Appendix B

Preliminary Hazard Assessment

Edify Energy

Darlington Point Solar Farm

Preliminary Hazard Assessment

DPSF/PHA/001

Issue 1 | 2 August 2018

Job number 254766-10

Arup
Arup Pty Ltd ABN 18 000 966 165

Arup
Level 17
1 Nicholson Street
East Melbourne VIC 3002
Australia
www.arup.com

ARUP

Contents

Appendices

1 Executive Summary

A preliminary hazard assessment (PHA) has been completed for the battery energy storage system (BESS) to be located at the Darlington Point Solar Farm (DPSF) as directed by the Department of Planning and Environment.

This study considers the risks associated with the use of lithium ion (Li-ion) technology used in the BESS.

The results show that the low-level hazards can be prevented and/or mitigated by employing a combination of common measures, including following appropriate Australian and international standards, specific fire-fighting and battery system operational training, setbacks, physical protection and control systems measures.

In this study two potential configurations of battery energy storage are considered in the risk assessment.

The first is a cubicle-based installation made up of multiple cubicles, with each cubicle unit made up of some 14,400 individual lithium ion cells to store 100 kWh of energy. Units are then grouped together in a cluster with and inverter unit to make up the operational component. In this configuration, each unit is and integrated safe package and installed with appropriate segregation to minimise the risk of fire spreading between units.

The second configuration consists of similar cubicles of lithium ion cells grouped together in a containerised pod that provides internal protection around each cell but relies on external cooling via a HVAC system, and fire detection and suppression systems to contain any hazardous events to the combined containerised module.

1.1 Findings and Recommendations

1.1.1 Findings

The SEPP33 screening study as detailed in section 8.9 of the Environmental Impact Statement, showed that the facility did not meet the criteria to be classified as a hazardous or offensive industry as all hazardous chemicals were at or below the threshold limits of SEPP 33 as detailed later in Table 4.

No unacceptable risks are present on the project and appropriate controls are proposed or are in place. Risks evaluated go beyond the typical scope of a PHA and are based on best practice.

Appropriate ‘default’ controls will be in place based on current and highly relevant experience on the Gannwarra Energy Storage System project also being developed by Edify Energy.

The only relevant risks to SEPP33 relate to the battery facility. The DPSF has the same risk profile as other solar farms which are located across Australia and are demonstrated to not pose a hazard or offensive risk to the public.

It is demonstrated that, should a thermal runaway event occur within a battery unit or an external heat source be applied, the effects will be contained to the unit or container respectively without the potential for a cascading effect to other battery units.

There were no off-site risks due to the localised nature of the consequences and separation of the BESS from public places. A summary of this assessments findings on societal risk are provided in Table 1.

Table 1: The risk to society posed by the potential hazards identified in the DPSF battery system

Hazard	**Risk to Society**	**Reasoning**
Explosion / Flammable Gas	No	The blast radius calculated for a worst case explosion of flammable gas build up from the containerised battery system, in the case of all mitigating systems failure, was below the SEPP 33 guidelines injury threshold of 7 kPa at a distance of 20m. The nearest offsite boundary is a minimum of 100m from the battery system location. This therefore does not present a risk to society. No explosion risk exists for the Powerpack battery system that meets the requirements of UL 1973 (or equivalent).
Toxic Liquid	No	A toxic liquid spill can occur only in very, very small quantities and is contained within a battery module. This does not present a risk to society.
Fire / Flammable Liquid	No	The worst case fire event has the potential to spread from container to container. This scenario is highly unlikely to occur due to the many prevention measures that would all be required to fail simultaneously; however, if the event were to occur it will be contained by including a gravel buffer zone around the battery system of at least 20m.
Toxic Gas	No	A toxic gas cloud will occur only in small quantities and will largely be contained in a battery container or vicinity of the BESS. The cloud will form only in the case of battery abuse or accident, not during normal operation. Even given worse case wind conditions this amount of toxic gas does not present a risk to society.
Electrocution	No	The battery system and any live components will be a minimum of 100m from the site boundary, there is no public access onto the site and minimal staff on site at any one time. Therefore, electrocution does not present a risk to society.
Crush	No	The risk of crushing is localised to a single battery container and therefore does not present a risk to society.

1.1.2 Recommendations

- Undertake an updated PHA if battery technology changes significantly from the two options assessed in this review.
- Undertake detailed safety in design processes during implementation of the project as per normal delivery requirements
- Review and update risk assessment specifically for the battery project at time of implementation
- Implement proposed control measures identified in PHA risk register assessment table including that:
  - Should containerised battery modules system be the chosen, that they are separated by a minimum of 5m to reduce the likelihood of an escalation to other modules in the rare event a fire or explosion event occurs;
  - Should the cubical battery module system be chosen that the supplier can demonstrate certification to UL1973 (or equivalent), that a minimum separation to side and rear walls be 25mm (or the manufacturers recommended minimum if greater) and a minimum separation of 2m from the front grill wall of the cubical (or the manufacturers recommended minimum if greater); and
  - No matter which battery system is chosen, that the BESS is surrounded by a 20m barren earth finish (such as crushed rock) to minimise the likelihood of a passing grass fire to impact the BESS or for an event in the BESS to generate a grass fire that moves off site or into the solar array field.

2 Introduction

This document was prepared by Arup for Edify Energy to support the development of the proposed Darlington Point Solar Farm (DPSF). The DPSF will be a utility-scale photovoltaic solar farm with battery storage located near the TransGrid Darlington Point Substation in Darlington Point, New South Wales.

The proposed Battery Energy Storage System (BESS) facility will be developed at a later stage, subsequent to the construction of the solar farm facility, and would operate to charge and discharge electricity to suit market conditions, including the ability to store energy generated from the solar farm for discharge during peak periods outside of solar generation hours.

While the determined capacity and technology of the BESS facility is not yet finalised, it is anticipated that the facility could consist of a 100MWh facility based on lithium ion storage technology. The final decision on the preferred technology provider and detailed technology specification will be confirmed during the detailed design phase of the project, and will be required to comply with appropriate Australian and international standards, licences and codes.

2.1 Background and Screening Study

A screening study for the proposed Darlington Point Solar Farm and associated battery energy storage facility was undertaken in accordance with DP&E's *Applying SEPP 33 Guidelines: Hazardous and Offensive Development Application Guidelines* (DOP, 2011a), as part of the Environmental Impact Statement (EIS) for the project dated 16 April 2018.
The results and recommendations of the SEPP 33 screening study indicated the following:

- A Preliminary Hazard Assessment (PHA) was not required for dangerous goods to be stored on the proposed site;
- A number of conservative management measures were proposed to be implemented on the project as outlined in Table 2:

Table 2: Safeguard and Mitigation Measures

No.	Safeguard and mitigation measures
HM1	The DPSF site would manage the fire risks associated with the BESS by: ▪ Installing reliable, automated monitoring and control systems, with alarm and shutdown response capability. ▪ Taking reasonable and safe measures to prevent the risks of external heat effects in the event of a bushfire. ▪ Designing appropriate separation and isolation between battery cubicles, and between the BESS and other infrastructure, in accordance with the manufacturers recommendations, and including gravel set-off areas around the facility. ▪ Compliance with all applicable Australian codes and standards. ▪ Preparation of a BESS-specific fire response plan, in conjunction with the NSW Rural Fire Service. ▪ Installing adequate supplies of firefighting water within close proximity to the BESS facility if required by the BESS specific fire response plan.
HM2	▪ Fuels and pesticides/herbicides in use at the site will be stored at the laydown area in appropriately bunded areas designed in accordance with AS1940-2004.

Although the initial screening study did not demonstrate the requirement to undertake a Preliminary Hazard Assessment, as part of the response to submissions process for the development consent process, the NSW Department of Planning & Environment has determined that a PHA is required given the scale of the proposed BESS.

This report documents the completion of the PHA as requested by NSW Department of Planning Environment. In the assessment, two different battery configuration systems have been considered. They are:

- modular cubicle cabinets (similar to the Tesla Powerpack system) that are installed in an array around an inverter pack as illustrated in Figure 1 and Figure 2; and
- containerised modules (containerised system) that have been preassembled in modified shipping containers prior to transport to site as illustrated in Figure 3.

Figure 1: Single Powerpack cabinet (100kWh)

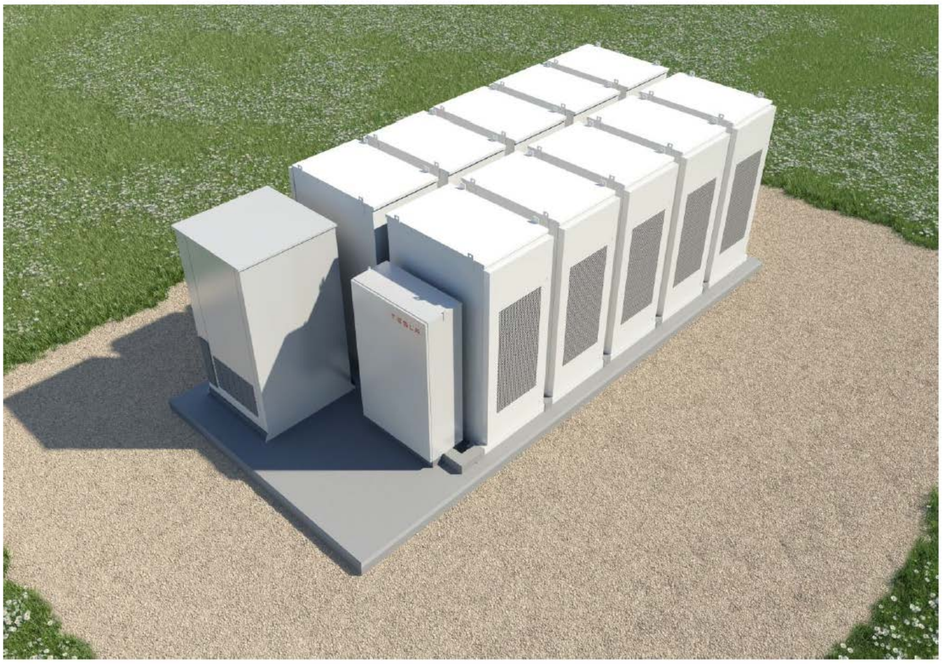

Figure 2: Multiple Powerpacks installed in an array

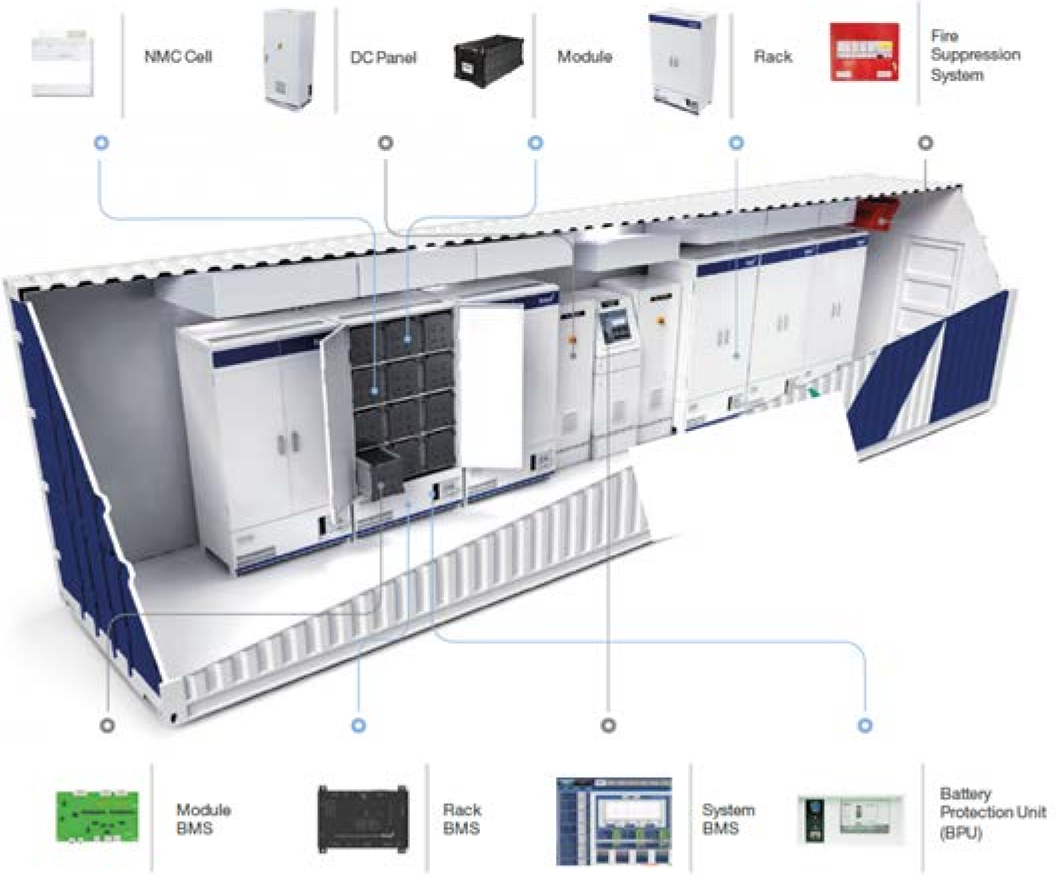

Figure 3: Example of a containerised battery energy storage system module

The following potential events have been considered for each of the BESS options:

- Fire;
- Explosion;
- Toxic Liquid Leak;
- Flammable Liquid Leak;
- Toxic Gas Leak;
- Electrocution; and
- Crushing.

3 Site Description

The DPSF will be a utility-scale photovoltaic solar farm with associated battery storage located near the TransGrid Darlington Point Substation in Darlington Point, in the Murrumbidgee Council area of New South Wales.

The site is zoned RU1 - Primary Production under the Murrumbidgee Local Environmental Plan 2013 (Murrumbidgee LEP) and is largely comprised of flat, open grasslands with some discrete pockets of remnant native vegetation. Historically the site has not been intensively farmed for agriculture and the properties have been used long-term for livestock grazing - sheep at Tubbo Station and cattle at the Anderson property.

The site is situated approximately 1.6 km south of the Murrumbidgee River. There are no mapped watercourses within the site, however parts of the site have been subject to inundation as a result of recent and historic major flood events.

One 330 kV and two 132 kV TransGrid overhead transmission lines cross the site from west to east, and a 33 kV Essential Energy overhead transmission line runs north-south near the eastern boundary of the site. The easements for the transmission lines would not be impacted by the proposed development of the DPSF, which has been designed to meet the minimum allowable distances for construction adjacent to transmission lines and towers.

The site is surrounded by farms, agribusiness and some private residences. A series of poultry farms owned by Baiada Poultry Pty Ltd are situated on land owned by Arrow Funds Management to the west of the site, on the other side of Donald Ross Drive. Some workers' accommodation is provided at the Baiada farms, the nearest of which is located around 100 m to the west of the DPSF site. The nearest private residence is located around 800 m to the north of the site.

Further from the DPSF site, Griffith Airport is located to the north of the site, approximately 49 km away. Narrandera Airport is located to the south-east of the site, approximately 45 km away.

3.1 Battery Storage Location

3.1.1 Area

The overall solar farm development is over an area of approximately 1,042 hectares, however the expected physical size of the BESS component is expected to be an area of approximately 2 hectares, located adjacent to the substation and a minimum of 100m from the nearest public road, Donald Ross Drive as shown in Figure 4.

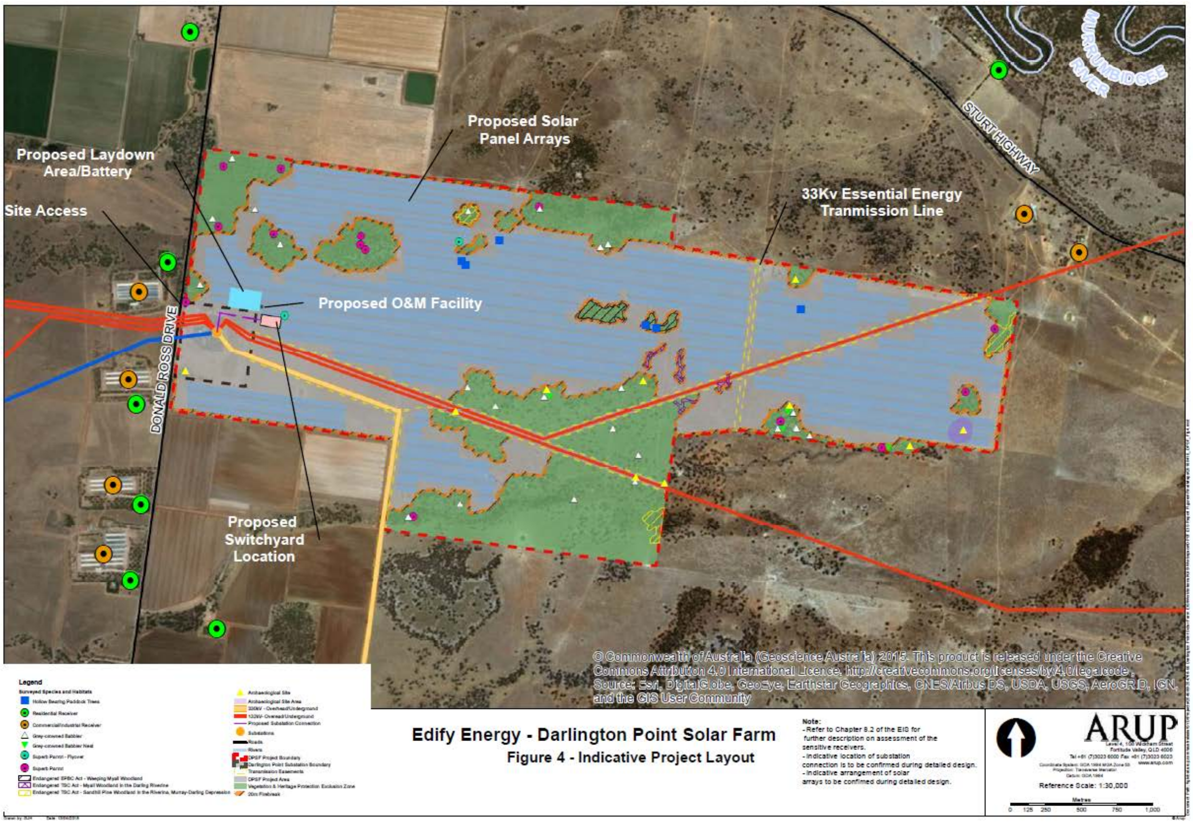

Figure 4: Proposed Darlington Point Solar Farm

A review of historic and current land uses, attributes and capabilities of the DPSF site was undertaken and assessed using the Land Use Conflict Risk Assessment (LUCRA) tool. Historically, the western portion of the DPSF site has been used for cattle grazing, however, the property owner is retiring the land from this use, by significantly reducing live stocking. The eastern portion of the DPSF site is currently used for sheep grazing, as part of a large broadacre commercial operation.

From a review of publicly available registers, no current or historic mining or exploration licences or new mineral or energy titles are located within or in close proximity to the DPSF site. However, one metallic and industrial deposit (Tubbo Sand Pit) is located approximately 2 kilometres to the east of the DPSF site, however, consultation with Murrumbidgee Council has indicated that the DPSF project would not impact on its operation.

The DPSF project will be wholly contained on private property through purchase of the Anderson property and a lease agreement with the land owners of the Tubbo Estate. The DPSF project would not have a direct impact on land use associated with public areas, residential or business properties.

3.1.2 Population

Darlington Point, located approximately 10 km north of the DPSF site, is a small town of approximately 1,160 people located on the banks of the Murrumbidgee River in the north of the Murrumbidgee LGA (ABS, 2016). Coleambally, the other main town within close proximity to the DPSF site, is approximately 20 kilometres south-west of the DPSF site and had a population of 1,331 people in the 2016 Census. The township of Jerilderie, which is approximately 100 kilometres south of the DPSF site, had a population of 1,029 people (ABS, 2016). The wider Murrumbidgee LGA had a population of 3,836 people (ABS, 2016).

3.1.3 Offsite and Natural Hazards

There are no offsite hazards which would represent a significant threat to the proposed facility. The following natural hazards have been assessed and determined as follows in Table 3: Offsite and Natural Hazards:

Table 3: Offsite and Natural Hazards

Natural Hazard	Overview
Wind	The project site is located in a Region A wind zone (lowest wind speed region) as determined in accordance with AS1170. All project elements will be designed to meet this wind speed requirement with appropriate structural ratings.
Seismic	The project site is not in a seismic zone as determined by AS1170. All project elements will be designed to meet this requirement with appropriate structural ratings.
Flooding	A preliminary flood assessment for the project has determined an indicative maximum flooding depth of approximately 500mm for most of the site. All project elements will be designed to meet minimum flood criteria to prevent damage for Q100 flood levels. A detailed flood study will be undertaken to determine Q100 flood levels.
Extreme Temperatures	The maximum and minimum temperatures as measured at the Griffith Airport AWS meteorological station are 46°C and -5.9°C respectively. The facility will be designed to operate in these temperature ranges.

Natural Hazard	Overview
Bushfires	Potential for grassfires in the region. A bushfire management plan and appropriate mitigations will be in place to minimise this risk.
Lightning Strikes	Potential for lightning strike to facility. A detailed lightning protection study will be undertaken for the project and appropriate mitigation measures put in place to minimise this risk if appropriate.

3.1.4 Site Presence and Security

Both facilities will be covered by an operations and maintenance contract which provide for regular and appropriate maintenance and inspections of both facilities as well as continuous remote monitoring of the system from a remote location.

When the solar farm and BESS facility is constructed, operations personnel will attend site periodically as required for routine and scheduled maintenance activities, but the site will not be permanently staffed. The site will be remotely monitored from an operations facility utilising the site SCADA system for continuous site monitoring and operations. This site based SCADA system will be designed to provide alarms and automatic operations to manage events.

Both the solar farm and the proposed BESS will have appropriate security provisions including security fencing and remotely monitored CCTV security cameras as well as appropriate security access requirements to restricted areas.

3.2 Process

3.2.1 General Overview

The proposed BESS is expected to operate in conjunction with the Darlington Point Solar Farm to provide the following functions within the electricity market:

- Charging and discharging of energy from the solar farm or 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

In order to achieve the above, the BESS will operate in any of the following modes:

- Charging of the battery from the solar farm;
- Charging of the battery from the external electrical grid; or

- Discharging of the battery to the external electrical grid.

It is noteworthy that operations of the proposed facility do not require any ongoing feedstock or consume any Dangerous Goods as part of the operational processes.

3.2.2 Overview

Both proposed battery technologies used will consist of lithium ion battery technology. Each option consists of modules that are likely to made up to 14,400 individual lithium ion 3.6 volt, 2.4 amp hour cells (NFPA, 2016). It should be noted that the use of lithium ion batteries is generally not considered to be a ‘process’ in the conventional sense as there is no consumption or feedstock of chemicals required to be consumed or provided to facilitate its use. Instead, the system works through an electrochemical process which is inherently part of a process on the equipment supplied by the Original Equipment Manufacturer (OEM) and does not require any provision of any additional chemicals or materials to facilitate operation.

The overall system will comprise of an alternating current (AC) coupled lithium ion battery system with a bi-directional (charge and discharge) power conversion system and site controller. 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 connected together to form an integrated system. The BESS, if installed, will be required to confirm with the following safety standards:

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

An indicative cubicle based battery energy system is shown in Figure 1 and an indicative containerised battery energy storage system is shown in Figure 3 earlier in this document.

3.2.3 Storage

It is expected that the lithium ion battery system will be classified as UN 3480 ‘lithium-ion batteries” and as a Class 9 dangerous good under ADG7. ADG7 requires all dangerous goods, including lithium ion batteries, to be carried in a secure, safe and environmentally controlled manner (ABRI, 2018).

There are other minor stores of chemicals expected on site, with estimated quantities as follows in Table 4:

Note that all quantities of hazardous substances stored on site are below the threshold quantities of SEPP33 and do not present an off-site risk.

Table 4: Hazardous substances and other chemicals at Darlington Point Solar Farm

Substance	Hazardous Class	Total Storage on Site	Threshold Quantity	SEPP 33 Threshold Level Findings	Comment
Solid Lithium Ion Batteries	Dangerous Goods Class 9	Approx. 800 assembled units	Not applicable	Not applicable	Installed as part of the battery units as solid material inside cells.
Petrol	Dangerous Goods Class 3	<1 tonne	>2 tonne	Below	On site storage for minor site use (eg. lawn mowing).
Pesticides	Dangerous Goods Class 6.1	<2.5 tonnes	2.5 tonnes	Below	Used for weed control if required (localised weed spraying).
Diesel	Combustible Liquid	<1 tonne	Not applicable	Not applicable	On site storage for minor site use (eg. small standby generator)
Refrigerant (R134a)	Dangerous Goods Class 2.2 (Non-Toxic Compressed Gas	Approx. 350 kg	Not applicable	Not applicable	Installed as part of the cooling system of the battery units (similar to air conditioning).
Miscellaneous Minor Chemicals Store	Dangerous Goods Class 2.2, 3, 5.1 and 8	< 1 tonne and <1 m^3	Thresholds all above indicated total storage	Significantly below	On site storage for minor site maintenance activities (eg. cleaning chemicals)
Ethylene Glycol (50/50 mixture with water	Not applicable (Non-Hazardous Substance)	Approx. 3 m^3	Not applicable	Not applicable	Installed as part of the cooling system of the battery units (similar to car radiators).
Transformer Oil	Not applicable (Non-Hazardous Substance)	Approx. 45 m^3	Not applicable	Not applicable	Minor thermal oil used in kiosk transformers (similar to residential area kiosk transformers).

3.2.4 Transport

There is no significant ongoing transport of any hazardous materials or dangerous goods to the site on a routine basis as part of the operational requirements of the solar farm and the BESS. Most dangerous goods (including the lithium ion batteries) will be delivered as a one-off delivery during the construction of the project. Fuel and pesticides will be delivered in minor amounts as consumption dictates.

The quantities of dangerous goods to be transported are well below the threshold quantities outlined in Table 2 of SEPP 33.

4 Detailed Hazard Analysis

4.1 Hazard Identification

A hazard identification process was undertaken during a workshop with project personnel to identify hazards, and assess their likelihood, consequence and risk level. The following key items were noteworthy with respect to the hazard identification process:

- A study team comprising of four key personnel who are involved in the construction and operations and maintenance of the proposed project was assembled with specific experience in both large-scale solar and battery energy storage systems;
- Previous risk assessments for other similar projects were reviewed and any relevant risks identified were assessed.

The identified hazards were recorded in the PHA Risk Register in Appendix A and the risk analysis undertaken for each identified risk as further outlined in this document and based on the general approach outlined in *AS/NZS 31000 – Risk management – principals and guidelines.*

4.1.1 Overview

The primary source of potentially harmful hazards are the lithium ion battery cells that make up the BESS. All other components of the project are typical and widely used electrical equipment which is typically present at the solar farm and other HV electrical facilities.

For the purposes of completeness, assessment of minor volumes of dangerous goods and other materials are also included in the analysis where these may be present for both the combined solar farm and the battery facility. It is noted that many of these materials are not actually specifically relevant to the SEPP 33 process or are significantly below the threshold volumes.

4.1.2 Project Components

This PHA specifically covers the risks associated with the BESS.

4.2 Consequence Analysis

A consequence analysis was undertaken based on an assessment of the expected consequence of the risk with respect to the health & safety, environmental and financial consequences. Each individual risk was given a consequence rating in accordance with the criteria outlined in Table 5.

Table 5: Consequence rating matrix

Score	Rating	Health & Safety	Environmental	Financial
1	Low	Minor first aid or no injury.	Minor harm to the environment (eg. noise complaint).	<100k loss
2	Minor	Disabling injury (less than 5 days off work).	Temporary harm to the environment (eg. small area of contamination).	$100k - $1m loss
3	Moderate	Serious injury (amputation, permanent disability).	Harm to the outside environment.	$1m - $10m loss
4	Major	One fatality.	Extensive damage to the environment (eg. large area of contamination).	$10m - $100m loss
5	Catastrophic	More than one fatality.	Massive, irreversible damage to the environment.	>$100m loss

It should be noted that the consequence assessment was undertaken based on a fundamental assumption that recommended controls and measures would be put in place.

Due to the differences in the two battery systems being considered there are different consequential outcomes to be considered for some of the underlying events. Where this is appropriate, the discussion will identify which battery system (Powerpack or containerised) is being discussed otherwise the discussion applies to both systems.

4.2.1 Consequence of Fire

Fires within a lithium ion battery system can be initiated by an internal event such as a thermal runaway in one or more of the individual cells or by an external source such as a bushfire. As there have been no recorded fire events in lithium ion battery energy storage systems, the NFPA have undertaken tests of an individual cubicles (100kWh) which involved direct flame impingement from a butane fire as well as an internal simulation of a thermal runaway event (NFPA,2016).

It should be noted that there is an international standard for batteries (UL 1973 – *Batteries for use in light electrical rail applications and stationary applications*) that specifies in section 2.4.1 a number of construction requirements, performance tests, and production tests for stationary battery systems, including an external fire test and an internal fire test. The external fire test requires that the battery system not pose an explosion hazard if attacked by an external fire. The internal fire test demonstrates that a single battery cell failure within the centre of the battery pack will not result in a cascading thermal runaway of battery cells resulting in a propagating fire from the battery pack and/or an explosion of the battery pack (NFPA, 2016).

It should be noted that Tesla, the supplier of battery pack for the NFPA tests conforms to this standard, among others.

External Fire (Powerpack)

The external fire test by the NFPA involved placing a propane burner on the side of the Powerpack with recoding equipment and cameras arranged on and around the pack to record observations as shown in Figure B 1 in Appendix B. The burners operated for one hour, by which time thermal runaway within the lithium ion cells was underway. It took another 2.75 hours for self-extinguishment.

The tests showed that a direct heat source could induce the Powerpack into thermal runaway and result in electrolyte ignition of the electrolyte material. Flames remained mostly confined to the Powerpack itself. Weaker flames were observed from the exhaust vent and the front door grill, as illustrated in Figure B 2 in Appendix B.

It can be observed that the fire is in fact lazy and that it only exposes flame outside the cubicle at the front door grill and the relief valve on top of the cabinet. Also, it should be noted that there is no combustion of the outside cabinet panels even from the direct propane fire. Combined these two factors indicate that there is a decreased likelihood that fire will spread from one cabinet to another cabinet in the same group.

Gas samples were taken from the vent throughout the test. Carbon monoxide (CO) and hydrogen fluoride (HF) were detected. No chlorine or methane was detected.

No projectiles, explosions or bursts were observed during the test.

Internal Fire (Powerpack)

The internal fire test was initiated by the use of six 1/8th inch diameter 25 Watt cartridge heaters placed in the centre of the module. Current was applied to all six heaters simultaneously, which resulted in the simultaneous runaway of ten lithium ion cells. This method was deliberately designed to overcome the passive protection mechanisms of the Powerpack.

Once heating was turned off, further lithium ion cells in the same level (one of 16 in a Powerpack) were induced to also thermally runaway for approximately 15 minutes. White smoke was observed however, no flames were observed as shown in Figure B 3 in Appendix B. The event self-extinguished without thermal runaway occurring beyond the level that was heated.

No projectiles, explosions or bursts were observed during the test.

Fire test conclusions

From these tests, it can be concluded that significant heat input is required to generate conditions that will have the lithium ion cells thermally run away. The design of the cubicles themselves (if designed to UL 1973) limit the consequences to the individual cubicle.

Separation is required in front of the grill side of the cubicles by up to 2m and an air gap (minimum 25mm) between cubicles to prevent direct conduction occurring.

No offsite consequences are expected given the BESS is a minimum of 100m from the nearest road.

4.2.2 Consequence of Explosion (Containerised)

With battery cabinets located inside a container, there is the potential for decomposition products that are flammable to accumulate in the container.

A confined vapour cloud explosion was modelled for a vapour release scenario inside a battery container. Battery system supplier information suggests that, at high temperatures (100°C or more), cells are designed to vent to release internal gas pressure. The volume of gas vented by cells in a single container was assumed to be 400 L, based on the information provided. Teng et al. (2015) 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 vapour mass composition was derived based on the data shown in Table 6. At 100°C, 400 L of the above mixture has a mass of 382 g. Assuming that the batteries and other equipment inside the container take up 50% of the available space, 60.6m^3 was available for the hot gas mixture to accumulate.

Table 6: Gas composition of a standard LiPF6-EC-DEC electrolyte during a high temperature event.

Material	Gas composition by mass (%)
Carbon Monoxide (CO)	34.8
Carbon Dioxide (CO_2)	0.2
Methane (CH_4)	0.3
Ethane (C_2H_6)	0.7
Ethylene (C_2H_4)	63.9

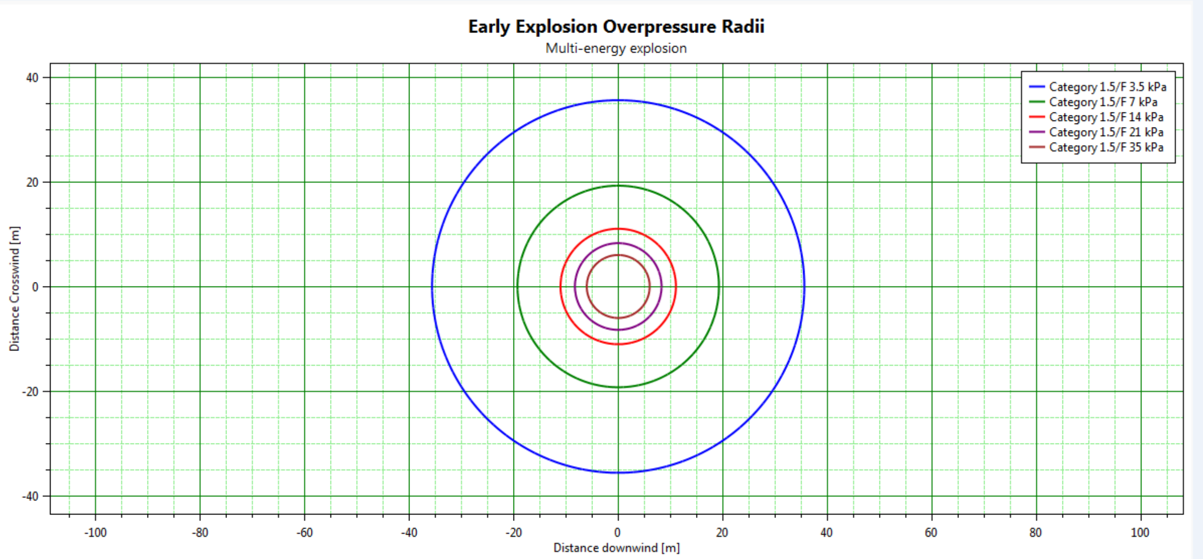

Figure 5: The overpressure at radius radii resulting from a gas explosion event in a battery container at the DPSF

A confined vapour cloud explosion (VCE) was modelled in DNV GL's Phast v7.21 software. The results are presented in Figure 5. The results of the consequence modelling show that the more severe contours (14 kPa, 21 kPa and 35 kPa) are restricted to within 10 m of the blast epicentre. The guidance in the SEPP 33 Guidelines suggests that 7 kPa is an appropriate cut-off for significant injury or fatality to individuals. As such, the risk to human life in an explosion event is contained within a 20m radius. The risk to neighbouring containers was also considered, to assist with separation distance guidance. Anderson et al. showed that ISO shipping containers sustained "minor" damage at 2 psi overpressure (approx. 14 kPa) and "significant" damage at 5 psi overpressure (approx. 35 kPa). As such, a 10m separation distance between containers would be sufficient to limit damage to 'minor' levels, however this is an overly conservative assumption given the likelihood of an explosion event occurring. A minimum of 5m is recommended and should an explosive event occur it is expected that damage will occur to nearby battery modules.

No offsite impacts are expected from a VCE scenario as the BESS will be located a minimum of 100m from Donald Ross Drive. Further, given the blast resilience of the containers, any damage as the result of an explosion is likely to be very localised and unlikely to lead to a cascade effect. This would only affect operational or firefighting staff in the unlikely event an explosion occurred, should they be present. This should be addressed in the Emergency Response Plan for the site.

4.2.3 Consequence of Fire (Containerised)

A fire event initiating in the battery container was modelled. The parametric fire curve from AS 1530.4:2014 *Methods for fire tests on building materials, components and structures. Part 4: Fire-resistance tests for elements of construction* was used to determine the upper bound of the likely fire temperature. The parameters used in the modelling are as follows:

Table 7: Parameters utilised in the fire modelling

Parameter	Value
Length of container (m)	12.2
Width of container (m)	2.44
Height of container (m)	2.6
Temperature at open end (°C)	1000
Temperature at closed end (°C)	600
Emissivity (-)	1

The following modelling assumptions were made:

- The end of the container (shown in orange in Figure 9) was assumed to be open to create the conditions for a worst-case fire with sufficient oxygen flow;
- The heat flux from the emitting surface was assumed to be uniform;
- No heat loss was assumed to intermediate media (i.e. to air or smoke);
- The temperature of the long side of the container was taken to be the linear average of the two end temperatures (i.e. 800°C); and
- The container was assumed to be a black body for the purposes of the calculations (worst case)

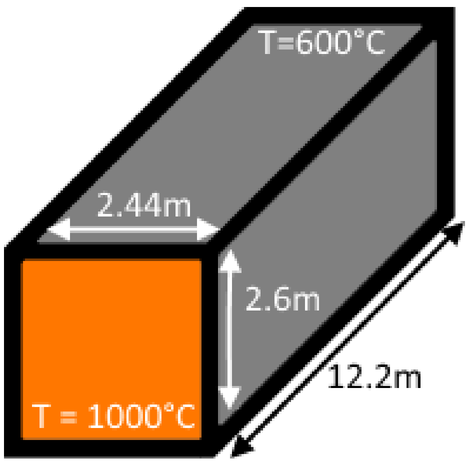

Figure 6: The fire modelling layout, showing the container dimensions and temperature assumptions at each end of the container.

Table 8: The model assumptions for the two radiant heat sources

Heat Source	Temperature (°C)	Height	Width
1 – Front	1000	2.6	2.44
2 – Side	800	2.6	12.2

Two radiative heat sources were considered in the analysis. The heat flux emitted by each heat source was calculated using the Stefan-Boltzmann Law:

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

The heat flux received was calculated according to the following equation:

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

The view factor, Ø, 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.

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

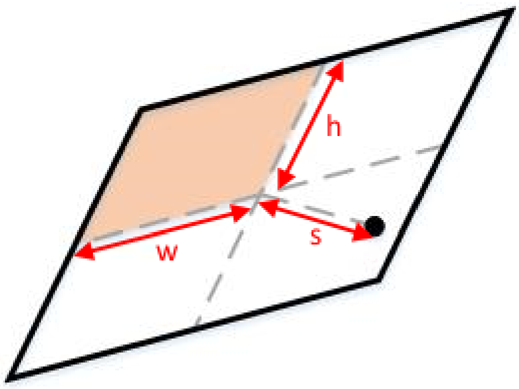

Figure 7: Key geometry in the fire model

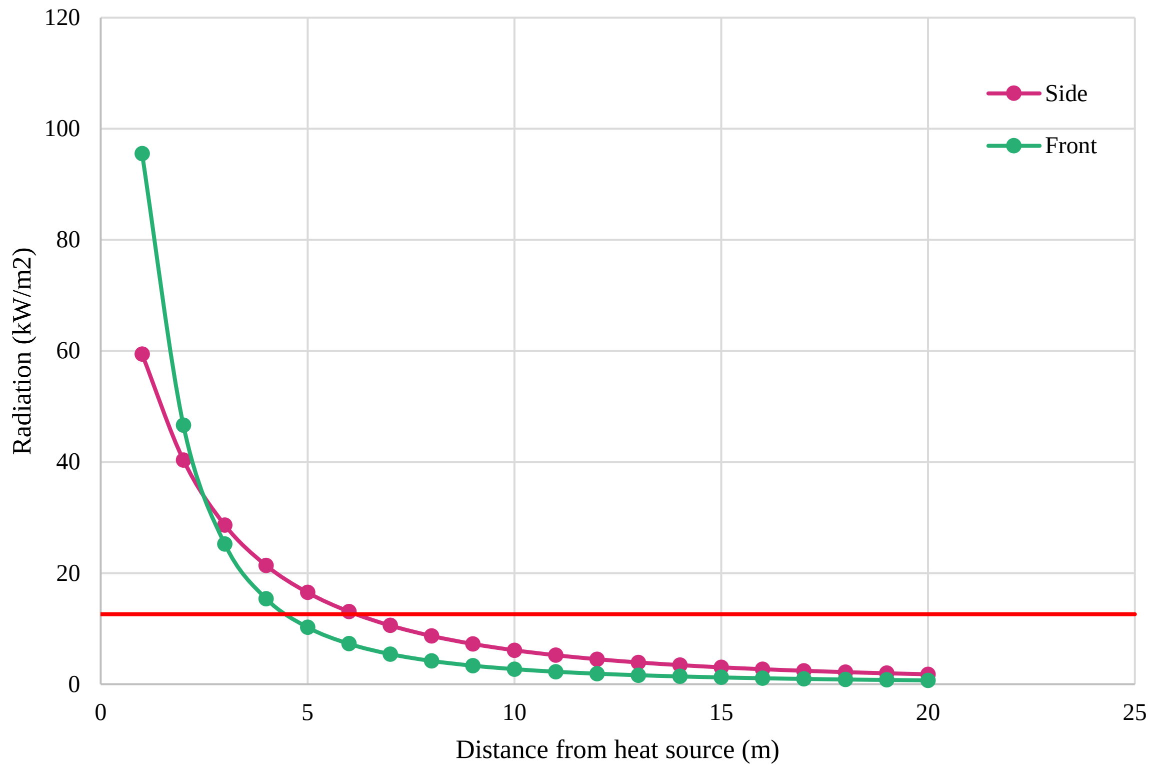

Figure 8: The fire model results showing radiation at a given distance from the battery container on fire

The results of the analysis are shown in Figure 8, with the red line at 12.6 kW/m^2 showing exposure limits relevant to HIPAP 4. According to HIPAP 4 the consequences for 12.6 kW/m^2 heat radiation are:

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

The fatality consequence is unlikely to have a direct off-site impact as the BESS is located a minimum of 100m from the nearest road. There exists a risk of on-site staff being exposed to a fatally high level of heat radiation at extremely close proximity to the fire. HIPAP 4 states that there is a "chance of fatality for instantaneous exposure" at 23 kW/m^2 radiation.

Given that any fire would take some time to reach the temperatures modelled, the risk of fatality as a result of direct exposure to heat radiation is limited to people inside the container itself and directly adjacent. It is recommended that on-site staff are trained to evacuate when the life safety risk associated with fighting a small fire in the containers is too high.

The most significant life safety risk as a result of a fire such as this is that the heat radiation causes a grassfire to start. Any ember from a fire could cause vegetation that is sufficiently dry, to ignite. It is recommended that a radius of at least 20m of the battery containers is cleared of vegetation, with the ground to be covered in crushed rock or a similar material.

There is some potential for heat radiation to cause structural damage to neighbouring containers. This should be considered, in conjunction with the results of any detailed fire modelling, when the design and layout of the battery containers is undertaken. Beyond structural damage, there is only localised risk to life and property, and it is concluded that the consequence of a fire event is the potential for harm to a single person should they be present.

4.2.4 Consequence of Toxic Gas (both Powerpack and containerised)

The consequence of a toxic gas cloud accumulating in the container was calculated based on the hypothetical volume of gas that could be emitted from a lithium ion battery, and the approximate composition of that gas. The electrolyte mix chosen was again $LiPF_6$-EC-DMC. The volume of gas released by a containerised battery system is 400L.

Two cases of toxic gas emission were considered. The first involved emissions evaporating from a liquid electrolyte pool, without combustion. The gaseous products created (CO, CO_2, C_2H_4, C_2H_6 and CH_4) were generated in different proportions. The gas composition was based on the work of Teng et al. (2015).

The second case assumes the electrolyte is combusted, for example during a thermal runaway event, and hydrogen fluoride (HF), phosphoryl fluoride (POF_3) and phosphorus pentafluoride (PF_5) are produced in different proportions based on the work of Andersson et al. (2013), although the exact proportions were not given. The proportions and other key parameters are shown in Table 9.

Table 9: The composition and volume of gas generated in the modelling of a toxic gas event in the DPSF battery system

Toxic Gas Case	Gases Created and Approximate Proportions	Volume of Gas in Container
Non combusted Electrolyte	CO (36%), CO_2 (<1%), C_2H_4 (54%), C_2H_6 (<1%) and CH_4 (9%)	400 L
Combusted Electrolyte	HF, POF_3 and PF_5	400 L

In both cases the hazard is only present inside the container, and any gas escaping the container would quickly dissipate below toxic levels. Thus, in both cases the potential harm from a toxic gas consequence is limited to a single person entering the container to conduct maintenance or for firefighting purposes. Staff and emergency firefighters should be made aware of this risk and wear breathing apparatus until it is proven that the air is safe to breathe.

4.2.5 Consequence of Electrocution (both Powerpack and containerised)

The risk of electrocution is present in the DPSF facility, albeit only in a very localised area. The consequence of an electrocution event will vary from minor injury to death of the maintenance employee in the container. The battery management system SCADA control and use of qualified electricians will limit this risk.

4.2.6 Consequence of Crushing (both Powerpack and containerised)

There exists the risk of a heavy piece of equipment, such as a battery pack, falling on an operator inside the container, or vehicle crashing into a battery container or unit whilst a maintenance worker is inside or nearby.

4.3 Estimation of Likelihood of Hazardous Events

A likelihood analysis was undertaken in which each individual risk was given a likelihood rating based on the criteria outlined in Table 10.

Table 10: Likelihood matrix

Score	Rating	Likelihood
A	Almost Certain	Is expected to occur in most circumstances. Occurs more often than once in two years or is almost constant.
B	Likely	Will probably occur in most circumstances. Not unusual. Occurs once in every 2 to 5 years.
C	Possible	Might occur at some time. Possible sequence of coincidence is unusual. Occurs once in 10 years.
D	Unlikely	Could occur at some time but would require remotely possible coincidences. Occurs once in 50 years.
E	Rare	May occur in exceptional circumstances. Occurs once in 100 years or more.

It should be noted that the likelihood assessment was undertaken based on a fundamental assumption that recommended controls and measures would be put in place.

The likelihood of hazardous events occurring was estimated using fault tree analysis for each consequence at the DPSF battery system. A detailed discussion also accompanies each consequence identified. The type of likelihood analysis used for each potential consequence is shown in Table 11.

Table 11: Potential consequences in the DPSF hazards assessment and a summary of the consequence analysis employed

Consequence	Type of Likelihood Analysis	Details
Flammable Gas/Explosion	Semi-Qualitative Analysis	Discussion and fault tree analysis plus prevention measures (e.g. container separation distance) designed based on outputs from PHAST engineering consequence modelling
Toxic Liquid	Qualitative	Discussion and fault tree analysis
Flammable Liquid/Fire	Semi-Qualitative Analysis	Discussion and fault tree analysis, plus prevention measures (e.g. setback distance) designed based on outputs from fire engineering consequence modelling
Toxic Gas	Qualitative	Discussion and fault tree analysis
Electrocution	Qualitative	Discussion and fault tree analysis
Crushing	Qualitative	Discussion and fault tree analysis

4.3.1 Likelihood of Explosion (containerised)

There are two categories of initiating events which could lead to an explosion event. Figure 9 shows the major fault pathways for an explosion event to occur involving the battery system at DPSF.

The first is a battery cell being punctured and spilling electrolyte onto the ground, forming a pool, which vaporises, that accumulates in the container, creating the fuel for an explosion event. The likelihood of this occurring is extremely low for lithium ion batteries, as there is no free liquid electrolyte in solution (Telsa, 2017; NFPA, 2016). In the USA, the National Fire Protection Agency (NFPA) and International Fire Code (IFC) have modified the relevant codes that assess lithium ion batteries to reflect the limited amount of liquid electrolyte, with assessment of risk now based on the weight of lithium ion batteries in an installation. Thus, it was concluded that a pool of electrolyte initiating event would be *Rare* event should it occur.

The second category of initiating event is battery cells venting gases into the container, typically due to overheating, abnormal chemical mixing or electrical issues such as low voltages, charge imbalances, or operation over or under safe discharge/charge rate windows. Without any mitigation measures, these initiating events would be reasonably likely to occur; however, many mitigation measures exist to prevent cell heating, physical damage and electrical operation outside of the design boundaries. These specific mitigation measures are covered in detail in section 4.3.4, which relates to fire but can also be applied to explosions as the triggering events are the same (e.g. cell damage, cell heating). Based on the many mitigations measures deployed, the independence of mitigation controls and the effectiveness of the mitigation measures, it was concluded that the likelihood of these initiating events occurring is *unlikely*.

In addition to an initiating event, in order for an explosion to occur the container which contains the battery system must be sufficiently sealed such that the gas accumulates, and, there must be an ignition source present. That is, a gas cloud must be created and then something must ignite the cloud. All lithium ion battery systems considered at the DPSF included a HVAC system to ventilate the battery container, so this system must fail, or the gassing event must be too quick for the HVAC system to exhaust the cloud, in order for a build-up of gas to occur in the container. Finally, the container pressure relief valve must fail if the pressure inside the container increased above its set point. The chance of the HVAC system and the pressure relief valve both failing, or being overwhelmed in a very short gas cloud release, is considered *unlikely*.

Thus, for an explosion to occur a *rare* or *unlikely* initiating event must occur, and an *unlikely* failure of mitigation measures must occur for an explosion consequence to occur. Thus, it was concluded that an explosion at the DPSF is *rare*, if the recommended mitigation measures are utilised.

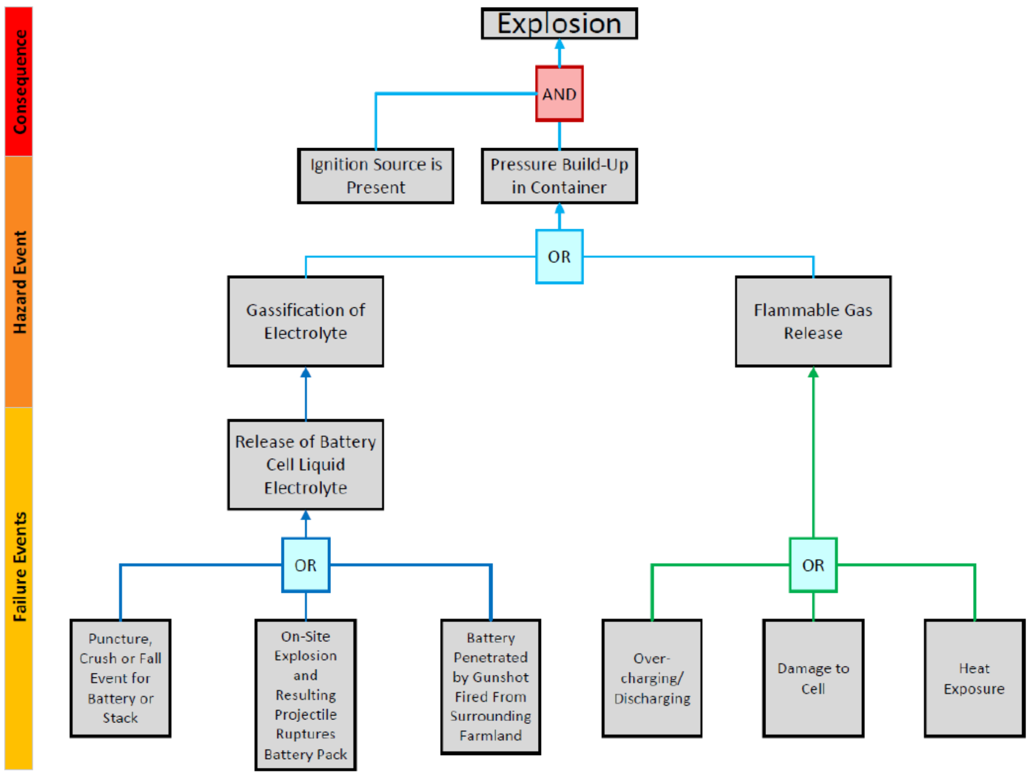

Figure 9: Explosion event fault tree

4.3.2 Likelihood of Explosion (Powerpack)

As discussed in section 4.2.1, the NPFA fire tests demonstrate that if the Powerpack cubicle is designed to meet the requirements of UL 1973 that even under circumstances of significant heat input that individual cell bursts are contained within the cabinet structure and that there is no simultaneous event that puts explosive pressures on the cabinet construction. It is not plausible for an explosion to occur.

4.3.3 Likelihood of Toxic Liquid or Toxic Gas (Containerised)

The initiating events of a toxic gas event are the same as for an explosive event (Section 4.3.1), with the exception that there is no ignition source. Figure 10 shows the major fault pathways for a toxic liquid or toxic gas event to occur involving the battery system at DPSF.

In the absence of an ignition source a gassing event leads to a build-up of toxic gas, creating a hazard to maintenance staff and in the case of a fire (which may be the cause of the gas cloud) a potential hazard to fire-fighting staff if they are required to enter the container. A toxic gas build-up is more likely to occur than an explosion, as an ignition source is not required. In addition, with appropriate mitigation measures installed such as gas sensors, maintenance and fire fighter specific lithium-ion hazard training, BMS system controls and pressure relief valve installation, the likelihood of a toxic gas build-up is assessed as *rare*.

The initiating events for a toxic liquid event are those discussed in Section 4.3.1, and include a battery cell being punctured and electrolyte spilling out. The initiating events could include a crash event from a vehicle accident, vandalism or animal ingress into the container. Regardless of the initiating event, the end result would be the puncture or crushing of one or more battery cells, theoretically leading to the spillage of liquid electrolyte. However, as discussed in Section 4.3.1, lithium ion batteries differ in this regard in that they do not contain liquid electrolyte, and hence the chance of liquid spilling is *unlikely*. As a result, it is concluded that the likelihood of such a toxic liquid pool event occurring is *rare*.

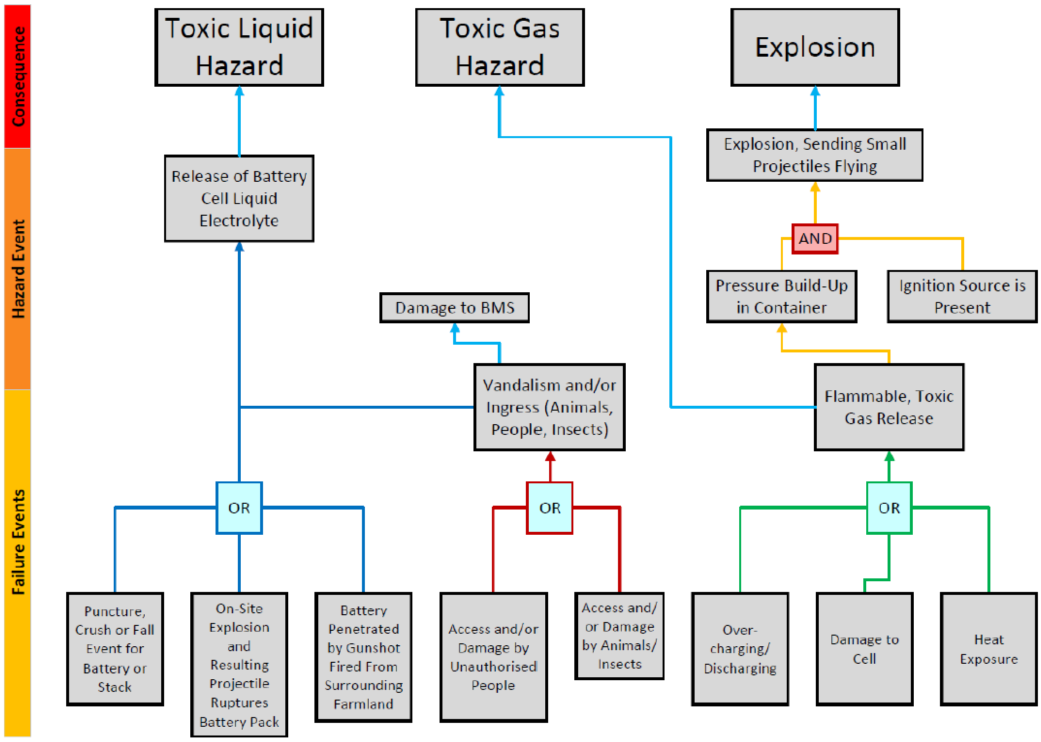

Figure 10: Toxic liquid or toxic gas hazard fault tree

4.3.4 Likelihood of Flammable Liquid and Fire (Containerised)

There are two distinct initiating event pathways that lead to a fire in the battery container and then a number of sub-pathways leading to these two initiating events as shown in Figure 11. The first initiating event is the formation of a toxic liquid pool inside the container from spillage of battery electrolyte, which in the presence of an ignition source starts a pool fire. As discussed in Sections 4.3.1 and 4.3.2, the likelihood of an electrolyte pool forming is *rare*, due to the absence of liquid electrolyte in lithium ion batteries.

The second initiating event leading to a fire in the battery system at DPSF is the potential for thermal runaway in one or more battery cells. The likelihood of this event occurring is greater than any other hazard initiating event in the DPSF system; and the potential consequence is higher in comparison to other potential consequences at the DPSF.

A thermal runaway event can be caused in a number of ways. The major pathways are highlighted in Figure 11, although it should be noted that this fault tree is not exhaustive. The major initiating event pathways that lead to thermal runaway and fire consequences are:

- An elevated temperature in the battery container, created by either an external heat source, such as extreme weather events (and in particular a bushfire event), or a failure of the HVAC system;
- A mechanical failure which leads to damage to battery cells that allowing for fast chemical mixing and overheating; and
- An electrical failure event, such as over-charge or discharge, over or under voltage, or a short circuit failure, creating an electrical current flow which heats the cell above its safe operating range

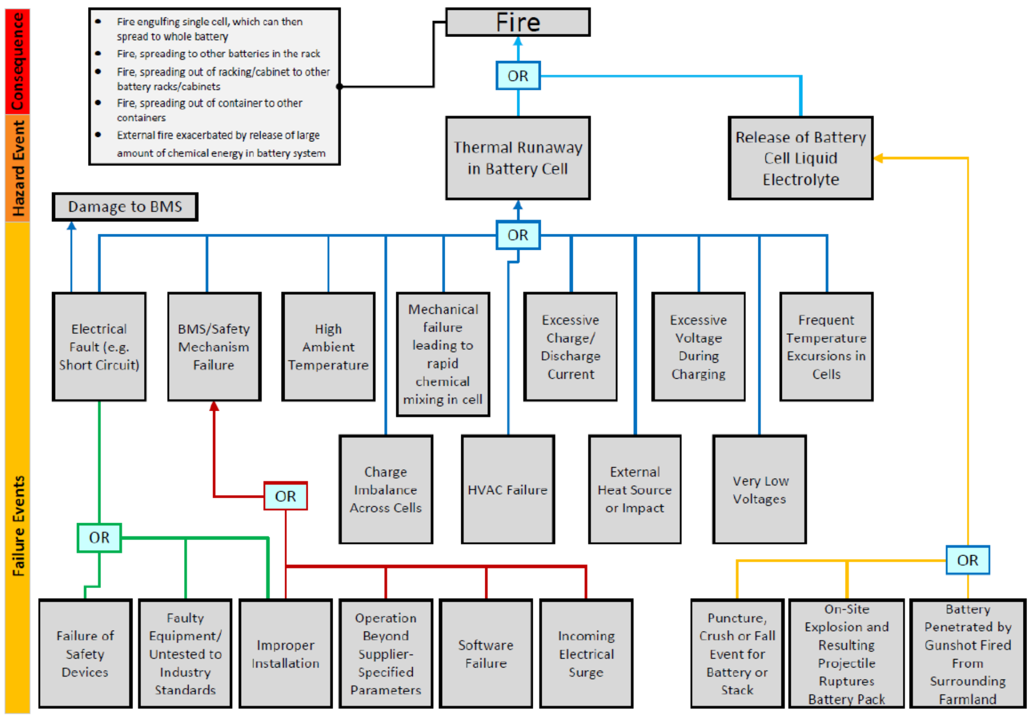

Figure 11: Fire hazard fault tree

Without any mitigation in place the likelihood of thermal runaway in a battery cell is *almost certain*, due to the unstable nature (positive feedback loop) of the exothermic reactions that occur in a lithium ion cell operated above a specified temperature limit and the number of individual batteries in the BESS. However, there are many prevention measures which are employed in the battery management system and the internal design of the racks in the cabinets, and indeed many prevention measures that are mandated by battery manufacture, transport and installation standards, which result in the likelihood of a fire occurring decreasing significantly. Many of these prevention/mitigation measures are listed in Table 12, which clearly shows which of the three initiating event pathways each measure relates to, and at what level of the battery system the measure is implemented at. Any standards that require the prevention/mitigation measure to be deployed are included.

The likelihood of an elevated battery temperature event triggering thermal runaway in the battery cells is very unlikely to begin with, as it is based on the HVAC equipment failing during high temperature weather event where maintenance staff do not have the time to respond to the issue before the battery container overheats. Prevention measures, including a redundant HVAC power system, a redundant and/or portable HVAC system for short term use in case of primary HVAC failure, and a cleared exclusion zone around the battery system area. If these measures are deployed the likelihood of this initiating event occurring is *unlikely*.

A mechanical failure initiating event is also very unlikely, as it would involve a vehicle accident with the battery system or similar event impacting the container. Prevention measures, such as a separation barrier between the access road and battery container, can effectively remove the chance of a vehicle accident. Thus, it was concluded that the likelihood of this initiating event occurring is also *unlikely*.

The chance of an electrical event initiating cell heating, and eventual thermal runaway, is more likely than the other initiating events and is not insignificant. This is the typical initiating event for fires in lithium ion batteries, although fires in large scale lithium ion facilities are rare (NFPA, 2016). As a result of this very real risk of thermal runaway, battery cell and system designers have implemented a range of prevention measures aiming to prevent high charge/discharge rates, over or under voltage events, short circuits and other electrically initiated failure models. These occur at the cell, battery, and system level, and also include prevention measures targeting the control system, cabling and inverters. Many of these prevention measures are included in Table 12. With the implementation of these measures, the likelihood of a thermal runaway event can be reduced significantly, until the likelihood of an electrically initiated thermal runaway event is *unlikely*.

Level of Battery System	Electrical	Mechanical	Controls, Planning and Training
Battery Cell	Temperature sensor on each cell	Certified to UL1973, which includes cell construction requirements like electrolyte containment, thermal management, enclosures, wiring and others. It also includes static force, impact, drop, thermal cycling, internal fire, external fire and moisture resistance tests	
	Short circuit protection on each cell		
Battery Pack and Racking	Includes rack and/or battery pack isolation	Procure battery racking specifically designed by the battery system supplier, or alternatively have a structural engineer certify the battery racking to reduce likelihood of crush events	Consider batteries certified to IEC 61427-2 (On-grid renewable energy specific standard)
		Minimise the height to which battery packs are stack if access is required	
		Pack includes heat sink plates and holes for airflow cooling	
		Includes rack and/or battery pack isolation	
BMS/Control System	Temperature sensor on each cell		Disconnect if HVAC fails
			Alarm system should cover: high/low voltage, high/low charge/discharge current
			State of charge balancing across cells
			Consider batteries certified to IEC 62619 which includes battery-BMS interaction test requirements including cell balancing, overcharge protection testing, overheating control prevention and overvoltage protection testing
Battery Container		Certified to ISO 668 and ISO 1496.1 (or AS 3711.4:2015 which is mod version)	

Table 12: Fire risk mitigation measures

4.3.5 Likelihood of Electrocution (Powerpack and Cotainerised)

There are three main initiating events that can create lead to an electric shock hazard. These three pathways are water ingress/humidity in the container, electrical component failures and software/control system failures as shown in Figure 12.

The ingress of water or high levels of humidity in the container can lead to electrical arcing and short circuiting which poses an electrocution hazard to operational staff. High humidity levels could be created if a condensing HVAC system is specified incorrectly, if the existing HVAC system doesn't dehumidify adequately during high humidity events, or if water is able to enter the container and evaporate. Mitigation measures available to reduce the likelihood of water ingress and high humidity inside the container include

- Using containers certified to IP57 or higher, which specifies the ability for dust and small objects (first digit) and water (second digit) to enter the container when closed;
- Specifying a HVAC system capable of dehumidifying the container if a humid external environment is expected;
- Specifying a non-condensing HVAC system so as to not increase the humidity inside the container during air cooling;
- Measuring humidity level in the container via sensor systems integrated with the BMS/system level control, and have the system disconnect if high humidity levels are detected;
- Checking the container for leaks as part of the regular maintenance schedule;
- Specifying a backup power system for the HVAC system;

- Having the control system disconnect the battery unit if the HVAC system is not functioning; and
- Locating the containers at a high point in the landscape and above flood levels, to prevent the risk of natural water catchment flows entering the container.

With the utilisation of these mitigation measures the likelihood of an electrocution event occurring due water ingress or high humidity initiating events is *unlikely*.

The second pathway leading to an electrocution event is electrical component failure, typically via short circuiting or operator error. For example, insulation on a live cable wearing through and touching the metal battery racking, making the container live, or an operator inadvertently creating a circuit with hand tools whilst checking the system. Operator error can be mitigated by;

- Specific training on the lithium ion battery system, typically included with the battery supplier information and sometimes offered directly in the supply contract;
- Design of battery racking and battery packs in a way that facilitates safe maintenance operation;
- Maintenance staff to follow standard operating procedures (SOPs); and
- Conduct maintenance activities with no active load where possible.

Electrical component failure can be mitigated by:

- Regular maintenance of the battery system components in accordance with supplier specifications;
- Control system/BMS isolation of battery system in the case of any abnormal current or voltage activity;
- Keeping the operator side voltages low as long as possible in the design of the entire container system; and
- Incorporating fuses and disconnect switches in the system wherever possible to provide redundancy to a control system disconnect with mechanical/electrical disconnection.

Assuming the mitigation measures above are deployed at the DPSF battery system site the likelihood of an electrocution event initiated by an electrical component failure occurring is *unlikely*.

The final pathway leading to an electric shock event is the failure of the BMS and/or associated control system. This could allow for large current and/or voltage fluctuations, potentially creating arcing between terminals and conditions for short-circuiting. There are, however, many levels of control system architecture, and mechanical isolation switches and circuit breakers that must all fail for this event to occur. It is for this reason considered *unlikely* that this pathway would lead to an electrocution hazard. The potential for a control system failure to lead to a cell heating and thermal runaway failure event is more likely, and was discussed in Section 4.3.4.

Finally, regardless of the initiation pathway, for an electrocution event to occur a person must be present inside the container of the battery system unit at fault.

Typical maintenance programs for a lithium ion battery involve a once yearly visual inspection and clean (2 hrs), a 5 yearly HVAC and consumables replacement (1 hr) and a more significant maintenance check at 10 years (1 hr). Thus, over the course of 10 years a maintenance operative will only be present in any one battery container for less than 1 day out of 3,652, plus any unscheduled maintenance required due to failure.

Overall, given the *unlikely* event of an operator being in the container and the *unlikely* rating for each causal pathway, it is concluded that the overall likelihood of an electrocution event occurring is *rare* if the mitigation measures discussed are employed.

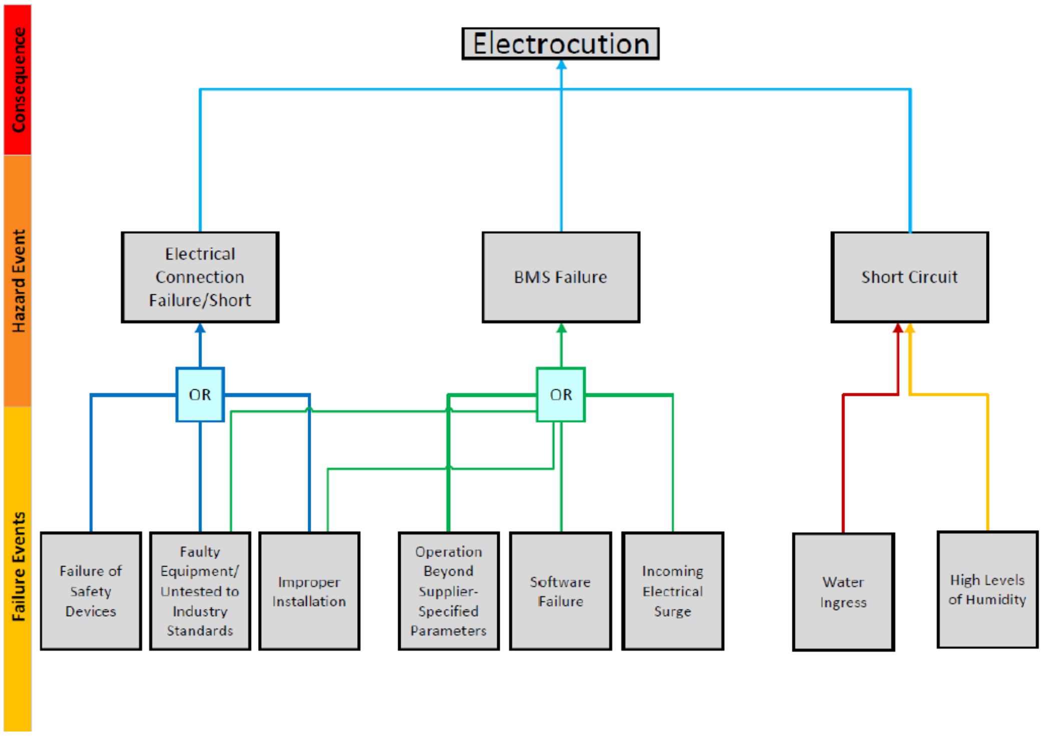

Figure 12: Electric Shock hazard fault tree

4.3.6 Likelihood of Crushing (Containerised)

There are two initiating pathways identified that could lead to a crush event nearby the battery system at DPSF. These are an external impact on the battery container large enough to crush the container and a failure of the battery racking such that the battery packs collapse onto a maintenance operator below, as shown in Figure 13.

Crushing as a result of a large external impact, can be mitigated by an earthen protection barrier (bund) or impact barrier between the battery containers and the main access road, such that any vehicle will crash into the barrier rather than a battery container, to potentially remove the possibility of this specific initiating event (dependent upon the effectiveness of the bund or barrier).

If this measure is implemented, and implemented correctly, the likelihood of an external impact leading to a crushing event is *unlikely*.

The second initiating pathway, the effect of one or more battery packs falling from an elevated position in the container on a person, can be effectively mitigated by:

- Installing battery rack in accordance with supplier specifications;
- Installing battery racking and battery packs in accordance with the appropriate installation standards;
- Specifying a battery rack that is appropriate for the battery packs if no guidance is given by the supplier;
- Minimising the amount of heavy equipment and battery backs stacked above shoulder height in the container as much as possible
- Using correct operational procedures and maintenance staff training; and
- Implementing racking design that allows access to all battery packs without additional assistance (e.g. ladders), and discourage scaling of racks to reach heights

Assuming these mitigation measures are implemented the likelihood of a crush event occurring due to a falling battery pack inside the container is *unlikely*. Finally, a crushing event can only occur when an operator is present in the container, which was previously established to be approximately 1 day in 3,652 for planned maintenance. Given the *unlikely* event of a maintenance operator being present in the container, and the *unlikely* events required to initiate a crush event to occur, it is concluded that a crush event at the DPSF is *rare* if the mitigation measures discussed above are deployed.

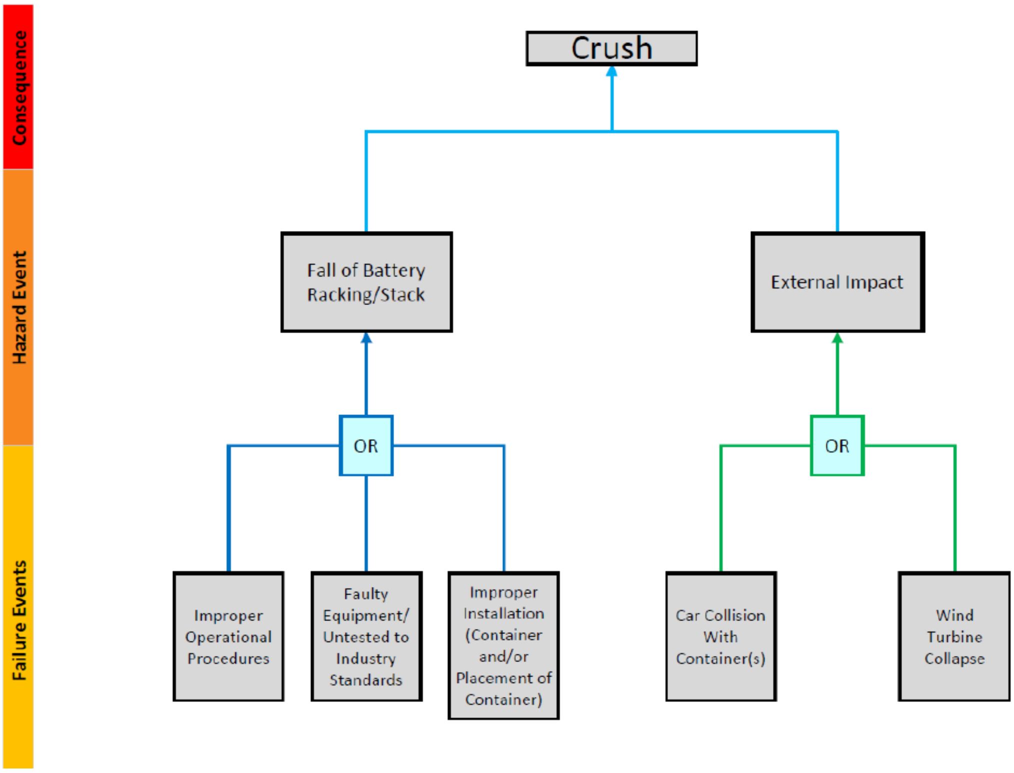

Figure 13 : Crush hazard fault tree

4.4 Risk Assessment and Presentation of Risk Results

Based on the hazard identification, consequence assessment and likelihood assessment, an overall risk assessment was completed using the following risk matrix (Figure 14) in order to determine the risk rating:

Risk Impact (based on principles of AS/NZS 31000)					
Likelihood	**Consequence**				
	1. Low	**2. Minor**	**3. Moderate**	**4. Major**	**5. Catastrophic**
A. Almost Certain	Low	Medium	High	Extreme	Extreme
B. Likely	Low	Medium	High	Extreme	Extreme
C. Possible	Low	Low	Medium	High	Extreme
D. Unlikely	Low	Low	Medium	High	High
E. Rare	Low	Low	Low	Medium	High

Figure 14: Risk matrix for Darlington Point Solar Farm

The results of the risk identification and risk assessment process is documented in the table included in Appendix A.

4.5 Societal Risk

The guidance in HIPAP 4 *Risk Criteria for Land Use Safety Planning* (Dept. Planning and Environment, 2011) suggests that the qualitative criteria in a general sense that must be considered are

- 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;
- The effects of significant events should, wherever possible be contained within the site boundary; and
- Where the risk from an existing installation is already high, further development should not pose any incremental risk.

An analysis of the significant events in the BESS that could have societal risk impact are detailed below in Table 13. The most significant mitigation feature for societal risk is the separation distance from the BESS to the nearest public road, Donald Ross Drive.

Table 13: The risk to society posed by the potential hazards identified in the DPSF battery system

Hazard	Risk to Society	Reasoning
Explosion / Flammable Gas	No	The blast radius calculated for a worst case explosion of flammable gas build up from the containerised battery system, in the case of all mitigating systems failure, was below the SEPP 33 guidelines injury threshold of 7 kPa at a distance of 20m. The nearest offsite boundary is a minimum of 100m from the battery system location. This therefore does not present a risk to society. No explosion risk exists for the Powerpack battery system that meets the requirements of UL 1973 (or equivalent).
Toxic Liquid	No	A toxic liquid spill can occur only in very, very small quantities and is contained within a battery module. This does not present a risk to society.
Fire / Flammable Liquid	No	The worst case fire event has the potential to spread from container to container. This scenario is highly unlikely to occur due to the many prevention measures that would all be required to fail simultaneously; however, if the event were to occur it will be contained by including a gravel buffer zone around the battery system of at least 20m.
Toxic Gas	No	A toxic gas cloud will occur only in small quantities and will largely be contained in a battery container or vicinity of the BESS. The cloud will form only in the case of battery abuse or accident, not during normal operation. Even given worse case wind conditions this amount of toxic gas does not present a risk to society.
Electrocution	No	The battery system and any live components will be a minimum of 100m from the site boundary, there is no public access onto the site and minimal staff on site at any one time. Therefore, electrocution does not present a risk to society.
Crush	No	The risk of crushing is localised to a single battery container and therefore does not present a risk to society.

4.6 Individual Risk

The risk to individuals is considered insignificant, based on the discussions in the previous sections of this report. In particular, this conclusion is based on the following:

- The consequence of all major hazards with the recommended prevention/mitigation measures in place is, in the worst case, one fatality.
- This consequence is contained to two specific groups, namely firefighters and maintenance staff. Both groups are easily targeted with training

programs specifically tailored to the battery system on site, so they are aware of the major risks they may face;

- Both groups of at risk individuals are only at risk when inside the battery container (for the containerised solution), a designated area, which is accessed infrequently; and

- The likelihood of the major hazards occurring is at most *unlikely*, and in many cases, is *rare.*

5 Conclusions

A PHA has been completed for the Darlington Point Solar Farm. Specific studies have been completed for Battery Energy Storage System. The studies included:

- Explosion;
- Toxic gas release;
- Toxic liquid release;
- Electrocution;
- Crushing;
- Flammable liquid release; and
- Flammable gas release.

As the BESS is located a minimum of 100m from the nearest public road there are no consequences from a hazardous event that could off-site impact. As the facility is largely unmanned due the number of automated and risk mitigation features at the proposed facility there is *rare* likelihood that there will be serious consequences due to the use of potentially hazardous substances (lithium ion batteries) on site.

References

Johan Anderson, Fredrik Larsson, Petra Andersson1 and Bengt-Erik Mellander, (no date) *Thermal modelling of fire propagation in lithium-ion batteries*, working paper, SP Technical Research Institute of Sweden, Borås, Sweden, Applied Physics, Chalmers University of Technology, Göteborg, Sweden

NFPA (2016), Blum AF and Long RT Jnr, Hazard Assessment of lithium ion battery energy storage systems, https://www.nfpa.org/-/media/Files/News-and-Research/Resources/Research-Foundation/Research-Foundation-reports/Other-research-topics/RFFireHazardAssessmentLithiumIonBattery.ashx?la=en

New South Wales Department of Planning and Environment, (2011). Planning guidelines for hazardous developments, various working papers, http://www.planning.nsw.gov.au/Policy-and-Legislation/Hazards/Industrial-Hazards

Shipping container Sizes and Volumes, (2017). Accessed 4th December 2017 at http://www.australiatrade.com.au/Shipping/ContainerSizeSales/

Xin Teng, Chun Zhan, Ying Bai, Lu Ma, Qi Liu, Chuan Wu, Feng Wu, Yusheng Yang, Jun Lu. And Khalil Amine, (2015). *In Situ Analysis of Gas Generation in Lithium-Ion Batteries with Different Carbonate-Based Electrolytes*, Beijing Key Laboratory of Environment Science and Engineering, School of Materials Science and Engineering, Beijing Institute of Technology, Beijing 100081, China

Abbreviations

ADG7 -	Australian code for the transport of dangerous goods by road and rail, edition 7.5, 2017
AS –	Australian Standards, the primary issuer of technical standards in Australia, including batteries and associated equipment and installation
BESS -	Battery Energy Storage System
BMS –	Battery Management System
DPSF-	Darlington point Solar Farm
HIPAP -	Hazardous Industry Planning Advisory Papers
HVAC –	Heating, Ventilation and Cooling
HV –	High Voltage
IEC –	International Electrotechnical Commission, an issuer of many electrical standards, including batteries and related equipment
LV –	Low Voltage
MW –	Mega-watt, a unit of power often used in electrical systems
MWh –	Mega-watt hour, a unit of energy often used in electrical systems
NFPA –	National Fire Protection Association (USA)
NSW –	New South Wales
PCU –	Power Control Unit
PHA –	Potential Hazards Analysis, as defined in the SEPP 33 Guidelines
PHAST –	Engineering Fire Modelling software package
PV –	Photovoltaic
SEPP 33 –	State Environmental Planning Policy Number 33
UN –	United Nations
UL –	Underwriter Laboratories, a battery testing certification organisation

Chemical Formulae

Carbon Dioxide (CO_2)

Carbon Monoxide (CO)

Diethylene carbonate (DEC) (non-standard)

Ethane (C_2H_6)

Ethylene (C_2H_4)

Ethylene carbonate (EC) (non standard)

Hydrogen fluoride (HF)

Methane (CH_4)

Phosphoryl fluoride (POF_3)

Phosphorus pentafluoride (PF_5)

Appendix A

PHA Risk register

PHA Risk Register

			Risk (considering current and proposed controls)			
Facility/Event	Cause/Comment	Possible Results/Consequences	Existing Controls	Likelihood	Consequence	Risk
Bushfire	Bushfire external to site causes fire to battery storage facility	Damage to the battery facility and the solar farm	• Implementation of a fire break around the site • Implementation of a bushfire management plan • Coordination with local fire authorities • Provision of fire water on site (20kL)	Rare	Moderate	Low
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 • Provision of fire water at site if required by local fire authorities	Rare	Moderate	Low

			• Use of thermal CCTV security cameras to identify fires remotely			
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
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
Animals and snakes	Personnel injury by animal or snake bits	Consider risk of fauna presence for all site based risk assessments Have appropriate emergency contacts for the site Have appropriate first aid training and equipment on site	• Consider in SWMS • Have a trained snake handler at site during construction if required	Possible	Moderate	Medium
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

Appendix B

NFPA Battery Powerpack Test Photographs

B1

Figure B 1: Burner assembly and positioning

B2

Figure B 2: External fire test after 2 hours

B3

Figure B 3: Internal fire test at peak smoke production