Sapphire Solar Farm

Environmental Impact Statement

Volume 3 - Appendices

Appendix K
Hazards and Risk Assessment

CWP Solar

Final Report | 4th December 2017

Preliminary Hazards Assessment for Sapphire Solar Farm and Battery Installation

Including Risk Screening as a Potentially Hazardous Industry

Contents

1. Executive Summary

This report presents a risk screening and preliminary hazards assessment (PHA) of the approximate 50MW/100MWh battery system at the proposed Sapphire Solar Farm (SSF) development. The risk screening and PHA was carried out in accordance with the New South Wales (NSW) Department of Planning and Environment's SEPP 33 Guidelines, which apply to potentially hazardous developments in NSW. The SEPP33 guidelines apply a three stage assessment process; initial risk screening, risk prioritisation and detailed risk analysis.

The risk screening considered lithium ion, advanced lead acid and vanadium flow battery storage options, and found that if a precautionary approach is adopted, a PHA would be required in all cases for the SSF.

The risk prioritisation considered lithium ion batteries, and found that the not-insignificant but low level hazards related to the battery system included electrocution, crushing and toxicity, whilst the medium level hazards included fire and explosion. The latter two were analysed using the risk engineering software package PHAST, whilst the low level hazards were subjected to a qualitative risk analysis in accordance with the SEPP 33 Guidelines.

The results show that the low level hazards can be prevented by employing a combination of common measures, including following all applicable AS/NZ Standards, specific fire-fighting and battery system operational training, setbacks, physical protection and control systems measures. Mitigation measures are also available to reduce the severity of the hazards should they occur. There were no risks to society due to the localised nature of the consequences, and very minimal risks to the environment.

The likelihood of an explosion event occurring is very low, and prevention measures exist to reduce the risk further. Modelling of the potential blast radius suggest that it is very unlikely that a cascade event occurs (where one battery-filled container causes another to explode and so one), and in both cases there are no offsite impacts due to the limited (40m) blast radius compared to the distance to the site boundary and key infrastructure. There is no risk to society due to the localised nature of the consequences, and no risk to the environment.

There is potential for a fire event in the battery system to initiate a bushfire in the surrounding grazed grasslands, which presents the only potential impact to society from the SSF; however, many prevention measures exist to dramatically reduce the likelihood of a fire starting in the battery system, and effective mitigation measures exist to contain the fire within the battery system area if it were to eventuate. With application of the risk management measures and an effective fire management plan, we conclude that there is a very low risk to society of a battery system initiated fire event, and very minimal risks to the environment.

The results in the report would recommend the following action

- A separation and impact prevention barrier between the access road and battery system be constructed, in order to prevent accidental vehicle impact to a battery container
- A minimum 20m asset protection zone be constructed around outermost containers of the battery system as a fire barrier, which would comprise gravel (or similar non-combustible ground cover) and an accompanying fence to prevent ingress
- Battery containers be spaced at a minimum of 2m apart, subject to final procurement
- HVAC redundancy should be considered
- Fire suppression in each container should be considered
- A pressure release exhaust in the container in the event of an explosion should be provided
- Procure batteries certified to one or more transport and dangerous goods standards for transport, as appropriate, typically including UN 3480 or UN 3481, UN 38.3 and/or IEC 62281
- Consider procurement of a battery system that is certified to UL 1642, UL 1973, IEC 61427-2 and IEC62619

- Installation certified to all relevant Australian Standards (e.g. AS 4777), and consider complying with draft standard AS 5139:2017 where possible, in case this standard comes into effect for large scale installations in future

Finally, this report presents a preliminary hazard analysis only, which primarily considers the risk to society rather than the risks to individual workers on the SSF site. We would anticipate that risks to workers would be addressed through appropriate management systems employed during both construction and operation of the project.

2. Findings and Recommendations

2.1 Findings

The PHA analysis identified six non-negligible potential hazards at the SSF related to the battery system. These hazards included toxic liquid, toxic gas, flammable liquid/fire, flammable gas/explosion, crushing and electrocution. The risk screening, prioritisation process and incorporation of other factors based on industry experience resulted in the flammable liquid/fire and flammable gas/explosion hazards being investigated using quantitative consequence analyses, whilst the remaining four hazards were subjected to a qualitative analysis only. The qualitative analysis drew upon relevant standards, codes and published literature. The level of analyses conducted, resulting likelihood of occurrence and resulting consequence of occurrence are listed in Table 1.

Table 1: Summary of PHA findings

Hazard	Level of Risk Analysis	Consequence of Occurrence (worst case)	Likelihood of Occurrence
Explosion/Flammable Gas	Semi-Qualitative (Level 2)	1 Fatality	Very Unlikely
Toxic Liquid	Qualitative (Level 1)	1 Fatality	Extremely Unlikely
Fire/Flammable Liquid	Semi-Qualitative (Level 2)	20 Fatalities	Extremely Unlikely
Toxic Gas	Qualitative (Level 1)	1 Fatality	Extremely Unlikely
Electrocution	Qualitative (Level 1)	1 Fatality	Very Unlikely
Crush	Qualitative (Level 1)	1 Fatality	Very Unlikely

A fire in the battery system is the largest consequence identified, due to the ability of a fire onsite to initiate a bushfire in the surrounding grazing lands. The likelihood of this event occurring is extremely unlikely, due to the large number of prevention measures available that would all need to fail simultaneously, the small area of the potential heat radius and the effective mitigation measures available (including a cleared separation distance). All low or no cost prevention and mitigation measures are recommended, and the report also suggests for consideration a small number of addition measures for added safety.

The findings of this PHA have been/will be incorporated, as appropriate, into a number of work paths in the SSF project, including

- The preliminary environmental impact statement

- The battery system procurement process
- The bushfire management plan for the site
- The final HAZOP study if required
- The detailed fire safety study
- Standard Operation Procedures (SOP's) for the site
- Community engagement documentation
- Site layout and design, in particular the battery system location selected
- Overall SSF design in general

2.2 Recommendations

The recommendations from this PHA are separated into two categories; recommendations to mitigate the consequences of major incidents and recommendations to reduce the likelihood of major incidents occurring. These recommendations are summarised below, with a full list of control measures given in Section 7.

Table 2: Summary of key mitigation measures to limit the consequence of major incidents at the SSF

Hazard	Key Mitigation Measures to limit Major Incident Consequences
Explosion/Flammable Gas	• Containers separated by minimum distance as specified by supplier. If no distance is specified, install containers with a minimum 2m clearance on all sides • Include a 20m buffer of non-combustible material (e.g. gravel) surrounding the battery system. Fence to area to prevent unauthorised access and animal ingress • Include pressure release valve in container to direct an explosion to designated space/direction
Toxic Liquid	• Battery system-specific maintenance and fire fighter training
Fire/Flammable Liquid	• Install a fire suppression system in each container • Containers separated by minimum distance as specified by supplier. If no distance is specified, install containers with a minimum 2m clearance on all sides • Ground cover around containers should be gravel, and extend to a minimum 20m buffer around the outermost containers. A fence should be present to prevent animal and person ingress.
Toxic Gas	• Consider installing gas sensors inside container to protect maintenance staff • Battery system specific maintenance and fire fighter training
Electrocution	• Consider separating the DC cable running from the battery units back to the first overcharge circuit breaker, in case of short circuit, to prevent escalation • Battery system-specific maintenance and fire fighter training
Crush	• Battery system-specific maintenance and fire fighter training

Table 3: Summary of key prevention measures to reduce the likelihood of major incidents at the SSF

Hazard	Key Prevention Measures to reduce Major Incident Likelihood
Explosion/Flammable Gas	• Consider a HVAC system capable of air cycling as well as thermal control • Consider redundant HVAC system as backup, in addition to backup power • Variety of additional BMS/Control System solutions to reduce electrical abuse that leads to gassing of battery cell • Variety of additional BMS/Control System solutions to reduce electrical abuse that leads to gassing of battery cell • Consider additional physical overcharge protection (e.g. breakers) at system, rack, battery and cell level
Toxic Liquid	• Measures as for Crush incidents • Clear operating procedures for maintenance staff and fire-fighters
Fire/Flammable Liquid	• Variety of BMS/Control System solutions to reduce thermal runaway events • Consider additional physical overcharge protection (e.g. breakers) at system, rack, battery and cell level • Consider redundant HVAC system as backup, in addition to backup power

	• Separation of DC cabling back to first overcharge breaker circuitry • Measures as for Crush incidents • Containers separated by minimum distance as specified by supplier. If no distance is specified, install containers with a minimum 2m clearance on all sides. • The surrounding grassland area should be kept well grazed to a distance of 200m surrounding the battery system.
Toxic Gas	• Clear operating procedures for maintenance staff and fire-fighters • Measures as for Explosion/Flammable Liquid and Crush incidents
Electrocution	• Clear operating procedures for maintenance staff and fire-fighters • Prevent water incursion with appropriate IP rated container • Prevent humidity build up with appropriate HVAC selection and potentially dehumidifier if required • Install a fire suppression system in each container
Crush	• Include bund crash wall between access road and battery containers • Procure certified battery racking that is appropriate for battery pack • Install battery racking in accordance with supplier specification and installation standards

In addition to the specific control measures detailed for each potential hazard, the following standards are worth considering when procuring the final battery system at SFF. In particular we would recommend

- Procure batteries certified to one or more transport and dangerous goods standards for transport, as appropriate, typically including UN 3480 or UN 3481, UN 38.3 and/or IEC 62281
- Consider procurement of a battery system that is certified to UL 1642, UL 1973, IEC 61427-2 and/or IEC62619
- Installation certified to all relevant Australian Standards (e.g. AS 4777), and consider complying with draft standard AS 5139:2017 where possible, in case this standard comes into effect for large scale installations in future

Finally, three battery system locations were considered in this PHA. The eastern most site was used for all analysis as it is the closest to major infrastructure, where consequences could escalate. A battery system at this site was found to have negligible society risk (using the F-N curve method), and thus we can recommend any of the three battery location options.

3. Introduction

This document was prepared by Arup for CWP Solar Pty Ltd (CWP Solar) to support the development of the proposed Sapphire Solar Farm Pty Ltd (SSF). The SSF will be a utility-scale photovoltaic solar farm with battery storage at Kings Plains, within the Inverell Shire Local Government Area (LGA) 30 km east of Inverell in northern NSW. The facility would have an electricity generation capacity of approximately 170 megawatts (MW) at the point of connection, producing enough energy (390 GWh) to power the equivalent of 68,000 average NSW households each year. Moreover, the addition of battery-based storage (approx. 100 MWh) will allow for SSF (along with the Sapphire Wind Farm (SWF)) to dispatch scheduled and reliable renewable energy to the National Electricity Market (the NEM).

This report details the application of the NSW Department of Planning and Environment's SEPP 33 Guidelines to the proposed battery energy storage system at the SSF. The results, process and final risk mitigation strategies of the preliminary hazards screening and risk assessment process are described herein. The battery storage system will consider lithium-ion, advanced lead acid and flow battery chemistry options, as these technologies are the most mature, cost effective and safe. The battery system procurement is not yet finalised, so this screening and risk assessment applies the SEPP 33 Guidelines to a 'worst case' battery from each of the three options considered.

4. Site Description

The SSF is located on land, some of which includes the same parcels as the SWF project, within the Inverell Shire Local Government Area (LGA) 30 km east of Inverell in northern NSW. General access to the proposal site (the 'Site') is from either the Gwydir Highway or Kings Plains Road with immediate access to the study area via Waterloo and Western Feeder roads.

The Site comprises cleared agricultural land used for grazing and/or cultivation, with some portions having previously been subject to open-cut sapphire mining and quarrying. Long-term land leases have been negotiated for the life of the project with the five host landowners. At the conclusion of the Proposed Development, the Site will be decommissioned and returned to a suitable condition to allow the resumption of agricultural activities.

The existence and proximity of SWF provides the opportunity to co-locate certain facilities and share the same point of connection to the TransGrid 330 kV network through the SWF substation (the 'Substation'). This connection option will minimise the overall impact of the development while maximising the use of an existing connection asset.

The Proposed Development is located in a sparsely populated rural setting. Surrounding land is primarily agricultural in use, with associated dwellings comprising a mix of involved and non-involved residences, totalling eight within a 2 km radius of the study area. Of note, all eight residences are associated with SWF either through a host or neighbour agreement and consultation with all owners has been ongoing from inception of the proposed solar development.

4.1 Battery Storage Location

Three potential battery storage location options have been developed. All the potential sites are relatively flat, with good road access and are a significant distance from major off-site infrastructure. In the analysis shown in this report the most easterly site is used for risk screening, as this site is the closest to major on- and off-site infrastructure and operational personnel. Figure 2 shows the relative distances to significant infrastructure, whilst Table 4 shows the distances to other significant off-site locations and the site boundary. The surrounding land is rural, grazed or ungrazed grassland with a population density below 5 persons/hectare. The land is zoned as rural 1a, and further details related to land use can be found in the SSF preliminary Environmental Impact Statement (EIS) document. As shown in Figure 1 the battery system locations sit along the access road, on top of a wide crest of hillside that falls away to the north-east and south-west. The nearest wind turbine in the existing SWF is approximately 30m to the west of the eastern-most battery system on the southern side of the access road. The SSF would involve approximately 200 staff on site during construction, and up to 10 staff on site during operation. The operational staff will be primarily for maintenance.

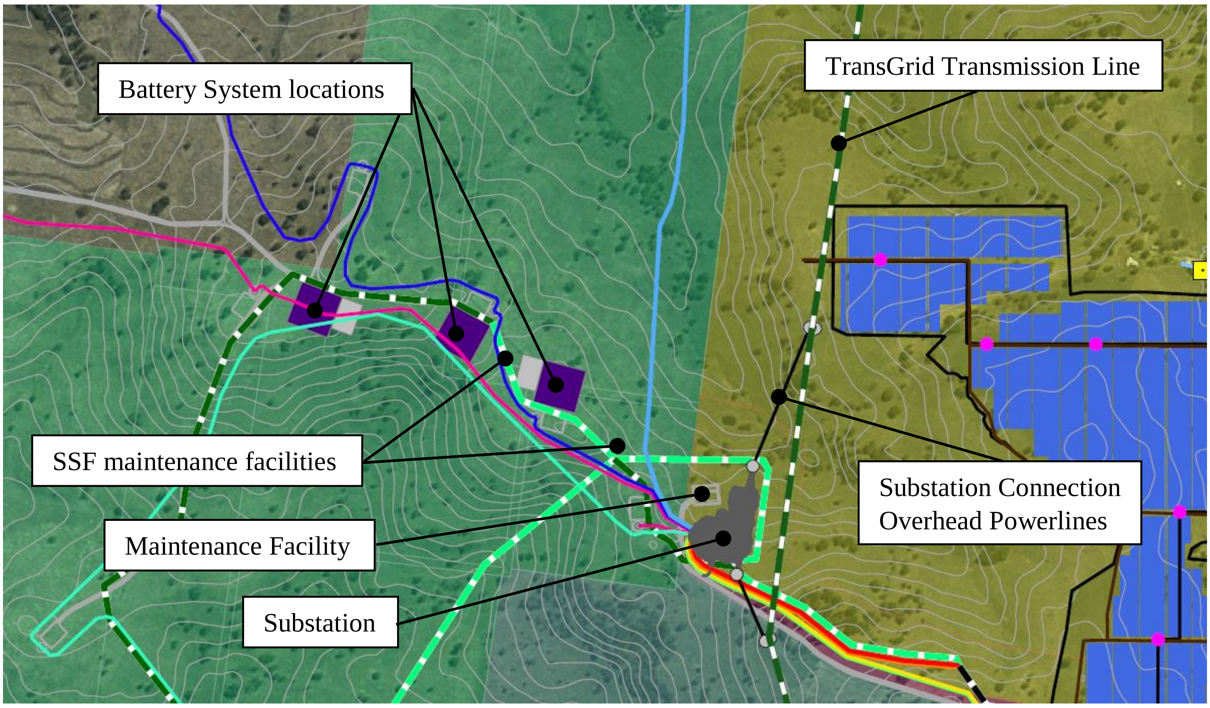

Figure 1: The three possible options for battery system location and the surrounding infrastructure. Contours are spaced at 1m intervals.

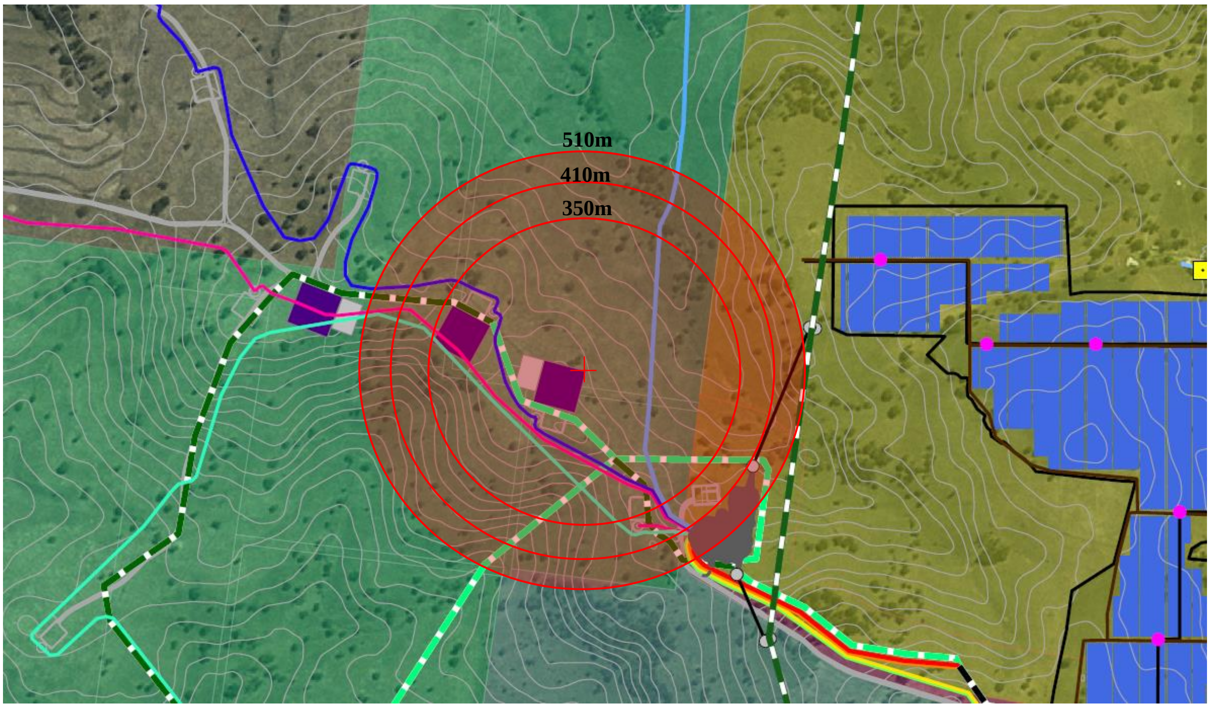

Figure 2: The distances from the closest battery system location to the surrounding infrastructure

Table 4: The distance from the eastern-most battery system option (as shown in Figure 2) to the nearest important landmarks and boundaries.

Location	Distance from Battery Storage Location
Site Boundary SSF	530m
Site Boundary SWF	1,400m
Nearest Residence	1,440m
Nearest Road	1,575m
Nearest non-involved landholding	1565m
Nearest Wind Turbine	30m

4.2 Process

The Sapphire Solar Farm

SSF would generate electricity through the conversion of solar radiation to electricity through the use of PV panels laid out across the proposal site in a series of modules, mounted on steel racks with piled, screwed or ballasted supports. Other infrastructure on site would include the battery energy storage facilities, electrical power conversion units, underground and/or above ground electrical cabling, telecommunications equipment, amenities and storage facilities, vehicular access and parking areas, along with security fencing and gates.

SSF will connect to the TransGrid Substation constructed to connect SWF to the electricity network. While SSF could operate as a stand-alone generator/battery-based storage facility, it is proposed that the project may operate in parallel with the Sapphire Wind Farm project to provide firm, dispatchable electricity to the National Electricity Market (NEM). The connection configuration considered within this EIS accommodates for both scenarios, which will allow the battery-based storage facility within SSF to be available to charge from SSF, SWF and/or the NEM, and to discharge all its stored electricity to the NEM.

The Battery System

The battery system would enable electricity generated by the SSF (and the SWF) to be stored for later dispatch to the NEM grid. Each unit of the battery system itself will consist of stacks of chemical batteries arranged in a standard shipping container or equivalent proprietary design from the selected supplier. Each container would store approximately 0.5 to 1.3 MWh of electrical energy, depending on the supplier, container size and specific chemistry, and includes the Battery Management System (BMS) architecture, Heating Ventilation and Cooling (HVAC) system, initial safety measures and access for operational personnel via an access door. An indicative containerised battery energy storage system is shown in Figure 3.

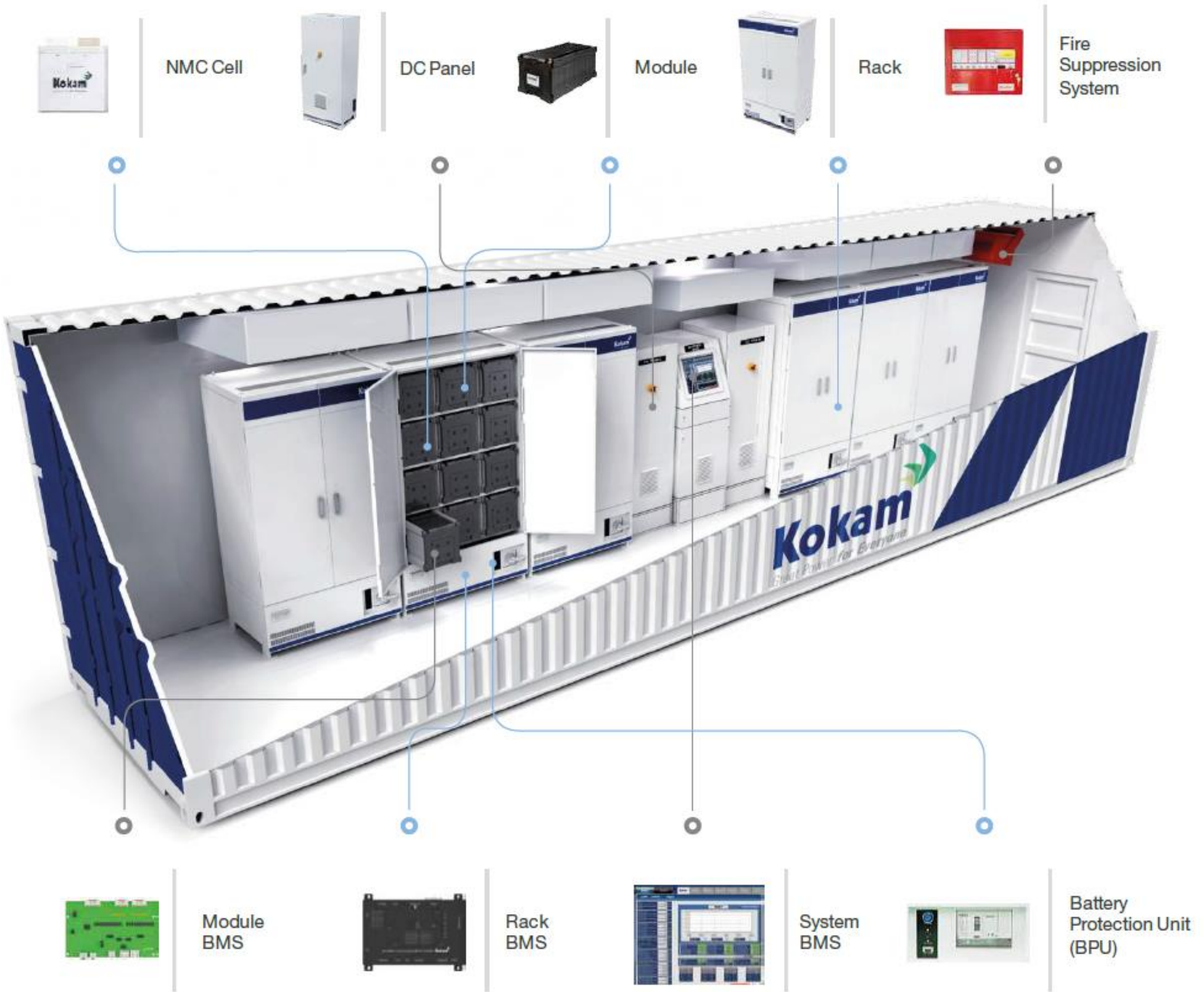

Figure 3: An indicative containerised battery energy storage system © Kokam

During electricity storage power flows from the SSF/SWF substation via underground electrical cabling to the each container. The power flow is controlled by the BMS and is directed through the individual battery terminals, charging the chemical battery storage cells. During discharge, this process is reversed. As the chemical reactions are allowed to reverse, power flows from the battery cells via the BMS, through an electrical cable connection and back to the substation. Flowing through a series of step up voltage transformers, the power is eventually transmitted via the 330kV transmission line shown in Figure 1 to the wider NEM.

An electrical cable supplies the HVAC and fire systems in each container, which also typically have an additional backup power supply as dictated by the level of risk. Detailed information on the location of the electrical cabling is included in Appendix A. Fire suppression systems are typically of the sprinkler type, with a variety of different fire retardants being employed depending on the manufacturer's recommendations.

4.3 Hazardous Materials

Some batteries for energy storage are classified as a dangerous goods according to the Australian Dangerous Goods Code (ADGC), whilst others remain unclassified despite their chemical constituents being classified separately. In this report we adopt a conservative approach, as outlined in the SEPP 33 Guidelines. We include in the screening analysis any battery options under consideration, define this battery as the 'worst case', and where a battery type isn't listed specifically in the ADGC we classify it by its major constituent chemical.

We note for clarity, only one 'Battery Option' listed in Table 5 will be pursued in the development of SSF. The options are shown here for comparison, and the 'Quantity on Site' of hazardous materials is for the full battery system. The 100MWh battery size is approximate as design is still in the preliminary stages. For the purpose of this PHA the exact size (within reason) of the battery bank is immaterial, as all except one of the major consequences occur within a single container. In the final case of fire escalation, it is the separation distance from the outermost container to the surrounding grassland, rather than the number of battery containers, that affects the level of the consequence and the likelihood of it occurring. Hence, the 100MWh battery system should be taken as an indicative figure, although findings and recommendations would apply equally to a system of up to 200MWh.

The battery chemistry options considered in the SSF development are Lithium-ion, Lead Acid (Advanced) and Vanadium Flow Batteries (VFB). Both Lead acid and Lithium-Ion batteries are listed specifically in the ADGC, whilst VFB are not. We assign VFB, for the purpose of the screening method in SEPP 33, to Vanadium Pentoxide (V_2O_5) as this is the common chemical compound (and ionic variations of it) used in most VFB systems. Vanadium Pentoxide exists in the ADGC, albeit in solid form, and is classified as a toxic substance. The hazardous materials potentially present on site for each of the Battery System options is shown in Table 5.

Table 5: Hazardous materials in the Battery System, Quantities on Site and the classification of each good.

Battery Option	Hazardous Material	UN Code	ADG Class	Quantity on Site (tonnes)
Lithium ion batteries certified to UN 34.80	Lithium Ion Batteries	3480	9	1,700 tonnes
Wet lead acid batteries	Batteries, Wet, Filled with Acid, electrical storage	2794	8	2,500 tonnes
Vanadium Flow Battery	Vanadium Pentoxide, non-fused form	2862	6.1	120 tonnes

Application of the SEPP 33 Guidelines for a Battery System, as opposed to a hazardous goods store, is somewhat different. Quantities listed are estimated based on the mass of the batteries without container and ancillary services (e.g. BMS, cabling, HVAC), and as such represent both an average and maximum mass for the purpose of the screening tests. Material Safety Data Sheets (MSDS) are typically not available for batteries themselves, but are available for the chemical constituents.

A full site plan (to scale) is included in Appendix A, with the location of the 3 proposed Battery System locations marked.

Battery Storage and Containerisation

The SSF will utilise between approximately 75 and 200 battery storage containers, depending upon the final supplier choice. Each container can be thought of as a "Babushka doll" of battery storage, comprising containers, batteries and battery cells. Each container houses, as detailed in Figure 3, many batteries that are typically stacked vertically into racks and placed in rows throughout the container in a convenient arrangement for maintenance staff to access the batteries. Within each battery, many battery cells are connected together in series and parallel to obtain the desired output voltage and current. Chemical battery cells come in a range of different form factors (shapes), so the shape of the assembled battery also often differs. Each cell is sealed (although some have pressure valves for gas release) with protruding electrical terminals, and undergoes a range of safety testing procedures as part of the international and national standards regimes, including crush, penetration, thermal runaway, electrical short and drop testing. These cells are packed into battery casings, typically made from plastic, and which often have some additional, basic safety mechanisms to prevent short circuiting and overheating.

The batteries are stacked and connected to the BMS, which provides a range of safety measures including preventing overcharging and current surges, maintaining voltage levels and ensuring the systems cut out in the event of electrical shorts, overheating or other unplanned events.

A HVAC system is included with all battery systems, maintaining the batteries in the container within safe and optimal operational temperature limits (varying between 15 and 50 degrees depending on exact chemistry and electrolyte).

5. ‘Potentially Hazardous Industry’ Screening Process

The NSW Department of Planning’s *Applying SEPP33* document (2011) outlines the screening and risk assessment process for a potentially hazardous development. The process is outlined graphically in Figure 4. The document suggests that the potential risk of a proposed development typically depends on five main factors:

- the properties of the substance(s) being handled or stored;
- the conditions of storage or use;
- the quantity involved;
- the location with respect to the site boundary; and
- the surrounding land use.

Incorporating these factors, and following the procedure outlined in Figure 4 and detailed in the SEPP33 guidelines (NSW Dept. of Planning, 2011), a risk screening analysis was completed for the battery options under consideration at SSF.

The total hazardous materials included on site were presented in Section 3.3. Table 6 below presents the hazardous materials present on site for each different battery option, the material class according to the ADGC and UN systems, the screening method applicable in SEPP 33 and threshold to trigger a PHA for each material.

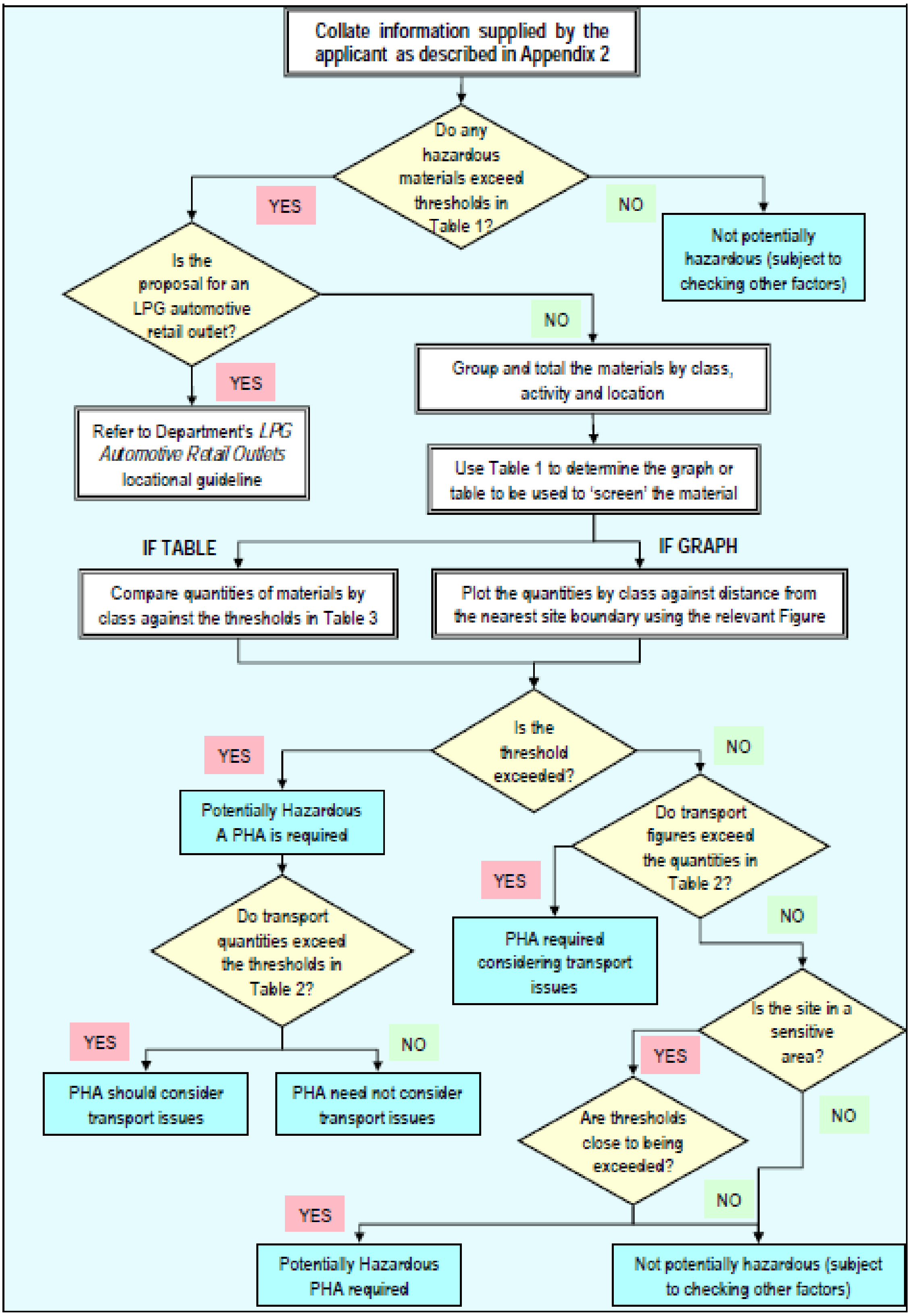

Figure 4: The potentially hazardous industry risk screening procedure outlined in the *Applying SEPP33* (NSW Dept. of Planning, 2011).

Table 6: List of Hazardous Materials on site in each of the possible battery systems, their quantities and screening thresholds

Battery Option	Hazardous Material	UN Code	ADGC	Assessment Method	Screening Limit	Quantity	Threshold Exceeded?
Lithium ion batteries certified to UN 34.80	Lithium Ion Batteries	3480	9	No assessment required in screening process	No limit in screening process	1,700 tonnes	No
Wet lead acid batteries	Batteries, Wet, Filled with Acid, electrical storage	2794	8	SEPP33 Table 3	50 tonnes*	2,500 tonnes	Yes
Vanadium Flow Battery	Vanadium Pentoxide, non-fused form	2862	6.1	SEPP33 Table 3	2.5 tonnes**	120 tonnes	Yes

* Table 3 in SEPP33 assigns a 5, 25 and 50 tonne screening limit based on Packing Group (PG - I,II or III) in the ADGC. However, PG numbers were removed from the ADGC in 2015 for a number of items, including most chemical batteries. PG numbers are reflective of the flammability of a liquid (flash and boiling point), and based on Table 2.3.2.6 in the ADG C PG III has been assumed for the SEPP33 screening process for chemical batteries in absence of specific a PG. PG III correlates to a Screening Limit of 50 tonnes in the *Applying SEPP 33* Guidelines (Table 3, pg. 37).

** This selected chemical compound is indicative of a vanadium flow battery system. The listing in the ADGC is for the solid form, as a dry powder. If a flow battery option were to be investigated further the specific chemical compound may differ slightly, but it is likely it would still fall under Class 6.1 (toxic substances).

5.1 Summary of Screening Method

The SEPP 33 screening process does not specify a screening threshold for ADGC Class 9 materials (Miscellaneous Hazardous material). As Lithium-Ion batteries are categorised as a Class 9 goods, this Battery Option would not trigger a PHA based solely on the screening threshold. Both Lead Acid and a VFB option would trigger a PHA as the quantity of material on site exceeds the screening thresholds allocated for the ADGC and Packing number applicable to each battery option.

5.2 'Other Factors'

The SEPP 33 documentation is clear that the hazardous materials screening method applied in Table 6 will not be considered in isolation when determining whether an industry is considered potentially hazardous, and would therefore require a PHA to be carried out. Through the documentation this is often referred to as 'other factors'.

Whilst what is included as 'other factors' is not specifically defined, examples are given indicating that it must include issues such as the combination of two previously below threshold hazardous goods to create a significant risk, risks to people, property or environment not captured in the ADG Code and risks inherent in the construction of products that utilise dangerous goods in their operation.

Taking a precautionary approach, we identify the following other factors that may warrant consideration in the screening process to determine whether the proposed battery system at SSF would be considered potentially hazardous:

- The inherent risk of fire when locating large volumes of stored electro-chemical energy on site. These risks can and would be mitigated, but without control systems in place the risk could be significant.
- The possibility of a cascading failure involving the battery system. This could be in the form of an externally initiated bushfire, electrical surge or wind turbine collapse onto the battery system, and the otherwise minor consequence could then trigger a major consequence as failure (e.g. larger area of effect) of the battery system also contributed.
- The rapid emergence of battery systems in Australia, in particular Lithium-Ion battery systems, and the lack of existing large-scale examples on which to base best-in-class safety mitigation strategy. In this respect, the completion of PHA in line with the SEPP 33 Guidelines that includes the assessment of a large scale Lithium-Ion battery-based energy storage facility may be useful as a benchmark for future facilities.

5.3 Result of Screening Method

As a result of numerous factors, including the preliminary screening and the commercial viability, Lithium-Ion batteries seem the most likely battery option in the proposed SSF development. The remainder of this study therefore considers the Lithium-Ion battery as the hazardous material on site. In the remaining sections we present a PHA for Lithium-Ion battery storage, adopting the conservative approach that being one of the first Lithium-Ion battery facilities to be built in NSW at significant scale, a PHA would be required despite Lithium-Ion batteries not having a specific screening threshold at the screening stage of the SEPP 33 assessment.

6. Risk Screening and Prioritisation

This section presents the hazard identification, screening and prioritisation procedure carried out in line with the SEPP 33 guidelines. This process, as demonstrated in Figure 4, begins by prioritising risks with any significant potential to harm people, property or environment to be analysed further.

6.1 PHA Risk Prioritisation Process

The first stage of the MLRA is to carry out the risk classification and prioritisation step using a modified version of the IAEA risk classification method (Dept. of Planning, 2011, pg. 37). The modified version, as shown in Figure 5, categorises potential risks into 3 categories (low, medium and high potential to cause harm). The levels 1, 2 and 3 determine the amount of detail required in the hazard analysis to follow. The simplified analysis includes a number of simplifications including the following key assumptions

- Only the most important variables are used in assessing risk (such as population density, frequency of loading/unloading operations)
- Estimates of probability and consequences are rounded to the nearest order of magnitude
- The entire inventory is initially assumed to be involved
- For physical and toxic effects, 100 percent fatality is assumed within an area where 50-100 percent lethality would be expected; outside this range, no fatalities are assumed
- No explosion overpressure or heat radiation calculations are carried out - the lethal radius is assumed to be the distance to the lower flammable limit (LFL) in the case of explosion and the actual fire area in the case of flammables
- Only one weather pattern is used
- Basic probabilities are generic but are modified later.

In making these simplifying assumptions, the modified IAEA method allows for quick screening of ‘worst credible events’, and highlights the risks that should be further investigated. It is not intended that the results be used without further analysis. The modified IAEA risk prioritisation method is separated into five stages, which involves classification of activates and inventories, estimating consequences, estimating likelihoods of occurrence, and finally combining the two to assess the level of risk to society.

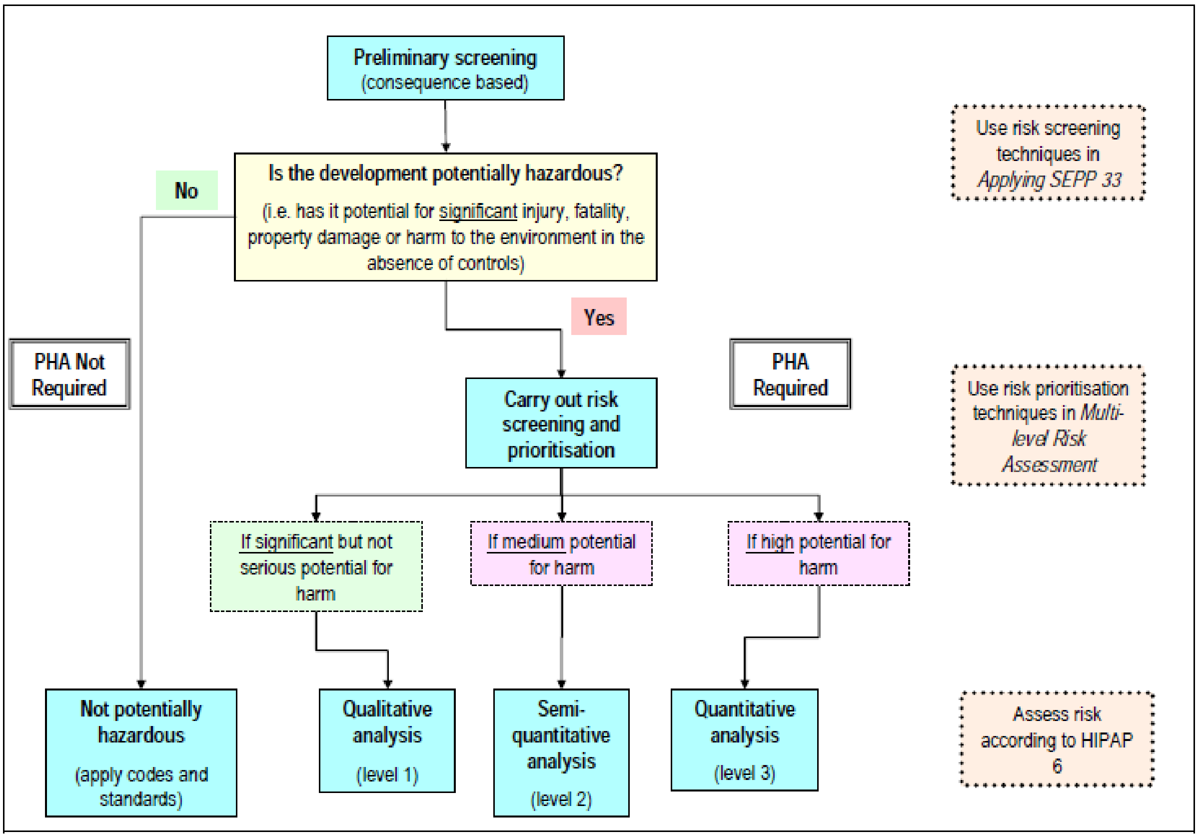

Figure 5: The Multi-level Risk Assessment process as presented in Figure 11 in SEPP33 Guidelines

6.2 Risk Prioritisation Analysis

6.2.1 Classification of Activities and Inventories

A 'worst case' Lithium-Ion battery was assumed for the analysis based on the most risky aspects of all supplier information received. Classification was as in Table 7.

6.2.2 Estimation of Consequences

The area around the site is sparsely populated farmland, hence a population density of 5 persons/ha is selected from IAEA Table VI. Within the area of effect (100 to 300m depending on the activity) there are no offsite installations or people, and thus we assume the populated fraction of the circular effect area to be 5% in line with Table VII in the Dept. of Planning's (2011) MLRA guidelines. We assume no mitigation correction factors (i.e. Correction Factor for Mitigation = 1) for worst case plausible scenario.

6.2.3 Estimation of Probabilities of Major Accidents

The method used for estimating probability is based on probability numbers related to the type of installation and substance involved, together with correction factors for:

- the frequency of loading/unloading operations (n_l)
- safety systems associated with flammable substances (n_f)
- organisational and management safety (n_o)
- wind direction towards the populated area (n_p)

The probability number is then given by the formula

$$N_{i_s} = N^*_{i\,s} + n_l + n_f + n_o + n_p$$

We estimate values based on the guidance in SEPP 33, and shown in Table 8. We assume above average organisational safety, given the facilities greenfield status and the guidance provided by this battery systems hazard review.

6.2.4 Estimation of Societal Risks

The estimation of societal risks combines the previous likelihood and consequential analyses to assess hazardous substances using a F-N risk plot, which is shown in Figure 7. The negligible and acceptable lines on the F-N plot are as defined in the NSW Dept. of Planning's MLRA guidelines (2011).

Table 7: Estimation of Consequences results using IAEA method detailed in Dept. of Planning's Multi-Level Risk Assessment guidelines (2011).

Material	Site Inventory	Type of Substance	Reference no. From IAEA Table IV(a)	Effect Category from IAEA Table V	Effect Area Category (A)	Population Density (d)	Population Correction Factor (f_A)	Mitigation Correction Factor (f_m)	External Consequences Estimate ($C = A*d*f_A*f_m$)
Lithium-ion Batteries	1,700 tonnes	Explosive (in packages)	15	X	Not available, advice is complete a full QRA	5 persons/ha	N/A	1	Requires detailed QHA
		Toxic Liquid (Battery electrolyte)	17	CII	1.5 ha	5 persons/ha	0.1	0.05	0.75 Fatalities, rounded up to 1 Fatality
		Flammable liquid (Battery electrolyte)	3	DII	6 ha	5 persons/ha	0.1	1	3 Fatalities

Table 8: IAEA Estimation of Probabilities of Major Accidents using IAEA method detailed in Dept. of Planning Multi-Level Risk Assessment guidelines (2011).

Material	Type of Substance	Reference no. From IAEA Table IV(a)	Average Probability Number (N*i,s)	Correction Parameter For Loading/Unloading Operations Frequency (nl)	Correction Parameter (nf) for Flammables	Correction Parameter (no) for Organisational Safety	Correction Parameter (np) for Wind Direction Towards Populated Area(s) in the Affected Zone	Probability Number N (N = N*i,s+ni+nf +no+np)	Frequency Events per Year (P)
Lithium-ion Batteries	Explosive (in packages)	15	7	0.5	0.5	0.5	0.5	9	1×10^{-9}
	Toxic Liquid (Battery electrolyte)	17	5	0.5	N/A	0.5	0.5	6	1×10^{-7}
	Flammable liquid (Battery electrolyte)	3	8	0.5	N/A	0.5	0.5	9.5	1×10^{-10}

Table 9: IAEA Estimation of Probabilities of Major Accidents (Dept. of Planning, 2011)

Material	Hazard	Fatalities per accident (C)	Accidents per year (P)
Lithium-ion Batteries	Explosive (in packages)	Requires QHA	1×10^{-9}
	Toxic Liquid (Battery electrolyte)	1	1×10^{-7}
	Flammable liquid (Battery electrolyte)	3	1×10^{-10}

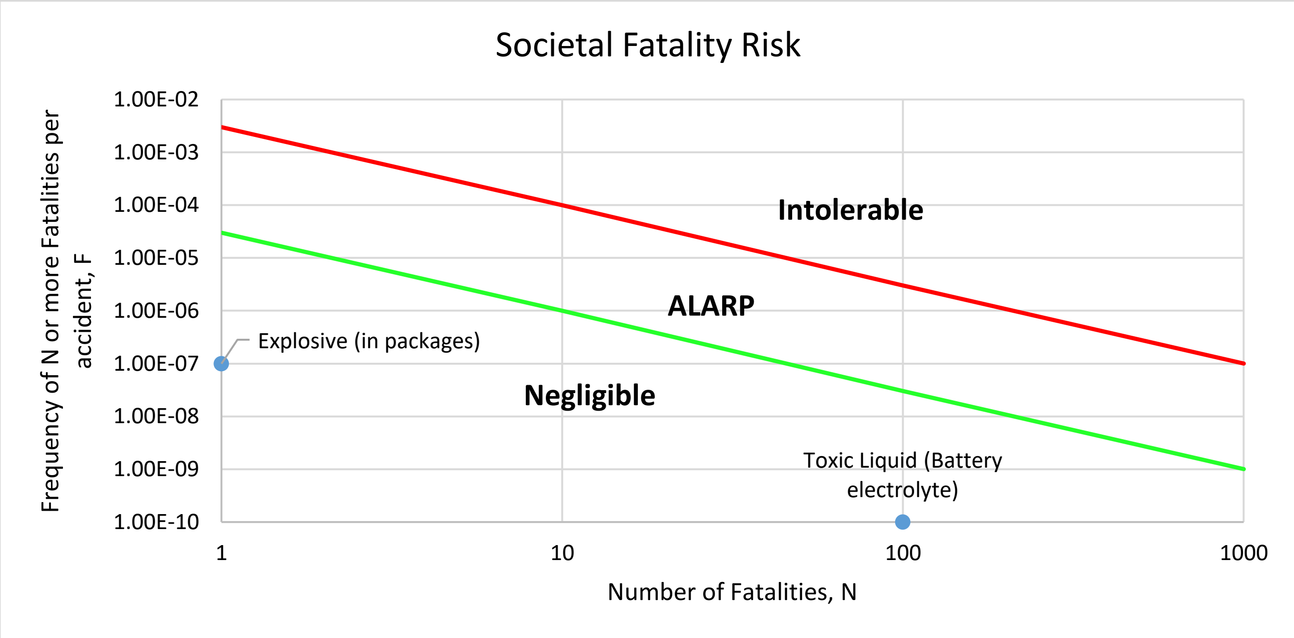

Figure 6: Risk prioritisation results. Note that the case of explosion is not shown, as a value for C cannot be calculated using the simplified IAEA analysis method.

6.3 Risk Prioritisation Results

The Risk Prioritisation process suggests that the risk posed by the battery system are largely low, but not negligible, with the risk of explosion requiring a full Quantitative Hazards Assessment (QHA). It should be noted that in the modified IAEA method any substance over 1,000 tonnes that has any chance of exploding, however unlikely *and* however small the consequences, a full Quantitative Hazards Analysis (QHA) is recommended.

The screening method is overly simplistic in this regard, and given that both the consequence and likelihood of an explosion ever occurring in the battery system are low, we pursue a Semi-Qualitative Analysis. We pursue this with the following understanding;

- There has never been a significant explosion event related to Lithium-ion batteries for energy storage purposes to our knowledge
- For an explosion to occur, a flammable gas must build up in a sealed environment to create an increase in pressure when an ignition event occurs. Other than at the very small cell level of the battery system this build up does not occur, until the gas collects in the whole container. Due to the small volume of gassing that takes place and the lack of hermetically sealed surfaces, the risk of a pressure build up is minimal.
- At the cell level, gas build up occurs only during non-normal operation. When gas build up does occur, cell explosion is a small, audible popping noise made by the cell container (thin metallic or plastic pouch or cylinder) rupturing. These failures are common in thermal runaway testing of cells as part of Lithium-ion battery testing in standards such as UL 1973 and UN 3480.

Thus we conclude that for the explosion risk to Lithium-ion batteries at SSF, a more detailed qualitative discussion coupled with modelling of ignition of a 400L gas cloud of typical Lithium-ion gassing chemicals is appropriate. This is explained in detail in the following sections. We also include in further (Level 2) analyses a toxic gas hazard, which is simply the case where the same 400L cloud builds up but is not ignited, and presents a hazard to maintenance staff and potentially fire-fighters.

The risk prioritisation results for the toxic liquid and flammable liquid hazards posed by the battery system suggest a qualitative (Level 1) analysis will be sufficient, based on Figure 6, given that the likelihood of occurrence is less than 1 x 10-7 per year and the consequences minimal; however, given the current lack of uncertainty around the safety aspects of lithium-ion technology, we pursue a semi-qualitative analysis (Level 2) when assessing the risk from flammable liquids. This modelling encompasses the risk of a thermal runaway initiated fire, which as discussed, presents the most significant risk associated with Lithium-ion batteries.

We pursue a qualitative (Level 1) analysis for toxic liquids in line with the IAEA risk prioritisation method, and also include a number of other qualitative (Level 1) analyses for other small but non-negligible risks presented by the battery system. All risks that are considered non-negligible and warrant further analysis in some form are listed in Figure 6.

Table 10: The results of the Risk Prioritisation process detailed in the Dept. of Planning's MLRA (2011)

Hazardous Substance	Risk Type	Level 1: Qualitative Analysis	Level 2: Semi-Qualitative Analysis	Level 3: Quantitative Analysis
Lithium-ion Batteries	Explosive		Yes	
	Toxic Liquid (Battery electrolyte)	Yes		
	Flammable Liquid (Battery electrolyte)		Yes	
	Toxic Gas		Yes	
	Electrocution	Yes		
	Crush	Yes		

7 Detailed Hazards Analysis

7.1 Hazard Identification

Hazards were identified using a variety of methods, including a HAZID session with Arup's energy storage and risk analysis teams, a site visit to the SSF and walkover of the three battery system location options, information received from battery OEM suppliers so far in the procurement process, prior battery hazards (particularly fire) studies in literature and from industry, and liaison with the NSW Dept. of Planning and Environment through CWP Renewables.

The potentially hazardous events that could occur at the SSF in relation to the battery system are presented in the Hazard Identification Word Diagram in Table 11. The diagram does not include the likelihood of these events occurring, and many events are extremely unlike utilising just standard practice mitigation measures. It is also worth noting that many of these hazards result in the same consequence (e.g. both thermal runaway and electrical short circuit lead to a fire), which for the Lithium-ion batteries proposed at SSF include fire (internal and externally initiated), toxic liquids and flammable liquids (see Table 10).

One hazard of particular importance to Lithium-Ion batteries is the possibility of thermal runaway. Thermal runaway is a process whereby a failure of some kind initiates a high temperature in the battery cells, which leads to exothermic reactions in the cells, releasing more heat and creating a further rise in temperature. Thermal runaway then results in more heat being generated than can be removed from the cell, and a fire results. The larger risk is that a fire then heats neighbouring cells and more runaway exothermic reactions occur, and the fire continues to spread from cell to cell. This can then cascade from battery to battery, potentially from each rack to the neighbouring rack, and then potentially (although unlikely) from container to container if the heat flux generated is large enough.

The Thermal Runaway hazard can and would be mitigated by a series of safety measures, occurring at the cell, battery, BMS, battery rack and container level of the battery system. Standards for Lithium-Ion batteries include thermal runaway testing at the cell level and battery level, and install standards in some counties assess the system or container level, although these standards do not yet exist in Australia. Regardless, this is the most significant hazard identified and has been modelled in further detail in this report.

A second consideration that will be investigated further is the case of an externally initiated fire engulfing the batteries, and the battery system being exposed to a high heat flux, creating thermal runaway, and ultimately releasing the stored chemical energy to exacerbate the existing external fire on site.

The possibility of the battery releasing gaseous emissions, due to an overcharge or thermal event, presents an explosion and toxicity hazard for maintenance and/or fire-fighting staff. Whilst the likelihood of this event is minimal, the consequences are significant and as such this hazard and the two resulting potential consequences are considered in further detail.

The final hazard considered in detail is the impact of an electrolyte pool fire. Whilst this is extremely unlikely as lithium Ion batteries do not store electrolyte in liquid form, but rather it is absorbed into the solid electrode materials, the consequences were still modelled as it is relatively simple to show the impact of such an event at a reasonable level of detail.

In addition to the battery system hazards assessed in this report, the Photovoltaic (PV) system used in the SSF presents a risk of fire as a high power device. The fire risks associated with PV panel installations are similar to that of any electrical system, and typical mitigation measures apply (e.g. breakers at the PCU). The PV system is not without its own inherent fire risks and should be included in any follow up fire studies. These would be incorporated into a bushfire management and fire-fighting plan, as the methods for extinguishing the battery system and PV arrays can be different, depending on the specific battery system procured. Comparing unit-for-unit the short circuit current generated by a PV array is typically significantly lower than that of a battery unit, such that in the case of accidental terminal short circuit, the battery system presents a far more serious electrocution and fire risk than the PV array.

A full discussion of the mitigation measures available at the SSF, including those included and not included in applicable standards, is given in Section 7.3. Table 11 contains a list of common mitigation factors for each potentially hazardous event involving the battery system at the SSF.

Table 11: Hazard Identification Word Diagram. HVAC – Heating, Ventilation and Cooling, BMS – Battery Management System

Event	Cause	Consequence	Mitigation Factors
Thermal Runaway in battery cell	• Electrical fault (e.g. short circuit) • External heat source (e.g. bushfire, arson) • High ambient temperature • Mechanical failure allowing rapid chemical mixing in cell(e.g. crush, penetration, fall, internal structure failure) • Excessive charge/discharge current • Excessive voltage during charging • Frequent temperature excursions in cells • Charge imbalance across cells connected in series • Over-discharge, inducing very low voltage • BMS/safety mechanism failure • HVAC failure	• Fire engulfing single cell, which can then spread to whole battery • Fire, spreading to other batteries in the rack • Fire, spreading out of racking/cabinet to other battery racks/cabinets • Fire, spreading out of container to other containers	• Fire suppression system (water, foams, • BMS, particularly for voltage balancing, charge/discharge rate limiting and safety shutoff mechanisms • HVAC • Backup power supply for HVAC system • Containerised system to prevent escalation • Specific battery design to minimise thermal runaway risk (e.g. electrolyte additives, LFP rather than LCO chemistry) • Passive cooling devices integrated in battery pack • Pre-charge charging circuitry, initiated by BMS, to limit charge rates at low battery voltage • Charge interrupt devices (CID's) • Positive temperature coefficient (PTC) devices to physically limit current flow in overcharge case were BMS fails • Integrated protective circuitry to provide safety in case of internal short circuit failure, as part of certification procedure for Lithium Ion cell testing
Electrical connection failure/short	• Improper installation • Faulty equipment/untested to industry standards • Failure of safety devices	• Excess heat leading to fire • Electrocution of maintenance staff • Damage to BMS, with potential to disrupt larger system	• BMS detection and cut-off of faulty cell

BMS failure	• Improper installation • Faulty equipment/untested to industry standards • Operation beyond supplier specified parameters • Software failure • Incoming electrical surge	• Thermal Runaway and fire • Electrocution	• Robust BMS with back safety measures installed in accordance with appropriate regulation
Release of battery cell liquid electrolyte	• Puncture, crush or fall event for battery or stack • Onsite explosion and resulting projectile ruptures battery pack • Battery penetrated by gunshot fired from surrounding farmland	• Potential for electrolyte to form a pool fire • Potential for electrolyte to gasify, build up in container and explode	• Protected by shipping container against most small arms • No shooting signs at site boundary as deterrent
Fall of battery racking/stack	• Improper installation of batteries, both in container and placement of containers • Faulty equipment/untested to industry standards • Improper operational procedures	• Crush operational stuff • Potential for toxic material leakage	• Install in line with appropriate standards
Flammable gas release from battery	• Overcharging/discharging • Damage to cell • Heat exposure	• Potential for explosion if gas is allowed to build up and ignition source is present • Potential for explosion to send small projectiles flying, presenting a hazard to maintenance staff • Toxic gases presenting risk to maintenance staff/fire-fighting staff	• BMS to control overcharge/discharge and overvoltage • Charge interrupt devices (CID's) • Positive temperature coefficient (PTC) devices to physically limit current flow in overcharge case were BMS fails • Integrated protective circuitry to provide safety in case of internal short circuit failure, as part of certification procedure for Lithium Ion cell testing • Pressure release in battery cell, casing, cabinet and container in case of gas build up • HVAC system design to facilitate airflow throughout container to remove gas pockets

External impact	• Car collision with container/s • Wind turbine collapse onto battery container/s	• Crush and penetration of multiple cells, overheating, leading to fire	• Bunding between road access and battery systems • Separation distance between road access and battery system • Where possible, site battery system outside of wind turbine collapse impact zone
Vandalism and/or ingress (animals, people, insects)	• Access and/or damage by unauthorised personnel • Access and/or damage by animals or insects	• Damage to BMS, batteries, auxiliary electronics or safety systems • Potential hazard to vandals/animals • Potential for damage to battery system to create fire/toxic materials hazards	• Batteries enclosed in locked shipping container • Area fenced off to prevent access • Site boundary fenced to prevent accidental ingress • On site security protocols
External fire engulfs battery containers	• Bushfire • Substation/transmission line/PV/Wind infrastructure failure and subsequent fire initiation, spreading through surrounding grassland to Battery System	• Large amount of chemical energy in battery system engulfed by external fire is released, exacerbating fire	• Containers sealed • Cleared exclusion zone around battery system • Bushfire management plan includes management of surrounding grasslands • Fire-fighting on site is able to extinguish fire • Fire suppression system in containers with backup power supply • Separation distance between battery system and other flammable material, including materials stores and operations sheds • Separation between containers to limit heat transfer
Sustained heatwave	• Sustained environmental radiative heat output	• Cell overheating and thermal runaway if HVAC not operational or sufficient	• HVAC system, with backup power source • Temperature monitoring and shutoff with BMS control
Water ingress	• Leaks in container during rain events	• Short circuit, leading to electrocution or fire	• Container certified to relevant standards • Container checked for leaks as part of maintenance regime

High levels of humidity	• Weather events • HVAC system does not de-humidify, or even adds moisture content over time (condensing type)	• Short circuit, leading to electrocution or fire	• HVAC to not contribute to humidity levels • HVAC to have dehumidify option, and container software management systems to measure humidity levels inside container

7.2 Consequence Analysis

The consequences identified in the screening analysis are further analysed in this section. Qualitative analysis is used for the Level 1 hazards identified; and we employ a fault tree and discussion to assess the consequences of these risks. The major consequences were assessed with specific safety engineering software packages, using supplier information where available as the basis for input assumptions and previous risk engineering work on lithium-ion batteries where specific supplier information was not available.

Table 12: Potential consequences in the SSF hazards assessment and a summary of the consequence analysis employed

Consequence	Type of Consequence Analysis	Details
Flammable Gas/Explosion	Semi-Qualitative Analysis	Engineering modelling using PHAST of a worst case event entailing a 400L gas build-up in non-ventilated container
Toxic Liquid	Semi-Qualitative Analysis	Calculation of maximum hypothetical liquid spill (litres of electrolyte) and estimation of resulting consequences
Flammable Liquid/Fire	Semi-Qualitative Analysis	Engineering modelling using PHAST of a $LiPF_6$-EC-DMC electrolyte pool fire in the battery container Engineering modelling of a thermal runaway event and resulting battery fire (cables, pack and electrolyte) using Arup developed fire engineering spreadsheets. The modelling assumed all cells were involved in the fire, and investigated the heat flux generated at different distances to ascertain the risk of the fire spread to the nearby grasslands and initiating a bushfire event.
Toxic Gas	Semi-Qualitative Analysis	Calculation of volume and type of toxic gas generated in a heating event, with estimation
Electrocution	Qualitative	Estimation of maximum consequence of electric shock
Crush	Qualitative	Estimation of maximum consequence of crush event

7.2.1 Consequence of Explosion

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 amount of gas vented by cells in a single container was assumed to be 400 L, based on supplier 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 mass composition was derived based on the data shown in Table 13. At 100°C, 400L of the above mixture has a mass of 382g. 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 13: Gas composition of a standard LiPF6-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

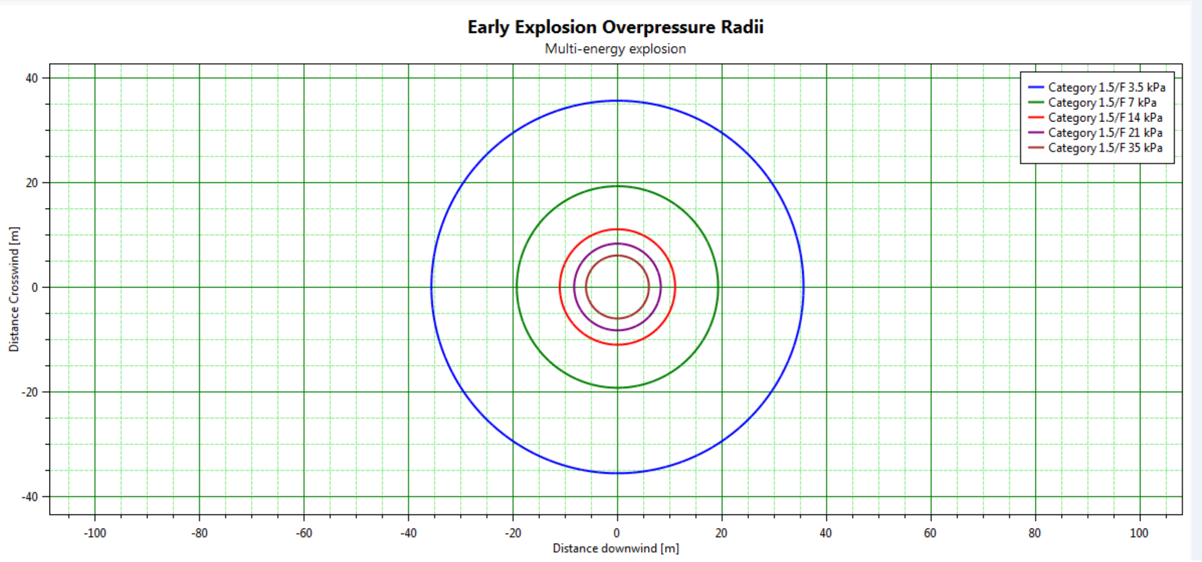

Figure 8: The overpressure at radius radii resulting from a gas explosion event in a battery container at the SSF

A confined vapour cloud explosion (VCE) was modelled in DNV GL's Phast v7.21 software. The results are presented in Figure 8. The results of the consequence modelling show that the more severe contours (14 kPa, 21 kPa and 35 kPa) are restricted to within around 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, which is likely an overly conservative assumption given the likelihood of an explosion event occurring. Thus, a minimum of 2m is recommended and developers can utilise Figure 8 for preliminary design guidance.

No offsite impacts are expected from a VCE scenario. 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 effect operational or firefighting staff. Thus, the consequence of a worst case explosion event is 1 fatality.

7.2.2 Consequence of Toxic Liquid

The consequence of a toxic liquid spillage was calculated based on the hypothetical volume of electrolyte that could spill from a lithium ion battery and the approximate composition of a typical lithium ion electrolyte. The electrolyte mix chosen was $LiPF_6$-EC-DMC, a common organic electrolyte used in lithium ion batteries. This was chosen as it is widely used, information for it was available from reputed suppliers (Sigma-Aldrich), and at least one of the battery suppliers being considered at the SSF disclosed that this is the electrolyte in their system. The volume of electrolyte in each battery pack was also obtained from this supplier.

The total volume of electrolyte in a single container represents the worst case, which for the system modelled was 3,700L of toxic liquid. The only risk presented by an electrolyte pool inside the container is that to operational or firefighting staff who may be exposed to either the liquid, or gaseous chemicals evaporating from the pool. Both situations, even in the worst case, only present a hazard to the single person entering the container. Thus, the worst case consequence of a toxic liquid hazard is 1 fatality.

The amount of electrolyte assumes the theoretical amount of liquid electrolyte in each battery pack, multiplied by the number of battery packs per container to calculate the total figure of 3,700L. This is an extremely conservative assumption, as in reality virtually no liquid electrolyte exists in a lithium ion battery. The electrolyte is absorbed into the anode and cathode material during cell construction, and even if punctured, no more than a few drops of liquid electrolyte typically ‘spill’ out. This is discussed further in Section 7.3.

7.2.3 Consequence of Flammable Liquid

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 14: 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)	800
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);
- The container was assumed to be a black body for the purposes of the calculations (worst case)

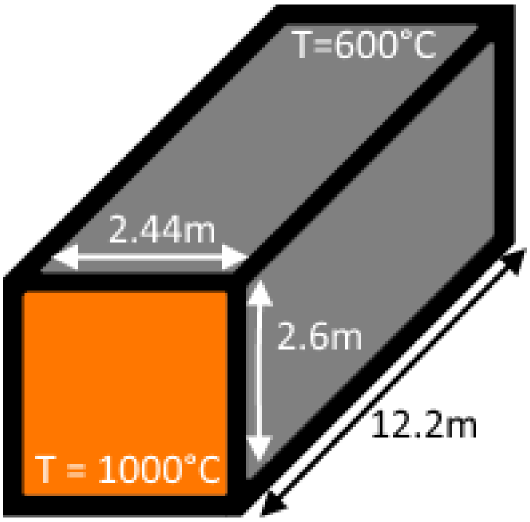

Figure 9: The fire modelling layout, showing the container dimensions and temperature assumptions at each end of the container.

Table 15: 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.

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

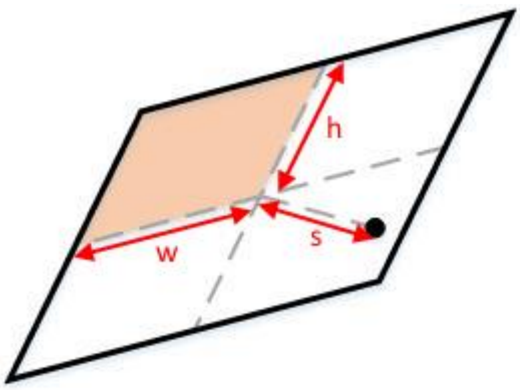

Figure 10: Key geometry in the fire model

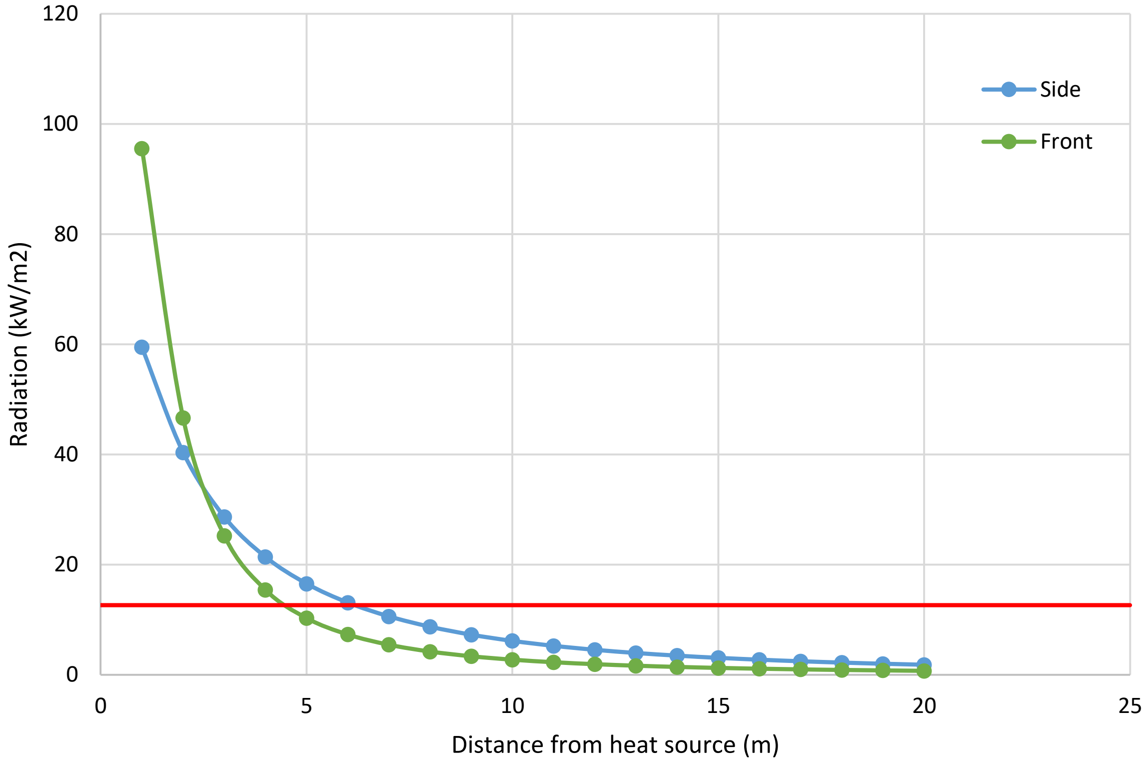

Figure 11: The fire model results showing radiation at a given distance from the battery container on fire

The results of the analysis are shown in Figure 11, with the red line at 12.6 kW/m^2showing exposure limits relevant to HIPAP 4. According to HIPAP 4 the following consequences for 12.6 kW/m^2 heat radiation are as follows:

- 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
- 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 battery storage areas are not on the edge of the site. 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 build up to 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. We recommend 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 or bushfire to start. Any ember from a fire could cause vegetation which has been sufficiently heated to ignite. As such, we recommend that all vegetation within a radius of at least 20m of the battery containers is cleared of vegetation, with the ground to be covered in gravel 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 we conclude that the consequence of a fire event with the previously discussed prevention measures in place is 1 fatality.

7.2.4 Consequence of Toxic Gas

The consequence of a toxic gas cloud building up in the container was calculated based on the hypothetical volume of gas that could emitted from a lithium ion battery, and the approximate composition that gas. The electrolyte mix chosen was again $LiPF_6$-EC-DMC. The volume of gas released by a containerised battery system was given by a supplier as 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 proportions and specific gases were assumed 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 HF, POF_3 and 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 16.

Table 16: The composition and volume of gas generated in the modelling of a toxic gas event in the SSF 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 within the container, and any gas escaping the container would quickly dissipate. Thus in both cases the toxic gas consequence is limited to a single person entering the container to conduct maintenance or for firefighting purposes, so the worst case consequence is 1 fatality.

7.2.5 Consequence of Electrocution

The risk of electrocution is present in the SSF battery system, although the area of effect is very local. The consequence of an electrocution event will vary from minor injury to death of the maintenance employee in the container. Therefore, in the worst case, an electrocution event would result in a consequence of 1 fatality.

7.2.6 Consequence of Crushing

The crushing hazard is the risk of a heavy piece of equipment, such as a battery pack, falling on an operator inside the container, or, a wind turbine or car crashing into a battery container whilst a maintenance worker is inside. Whilst the consequence to the individual in this case ranges from minor injury to death, it is again limited to the single individual inside the battery container. Thus the potential worst case consequence of a crushing event is 1 fatality.

7.3 Estimation of the Likelihood of Hazardous Events

The likelihood of hazardous events occurring was estimated using fault tree analysis for each consequence at the SSF battery system. A detailed discussion also accompanies each consequence identified. The type of likelihood analysis used for each potential consequence is shown in Table 17.

Table 17: Potential consequences in the SSF 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
Crush	Qualitative	Discussion and fault tree analysis

The event tree in Figure 12 (and continuing to Figure 13) shows the sequence of events that lead to the major consequences listed above in Table 17. For brevity, only the major events and significant consequences are shown in the even tree. The event tree highlights the cascade of events that could occur to create the identified hazards, and highlights when multiple pathways are available.

The event tree shows that the majority of hazardous consequences associated with the SSF battery system relate to cell heating, leading to a thermal runaway event and potential failure cascade of more battery cells. Additionally, the possibility of a brute force impact or electrical issues are other possible triggers that could lead to significant consequences with no cell heating component, such as toxic liquid, toxic gas or explosion risks.

The following sections discuss the likelihood of each major consequence occurring, including the typical mitigation measures, applicable standards and recommended additional mitigation steps that are available to reduce the risk likelihood. Using a qualitative approach, the likelihood of an event occurring is estimated on a scale ranging from *extremely likely*, *very likely*, *likely*, *neither likely nor unlikely*, *unlikely*, *very unlikely* and *extremely unlikely*.

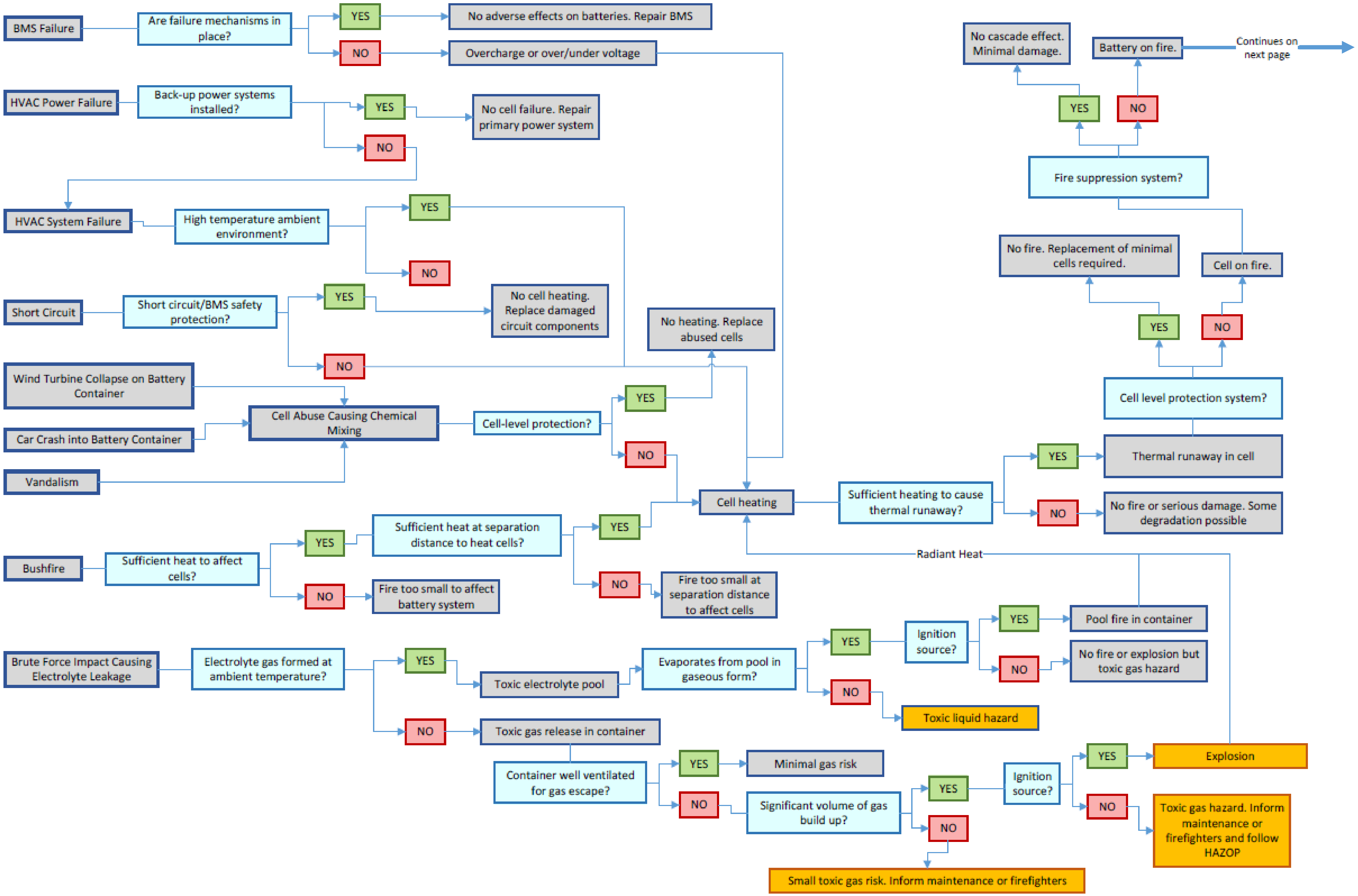

Figure 12: Event tree for the SSF battery system PHA. Note the event tree continues on the following page.

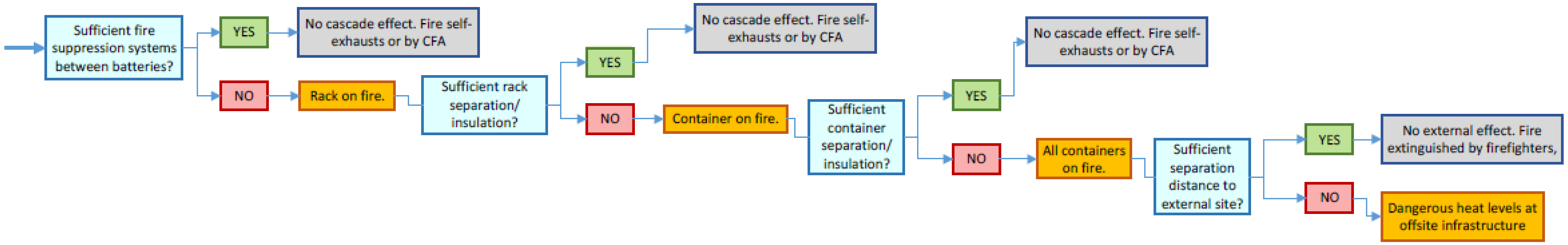

Figure 13: Event tree for the SSF battery system PHA (continued).

7.3.1 Likelihood of Explosion

The SEPP 33 screening and prioritisation steps highlighted explosion as a medium level hazard subject to a semi-qualitative analysis. Figure 14 shows the major fault pathways for an explosion event to occur involving the battery system at SSF.

There are two categories of initiating events potentially leading to an explosion event. The first is a variety of means by which a battery cell may be punctured and spill electrolyte onto the ground, forming a pool from which a gas cloud evaporates and builds up in the container, creating the fuel for an explosion event. The likelihood of this occurring is almost zero 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 this lack liquid electrolyte, with assessment of risk now based on the weight of lithium ion batteries in an installation. Thus we conclude that a pool of electrolyte initiating event is *extremely unlikely* to occur.

The second category of initiating event is a range of triggers that cause the battery cells to vent 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 abuse and electrical operation outside of the design boundaries. These specific mitigation measures are covered in detail in section 7.3.3, which relates to fire but applies equally to explosions as some of the triggering events are the same (e.g. cell abuse, cell heating). Based on the many mitigations measures deployable, the low level of dependence of each measure on other measures (independence of mitigation controls) and the level of maturity of many of the mitigation measures, we conclude 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 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 SSF 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, if a build-up of gas can occur in the container. Finally, the container pressure relief valve must fail if the pressure inside the container increased above ambient significantly, venting the container and exhausting the gas cloud. The chance of the HVAC system and pressure relief valve both failing, or being overwhelmed in a very short gas cloud release, is considered *very unlikely*.

Thus, for an explosion to occur an *unlikely* or *extremely unlikely* initiating event must occur, and a *very unlikely* failure of mitigation measures must occur for an explosion consequence to occur. Thus we conclude that an explosion at the SSF is *very unlikely* if the mitigation measures discussed above are utilised.

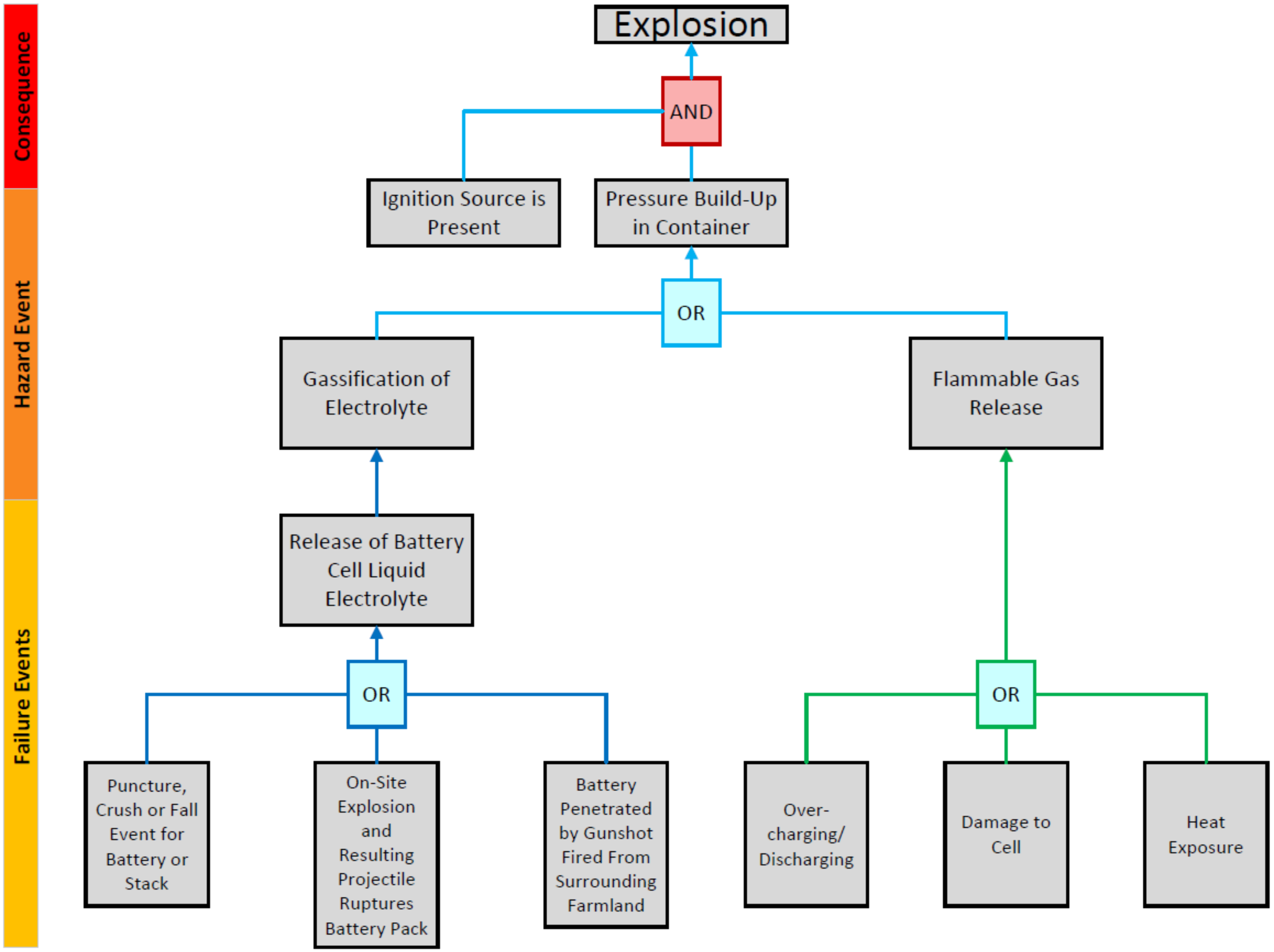

Figure 14: Explosion hazard fault tree for SSF battery system

7.3.2 Likelihood of Toxic Liquid or Toxic Gas

The SEPP 33 screening and prioritisation steps highlighted toxic liquid and toxic gas hazards as a low level hazard subject to a qualitative analysis. A semi-qualitative consequence analysis was performed as limited consequence information was available, however likelihood information relating to toxic liquid and gas risks is more readily available and thus a qualitative likelihood analysis is appropriate. Figure 15 shows the major fault pathways for a toxic liquid or toxic gas event to occur involving the battery system at SSF.

The initiating events of a toxic gas event are the same as for an explosive event (Section 7.3.1), with the exception that there is no ignition source. 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. As for an explosion, the build-up of a gas cloud requires the HVAC system to fail or be overwhelmed, a *very unlikely* event given the inclusion of a backup power supply and regular HVAC maintenance. A toxic gas build up is however more likely to occur than an explosion, as an ignition source is not required, which is the normal state for the battery system (i.e. *extremely likely*). 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 *extremely unlikely*.

The initiating events of toxic liquid event are those previously discussed in Section 7.3.1, and include various mechanisms by which a battery cell could be punctured and an electrolyte spill out. The initiating events could include a wayward gunshot from nearby farmland, a crush event from a falling wind turbine or car 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 previously discussed in Section 7.3.1, lithium ion batteries differ in this regard in that they do not contain liquid electrolyte, and hence the chance of liquid spilling in *extremely unlikely*. This report state the likelihood as extremely unlikely rather than impossible, adopting a conservative approach, as no specific studies assessing the amount of electrolyte spillage in lithium ion batteries that resulted from a full crushing event could be located, so a very small amount of spillage could not be ruled out completely. As a result the consequence of a pool fire (the worst case consequence of a toxic liquid pool event) was assessed in Section 7.2.3, and we conclude that the likelihood of such a toxic liquid pool event occurring is *extremely unlikely*.

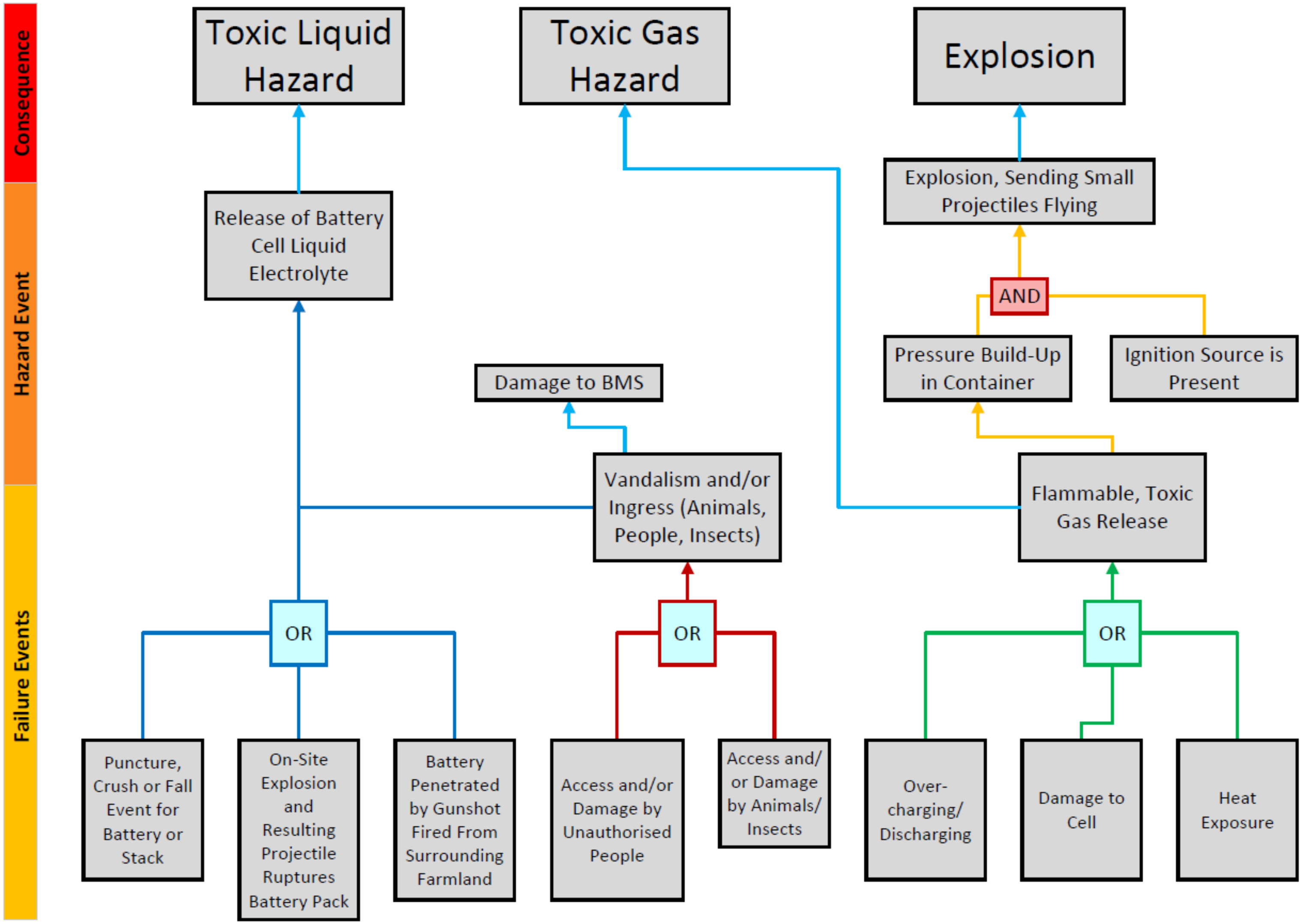

Figure 15: Toxic liquid or toxic gas hazard fault trees for SSF battery system

7.3.3 Likelihood of Flammable Liquid and Fire

The SEPP 33 screening and prioritisation steps highlighted flammable liquids and fire as a medium level hazard subject to a semi-qualitative analysis. Figure 16 shows the major fault pathways for a flammable liquid and/or fire event to occur involving the battery system at SSF.

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. 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 previously discussed in Section 7.3.2 and 7.3.1, the likelihood of an electrolyte pool forming is *extremely unlikely*, due to the absence of liquid electrolyte in lithium ion batteries.

The second initiating event leading to a fire in the battery system at SSF is the potential for thermal runaway in one or more battery cells. The likelihood of this event occurring is far greater than any other hazard initiating event in the SSF system; and the potential consequence is high in comparison to other potential consequences at the SSF, so this risk warrants the significant discussion in this PHA.

A thermal runaway event can be triggered by many initiating events and different pathways. The major pathways are highlighted in Figure 16, although it should be noted that this fault tree is non-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 event which leads to damage to battery cells in a way that allows for fast chemical mixing and overheating.
- 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

Without any mitigation in place the likelihood of thermal runaway in a battery cell is *very likely,* 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; however, there are many prevention measures which can be employed, 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 18, which attempts to show clearly 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 temperature event triggering thermal runaway in the battery cells is very unlikely to begin with, as it is based on a bushfire engulfing the battery system or the HVAC equipment failing in a 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, potentially a redundant and/or portable HVAC system for short term use in case of primary HVAC failure, and a comprehensive bushfire management plan and cleared exclusion zone around the battery system area should be considered. If these measures are deployed the likelihood of this initiating event occurring is *extremely unlikely*.

A mechanical failure initiating event is also very unlikely, as it would involve a car accident with the battery system or a wind turbine falling on the container. Prevention measures, such as a separation barrier between the access road and battery container, can effectively remove the chance of a car accident, and the collapse of a wind turbine unit is rare. Thus we conclude that the likelihood of this initiating event occurring is also *extremely 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 18. 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 *very unlikely*.

The three potential initiating events leading cell thermal runaway are *extremely unlikely, very unlikely* and *very unlikely*, and this we conclude that the likelihood of a thermal runaway event and the resulting fire occurring is *very unlikely*.

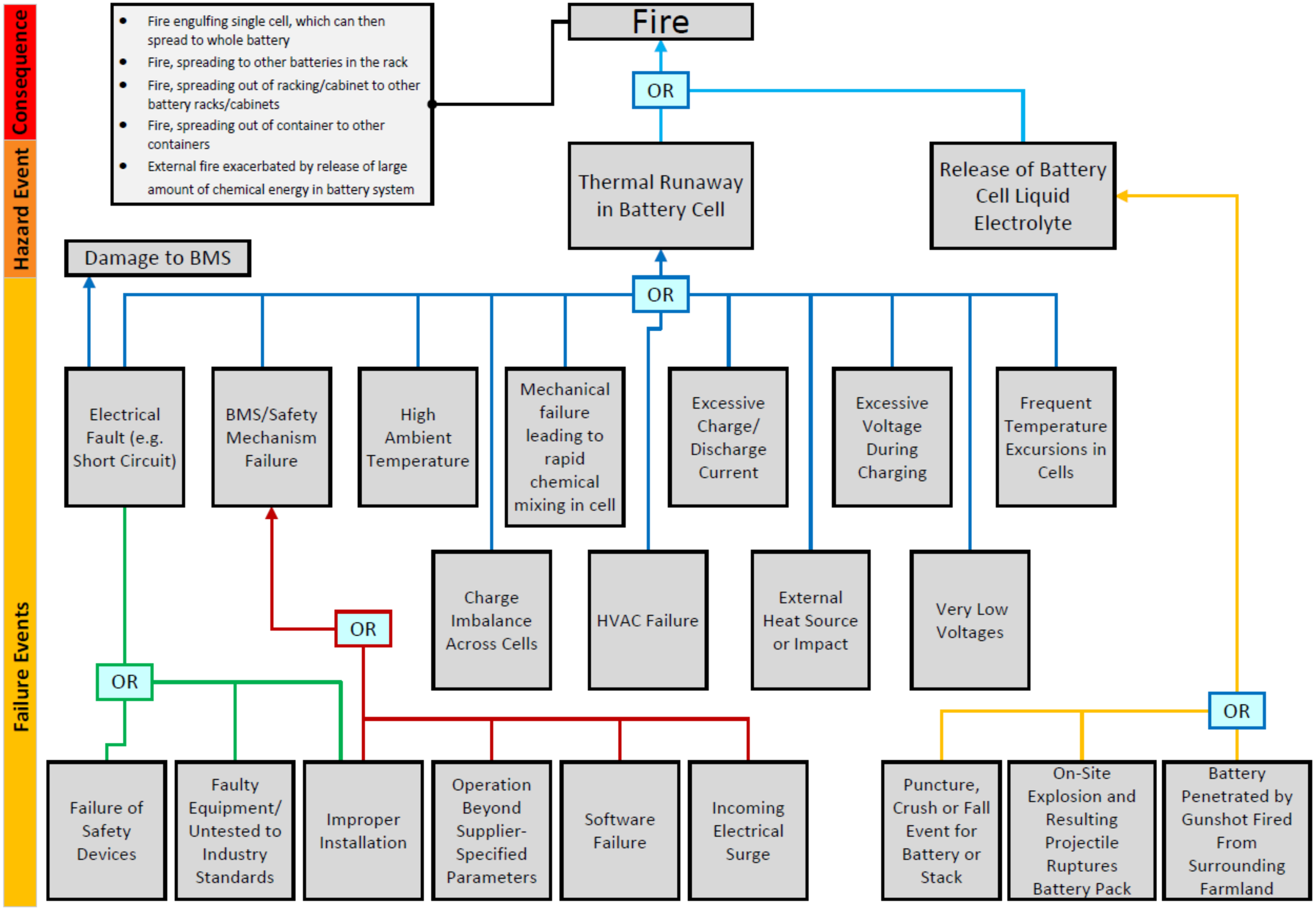

Figure 16: Fire hazard fault tree for SSF battery system

Table 18: Preventative fire risk mitigation measures available for the lithium ion battery system at SSF

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)	

	Install gas (e.g. CO) sensors to detect presence of cell gassing, as early detection system to prevent risk of toxic gas exposure and/or explosion	Fire suppression system in each container as recommended by battery supplier	
		Pressure release valve to direct an explosion inside the container to a safe area outside	
		Consider a mobile, redundant HVAC system that can cool a container in the case of HVAC failure on n a high ambient temperature day	
		Use container certified to IP57 or greater to prevent dust, insect and water ingress. IP56 may be sufficient. Details in IEC 60529.	
		Specifying a backup power system for the HVAC system	
		Select non-condensing HVAC system, and consider de-humidifying system if highly humid weather is likely	
		Consider a HVAC system capable of air cycling, so as to remove any toxic gas build up and remove hazard through dispersion	
Site		Clearance of minimum 20m from edge of site to grassland. Gravel covering or similar non-combustible material.	Develop a bushfire management system
		Fenced area around battery system to prevent ingress by people/animals	Battery system specific firefighting training and plan
		Separation and impact prevention barrier between access road and battery system	Battery specific maintenance SOP's and hazards training
		Consider separating the DC cable running from the battery units back to the first overcharge circuit breaker, in case of short circuit, to prevent escalation/fire	

7.3.4 Likelihood of Electrocution

The SEPP 33 screening and prioritisation steps highlighted electrocution as a low level hazard subject to a qualitative analysis. Figure 18 shows the major fault pathways for an electrocution event to occur involving the battery system at SSF. There are three main initiating event pathways which can create an electrocution hazard. These three pathways are water ingress/humidity in the container, electrical component failures and software/control system failures.

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 in 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 number) and water (second number) 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
- Check 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
- Locating the containers at a high point in the landscape, which all three sites are, 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 *very 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 has worn through and touches the metal battery racking, making the container live, or an operator accidentally touched a set of pliers to both positive and negative battery terminals simultaneously 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 SoP's
- 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

- 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 SSF battery system site the likelihood of an electrocution event initiated by an electrical component failure occurring is *unlikely*.

The final pathway potentially leading to an electrocution event is the failure of the BMS and/or associated control system. This could potentially 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, as well as mechanical isolation switches and circuit breakers that must all fail for this event to occur. It is for this reason considered *very 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 is discussed further in Section 7.3.3.

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 likelihood of an electrocution event being *very unlikely*, *unlikely* or *very unlikely* depending on the pathway, we conclude that the overall likelihood of an electrocution event occurring is *very unlikely* if the mitigation measures discussed are employed.

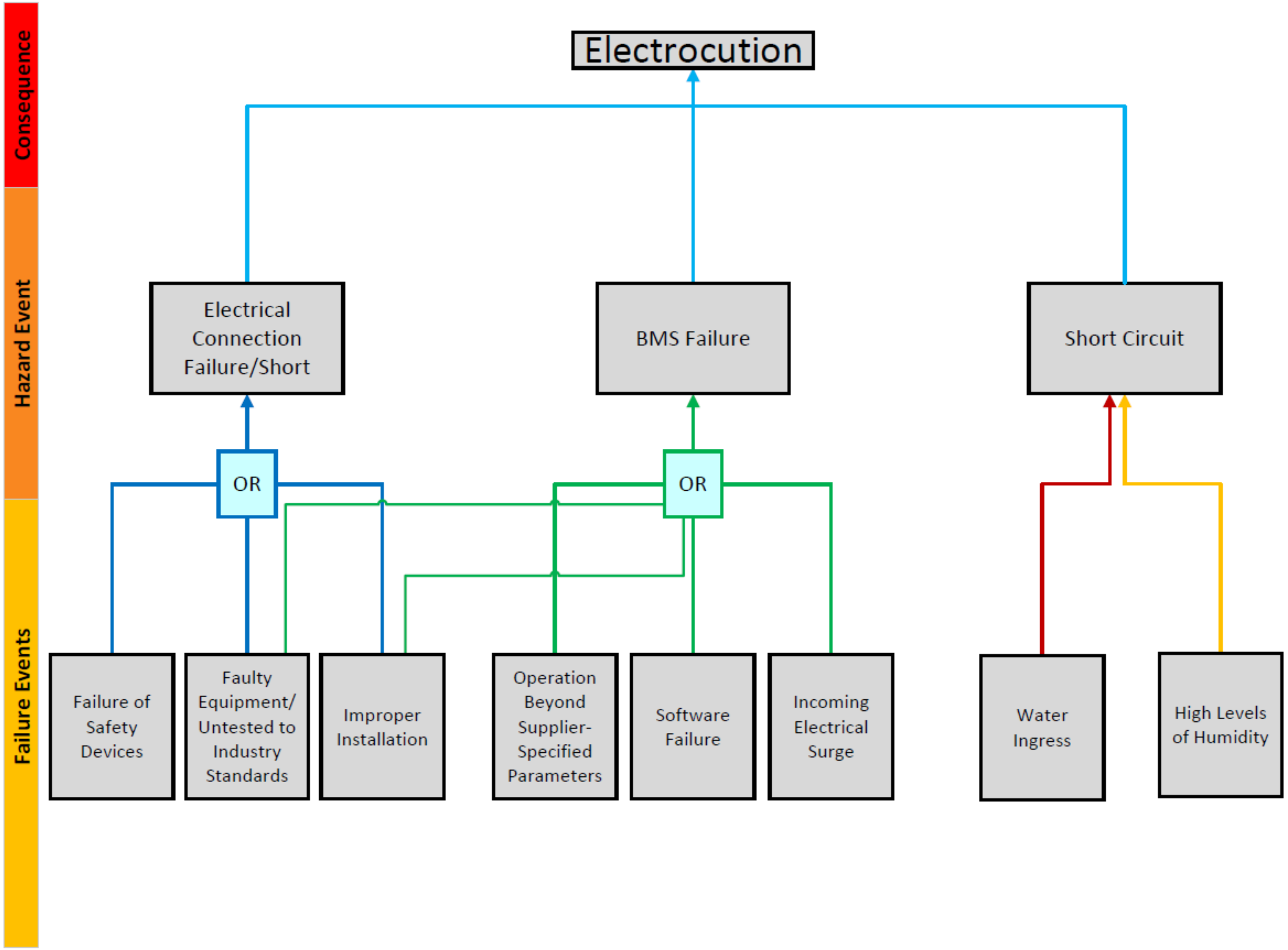

Figure 17: Electrocution hazard fault tree for SSF battery system

7.3.5 Likelihood of Crushing

The SEPP 33 screening and prioritisation steps highlighted crushing as a low level hazard subject to a qualitative analysis. Figure 18 shows the major fault pathways for a crush event to occur involving the battery system at SSF. There are two initiating pathways identified that could lead to a crush event nearby the battery system at SSF. 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.

The first initiating pathway, the crushing effect of a large external impact, can be mitigated by the following measures

- 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)
- Where possible, locate the battery system beyond the falling radius of any nearby wind turbines to remove the possibility of this specific initiating event

If these measures are implemented, and implemented correctly, the likelihood of this initiating pathway leading to a crushing event is *very 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 line with supplier specifications
- Installing battery racking and battery packs in line with the appropriate installation standards
- Specifying a battery rack that is appropriate for the battery packs if no guidance is given by the supplier
- Reducing 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
- Racking design that allows access to all battery packs without additional assistance (e.g. ladders), and does not encourage 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 *very 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 very unlikely events required to initiate a crush event to occur, we conclude that a crush event at the SSF is *very unlikely* to occur if the mitigation measures discussed above are deployed.

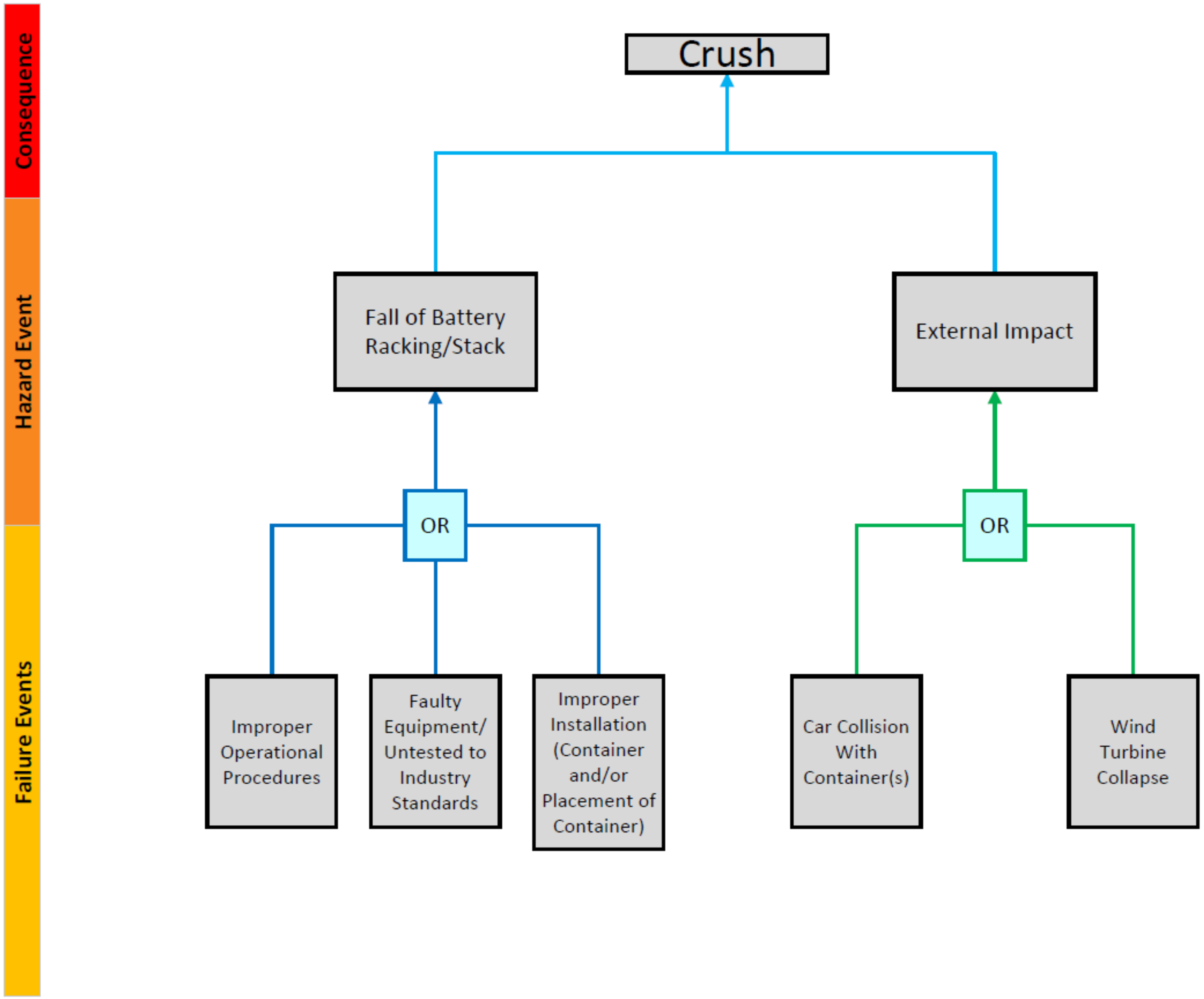

Figure 18: Crush hazard fault tree for SSF battery system

8 Risk Assessment

8.1 Risk to Society Assessment

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.

In addition to these qualitative guidelines, quantitative criteria exist for societal risk. These criteria use F-N curves to evaluate the risk to society based on the likelihood of the major consequence occurring and the number of fatalities it would cause if it did occur. The explanation given in Reasoning in Table 20 below incorporate the qualitative analyses, and where possible the quantitative elements of the analysis conducted.

Table 19: The risk to society posed by the major hazards identified in the SSF 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 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 approximately 530m from the battery system location. This therefore does not present a risk to society.
Toxic Liquid	No	A toxic liquid spill can occur only in very, very small quantities and is contained within a battery container. This does not present a risk to society.
Fire / Flammable Liquid	Potentially Yes, recommend detailed fire study	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 could be contained by including a gravel buffer zone around the battery system of at least 20m. The fire that could potentially be created is not a risk to society in itself, but the risk of a fire event initiating a bushfire is significant. Preliminary calculations suggest a bushfire in this area would develop a fire front of approximately 20,000 kW/m, which does present a significant risk to society. Therefore, a fire hazard that cannot be maintained on the site poses a potential risk to society if it triggers a bushfire in the surrounding area. With the inclusion of a buffer zone, firefighting measures in each container, and appropriate prevention measures (following ALARP) in place the risk to society of a battery system initiated bushfire event is considered insignificant (in the context of an F-N curve).
Toxic Gas	No	A toxic gas cloud will occur only in small quantities and will largely be contained in a battery container. 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 are approximately 560m 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.

8.2 Environmental Risk

The electrocution, toxic gas and crush hazards do not pose any threat to the environment. The toxic liquid hazard only poses a threat to the environment if it can be spread into local waterways or transmitted via other means. This could possibly occur during firefighting events, but with dedicated firefighting protocols this risk could be mitigation as the closest water source is a significant distance away. A full chemical analysis of the toxic pool hazard has not been completed and the risk to the environment would need to be explored in a detailed study if this event is considered to be somewhat likely after mitigation measures are put in place.

The explosion and fire risks are both considered not detectable. The worst case result for both events is a grass fire, which could be interpreted a number of ways. On the one hand, a bushfire is a naturally varying disturbance that does not impair resources, is not transmitted and does not accumulated, which would classify it as Not Detectable (See Table 20). On the other hand, extensive bushfires do disrupt local ecosystems, can spread to areas greater than 5000m^2 easily and can take 10 years to recover; but are not transmitted and cannot accumulate, so the environmental risk could be considered ‘Serious’. We leave the interpretation of the level of Environmental Risk to the assessing authority.

Table 20: Table of Environmental Consequences reproduced from the Dept. of Planning and Environment's HIPAP 4 guidelines (2011, Table 3, pg 14).

Consequence Type	Description
Catastrophic	Irreversible alteration to one or more eco-systems or several component levels. Effects can be transmitted, can accumulate. Loss of sustainability of most resources. Life cycle of species impaired. No recovery. Area affected 100 km^2.
Very serious	Alteration to one or more eco-systems or component levels, but not irreversible. Effects can be transmitted, can accumulate. Loss of sustainability of selected resources. Recovery in 50 years. Area affected 50 km^2.
Serious	Alteration/disturbance of a component of an ecosystem. Effects not transmitted, not accumulating or impairment. Loss of resources but sustainability unaffected. Recovery in 10 years.
Moderate	Temporary alteration or disturbance beyond natural viability. Effects confined<5000 m^2, not accumulating or impairment. Loss of resources but sustainability unaffected. Recovery temporarily affected. Recovery < 5 years
Not detectable	Alteration or disturbance within natural viability. Effects not transmitted, not accumulating. Resources not impaired

8.3 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, 1 fatality.

- This consequence is contained to two specific groups, namely firefighters and maintenance staff. Both groups operate in high risk environments on a daily basis, and as such are likely more tolerant to some level of risk. Both groups are also easily targeted with training programs specifically tailored to the battery system on site, so they are aware of the major risks ahead of time.
- Both groups of at risk individuals are only at risk when inside the battery container, a designated area, which can be managed appropriately
- Both groups are very rarely in the container. Maintenance staff will only be inside the container to conduct maintenance work, the planned component of which is on average 24 hours in 20 years, per container.
- The likelihood of the major hazards occurring is at most *very unlikely*, and in many cases is *extremely unlikely*.

9 Conclusion

A PHA was conducted on the proposed approximate 50MW/100MWh battery system at the SSF, in accordance with the SEPP 33 Guidelines, although the findings would apply equally to a system up to 200MWh. There were six major hazards identified for the lithium ion battery system; Toxic gas, toxic liquid, electrocution, crushing, fire/flammable liquid and explosion/flammable gas. The last two major hazards were considered significant enough to warrant an element of quantitative analysis, which was conducted using specific explosion (PHAST) and fire (Arup developed) modelling software. The consequence of all major hazards was contained to a small area around the site, limiting the risk of fatality to 1 in all cases. The likelihood of all events was either very unlikely of extremely unlikely, primarily due to the wide range and comprehensive nature of the preventative measures available. The key preventative/mitigation measures were summarised in this report for simple consideration during site planning.

As a result of the contained area or effect of all the major hazards, the risk to society of the proposed SSF battery system is considered negligible; however, it should be noted that the analysis conducted was of a preliminary nature only and detailed hazard studies may be warranted before the site begins construction.

Appendixes

Appendix A - A3 Site Layout

Abbreviations

BMS – Battery Management System

HVAC – Heating, Ventilation and Cooling

PCU – Power Control Unit

HV – High Voltage

LV – Low Voltage

NSW – New South Wales

PHAST – Engineering Fire Modelling software package

PV – Photovoltaic

UN – United Nations

UL – Underwriter Laboratories, a battery testing for certification organisation

IEC – International Electrotechnical Commission, an issuer of many electrical standards, including batteries and related equipment

AS – Australian Standards, the primary issuer of technical standards in Australia, including batteries and associated equipment and installation

PHA – Potential Hazards Analysis, as defined in the SEPP 33 Guidelines

SEPP 33 – State Environmental Planning Policy Number 33

HIPAP - Hazardous Industry Planning Advisory Papers

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

SSF – Sapphire Solar Farm

SWF – Sapphire Wind Farm

NFPA – National Fire Protection Association (USA)

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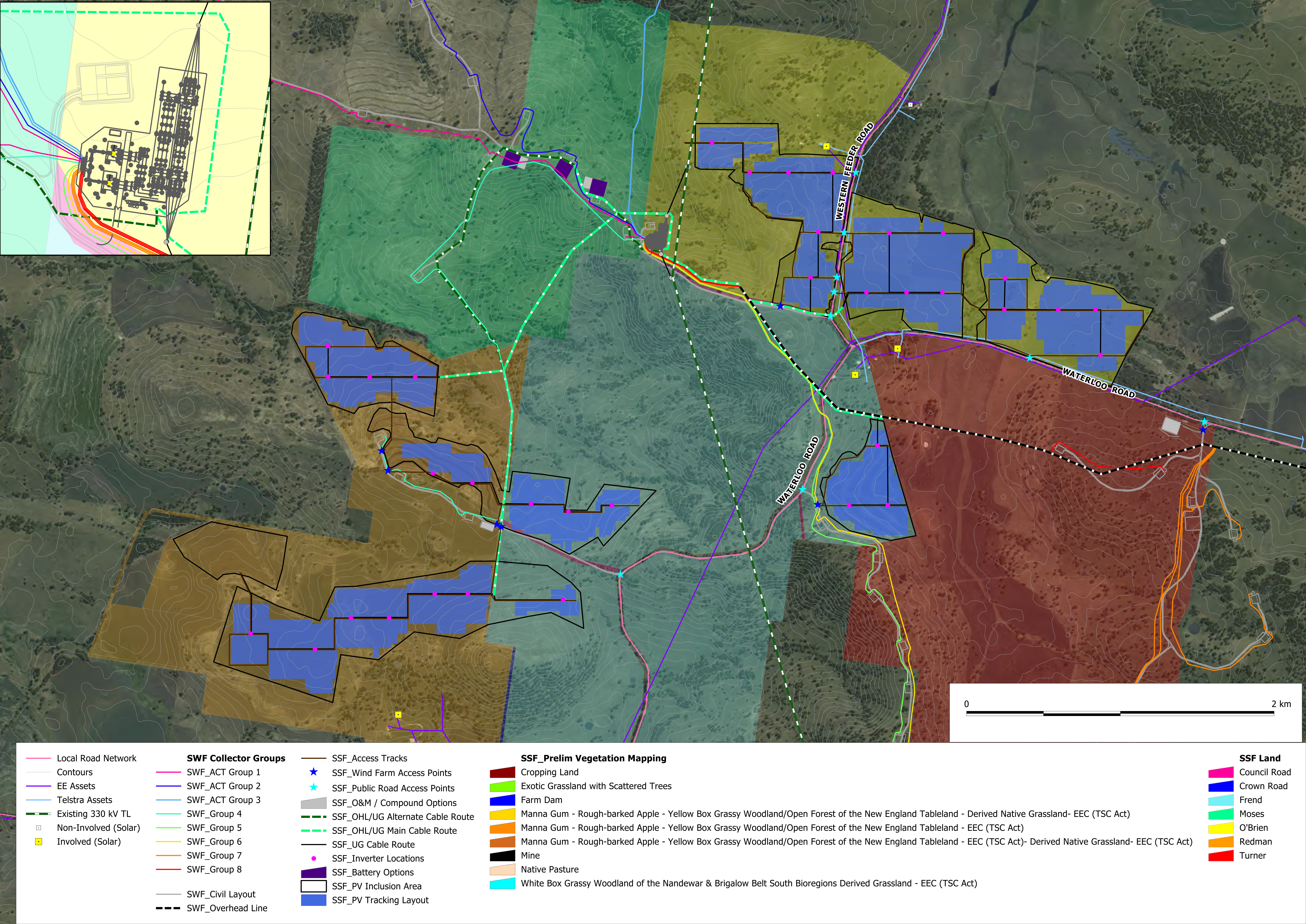
WESTERN FEEDER ROAD
WATERLOO ROAD
WATERLOO ROAD
0
2 km
Local Road Network
Contours
EE Assets
Telstra Assets
Existing 330 kV TL
Non-Involved (Solar)
Involved (Solar)
SWF Collector Groups
SWF_ACT Group 1
SWF_ACT Group 2
SWF_ACT Group 3
SWF_Group 4
SWF_Group 5
SWF_Group 6
SWF_Group 7
SWF_Group 8
SWF_Civil Layout
SWF_Overhead Line
SSF_Access Tracks
SSF_Wind Farm Access Points
SSF_Public Road Access Points
SSF_O&M / Compound Options
SSF_OHL/UG Alternate Cable Route
SSF_OHL/UG Main Cable Route
SSF_UG Cable Route
SSF_Inverter Locations
SSF_Battery Options
SSF_PV Inclusion Area
SSF_PV Tracking Layout
SSF_Prelim Vegetation Mapping
Cropping Land
Exotic Grassland with Scattered Trees
Farm Dam
Manna Gum - Rough-barked Apple - Yellow Box Grassy Woodland/Open Forest of the New England Tableland - Derived Native Grassland- EEC (TSC Act)
Manna Gum - Rough-barked Apple - Yellow Box Grassy Woodland/Open Forest of the New England Tableland - EEC (TSC Act)
Manna Gum - Rough-barked Apple - Yellow Box Grassy Woodland/Open Forest of the New England Tableland - EEC (TSC Act)- Derived Native Grassland- EEC (TSC Act)
Mine
Native Pasture
White Box Grassy Woodland of the Nandewar & Brigalow Belt South Bioregions Derived Grassland - EEC (TSC Act)
SSF Land
Council Road
Crown Road
Frend
Moses
O'Brien
Redman
Turner