Edify Energy

Steel River Battery Farm

Preliminary Hazard Analysis

Issue 5 | 3 June 2021

Job number 278292-00

Arup Australia Pty Ltd ABN 76 625 912 665

Arup
Level 5
151 Clarence Street
Sydney NSW 2000
Australia
www.arup.com

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		Name	Michael D'Souza / Ivy Chew	Veronica Goldsmith / Ben Smith	Nigel Cann
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Executive Summary

Background

Edify Energy Pty Ltd and Precinct Group are jointly developing a 28 MW advanced lithium ion battery energy storage facility known as the Steel River Battery, at the Steel River Industrial Park located in Mayfield, New South Wales.

The Project will connect to the local Ausgrid 33 kV electrical distribution network and will provide benefits to the local electricity network as well as network services to the wider New South Wales grid.

Project details are summarised in Table 1.

Table 1: Summary of project details

Project Detail	**Description**
Project Type	Stand-alone large scale battery storage connected to the National Electricity Market.
Electrical Connection	Ausgrid 33kV distribution network.
Battery Technology	Lithium ion battery system.
Battery Capacity	Up to 28MW
Battery Storage Duration	Up to 2 hours
Battery Configuration	Outdoor modular battery units or containerised battery system with ancillary balance of plant equipment.
Project Location	Proposed lots 1101 - 1102 Riverside Drive, Mayfield West. Part of future Stage 11 of Steel River Estate (Zoned IN1 General Industrial)

Methodology

This Preliminary Hazard Analysis (PHA) has been prepared in accordance with the relevant guidelines from NSW DPIE’s *Multi-level Risk Assessment* [1] and Hazardous Industry Planning Advisory Papers (HIPAPs) No. 4 – *Risk Criteria for Land Use Safety Planning* [2] and No. 6 – *Hazard Analysis* [3].

During the analysis of the identified risks, reference was made to the relevant general principles as defined by HIPAP 4 [2] Section 2.4.1:

- The avoidance of all *avoidable* risks;
- The risk from a major hazard should be reduced wherever practicable, even where the likelihood of exposure is low; and
- The effects of significant risks should, wherever possible be contained within the site boundary.

Recommendations have been made against each of the identified risks to ensure that the residual risks will be reduced So Far as is Reasonably Practicable (SFAIRP).

Hazards and Consequences

The hazards assessed to be 'medium' risk or higher in the hazard identification study (HAZID), or where offsite consequences were anticipated have been carried forward for qualitative assessment. The following hazards have been assessed:

- Security breach leading to injury;
- Electrocution from an electrical facility;
- Injury to construction or operations personnel;
- Exposure to dangerous goods during a site emergency;
- Battery fire; and
- Battery explosion.

The two hazards that were identified as having the potential to cause offsite impacts, namely a battery fire and battery explosion, were carried forward for quantitative consequence analysis.

As the final battery technology has not yet been chosen for the site, these hazards were considered for both modular/cabinet and containerised solutions.

For a fire in a modular/cabinet unit, in order to have a received radiant heat flux of less than 4.7 kW/m^2 at the site boundary, the required minimum separation distance between the:

- Front/end of the modular/cabinet unit and site boundary = 2.25 m; and
- Side modular/cabinet unit wall and site boundary = 9 m.

Similarly, in order to have a received radiant heat flux of less than 12.6 kW/m^2 on the adjacent modular/cabinet units, the required minimum separation distance between the:

- Front/end of the modular/cabinet unit and adjacent modular/cabinet unit = 1 m; and
- Side modular/cabinet unit wall and adjacent modular/cabinet unit = 5 m.

For a fire in a container, in order to have a received radiant heat flux of less than 4.7 kW/m^2 at the site boundary, the required minimum separation distance between the:

- Front/end of the container and site boundary = 5.5 m; and
- Side container wall and site boundary = 5.25 m.

Similarly, in order to have a received radiant heat flux of less than 12.6 kW/m^2 on the adjacent containers, the required minimum separation distance between the:

- Front/end of the container and adjacent container = 3.25 m; and
- Side container wall and adjacent container = 2.0 m.

For an explosion in a battery unit, a vapour cloud explosion of vented gas was modelled. An overpressure of 7 kPa – the accepted minimum for injury or fatality – was found to extend to a distance of 24 m, and an overpressure of 35 kPa – corresponding to significant damage of structures – was found to extend to a distance of 7.5 m.

Recommendations

Arup makes the following recommendations to ensure that the residual risks for the identified hazards will be reduced SFAIRP:

- Separate BESS 24 m from the site boundary unless the following are met:
  1. BESSs shall have a means to safely vent or prevent an explosion designed to NFPA 68, NFPA 69, or an international equivalent to reduce this risk SFAIRP.
  2. In the absence of more specific test data, containerised BESSs shall be separated from one another by not less than 3.25 m end to end and not less than 3 m side to side, and separated from the site boundary by not less than 10 m.
  3. In the absence of more specific test data, modular/cabinet BESSs shall be separated from one another by not less than 2 m end to end and not less than 5 m side to side, and separated from the site boundary by not less than 10 m.

  If specific test data exist, the recommended separation distances between units provided for in those data can be used in preference to the distances listed here. For example, the Tesla Megapack can be separated be 6 inches (155 mm) side-to-side or back-to-back (i.e. the sides of the unit without doors) as demonstrated by fire testing performed using the UL9504A Test Method, and as shown in Figure 11 in Section 4.1.3.
- Ensure the BESS manufacturer supplies the UL9540A fire test report for further refinement of separation distances.
- Ensure BESSs have a fire suppression system, if they are to be entered for maintenance. Additionally:
  1. It is preferred for the fire suppression system to not rely on shutdown of the battery cooling system.

The fire suppression system design should also consider the explosion hazard.

1 Introduction

1.1 Site Description and Surrounding Land Use

The subject site has a property description of Lot 12 DP 280089 with a street address of 27D Riverside Drive, Mayfield West. The site is currently approved for further earthworks and is situated within approved Lot 1102, part of future Stage 11 Steel River Business Park. The subject site has a combined total area of approximately 2.44 ha. The site is currently vacant IN1 General Industrial zone land.

1.2 Operational Process

The proposed Battery Energy Storage System (BESS) is expected to operate in conjunction with the electrical grid to provide the following functions:

- Charging and discharging of energy from the electrical grid for shifting of energy to peak consumption periods when electricity is needed the most; and
- Participate in the electricity market to provide ancillary services which help contribute to the stability and functionality of the electrical grid.

The primary modes of operation of the BESS are:

- Charging of the battery from the external electrical grid; or
- Discharging of the battery to the external electrical grid.

It should be noted that during regular operations of the proposed facility, no dangerous goods will be consistently used.

Two battery solutions are currently being considered for the site:

- Modular cubical cabinets (similar to the Tesla Megapack system, for example) that are installed in an array around an inverter pack as illustrated in Figure 1; and
- Containerised modules (containerised system) that have been preassembled in modified shipping containers prior to transport to site as illustrated in Figure 2

Both proposed battery technologies will consist of lithium ion battery technology. The system is expected to be highly modular and based on individual smaller power blocks to achieve the required system size. Each battery pack is comprised of multiple smaller lithium ion cells which are fully enclosed and connected to form an integrated system. The BESS will be required to conform with the following safety standards:

- UL 1642: *Standard for Lithium Batteries*
- UL 9540: *Standard for Energy Storage Systems and Equipment*

Figure 1 Indicative Tesla Megapack (example modular/cabinet unit)

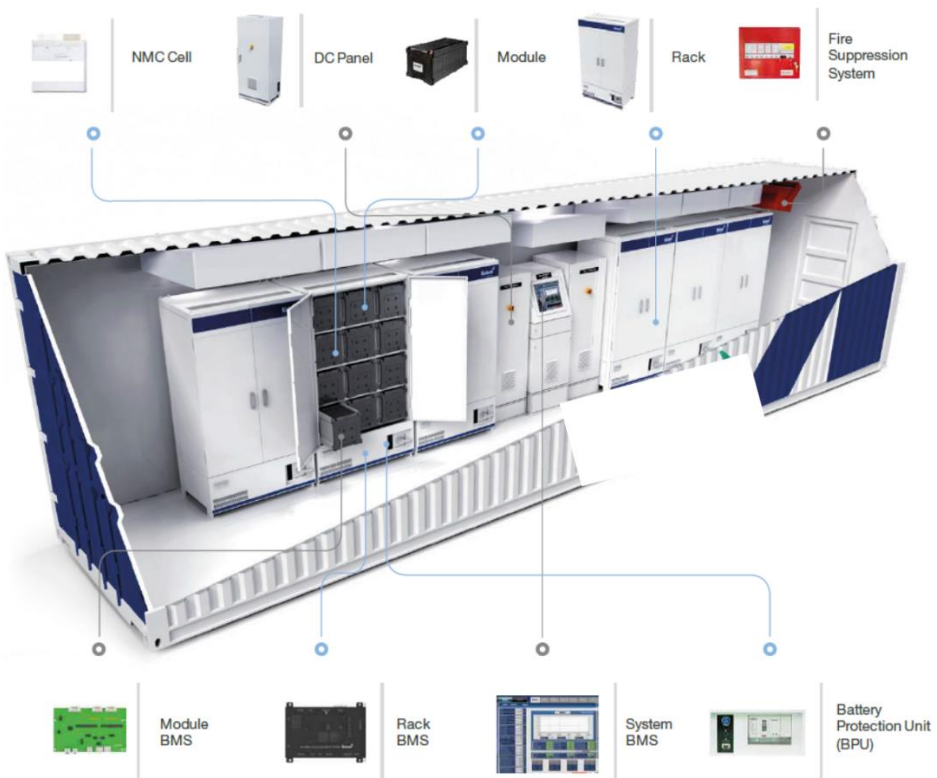

Figure 2 Indicative arrangement of containerised module

2 Applicability of SEPP 33

2.1 Dangerous Goods Used and Stored at the Facility

The list of dangerous goods to be used and stored at the facility has been based on the Darlington Point Solar Farm (DPSF) BESS dangerous goods storage. Table 22 below contains the estimated quantities of chemicals stored onsite.

Table 2: List of potentially hazardous goods used and stored at the facility

Item	UN No.	Dangerous Goods Class	Total Storage Onsite	Description
Lithium Ion Batteries	3481	9	~ 800 units	Installed as part of the battery units as solid material inside cells
Refrigerant (R 134a)	3159	2.2	~ 350 kg	Installed as part of the cooling system of some battery technologies (including the Tesla Megapack)
Miscellaneous Minor Chemicals Store	N/A	2.2, 3, 5.1, 8	< 1 t	Onsite storage for maintenance
Ethylene Glycol solution	3082	N/A, not a dangerous good	~ 3 t	Installed as part of the cooling system of some battery technologies (including the Tesla Megapack)
Transformer Oil	N/A, not a dangerous good		~ 45 t	Possibly in transformers

2.2 SEPP 33 Screening

It has been assumed that the goods stored onsite are stored in similar locations and so have been screened against SEPP 33 thresholds together, as per NSW Department of Planning, Industry and Environment's (DPIE's) *Applying SEPP 33* [4]. The screening can be found in Table 3 below.

Table 3: Screening against SEPP 33 thresholds

Dangerous Goods Class	Quantity	Threshold	Threshold Exceeded?
3	< 1 t	5 t	No
5.1	< 1 t	5 t	No
8 PGII	< 1 t	25 t	No

Note that Dangerous Goods Classes 2.2 and 9 are excluded from the risk screening. It should also be noted that no dangerous goods are expected to be transported (beyond the needs of minor maintenance) to or from the site on a regular basis and so no transportation screening has been undertaken.

As all the dangerous goods screened above do not exceed the SEPP 33 threshold, a PHA is not required for the development by SEPP 33. It should be noted that by taking a conservative approach to land use planning, a PHA has been prepared to address the potential risks that may arise from this development.

2.3 Relevant Guidance

This PHA has been prepared in accordance with the relevant guidelines from NSW DPIE's *Multi-level Risk Assessment* [1] and Hazardous Industry Planning Advisory Papers (HIPAPs) No. 4 – *Risk Criteria for Land Use Safety Planning* [2] and No. 6 – *Hazard Analysis* [3].

During the analysis of the identified risks, reference was made to the relevant general principles as defined by HIPAP 4 [2] Section 2.4.1:

- The avoidance of all *avoidable* risks;
- The risk from a major hazard should be reduced wherever practicable, even where the likelihood of exposure is low; and
- The effects of significant risks should, wherever possible be contained within the site boundary.

Recommendations have been made against each of the identified risks to ensure that the residual risks will be reduced So Far as is Reasonably Practicable (SFAIRP).

3 Hazard Identification

A hazard identification study (HAZID) was conducted for the site. This HAZID was conducted by personnel with relevant experience of grid scale BESS units.

The identified hazards and their qualitative likelihood and consequence scores can be found in Appendix A. The hazards assessed to be ‘medium’ risk or higher in the HAZID, or where offsite consequences were anticipated have been carried forward for qualitative assessment. The following hazards have been assessed:

- Security breach leading to injury;
- Electrocution from an electrical facility;
- Injury to construction or operations personnel;
- Exposure to dangerous goods during a site emergency;
- Release of firewater runoff;
- Battery fire; and
- Battery explosion.

These hazards have been discussed in more detail in Section 3.1 below.

3.1 Hazard Details

3.1.1 Security Breach

A security breach of the facility could credibly lead to theft of equipment or injury to personnel and individuals. This event is not considered likely to cause offsite impacts. Arup makes the following recommendations:

- Security fencing around the facility and separately around critical and hazardous assets should be installed;
- A CCTV security system should be installed; and
- Regular O&M inspections to monitor breaches should be undertaken.

As there is no potential for offsite impacts, the above recommendations are considered sufficient to mitigate the risk of this event.

3.1.2 Electrocution from Electrical Facility

Electrocution occurring in the BESS is a credible scenario that could lead to the injury or death of a maintenance worker. Arup makes the following recommendations:

- Electrical assets shall be installed in accordance with AS 3000: *Electrical Installations*; and
- Appropriately qualified maintenance personnel are to be used.

As there is no potential for offsite impacts, the above recommendations are considered sufficient to mitigate this risk.

3.1.3 Injury to Construction or Operations Personnel

During the construction and operation of the facility, there is a credible hazard associated with the injury of construction and operations personnel, respectively. This event is not considered likely to cause offsite impacts. Arup makes the following recommendations:

- The development of a Work, Health and Safety plan; and
- Detailed Safety in Design processes are to be carried out.

As there is no potential for offsite impacts, the above recommendations are considered sufficient to mitigate this risk.

3.1.4 Exposure to Dangerous Goods During Site Emergency

In the event of an emergency at the site, personnel may be exposed to dangerous goods and suffer injury. This event is not considered likely to cause offsite impacts. Arup makes the following recommendations:

- The development of a site-specific Emergency Response Plan;
- Appropriate signage and labelling to identify site-specific hazards are to be installed; and
- Emergency response workers are to be made aware of the response requirements.

As there is no potential for offsite impacts, the above recommendations are considered sufficient to mitigate this risk.

3.1.5 Release of Firewater Runoff

Following a fire event that requires extinguishing, the firewater used for extinguishment has the potential to be released into the environment without being controlled. This firewater is likely to be contaminated and will be required to be contained.

Broadly speaking, the contaminated firewater may be contained in one of two ways:

- Permanent containment system: the civil design of the site can be scoped such that it is possible to contain all runoff in a designated catchment area (e.g. a bund or some form of holding basin).
- Temporary containment: the site can be designed such that, in the event of a fire brigade response that may lead to contaminated runoff, drainage can be thoroughly sealed, and firewater contained on-site. In essence, this is a temporary bund.

The most appropriate approach is determined as a function of the choice of battery technology, the “acceptable loss” strategy (i.e. whether the response to a fire is to suppress and extinguish, or to allow the unit to burn while protecting adjacent units), the design and budget implications on the broader site development, and fire brigade input to all of the above. This is therefore a decision that is made as the project develops.

3.1.6 Battery Fire

As the final battery technology has not yet been chosen for the Site, this hazard has been considered for both modular/cabinet and containerised solutions.

A fire could credibly form in a lithium ion battery system as a result of a thermal runaway in one or more cells or from an external source such as a fire at the facility. The potential for this to have offsite impacts means it has been carried forward for consequence analysis in Section 4.1.

3.1.7 Battery Explosion

Flammable vapours may accumulate in the battery unit. This could result in a confined vapour cloud explosion (VCE) occurring. The potential for this to have offsite impacts means it has been carried forward for consequence analysis in Section 4.2.

4 Consequence Analysis

The two hazards that were identified as having the potential to cause offsite impacts, namely a battery fire and battery explosion, have been carried forward for quantitative consequence analysis.

4.1 Battery Fire

As the final battery technology has not yet been chosen for the site, this hazard has been considered for both modular/cabinet and containerised solutions.

4.1.1 Modular/Cabinet

A fire event in a battery container was modelled to assess the impact on its surroundings. The modelling assumed that the battery management system and other safety features are unable to control thermal runaway, leading to a fire in the container. Additionally, it is assumed that the fire suppression system is not functional as a worst-case scenario.

The dimensions of the Tesla Megapack were used as an indicative size for a modular/cabinet unit – approx. 7.14 m (L) x 1.60 m (W) x 2.36 m (H). Figure 3 shows a Tesla Megapack as an example of the modular/cabinet technology options.

Figure 3: Tesla Megapack (example modular/cabinet unit)

Key Assumptions and Fire Scenarios

The basis of the modelling is radiative heat transfer using the Stefan-Boltzmann Law and view factor method. Further description of this methodology and all equations used are presented in Appendix B.

The worst credible fire scenario has been considered in which all of the doors along the side of the modular/cabinet unit are left open.

- The temperature of the open side is set at 840 °C (flame temperature). This is representative of an emitting heat flux of 84 kW/m² which is used for fire spread design between buildings such as offices (Approved Document B) (HMCLG, 2010). While the units do contain batteries, which would have combustible contents and some plastic materials, the overall structure of the modular/cabinet unit and insulation is to be non-combustible and the majority of racking within the space is constructed of non-combustible metal. This results in a comparable fuel load. 840 °C is also within the flame temperature range recommended for use for fires based on the Fire Engineering Design Guide. While adiabatic flame temperature is based on the chemistry of a flame, within a compartment the overall compartment dynamics and air ratio influence the temperature of a flame.
- The radiating panel shall be 7.14 m x 2.36 m (at full door height and width) with 840 °C;
- The emissivity of the door opening is taken to be 0.9. This represents a conservative emissivity for a severe fire and a good radiator;
- The temperature of the end walls was set at 600 °C, which is generally the temperature at which flashover begins in a compartment as per the SFPE Handbook and CIBSE Guide E. This represents a severe fully developed fire throughout the modular/cabinet unit.
- It is assumed that the radiating panel shall be based on the full height and length of the modular/cabinet unit end wall with the dimension of 1.60 m (W) x 2.36 m (H) at 600 °C;
- The emissivity of the modular/cabinet unit end wall is taken to be 0.7. This represents the maximum steel emissivity that could be reached at high temperature (flashover temperature) based on research conducted by VTT [5];
- The heat flux from the emitting surface was assumed to be uniform; and
- No heat loss was assumed to intermediate media (i.e. to air or smoke).
- The basis of the fire modelling is to consider the worst-case conditions. It is a consequence-based assessment. In this context historical wind data does not affect the consequence assessment. Further as detailed above the fire modelling ignores that integrity and insulation rating of the unit, providing further conservativeness.

The fire scenario is represented pictorially in Figure 4.

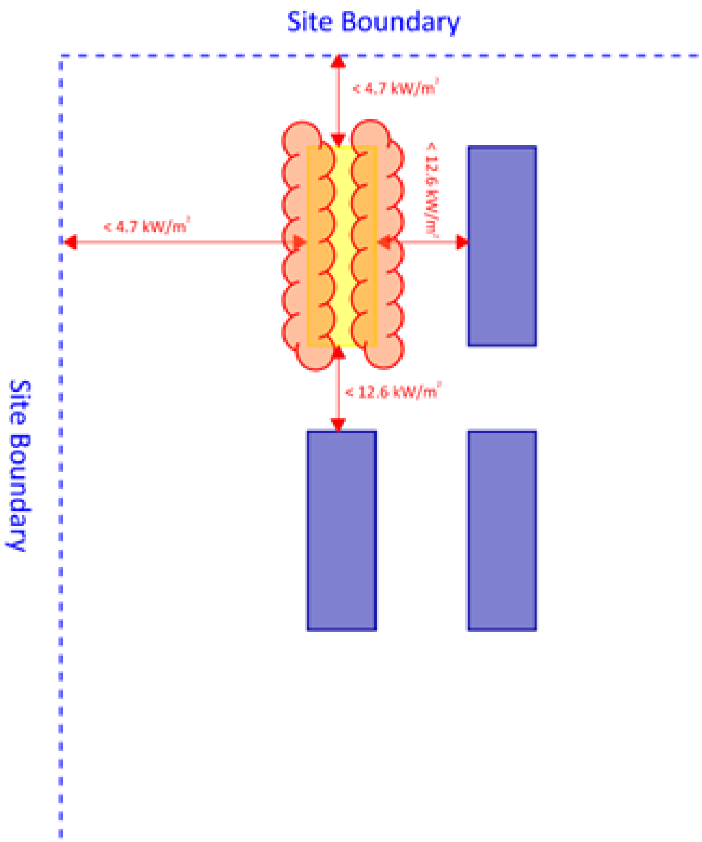

Figure 4 Pictorial representation of the fire modelling scenario

Acceptance Criteria

According to HIPAP 4 [2], a radiation intensity of 4.7 kW/m^2 will cause pain and burn injuries to humans. At 12.6 kW/m^2, it is known that:

- The temperature of wood can rise to a point where it can be ignited by a naked flame after long exposure;
- Thin steel with insulation on the side away from the fire may reach a thermal stress level high enough to cause structural failure;
- There is a significant chance of fatality with extended exposure and a high chance of injury.

Therefore, sufficient separation distance must be provided such that:

- The heat radiation received at the site boundary is less than 4.7kW/m^2; and
- The heat radiation on the adjacent modular/cabinet unit is less than 12.6kW/m^2.

Results

The results of the modelling are presented in Figure 5.

As shown in Figure 5, in order to have a received radiant heat flux of less than 4.7 kW/m^2 at the site boundary, the required minimum separation distance between the:

- Front/end of the modular/cabinet unit and site boundary = 2.25 m; and
- Side modular/cabinet unit wall and site boundary = 9 m.

Similarly, in order to have a received radiant heat flux of less than 12.6 kW/m^2 on the adjacent modular/container units, the required minimum separation distance between the:

- Front/end of the modular/cabinet unit and adjacent modular/cabinet unit = 1 m; and
- Side modular/cabinet unit wall and adjacent modular/cabinet unit = 5 m.

This is represented pictorially in Figure 10. However, as a conservative measure, it is recommended that the separation distances are as follows:

- Between the long sides of the modular/cabinet units shall not be less than 5 m;
- Between the ends of the modular/cabinet units shall not be less than 2 m; and
- The distance from the site boundary shall not be less than 10 m.

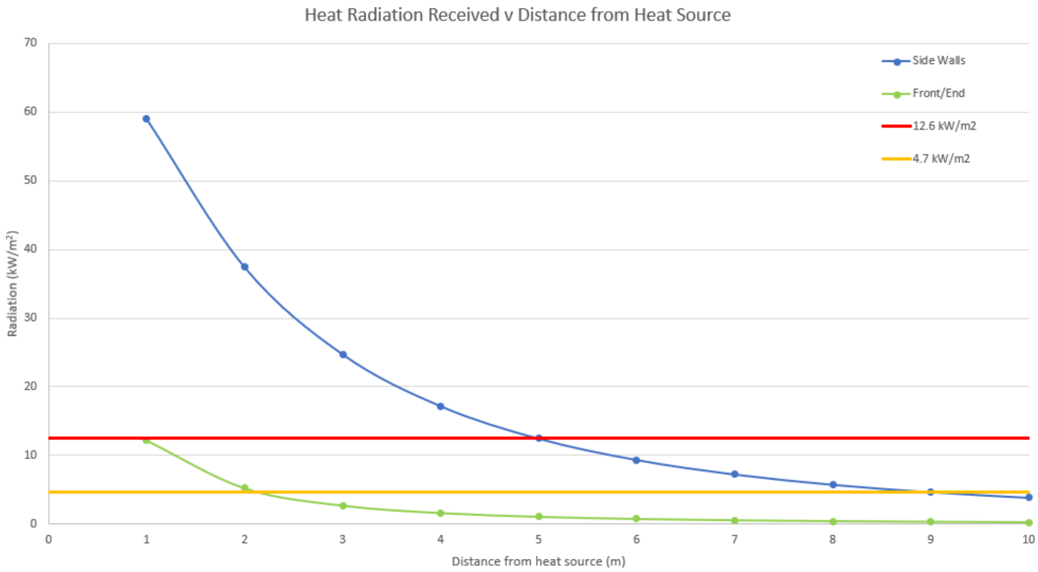

Figure 5 The results of the fire modelling, showing heat flux radiation plotted against the separation distance. The red line is set at 12.6 kW/m^2 while the orange line is set at 4.7 kW/m^2

4.1.2 Containerised

A fire event in a battery container was modelled to assess the impact on its surroundings. The modelling assumed that the battery management system and other safety features are unable to control thermal runaway, leading to a fire in the container. Additionally, it is assumed that the fire suppression system is not functional as a worst-case scenario.

It is understood from the Memo provided by Edify, the supplied battery container is a modified standard 40 ft shipping container - approx. 12.2 m (L) x 2.35 m (W) x 2.39 m (H). Figure 6 shows a typical modified shipping container of this type and Figure 7 shows the dimensions of the container. It will house battery cells and associated electrical infrastructure and be typically installed at ground level or slightly elevated on structure.

Figure 6 Typical 40 ft modified shipping container for battery energy storage (extracted from Edify Memo)

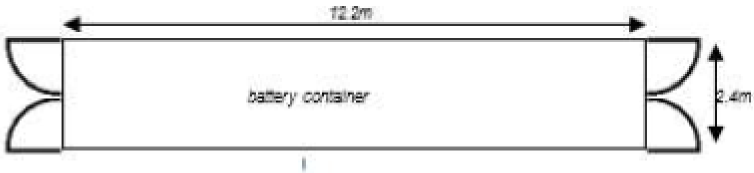

Figure 7 Containerised battery container layout illustrating the double-leaf door at both ends of the containers (extracted from Edify Memo)

Key Assumptions and Fire Scenarios

The basis of the modelling is radiative heat transfer using the Stefan-Boltzmann Law and view factor method. Further description of this methodology and all equations used are presented in Appendix B.

The worst credible fire scenario has been considered in which the double-leaf doors are left open at both ends of the container.

- The temperature of the open door is set at 840 °C (flame temperature). This is representative of an emitting heat flux of 84 kW/m² which is used for fire spread design between buildings such as offices (Approved Document B) (HMCLG, 2010). While the units do contain batteries, which would have combustible contents and some plastic materials, the overall structure of the container and insulation is to be non-combustible and the majority of racking within the space is constructed of non-combustible metal. This results in a comparable fuel load. 840 °C is also within the flame temperature range recommended for use for fires based on the Fire Engineering Design Guide. While adiabatic flame temperature is based on the chemistry of a flame, within a compartment the overall compartment dynamics and air ratio influence the temperature of a flame.

- It is assumed that the open double-leaf door is the full height and width of the container (see Figure 7), i.e. 2.4 m (W) x 2.4 m (H). The radiating panel shall be 2.4 m x 2.4 m (at full door height and width) with 840 °C;
- The emissivity of the door opening is taken to be 0.9. This represents a conservative emissivity for a severe fire and a good radiator;
- The temperature of the perimeter container walls was set at 600 °C, which is generally the temperature at which flashover begins in a compartment as per the SFPE Handbook and CIBSE Guide E. This represents a severe fully developed fire throughout the container.
- It is assumed that the radiating panel shall be based on the full height and length of the container side wall with the dimension of 12.2 m (L) x 2.4 m (H) at 600 °C;
- The emissivity of the container side wall is taken to be 0.7. This represents the maximum steel emissivity that could be reached at high temperature (flashover temperature) based on research conducted by VTT [5];
- The heat flux from the emitting surface was assumed to be uniform; and
- No heat loss was assumed to intermediate media (i.e. to air or smoke).
- The basis of the fire modelling is to consider the worst-case conditions. It is a consequence-based assessment. In this context historical wind data does not affect the consequence assessment. Further as detailed above the fire modelling ignores that integrity and insulation rating of the containers, providing further conservativeness.

The fire scenario is represented pictorially in Figure 8.

Acceptance Criteria

According to HIPAP 4 [2], a radiation intensity of 4.7 kW/m^2 will cause pain and burn injuries to humans. At 12.6 kW/m^2, it is known that:

- The temperature of wood can rise to a point where it can be ignited by a naked flame after long exposure;
- Thin steel with insulation on the side away from the fire may reach a thermal stress level high enough to cause structural failure;
- There is a significant chance of fatality with extended exposure and a high chance of injury.

Therefore, sufficient separation distance must be provided such that:

- The heat radiation received at the site boundary is less than 4.7kW/m^2; and
- The heat radiation on the adjacent container is less than 12.6kW/m^2.

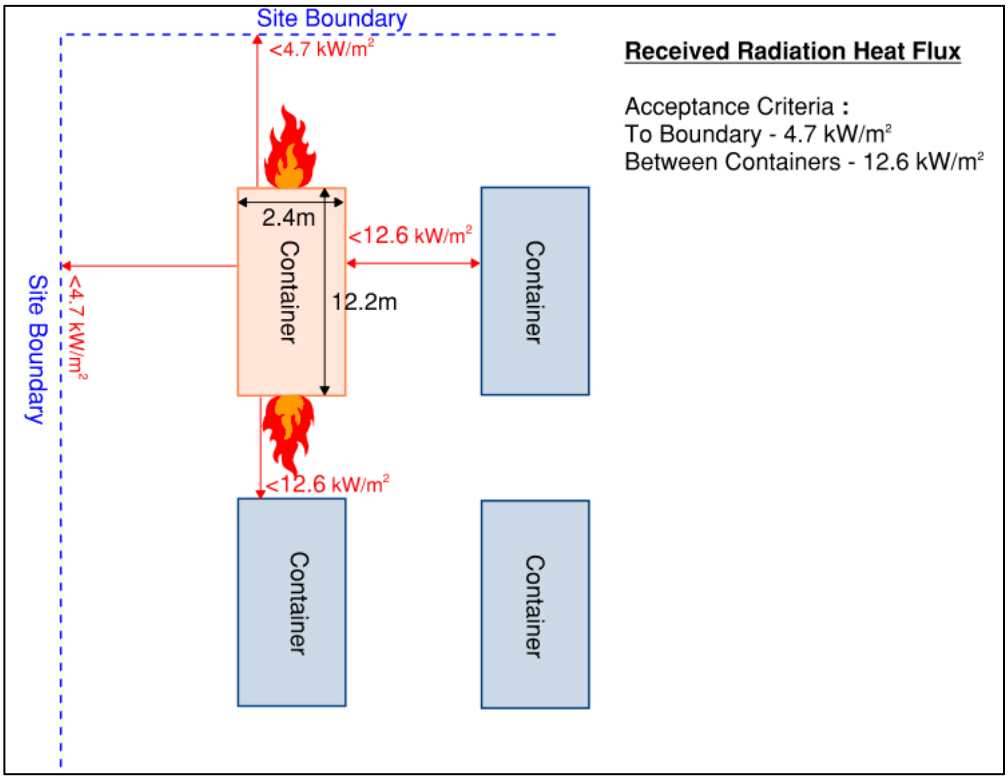

Figure 8 Pictorial representation of the fire modelling scenario.

Results

The results of the modelling are presented in Figure 9.

As shown in Figure 9, in order to have a received radiant heat flux of less than 4.7 kW/m^2 at the site boundary, the required minimum separation distance between the:

- Front/end of the container and site boundary = 5.5 m; and
- Side container wall and site boundary = 5.25 m.

Similarly, in order to have a received radiant heat flux of less than 12.6 kW/m^2 on the adjacent containers, the required minimum separation distance between the:

- Front/end of the container and adjacent container = 3.25 m; and
- Side container wall and adjacent container = 2.0 m.

This is represented pictorially in Figure 10. However, as a conservative measure, it is recommended that the separation distances are as follows:

- Between the long ends of the containers shall not be less than 3.25 m;
- Between the sides of the containers shall not be less than 3 m; and
- The distance from the site boundary shall not be less than 10m.

There is the potential for these values to be further refined upon review of the UL9540A fire test report that should be furnished by the BESS manufacturer.

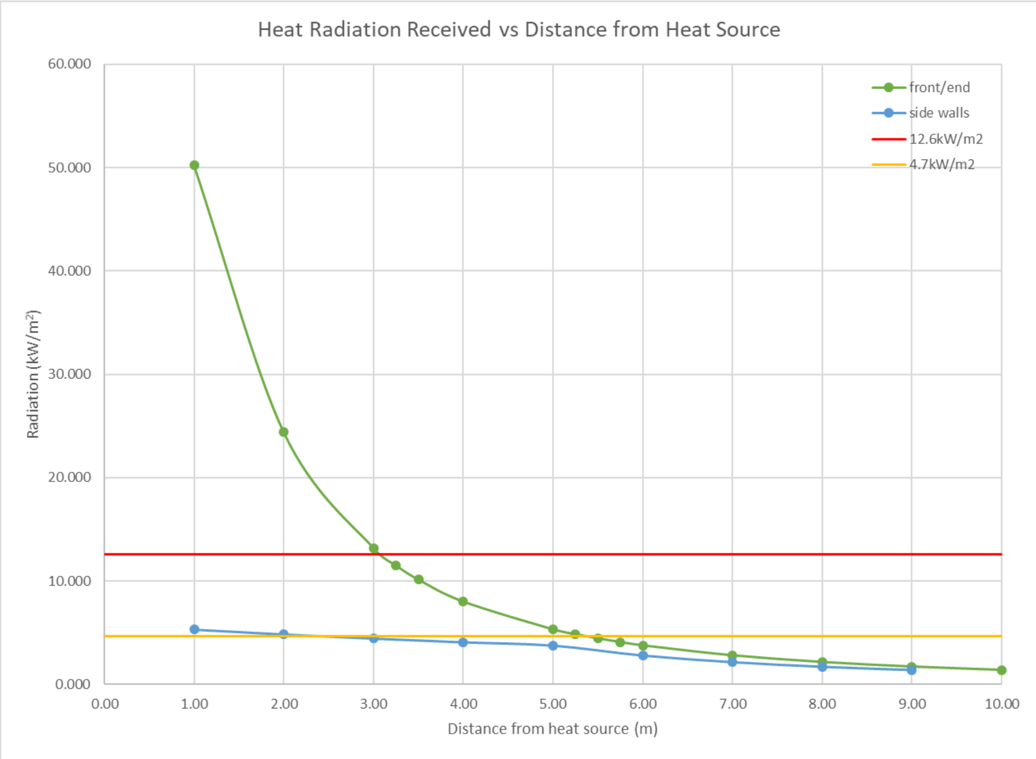

Figure 9 The results of the fire modelling, showing heat flux radiation plotted against the separation distance. The red line is set at 12.6 kW/m^2 while the orange line is set at 4.7 kW/m^2.

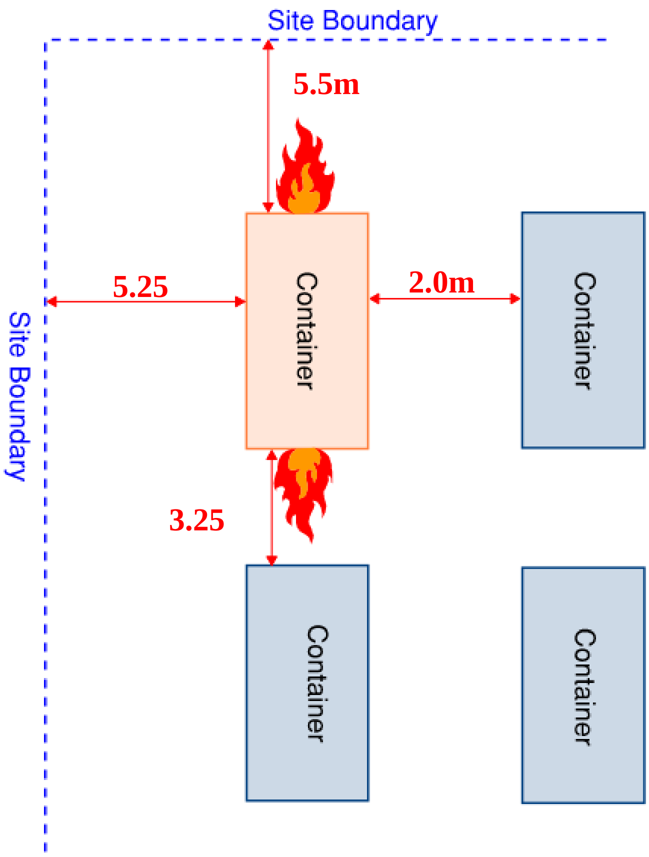

Figure 10 Pictorial representation of the fire modelling results.

Additionally, it is recommended that a containerised BESS, requiring entry for maintenance, have a fire suppression system. It is preferred for the fire suppression system to not rely on shutdown of the battery cooling system. The fire suppression system design should also consider the explosion hazard presented by offgassing, as discussed further in Section 4.2. These recommendations are considered sufficient to mitigate the offsite impact of this event SFAIRP.

4.1.3 Fire Tests

The analyses performed above are independent of the details of specific technology options; this is a conservative approach which allows for greater flexibility in the final selection of technology options as the project progresses.

However, in the course of performing this more conservative analysis, design and safety features are not taken into consideration. It is appropriate to consider these features if a more specific analysis has been performed. Typically, this analysis takes the form of a fire test performed to appropriate standards, such as those specified by the NFPA.

For example, the Tesla Megapack underwent fire testing using the UL9540A Test Method. The results of that testing, published in 2019, indicated that a separation distance of 6 inches (155 mm) between the sides and backs of Megapack units was acceptable to prevent fire spread from unit to unit. This is demonstrated in Figure 11.

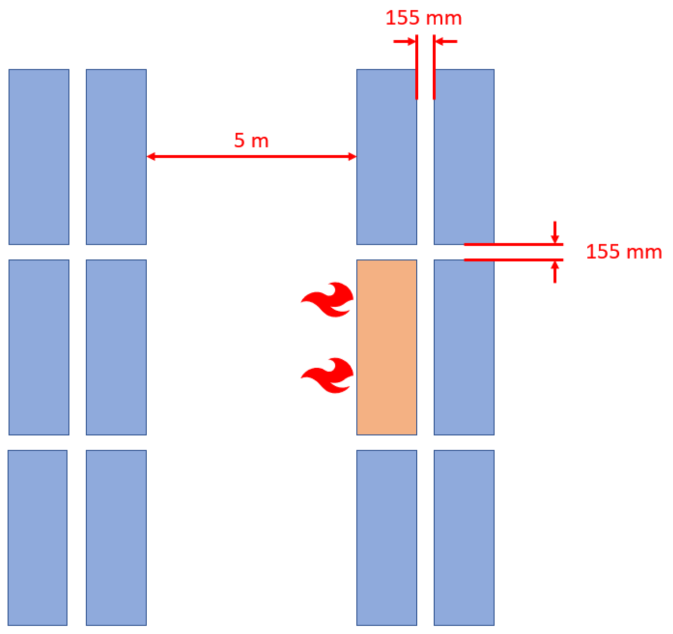

Figure 11: Acceptable spacing between Tesla Megapacks based on UL9540A testing results. (Note: 5 m separation is based on the analysis performed in this report.)

Should the Tesla Megapack be the technology option selected, the separation distances between units outlined in that 2019 fire test would be an appropriate basis for the BESS layout. Similarly, an equivalent fire test report for an alternative technology option would be applicable if that technology is ultimately used.

Arup recommends that the 10 m setback distance between the edge of the outermost battery unit in the BESS and the site boundary be maintained irrespective of the results of the fire tests.

4.2 Battery Explosion

As the final battery technology has not yet been chosen for the Site, this hazard has been considered for all technology options.

Due to the variety in BESS unit design options, a confined VCE was modelled for a vapour release scenario inside a battery container. Based on Arup's previous work, it is known that at high temperatures (100 °C or more), cells are designed to vent, to release internal gas pressure [6]. It is also known that for 20 ft containers, in a worst-case scenario, 400 L of hot gas will be released. This has been conservatively adjusted to be 800 L for the 40 ft containers being considered at the site. Teng et al. (2015) [7] give the compositions of gas generated by different electrolyte combinations at different charge levels. For 1:2 mixture of ethylene carbonate (EC) and diethyl carbonate (DEC), the composition of the released gas was derived from Teng et al.'s (2015) [7] testing and is shown in Table 4.

Table 4: Gas composition of a standard $LiPF_6$-EC-DEC electrolyte during a high temperature event

Material	Gas composition by mass (%)
Carbon Monoxide	34.8
Carbon Dioxide	0.2
Methane	0.3
Ethane	0.7
Ethylene	63.9

The scenario upon which the VCE model was based is an 800 L cloud of the released gas forming within the container. The indicative size of the container has been assumed to be 12.2 m (L) x 2.35 m (W) x 2.39 m (H), giving a volume of 68.5 m^3. Assuming that the batteries and other equipment inside the container take up 50% of the available space, 34.25 m^3 was available for the gas mixture to accumulate Modelling was performed using DNV GL's modelling software *Phast v8.22*.

Using the ideal gas law $pV = nRT$, where $p = 101325\ Pa$, $V = 0.8\ m^3$, $R = 8.314\ m^3PaK^{-1}mol^{-1}$, and $T = 373.15\ K$ gives 26.1 moles of the gas mixture and air. The molecular weight of the released gas has been calculated to be 28 g/mol which gives 732 g of fuel at 100 °C and 1 atm.

The Multi-Energy method was used to model the explosion behaviour. One of the parameters used in this method is the 'explosion strength', which is a number between 1 and 10, and is used to define the equation used in the calculations. Due to the highly confined nature of the scenario, an explosion strength of 7 was deemed most appropriate for the situation.

The inputs for the model are given in Table 5 below.

Table 5: Input parameters for the VCE model

Parameter	Value
Material	$LiPF_6$-EC-DEC mixture
Flammable mass in cloud (kg)	0.732
Volume of confined source (m^3)	34.25
Strength of explosion	7

The results are presented in Figure 12 and Table 6 below.

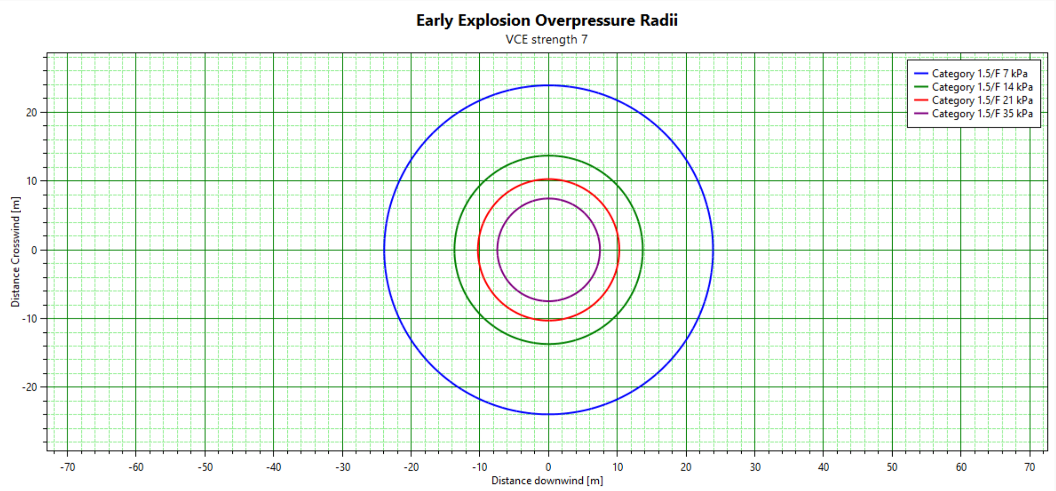

Figure 12 Overpressure contours for the VCE model

Table 6: Distances to overpressures of interest for VCE model

Overpressure (kPa)	Distance from blast centre (m)
7	24
14	14
21	10
35	7.5

HIPAP 4 [2] suggests that 7 kPa is an appropriate cut-off for risk criteria for offsite impacts. As such, it is recommended that a container without any explosion prevention or venting be at least 24 m from the site boundary to reduce the consequence of this risk. Alternatively, to reduce the likelihood and consequence of this event occurring, Arup makes the following recommendation:

- Procure a containerised BESS with explosion venting or an explosion prevention system designed to NFPA 68, NFPA 69, or an international equivalent.

The explosion venting or prevention system described above is considered sufficient mitigation to allow for the separation distances to the:

- Front/end of the container and adjacent container = 3.25 m
- Side container wall and adjacent container = 2.0 m

These recommendations are considered sufficient to mitigate the offsite impact of this event SFAIRP.

5 Findings and Recommendations

The two hazards that were identified as having the potential to cause offsite impacts, namely a battery fire and battery explosion, were carried forward for quantitative consequence analysis.

As the final battery technology has not yet been chosen for the site, these hazards were considered for both modular/cabinet and containerised solutions.

For a fire in a modular/cabinet unit, in order to have a received radiant heat flux of less than 4.7 kW/m^2 at the site boundary, the required minimum separation distance between the:

- Front/end of the modular/cabinet unit and site boundary = 2.25 m; and
- Side modular/cabinet unit wall and site boundary = 9 m.

Similarly, in order to have a received radiant heat flux of less than 12.6 kW/m^2 on the adjacent modular/cabinet units, the required minimum separation distance between the:

- Front/end of the modular/cabinet unit and adjacent modular/cabinet unit = 1 m; and
- Side modular/cabinet unit wall and adjacent modular/cabinet unit = 5 m.

For a fire in a container, in order to have a received radiant heat flux of less than 4.7 kW/m^2 at the site boundary, the required minimum separation distance between the:

- Front/end of the container and site boundary = 5.5 m; and
- Side container wall and site boundary = 5.25 m.

Similarly, in order to have a received radiant heat flux of less than 12.6 kW/m^2 on the adjacent containers, the required minimum separation distance between the:

- Front/end of the container and adjacent container = 3.25 m; and
- Side container wall and adjacent container = 2.0 m.

For an explosion in the unit, a vapour cloud explosion of vented gas was modelled. An overpressure of 7 kPa – the accepted minimum for injury or fatality – was found to extend to a distance of 24 m, and an overpressure of 35 kPa – corresponding to significant damage of structures – was found to extend to a distance of 7.5 m.

Arup makes the following recommendations to ensure that the residual risks for the identified hazards will be reduced SFAIRP:

- Separate the BESS 24 m from the site boundary unless the following are met:
  1. BESSs shall have a means to safely vent or prevent an explosion designed to NFPA 68, NFPA 69, or an international equivalent to reduce this risk SFAIRP.

2. In the absence of more specific test data, containerised BESSs shall be separated from one another by not less than 3.25 m end to end and not less than 3 m side to side, and separated from the site boundary by not less than 10 m.

3. In the absence of more specific test data, modular/cabinet BESSs shall be separated from one another by not less than 2 m end to end and not less than 5 m side to side, and separated from the site boundary by not less than 10 m.

If specific test data exist, the recommended separation distances between units provided for in those data can be used in preference to the distances listed here. For example, the Tesla Megapack can be separated be 6 inches (155 mm) side-to-side or back-to-back as demonstrated by fire testing performed using the UL9504A Test Method.

- Ensure the BESS manufacturer supplies the UL9540A fire test report for further refinement of separation distances.
- Ensure BESSs have a fire suppression system, if they are to be entered for maintenance. Additionally:

  1. It is preferred for the fire suppression system to not rely on shutdown of the battery cooling system.

The fire suppression system design should also consider the explosion hazard.

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[1] NSW Department of Planning, Industry and Environment (DPIE), *Multi-level Risk Assessment,* 2011.

[2] NSW Department of Planning, Industry and Environment (DPIE), *HIPAP No. 4 - Risk Criteria for Land Use Safety Planning*, 2011.

[3] NSW Department of Planning, Industry and Environment (DPIE), *HIPAP No. 6 - Guidelines for Hazard Analysis*, 2011.

[4] NSW Department of Planning, Industry and Environment (DPIE), *Applying SEPP 33*, 2011.

[5] T. P. a. L. Liedquist, *Steel Emissivity at High Temperature,* VTT Research Notes 2299, 2005.

[6] Arup, "Preliminary Hazards Assessment for Sapphire Solar Farm and Battery Installation," 2017.

[7] Xin Teng et al., "In Situ Analysis of Gas Generation in Lithium-Ion Batteries with Different Carbonate-Based Electrlytes," Beijing Key Laboratory of Environment Science and Engineering, School of Materials Science and Engineering, Beijing Institute of Technology, Beijing, 2015.

[8] National Transport Commission Australia, *Australian Code for the Transport of Dangerous Goods by Road & Rail*, *Edition 7.6,* 2018.

[9] US National Fire Protection Association, *Fire Hazard Assessment of Lithium Ion Battery Energy Storage Systems*, 2016.

Appendix A

HAZID Risk Register

A1 Risk Register

Facility/Event	Cause/Comment	Possible Results/Consequences	Risk (considering current and proposed controls)			
			Existing Controls	Likelihood	Consequence	Risk
Lithium Ion Cell Leakage	Damage to cells caused by external event	Leakage of battery materials requiring clean-up	Lithium batteries do not contain free liquid electrolytes Individual cells are used which minimises extent of release	Rare	Minor	Low
Damage to batteries from vehicle collision	Light vehicle strike to batteries	Damage to battery cells Electrical risks	Use of perimeter fence around battery facility Use of internal access roads with appropriate turning circles Limit of speed limit within fenced facility Earthing system installed as per normal electrical facilities	Rare	Moderate	Low
Transformer Oil Leakage	Corrosion of tank base or leakage of oil tank	Leakage of transformer oil to environment	Use of fully bunded oil storage for transformers in accordance with AS1940 Regular tank inspections included in O&M contract inspection requirements	Unlikely	Minor	Low
Overhead Line Failure	Collapse or fall of overhead electricity line onto battery storage facility	Falling of overhead line near facility	Location of all equipment outside TransGrid easements for overhead lines Normal electricity industry practice for plant shutdown Adherence to AS7000 for overhead lines	Rare	Minor	Low
Security Breach	Security breach into battery storage facility for theft of components	Theft of equipment or risk to personnel	Installation of security fencing around entire facility and also battery facility separately Installation of CCTV security system to monitor key areas O&M inspections to monitor for security breaches	Unlikely	Moderate	Medium
Fire Spreading Internally from Battery Packs	Spread of fire across battery facility between battery packs	Localised fire causing damage by spreading to facility	Separation distances between battery packs in accordance with manufacturer recommendations Adherence to bushfire management plan Coordination with local fire authorities Use of thermal CCTV security cameras to identify fires remotely	Rare	Moderate	Low

Facility/Event	Cause/Comment	Possible Results/Consequences	Risk (considering current and proposed controls)			
			Existing Controls	Likelihood	Consequence	Risk
Coolant leakage causing eye irritation	Minor spray in eye if working on battery coolant system	Minor leakage of coolant (typical of normal engine coolant) during minor maintenance activities at site	Use of appropriately qualified maintenance personnel Use of portable eye wash (squeeze bottle) for work on battery cooling system	Possible	Minor	Low
Electrocution from electrical facility	Electrocution due to electrical fault	Electrical fault causing personnel injury	Normal electrical standards including AS3000 and installation of appropriate earthing system Use of appropriately qualified maintenance personnel	Rare	Major	Medium
Damage due to lightning strike	Lightning striking facility and causing damage	Lightning strike causing damage to facility or personnel	Completion of a lightning risk assessment in accordance with AS1768 Include lightning protection measures if deemed necessary	Unlikely	Minor	Low
Flooding of facility causing damage	High rainfall and flooding to site	Damage to electrical equipment Restricted access to site	Undertake a site-specific flooding/hydrology study to determine site flood risk and Q100 flood levels Install all electrical equipment to be above the Q100 flood level with some freeboard Ensure suitable site access and egress at different locations	Rare	Moderate	Low
Miscellaneous and Small Stores of Dangerous Goods Being Spilled	Improper handling or storage of dangerous goods	Injury to personnel Minot spill to environment	Use an appropriately rated dangerous goods cabinet for small stores in accordance with Australian Standards Use appropriate bunding for chemicals stored in IBCs Provide all MSDSs on site and only use appropriately qualified personnel for handling Comply with appropriate transport requirements according to the Australian Dangerous Goods Code.	Possible	Low	Low
Explosion of Battery Cells	Explosion of cells from physical impact causing damage to equipment and personnel	Damage to surrounding equipment and injury to personnel	Liaise with battery OEM for relevant clearance distances And understand failure mechanics for battery explosion if relevant Use of perimeter fence around battery facility Use of internal access roads with appropriate turning circles Limit of speed limit within fenced facility	Rare	Moderate	Low

Facility/Event	Cause/Comment	Possible Results/Consequences	Risk (considering current and proposed controls)			
			Existing Controls	Likelihood	Consequence	Risk
Construction risks	General miscellaneous construction risks	Injuries to construction personnel	Develop a WHS plan Conduct detailed Safety in Design processes during project execution	Unlikely	Moderate	Medium
O&M risks	General miscellaneous O&M risks	Injuries to operations personnel	Develop a WHS plan Conduct detailed Safety in Design processes during project execution	Unlikely	Moderate	Medium
High wind events and seismic events	High wind or seismic events causing structural damage to equipment or battery packs	Damage to equipment and injury to personnel	Design in accordance with AS1170 considering appropriate wind speed and seismic design requirements	Rare	Minor	Low
Transport and delivery (manual handling)	Personnel injury through manual handling of equipment during operations	Personnel injury through inappropriate handling or spillage of handled equipment	Ensure a traffic management plan is in place during construction Adhere to requirements of a WHS plan and the ADG code Ensure site specific handling equipment of a ‘trolley’ is used for handling of battery equipment, including portable facilities for handling where appropriate	Unlikely	Minor	Low
Exposure to dangerous goods during site emergency	Site emergency event causing personnel injury through exposure to dangerous materials during site emergency	Site emergency event causing personnel injury through exposure to dangerous materials during site emergency	Have a site-specific Emergency Response Plan (ERP) for the facility Installation of appropriate signage and labelling to identify site specific hazards for different areas Liaise with emergency response workers for site specific response requirements	Rare	Major	Medium
Offsite impacts	Fire in or explosion of BESS with impacts extending past the site boundary	Societal and individual injuries and/or fatalities	Appropriate separation distances from the site boundary Ensure the BESS has a fire suppression system Containerised BESSs should have explosion venting or explosion prevention system	Rare	Major	Medium

Appendix B

Heat Radiation Calculations

B1 Heat Radiation Calculations

A fire event in a battery unit was modelled. In order to assess the worst credible case off-site risk, it was assumed that all fire prevention measures have failed and a unit has caught fire. One fire configuration was considered in which double doors at both ends of a container are open. Another fire configuration had doors along the long side of a modular/cabinet unit open.

The radiative heat flux emitted from the surface of the unit was calculated using the Stefan-Boltzmann Law:

$$j^*_{emitter} = \varepsilon\sigma T^4$$

where j^* is the radiant emittance, ε is the emissivity of the unit/smoke, σ is the Stefan-Boltzmann constant and T is the surface temperature. The heat flux received was calculated using the view factor method:

$$j^*_{receiver} = 4 \cdot \emptyset \cdot j^*_{emitter}$$

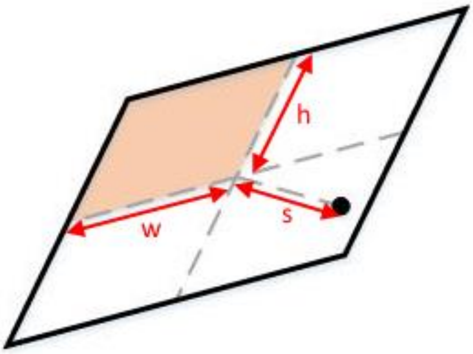
The view factor, $\emptyset$, is given by the equation

$$\emptyset = \frac{1}{2\pi}\left[\frac{a}{(1+a^2)^{1/2}}\tan^{-1}\frac{b}{(1+a^2)^{1/2}} + \frac{b}{(1+b^2)^{1/2}}\tan^{-1}\frac{a}{(1+b^2)^{1/2}}\right]$$

The parameters a and b are given by the following equations, where h is half the height of the surface, w is half the width of the surface and s is the perpendicular distance from the surface to the point of interest:

$$a = \frac{h}{s}\,; b = \frac{w}{s}$$

This is represented graphically as follows:



The radiative heat flux emitted was calculated using the Stefan-Boltzmann Law:

$$j^*_{emitter} = \varepsilon\sigma T^4$$