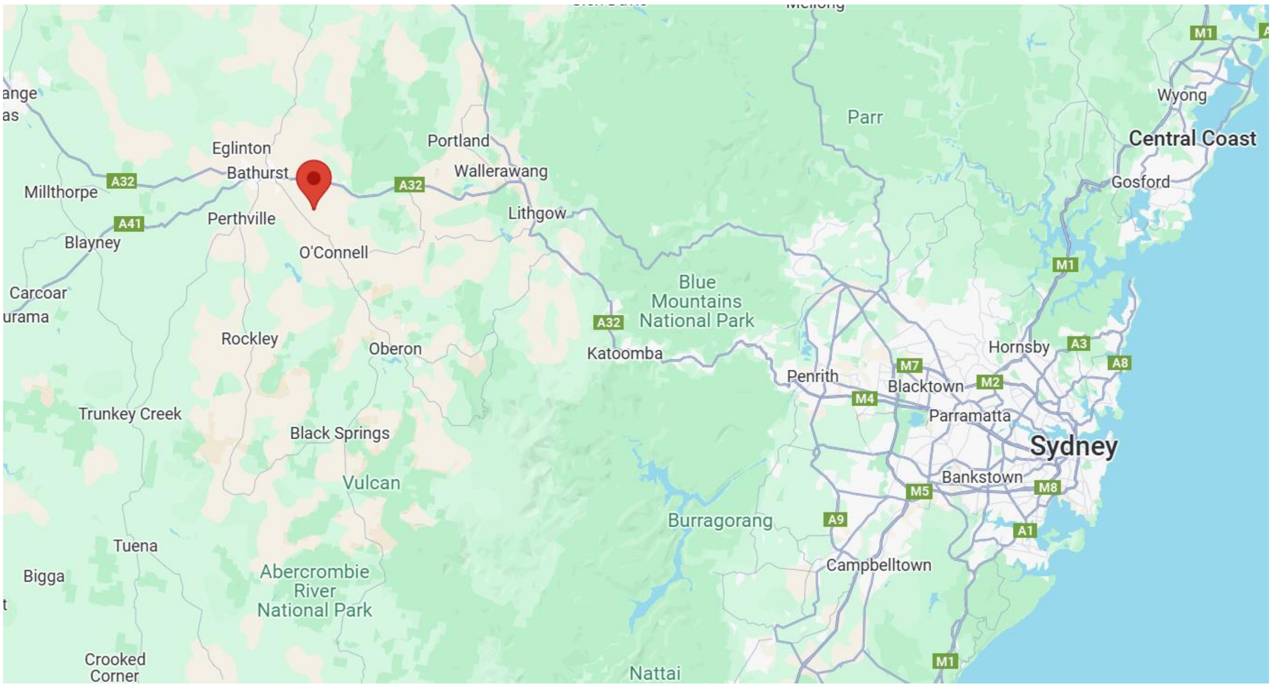


**Figure 3-1: Site location to Sydney and Bathurst**

## 3.2 Adjacent Land Uses

The land is located in a regional / rural area surrounded by the following land uses, which are adjacent to the site:

- North – Farmland / Railway (RU1 – Rural / SP2 - Infrastructure)
- South – Farmland (RU1 - Rural)
- East – Farmland (RU1 - Rural)
- West – Farmland (RU1 - Rural)

## 3.3 Sensitive Receptors

The nearest residential locations (R) are shown in **Figure 3-2**.

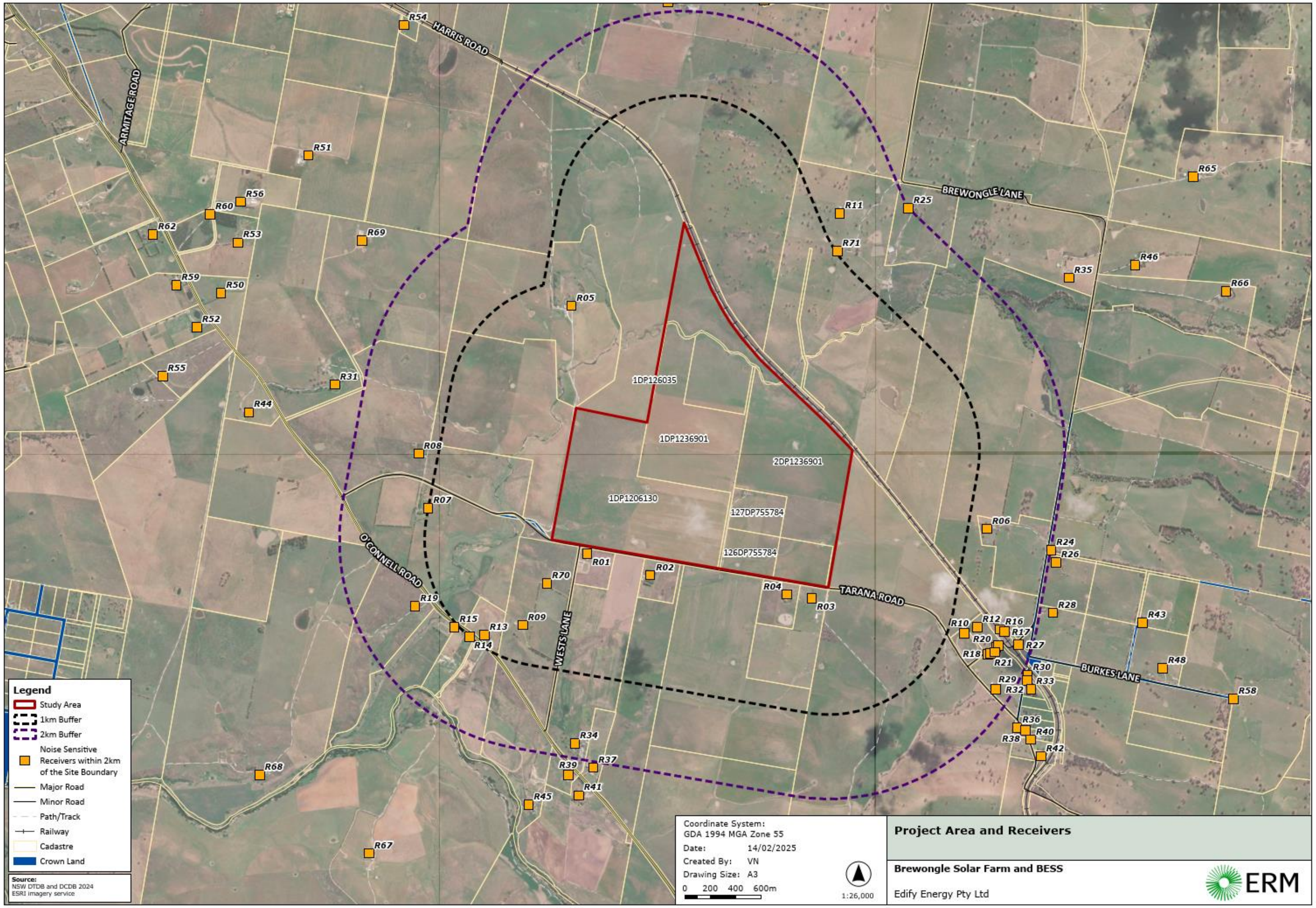


**Figure 3-2: Sensitive Receptors**

## 3.4 Detailed Description

The purpose of the project 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 generated from the photovoltaic generator array consists of photovoltaic modules connected in serial and parallel associations with total rated power of 90 MWac, and either a 90 MW / 180 MWh centralised or decentralised BESS.

Which 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.

### 3.4.1 String Combiner Box

The string boxes collect the power generated by the DC array, connect the strings in parallel to the inverter, and provide electrical protection to the PV field. To match the number of inputs of the inverters, several parallel strings will be concentrated to function as a single circuit. The string boxes will be installed in a shaded area and shall be easily accessible to facilitate maintenance. They will be placed behind the PV modules and use existing structure poles if possible, so that they remain shaded and to prevent damage caused by rainwater or other meteorological phenomena.

### 3.4.2 Inverters

The inverter converts the direct current produced by the photovoltaic modules to alternating current. It is composed of the following elements:

- One or several DC-to-AC power conversion stages, each equipped with a maximum power point tracking system (MPPT). The MPPT will vary the voltage of the DC array to maximize the production depending on the operating conditions.
- Protection components against high working temperatures, over or under voltage, over or under-frequencies, minimum operating current, mains failure of transformer, anti-slanding protection, protection against voltage gaps, etc. In addition to the protections for the safety of the staff personnel.
- A monitoring system, which has the function of relaying data regarding the inverter operation to the owner (current, voltage, power, etc.) and external data from monitoring of the strings in the DC array (if a string monitoring system is present).

Further details of the selected inverters and their quantities are shown in **Table 3-1**.

**Table 3-1: Details on Inverters Arrangement and Characteristics**

| Equipment | Quantity | DC Inputs | PV Power DC | DC/AC Ratio | BESS DC Converters Power |
|---|---|---|---|---|---|
| Inverter | 14 | 1 String Box of 7 string<br>20 String Box of 12 string | 5,002 kW | 1.087 | 2,300 kW |

| Equipment | Quantity | DC Inputs | PV Power DC | DC/AC Ratio | BESS DC Converters Power |
|---|---|---|---|---|---|
|  | 4 | 1 String Box of 6 string<br>20 String Box of 12 string | 4,982 kW | 1.083 | 2,300 kW |

### 3.4.3 Power transformer

The power transformer raises the voltage of the inverter AC output to achieve a higher efficiency transmission in the power lines of the photovoltaic plant.

### 3.4.4 Power station

The power stations or transformer stations are outdoor platforms. The voltage of the energy collected from the solar field is increased to a higher level to facilitate the evacuation of the generated energy. The inverters and power transformers will be housed in the power station. **Figure 3-3** shows an outdoors power station.

### 3.4.5 DC Coupled Battery Energy Storage System (BESS)

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

The BESS will enable the solar farm to be a flexible energy generation source, providing energy when it is required the most. The BESS converts electrical energy into chemical energy and stores the energy internally. It may also contribute towards network security Frequency Control Ancillary Services (FCAS) in the Region. A typical BESS is shown in **Figure 3-4**. In addition, layout for the BESS is contained in the layout shown in **Figure 3-5** which shows potential BESS storage configurations.

**Figure 3-3: Example of Outdoor Power Station**

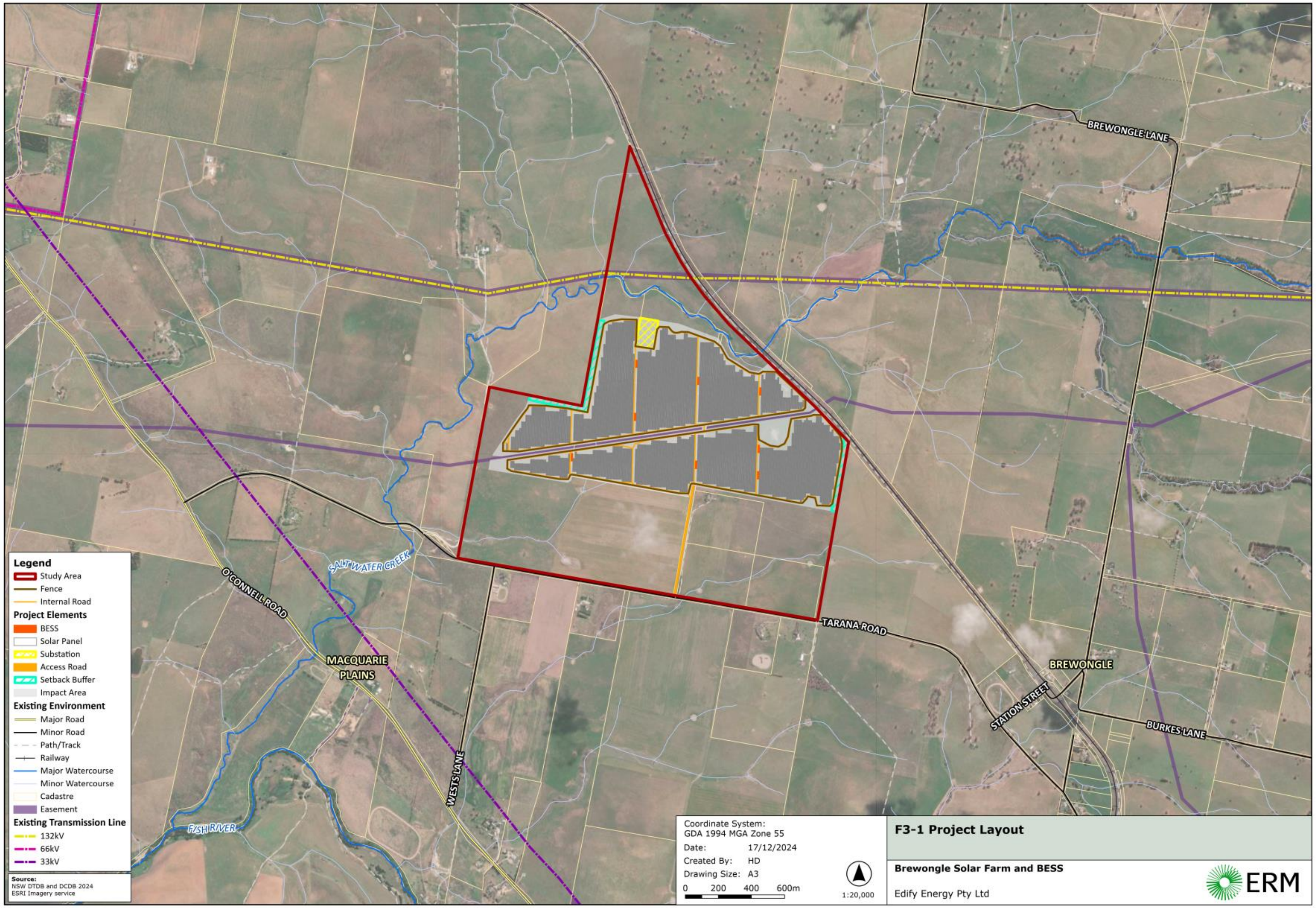
**Figure 3-4: Typical BESS**

## 3.5 Quantities of Dangerous Goods Stored and Handled

The classes and quantities of DGs to be approved in the project are summarised **Table 3-2**.

**Table 3-2: Maximum Classes and Quantities of Dangerous Goods Stored**

| Area | Class | Description | Quantity |
|---|---|---|---|
| BESS (Centralised) | 9 | Lithium Batteries (2 MWh capacity/unit) | 90 units |
| BESS (Decentralised) | 9 | Lithium Batteries (2 MWh capacity/unit) | 18 units |
| Power Station Transformer | C1 | Transformer oils | 4,000 L |



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ESRI Imagery service

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F3-1 Project Layout

Brewongle Solar Farm and BESS

Edify Energy Pty Ltd

Figure 3-5: Layout

# 4.0 Hazard Identification

## 4.1 Introduction

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

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

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

  Those incidents exceeding 4.7 kW/m$^2$ at the site boundary are carried forward for further assessment (i.e. frequency and risk). This is a conservative approach, as HIPAP No. 4 (Ref. [2]) indicates that values of heat radiation of 4.7 kW/m$^2$ should not exceed 50 chances per million per year at sensitive land uses (e.g. residential). It is noted that the closest residential area is approximately 620 m from the site, hence, by selecting 4.7 kW/m$^2$ as the consequence impact criteria (at the adjacent land uses), the assessment is considered conservative.

- *Explosion* - It is noted in HIPAP No. 4 (Ref. [2]) that a criterion is provided for the maximum permissible explosion over pressure at the site boundary (7 kPa) above which the risk of injury may occur and therefore the risk must be assessed. Hence, to assist in screening those incidents that do not pose a significant risk, for this study, incidents that result in an explosion overpressure less than 7 kPa, at the site boundary, are screened from further assessment. Those incidents exceeding 7 kPa, at the site boundary, are carried forward for further assessment (i.e. frequency and risk). Similarly, to the heat radiation impact discussed above, this is conservative as the 7 kPa value listed in HIPAP No. 4 relates to residential areas, which are over approximately 620 m from the site.

- *Toxicity* – Toxic by-products of combustion may be generated by a BESS fire; hence, toxicity has been assessed.

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

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

## 4.2 Properties of Dangerous Goods

The type of DGs and quantities stored and used at the site has been described in **Section 4**. **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 60.5ºC. 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.
- Li-ion battery fire and toxic gas dispersion.
- Electrical equipment failure and fire.
- Transformer internal arcing, oil spill, ignition and bund fire.
- Transformer electrical surge protection failure and explosion
- Electromagnetic field Impacts.

Each identified scenario is discussed in further detail in the following sections.

## 4.4 Li-Ion Battery Fault, Thermal Runaway and Fire

Lithium ion (Li-ion) batteries are composed of a metallic anode and cathode which allows for electrons released from the anode to travel to the cathode where positively charged ions in the solute migrate to the cathode and are reduced. The flow of electrons provides the source of energy which is discharged from a battery and used for work. In a Li-ion battery, the lithium metal composites (a composite of lithium with other metals such as cobalt, manganese, nickel, or any combination of these metals) oxidises (loses an electron) becoming a positively charged ion in solution which migrates through the battery separator to the cathode. At the same time, the lost electron travels through the circuit to the cathode. The lithium ions in solution then recombine with the electron at the cathode forming lithium metal within the cathodic metal composite. This process is shown in **Figure 4-1**.

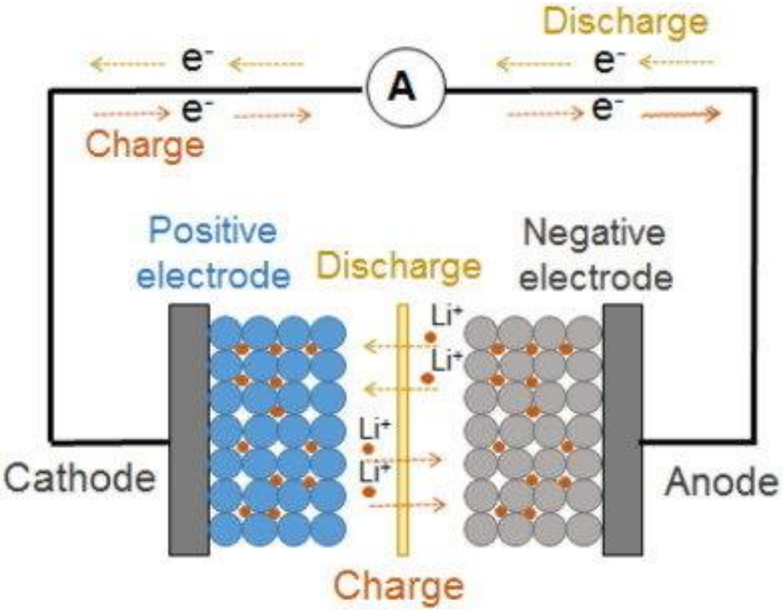


**Figure 4-1: Cathode and Anode of a Battery (Source Research Gate)**

Initial lithium batteries were designed around lithium metal (i.e. no composite structure) due to the high energy density yielded by the metal. However, when overcharging a battery, lithium ions can begin to plate on the anode in the form of lithium dendrites. Eventually, the dendrites pierce the separator within the battery resulting in a short of the battery which could result in heat, fire, or explosion of the battery. The technology evolved to move away from lithium metal to lithium ions (held within composite materials) which reduced the incidence of lithium dendrites forming resulting in an overall safer battery.

Despite the improvement in battery technology, there are several degradation mechanisms that are still present within the battery which can result in thermal runaway. These include:

- Chemical reduction of the electrolyte at the anode
- Thermal decomposition of the electrolyte
- Chemical reduction of the electrolyte at the cathode
- Thermal decomposition by the cathode and the anode
- Internal short circuit by charge effects

These effects arise primarily as a result of high discharge, overcharging, or water ingress into the battery which results in a host of by-products being formed within the battery during charge and discharge cycles.

As a result, Li-ion batteries are equipped with several safety features to prevent the batteries from charging or discharging at voltages which result in battery degradation, leading to shorting of the battery and thermal runaway. Safety features generally include:

- Shut-down separator (for overheating)

- Tear-away tab (for internal pressure relief)
- Vent (pressure relief in case of severe outgassing)
- Thermal interrupt (overcurrent/overcharging/environmental exposure)

These features are designed to prevent overcharging or excessive discharge, pressurisation arising from heat generated at the anode or from battery contamination. Protection techniques for Li-ion batteries are standard; hence, the potential for thermal runaway to occur in normal operation is incredibly low with the only exceptions being where batteries are manufactured poorly or due to manufacturing faults, or battery damage (i.e. battery cell is ruptured as this can short circuit the battery resulting in thermal runaway).

Given the ubiquitous nature of Li-ion batteries, thermal runaway is not considered a credible threat when used in a battery storage. 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.

Notwithstanding this, there is the potential for thermal runaway to occur which may consume the whole battery module which may result in offsite impacts or propagation risks to adjacent modules. Therefore, this incident has been carried forward for further analysis.

## 4.5 Li-ion Battery Fire and Toxic Gas Dispersion

As noted in **Section 4.4**, there is the potential for a BESS failure to occur resulting in a fire which may result in toxic by-products of combustion to form. 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
- Fluorine gases

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

### 4.5.1 Carbon Dioxide

Carbon dioxide is a colourless, odourless, dense gas which is naturally forming and is present in the atmosphere at concentrations around 415 ppm (0.0415%). At low concentrations carbon dioxide is physiologically impotent and at low concentrations does not appear to have any toxicological effects. However, as the concentration grows it increases the respiration rate with short term Exposure Limit (STEL) occurring at 30,000 ppm (3%), above 50,000 ppm (5%) a strong respiration effect is observed along with dizziness, confusion, headaches, and shortness of breath. Concentrations in excess of 100,000 ppm (10%) may result in coma or death.

Carbon dioxide is a by-product of combustion where hydrocarbon or carbon-based materials are involved. A typical combustion reaction producing carbon from a hydrocarbon has been provided in **Equation 4-1**. This reaction proceeds when there is an excess of oxygen to the fuel being consumed and is known as complete combustion as it is the most efficient reaction pathway.

$$\boldsymbol{C_3H_8(g) + 5O_2(g) \rightarrow 3Co_2(g) + 4H_2O(g)}$$

**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, it is not considered that the formation of carbon dioxide in a fire would be sufficient to result in downwind impacts sufficient to cause injury or fatality. In other words, there would be insufficient production of carbon dioxide to generate a plume of sufficient concentration to displace the required oxygen for a significant downwind consequence to occur. Therefore, this incident has not been carried forward for further analysis.

### 4.5.2 Carbon Monoxide

Carbon monoxide 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**.

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

As noted, in **Section 4.5.1** there is the potential for a fire to occur with the BESS units which could form carbon monoxide if there is insufficient oxygen to sustain complete combustion. However, it is noted that the combustible load within the BESS which could result in the formation of carbon monoxide is relatively low compared to the available oxygen in the surrounding atmosphere. Therefore, it is considered that the formation of carbon monoxide at levels which would result in a substantial downwind impact are not considered credible. Therefore, this incident has not been carried forward for further analysis.

### 4.5.3 Fluorine 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. [6]).

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

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

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

$$\boldsymbol{LiPF_6 + H_2O \rightarrow LiF + POF_3 + 2HF}$$ **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 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. [6]). 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. While there is the potential for a HF dispersion to occur in the event of a fire that may have substantial downwind impacts, the location of the BESS is rural with low population densities with substantial distances to the closest receptors. Therefore, it is expected that the HF would disperse prior to impacting sensitive receptors. Subsequently, this incident has not been carried forward for further analysis.

## 4.6 Electrical Equipment Failure and Fire

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

The type of equipment 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.

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

Transformers contain oil which is used to insulate the transformers during operation. If arcing occurs within the transformer (e.g. due to a low oil level), the high energy passing through the coolant vaporises the oil into light hydrocarbons (methane, ethane, acetylene, etc.) resulting in rapid pressurisation within the reservoir. To minimise the likelihood of such occurrence, transformers are fitted with a low oil pressure switches and a pressure surge switch (Buckholtz relay). These devices identify potential oil and pressure events within the transformer, isolating power and alarming operators.

Notwithstanding the protection systems, if the pressure rise exceeds the structural integrity of the reservoir, and the installed pressure relief devices, the reservoir can rupture allowing the release of oil into the bund. The rupture also allows oxygen to enter the reservoir. The temperature of the gases is above the auto ignition point, but this does not occur until oxygen is present. When oxygen enters the reservoir, the gases auto ignite which generates sufficient heat to ignite the oil in the bund. Notwithstanding this, transformers are ubiquitous units with a low potential for failure and the separation distance to the site boundary and other adjacent units would be unlikely to result in incident propagation and offsite impacts. Therefore, this incident has not been carried forward for further analysis.

## 4.8 Transformer Electrical Surge Protection Failure and Explosion

Transformers generate large amounts of heat as a result of the high electrical currents that pass through them; hence, oil is used as an insulating material within the transformers to protect the mechanical components. However, if the transformer gets an extreme surge of energy, such as that which could occur due to a lightning strike, and the electrical surge protection measures fail, the mineral oil may start to decompose and vapourise, resulting in gas bubbles of hydrogen and methane (Ref. [7]) as temperatures above the autoignition of the gases.

The formation of gases will increase the pressure within the transformer which can result in the transformer structure rupturing which allows the ingress of oxygen. As the oxygen enters, the concentration of flammable gases falls within the explosive limits which are above their autoignition temperatures which ignite resulting in increased formation of hot gaseous products resulting in an explosion. The explosion may generate significant overpressure, sparks and fire and would result in a whole transformer fire, as discussed in **Section 4.7**.

In order to protect against overheating and explosions, transformers have surge protection which programs them to shut down upon detection of an energy spike. However, this can have a slight delay which is too slow to stop an electrical overload, such as in the case of a major lightning strike or significant oil deterioration, leakage of water into the transformer, and physical damage such as a fallen tree (Ref. [8]). Therefore, there is the potential for an explosion to occur which may result in offsite impacts; however, as noted, these units are ubiquitous and have a low potential for failure. Therefore, this incident has not been carried forward for further analysis.

## 4.9 Electromagnetic Field Impacts

### 4.9.1 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.

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

### 4.9.2 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. [9]).

**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 due to the inverse square law (i.e. the intensity is reduced by the square of the distance).

**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 |

### 4.9.3 Exposure Discussion

A review of the site indicates there are no immediate residences adjacent to the area where the solar farm or BESS will be developed providing substantial distance for attenuation of EMFs. Based upon the typical levels which may be generated by transmission equipment the cumulative effect would not exceed the 2,000 mG limit for prolonged exposure. In addition, the closest residence is approximately 700 m away from the EMF generating sources at the solar farm; 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.

## 4.10 Gas Pipeline Impacts

A review of the surrounding area indicates there is a buried gas pipeline running through the Project Area. Incidents arising from the BESS and transformers may have an impact upon the gas pipeline which could result in a loss of containment and associated incidents (i.e. jet fire, flash fire, explosions, etc.).

Based upon the hazard identification conducted, the only real threats to the gas pipeline during operation are from BESS fires which will emit radiant heat. However, as the pipeline is buried, the earth above the pipeline will provide shielding from the radiant preventing heating or thermal damage to the pipeline.

The only other threats to the pipeline occur during the construction of the BESS and solar farm whereby any excavation works may result in the pipeline being impacted and damaged and subsequent loss of containment or create a point where corrosion can take hold resulting in an eventual failure as the metal pipework is corroded. Typical protection systems around pipelines include “before you dig” to identify the location of pipelines, marker signs and marker tape. The aim is to identify a pipeline before undertaking work or to alert site personnel the presence of a pipeline, or in the worst case if excavation occurs the marker tape is dragged to the surface before excavation impacts the actual pipeline.

The location of the pipeline is already known; hence, there is a low potential for excavation work to occur around the pipeline. In the event of a site error resulting in excavation along the pipeline, the marker tape should be identified prior to impact; however, this may only be the case if the operator is aware of what the marker tape means. Assuming, the protection systems work as intended, the potential damage to the gas pipeline should be minimised preventing damage and potential incident escalation.

It is noted, the protection of the gas pipeline relies on personnel working in the area to be aware of the gas pipeline and the protections associated with it. Therefore, to improve site personnel knowledge, the following recommendations have been made:

- The site induction shall include information regarding the gas pipeline including location and protections to identify the gas pipeline (i.e., marker tape, etc.).
- All personnel working at the site shall be inducted prior to commencing any work.
- Appropriate marking shall be provided along the length of the gas pipeline as required to minimise the potential for unauthorised works occurring within the vicinity of the gas pipeline, in conjunction with the Site Induction and relevant site-specific construction management plans.

It is noted that Edify and APA Group have conducted a preliminary risk workshop on the proposed project and potential impacts on the gas pipeline. The intention is to undertake subsequent risk workshops as the design progresses. Currently APA Group has not expressed any concerns with the current proposal and the pipeline.

Based upon the low risk of interaction with the gas pipeline based upon the protection systems incorporated and the recommendation induction, training and markings, it is considered that the potential for an offsite incident to occur as a result of the gas pipeline is negligible; hence, this incident has not been carried forward for further analysis.

# 5.0 Consequence Analysis

## 5.1 Incidents Carried Forward for Consequence Analysis

The following incident(s) were identified to have potential to impact off site:

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

The cited incident has been assessed in the following sections.

## 5.2 Li-ion Battery Fault, Thermal Runaway and Fire

There is potential that a Li-Ion battery may fault resulting in thermal decomposition and fire which may spread throughout the whole BESS fire if not isolated / protected. A detailed analysis has been conducted in **Appendix B** and the radiant heat impact distances estimated for propagation are shown in **Table 5-1**.

**Table 5-1: Radiant Heat from a Li-Ion Battery Fire**

| Distance (m) | Radiant Heat (kW/m$^2$) | |
|---|---|---|
| | Long Side | Short Side |
| 0.5 | 116.0 | 34.8 |
| 1 | 39.4 | 19.1 |
| 1.5 | 28.7 | 11.0 |
| 2 | 21.8 | 8.7 |
| 2.5 | 18.3 | 6.5 |
| 3 | 14.9 | 5.3 |

### 5.2.1 Centralised BESS Option

Based on the analysis it can be seen that incident propagation on the long side of the BESS would be unlikely to occur at a distance of 2 m and for the long side a distance of 1 m. The arrangement has been shown in **Figure 5-1**.

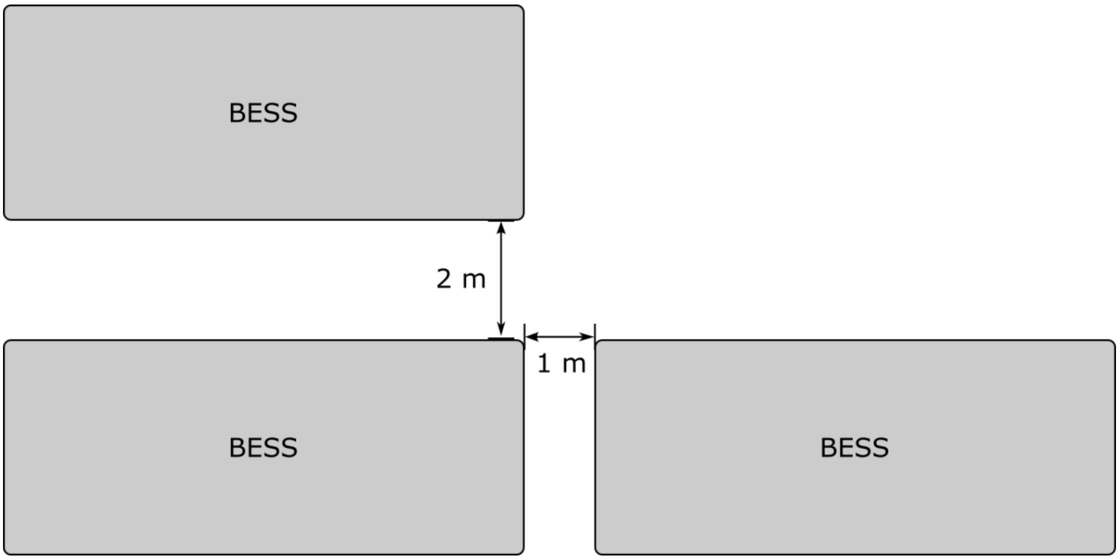


**Figure 5-1: BESS Container Required Separation Distances**

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

- A BESS container shall not be located within 2 m of an adjacent BESS container when orientated side to side. The separation distance may be reduced following selection of a supplier and the results of the UL9540A test data for the selected BESS container.
- A BESS container shall not be located within 1 m of an adjacent BESS container when orientated end to end. The separation distance may be reduced following selection of a supplier and the results of the UL9540A test data for the selected BESS container.

It is noted that the modelling results should be used as a guide for ongoing project development. As the models assume a conservative worst-case scenario, it is expected that the ultimate technology selection will provide further detail that can be used as the basis to reduce the recommended spacing requirements. Therefore, the total area required for the BESS units will be calculated in the detailed design phase of the project based of UL9540A test report.

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 project area to accommodate the number of BESS containers proposed for the development. The dimensions of the BESS, along with separation distances have been summarised in **Table 5-2**. The following assessment applies to the centralised BESS option as in the decentralised option BESS units are not located near other units thus achieving the required separation.

**Table 5-2: BESS Area Requirements**

| Item | Value |
|---|---|
| Length (m) | 6.07 |
| Width (m) | 2.44 |
| BESS Area without separation ($m^2$) | 14.8 |
| Length with separation included (m) | 8.07 |
| Width with separation included (m) | 6.44 |
| Total Area per BESS with separation ($m^2$) | 52 |
| Energy Storage per Unit | 2 MWh |
| Number of BESS (180 MWh) | 90 |
| Total Area Required ($m^2$) | 4,680 $m^2$ |
| BESS Compound | 16,000 m2 |

The required area is 4,680 $m^2$ is less than the 16,000 $m^2$. Therefore, even with additional conservatism for spacing or any restrictions at the site not accounted for, there is ample area to locate the BESS to achieve the required separation distances calculated in this report. In addition, the proposed BESS area is at least 200 m from the gas pipeline transmission easement.

### 5.2.2 Decentralised BESS Option

The decentralised BESS option would comprise BESS units/containers distributed across the Project area. It is expected that two (2) BESS containers would be located per decentralised location; hence, accumulation to unacceptable levels is not expected. Nonetheless, the following recommendation has been made to minimise the accumulation of risk in the distributed option:

- The maximum storage capacity at a distributed BESS location shall not exceed 20 MWh.
- The separation distance between any two BESS locations shall be 20 m.
- The minimum separation distance between a BESS location and the site boundary shall be 20 m.
- The minimum separation distance between a BESS location and the pipeline shall be 50 m.

The recommended separation distances are based on a worst-case scenario to ensure a conservative approach for a flexible design. As the detailed design progresses and specific battery supplier details become available, the BESS storage area will be reviewed to confirm that all required separation distances can be achieved.

### 5.2.3 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.

As the preferred BESS supplier has not been selected for this project is entirely speculative; hence, testing data cannot be provided to assess the required separation distance and thus a conservative method has been adopted. However, at the point of construction the batteries will have been selected and the test data will be available; therefore, the following recommendation has been made:

- The UL9540A test data for the batteries selected for the project shall be made available 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 during detailed design.

# 6.0 Conclusion and Recommendations

## 6.1 Conclusions

A hazard identification table was developed for the Brewongle Solar Farm PV & BESS project to identify potential hazards that may be present at the Project as a result of operations or storage of materials. A review of the facility indicated that the potential for offsite impact is unlikely due to the size and nature of the site; however, it was identified that there is the potential for incident propagation between BESS units; hence, these were carried forward for consequence analysis. The consequence analysis was performed to define minimum separation distances that must be achieved between BESS units to prevent incident propagation between BESS units.

Based on the analysis conducted, it is concluded that the risks at the Project boundary are not considered to exceed the acceptable risk criteria; hence, the project would only be classified as potentially hazardous and would be permitted within the current land zoning for the site. Furthermore, provided the recommended separation distances are complied with, incident propagation is unlikely to occur.

## 6.2 Recommendations

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

- The site induction shall include information regarding the gas pipeline including location and protections to identify the gas pipeline (i.e., marker tape, etc.).
- All personnel working at the site shall be inducted prior to commencing any work.
- Appropriate marking shall be provided along the length of the gas pipeline as required to minimise the potential for unauthorised works occurring within the vicinity of the gas pipeline, in conjunction with the Site Induction and relevant site-specific construction management plans.
- A BESS container shall not be located within 2 m of an adjacent BESS container when orientated side to side. The separation distance may be reduced following selection of a supplier and the results of the UL9540A test data for the selected BESS container.
- A BESS container shall not be located within 1 m of an adjacent BESS container when orientated end to end. The separation distance may be reduced following selection of a supplier and the results of the UL9540A test data for the selected BESS container.
- Any ventilation fans or ducts in the BESS container shall be constructed of non-combustible materials.
- The UL9540A test data for the batteries selected for the project shall be made available 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 during detailed design.
- The maximum storage capacity at a distributed BESS location shall not exceed 20 MWh.
- The separation distance between any two BESS locations shall be 20 m.
- The minimum separation distance between a BESS location and the site boundary shall be 20 m.

- The minimum separation distance between a BESS location and the pipeline shall be 50 m.

# 7.0 References

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

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

[3] New South Wales Government, “Environmental Planning and Assessment Regulation 2021,” New South Wales Government, Sydney, 2021.

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

[5] National Transport Commission (NTC), “Australian Code for the Transport of Dangerous Goods by Road & Rail, 7.9,” 2024.

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

[7] P. Hoole, S. Rufus, N. Hashim, M. Saad, S. Abdullah, A. Othman, K. Piralaharan, A. CV and S. Hoole, “Power Transformer Fire and Explosion: Causes and Control,” *International Journal of Control Theory and Applications,* vol. 10, no. 16, pp. 211-219, 2017.

[8] J. Demos, “What Causes Transformer Explosions and Burns?,” Durabarrier USA Fire Barrier Experts, 26 July 2021. [Online]. Available: https://firebarrierexperts.com/what-causes-transformer-explosions-and-burns. [Accessed 2 February 2022].

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

[10] Standards Australia, “AS/NZS 3000:2018 - Wiring Rules,” Standards Australia, Sydney, 2018.

# 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<br>• Incident propagation through battery cells<br>• Toxic smoke dispersion | • Batteries are tested by manufacturer prior to sale / installation<br>• Overcharging and electrical circuit protection<br>• Battery monitoring systems<br>• Batteries composed of subcomponents (i.e. BBU, cells) reducing risk of substantial component failure<br>• Batteries are not located in areas where damage could easily occur (i.e. within the fenced property)<br>• Electrical systems designed per AS/NZS 3000:2018 (Ref. [10]). |
| 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<br>• Isolated location<br>• Switch room separation from other sources of fire |
| Substation | • Arcing within transformer, vaporisation of oil and rupture of oil reservoir | • Transformer oil spill into bund and bund fire | • Bunded<br>• Isolated location |
| EMF | • Electric and magnetic equipment | • Generation of ELF EMF and injury / nuisance to surrounding area | • Large separation distances allow for attenuation of EMFs<br>• Cumulative impacts from equipment below acceptable thresholds.<br>• 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.

- 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**.

$$Q = \tau E F$$ **Equation B-1**

Where;

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

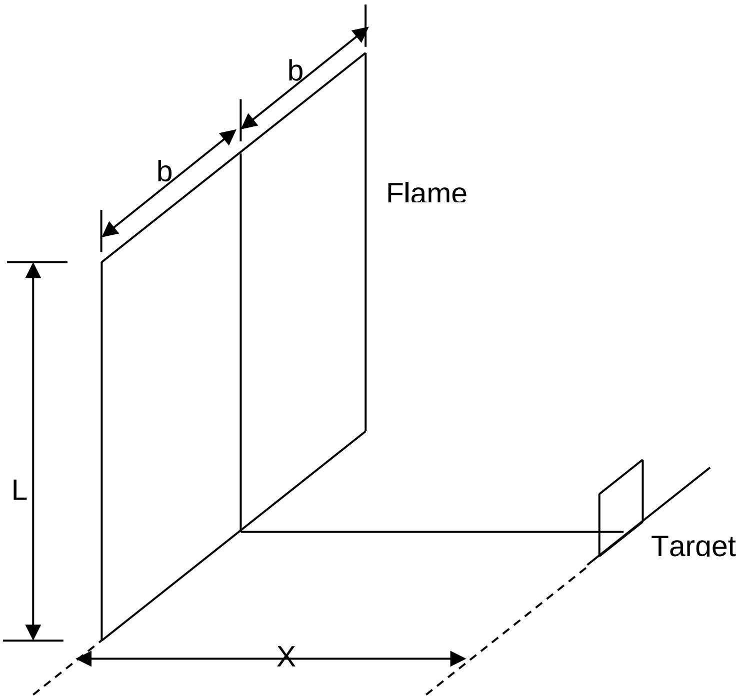
Each of the required inputs is determined in the sections following.

## B3. View Factor

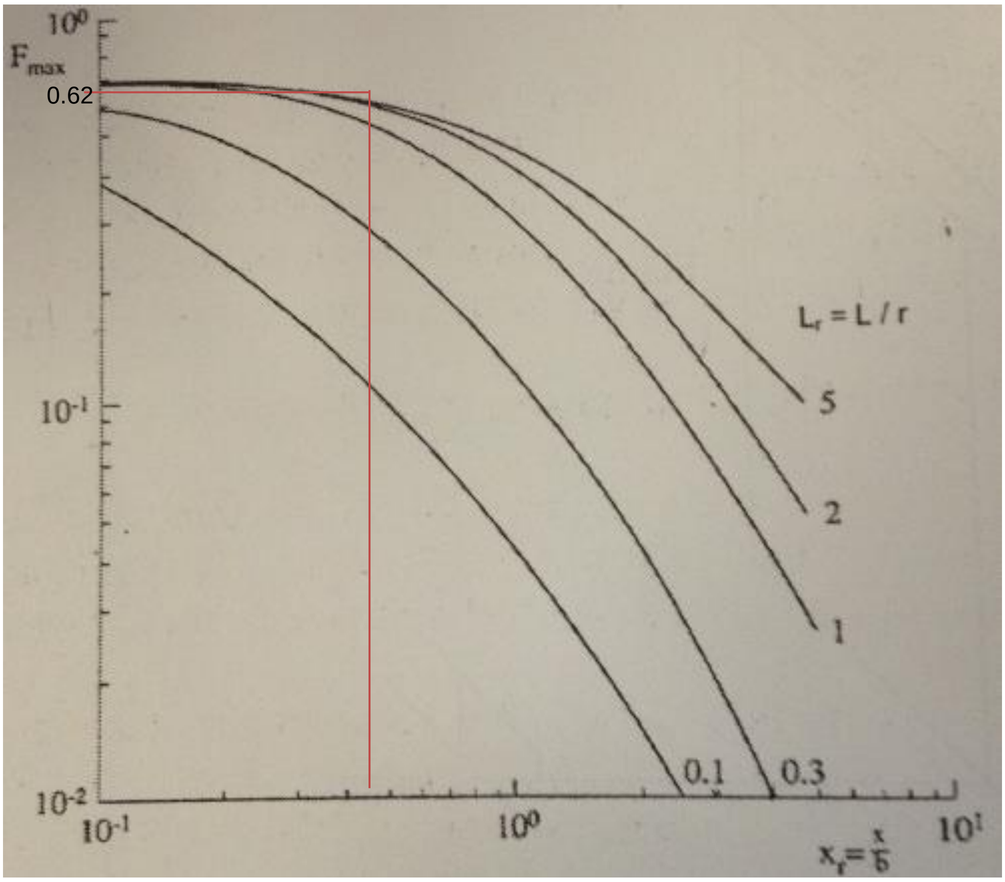
The view factor for a flat surface fire is estimated using the scenario shown in **Appendix Figure B-1** where the flame is the vertical surface of height L and length 2b with receiver located centrally and at a distance of X. Two dimensionless parameters are calculated, and the view factor read from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

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

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



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



**Appendix Figure B-2: Vertical Flame Maximum View Factor**

## 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
- 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 6.07 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 for input into **Equation B-2**.

It is necessary to calculate the Surface Emissive Power (SEP) of the radiant surface to calculate the radiant heat at the target. 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:

- $\varepsilon$ = flame emissivity (taken as 0.78)
- $\sigma = 5.67\text{x}10^{-11}$ 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 | 0.165 |
| Short side | 0.41 |

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 | 0.08 | 1 | 0.21 | 0.3 |
| 1 | 0.17 | 0.35 | 0.41 | 0.17 |
| 1.5 | 0.25 | 0.26 | 0.61 | 0.1 |
| 2 | 0.33 | 0.2 | 0.82 | 0.08 |
| 2.5 | 0.41 | 0.17 | 1.0 | 0.06 |
| 3 | 0.5 | 0.14 | 1.2 | 0.05 |

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 | 1.0 |
| 1 | 0.97 |
| 1.5 | 0.95 |
| 2 | 0.94 |
| 2.5 | 0.93 |
| 3 | 0.92 |

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/m$^2$) | |
|---|---|---|
| | Long Side | Short Side |
| 0.5 | 116.0 | 34.8 |
| 1 | 39.4 | 19.1 |
| 1.5 | 28.7 | 11.0 |
| 2 | 21.8 | 8.7 |
| 2.5 | 18.3 | 6.5 |
| 3 | 14.9 | 5.3 |